RIVER FLOOD MODELING OF AMOCHU RIVER USING GIS AND HEC-RAS: A CASE STUDY IN PHUNTSHOLING CITY, CHUKHA, BHUTAN

KINLEY DORJI

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Geographic Information Science)
2019

RIVER FLOOD MODELING OF AMOCHU RIVER USING GIS AND HEC-RAS: A CASE STUDY IN PHUNTSHOLING CITY, CHUKHA, BHUTAN

KINLEY DORJI

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Master of Science in (Geographic Information Science)
2019

Thesis entitled "River Flood modeling of Amochu River using GIS and HEC-RAS: A case study in Phuntsholing city, Chukha, Bhutan"

By KINLEY DORJI

has been approved by the Graduate School as partial fulfillment of the requirements for the Master of Science in Geographic Information Science of Naresuan University

Oral Defense Committee

.... Chair
(Assistant Professor Pipat Reungsang, Ph.D.)

.... Advisor
(Assistant Professor Sittichai Choosumrong, Ph.D.)

.... Internal Examiner
(Assistant Professor Kampanart Piyathamrongchai, Ph.D.)

Approved

....
(Professor Paisarn Muneesawang, Ph.D.)

for Dean of the Graduate School

Title RIVER FLOOD MODELING OF AMOCHU RIVER USING GIS AND HEC-RAS: A CASE STUDY IN PHUNTSHOLING CITY, CHUKHA, BHUTAN
Author KINLEY DORJI
Advisor Assistant Professor Sittichai Choosumrong, Ph.D.

Academic Paper Thesis M.S. in Geographic Information Science, Naresuan University, 2019
Keywords Amochu, Flood, Log Normal, Log-Pearson III, GIS, HEC-RAS, Phuntsholing city

ABSTRACT

The study area, Phuntsholing, commercial hub of Bhutan, is exposed to major threat to the flood as it is located at the proximity of the giant river, Amochu. Thus, the flood modeling of Amochu River was carried out to generate the flood inundation map to locate sites vulnerable to flooding and to obtained the impact of flood on the settlements of present and future plan city. Log Normal and Log-Pearson III techniques were used to find out the affected areas on both present and future city. However, it is observed that Log Normal technique will have the heavy impact on the city with the rapid time period than the Log-Pearson III technique. One-dimensional model in HEC-RAS was used to find the flood inundation map using the information from the observed peak discharge to get the depth of flood. The result showed that in the current Phuentsholing city, the major vulnerable regions by flood from 25 years till 1000 years will be the flood plain and shrub areas and the least affected areas will be agriculture and forest land. The study also displayed that in the upcoming city plan, Zone B, Zone E, Zone C will be the most vulnerable places and the least will be LAP and Zone A. The study also found that the depth of the river will be estimated to increase with increasing in time. The map also showed that inundated area will be increased with increasing in time especially at the riverine areas of the river. Thus, this study not only provides an identification of flood risk zones to serve as emergency services but also provides potential area for town planning by reclaiming

the land to certain height. These findings can be replicated to other flood prone regions for similar flood mapping.

ACKNOWLEDGEMENTS

This study would not have been possible without the perseverance assistance and expertise of my advisors. I therefore would like to express my immense gratitude and heartfelt appreciation to Assistant Professor Dr. Sittichai Choosumrong and Ms. Tanyaluck Chansombat, Lecturer, Department of Natural resources and Environment, Naresuan University for their esteemed guidance and support from the very beginning to the completion of my research work. I would remain unfathomed grateful to both of them for their unwavering support and making available at any time for making my thesis successful.

Nevertheless, I would also like extend my sincere gratitude to all my course professors Assistant Professor Dr. Kampanart Piyathamrongchai, Associate Professor Mr. Pathana Rachavong, Assistant Professor Capt. Dr. Chaiwiwat Vansarochana and Assistant Professor Dr. Natapon Mahavik for their valuable guidance and imparting knowledge's in GIS, which in fact facilitated us in many ways in carrying out our research work.

When I is replaced by we, even illness becomes wellness. Therefore, it would not be appropriate, if I do not convey my thankfulness to all my course mate for their utmost motivation and rendering gracious assistance at all times, especially to Mr. Sonam Tobgay, Mr. Tenzin Wangchuk and Miss. Zangmo in carrying out my Thesis.

Further, I also thank to National Center for Hydrology and Meteorology (NCHM) under Ministry of Economic Affairs, Royal Government of Bhutan for providing necessary hydro meteorological data of the study area and Department of Human Settlement, Ministry of Works and Human settlement for providing the proposed master plan of the future city of the study area.

Lastly, I also would like to thank Thailand International Development Cooperation Agency (TICA) and Royal Government of Bhutan for awarding the scholarship to pursue my Master in science (GIS) in Naresuan University, Phitsanulok, Thailand.

KINLEY DORJI

TABLE OF CONTENTS

Page

List of Tables

Page

List of Figures

Page

CHAPTER I

INTRODUCTION

Introduction and Significance of the Study

Flood is natural phenomena causing adverse condition in the flood prone areas by extensive inundation (Teng et al., 2017) . It occurs due to the overflow of water from the water bodies, such as river, lake, sea or large natural water basins or from an accumulation of rainwater on saturated ground in an aerial flood (Rahman, 2014). The consequences of floods, which may be direct or indirect, includes the loss of lives, economics damages, damages on the environment and the cultural heritage. They can also influence the life and activities of large population within and outside the flooded zone (Teng et al., 2017). Floods are caused from both natural factor such as heavy rainfall, high floods, tides and human factors by blocking channels, augmentation of drainage channels, improper use of land and deforestation around water regions. Increasing urbanization, growing impermeable land with higher flood proximities and runoff are due to the involvement of human activities resulting from increasing population. In addition, flood becomes more life-threatening when it is caused by climate change with socio-economic damage (Tingsanchali, 2012).

Flood causes major disaster all over the world. The physical damage in-terms of infrastructures and environment have huge impact on the living conditions of the people affected by the floods (Kovacs et al., 2017). The losses due the result of floods have increased drastically around the world (Rahman, 2014). The figure showed one-third of natural disaster is caused by flood and half the death is caused by natural disaster, worldwide (Donald W. Knight & Shamseldin, 2006) and more than 2.80 billion people has been affected by the flood since 1990 (Kovacs et al., 2017).

In Asia, more than half of its total area is affected by flood. In total, nine countries out of ten were affected by flood including China in first place (Kovacs et al., 2017). According to Rahman (2014) floods from South Asia had extensive impacts in the countries such as India, Nepal, Bhutan, Pakistan and Bangladesh resulting in death to more than 2,000 people and affecting approximately 30 million in the regions due to the lack of adaptive capacities. In south Asia, the southwest monsoon overtakes from June till September, receiving 70-80% of the rainfall in this area. Whereas, in the Himalayan-Hindukush region, melting of glaciers due to impact of climate change increase the flash floods in the mountainous areas and regions at the foothills (Rahman, 2014).

Likewise, Bhutan has been hit by heavy rainfall and flash floods in most of the regions and have a history of loss of lives and damages to property due to flooding. Major floods around Bhutan with significant damage has been experienced in 1993, July 1996, August 2000, May 2009, 2010, July 2015 and July 2016 (PTDP, 2018). The most severe floods were reported in 1994 and 2009 with the glacial lake outburst flood (GLOFs) and Cyclone Aila respectively. Cyclone Aila originated in the Bay of Bengal have brought unprecedented rainfall which has caused consequent flooding and landslides in and around the Bhutan. Out of 2674 glacial lakes in the world, 24 lakes are identified as posing severe GLOF threat in Bhutan (NEC, 2016). Severe flash floods triggered by monsoon rains in 2000, particularly in southern Bhutan along the border with India were observed at Barsachu, Dutikhola (small catchments) and Amochu sub-basins (Adhikari, 2015). The flash flood in the southern region in 2009 and July, 2016 has caused significant loss and damages to lives, properties and public infrastructures. In context of the NIWRMP, areas prone to monsoon flooding's in hectares has been shown in Figure 1 (NEC, 2016).

Generally, rivers of Bhutan are characterized by steep slopes in the upper catchment, which are subjected to intense seasonal rainfall and have high rates of erosion. As the rivers flow towards the southern foothills, the transition from mountainous areas to flat plains typically occurs and is accompanied by extensive flooding. Although flood occurs in most parts of the country, it is very recurrent in the southern region affecting the people and properties which are in proximity to the rivers. The towns of Phuntsholing, Sarpang, Gelephu, Samtse and Samdrupjongkhar received the maximum monsoon rainfall as per the past record. Geologically, southern Bhutan falls under Siwalik zone, where soil predominantly consists of sandstones, siltstones, clay, shale and boulder beds. These type of soils are very susceptible to erosion. The flooding thus, brings along the eroded sediments /debris from upstream and deposits it in the plains downstream degrading the farm land and other usable lands (PTDP, 2018).

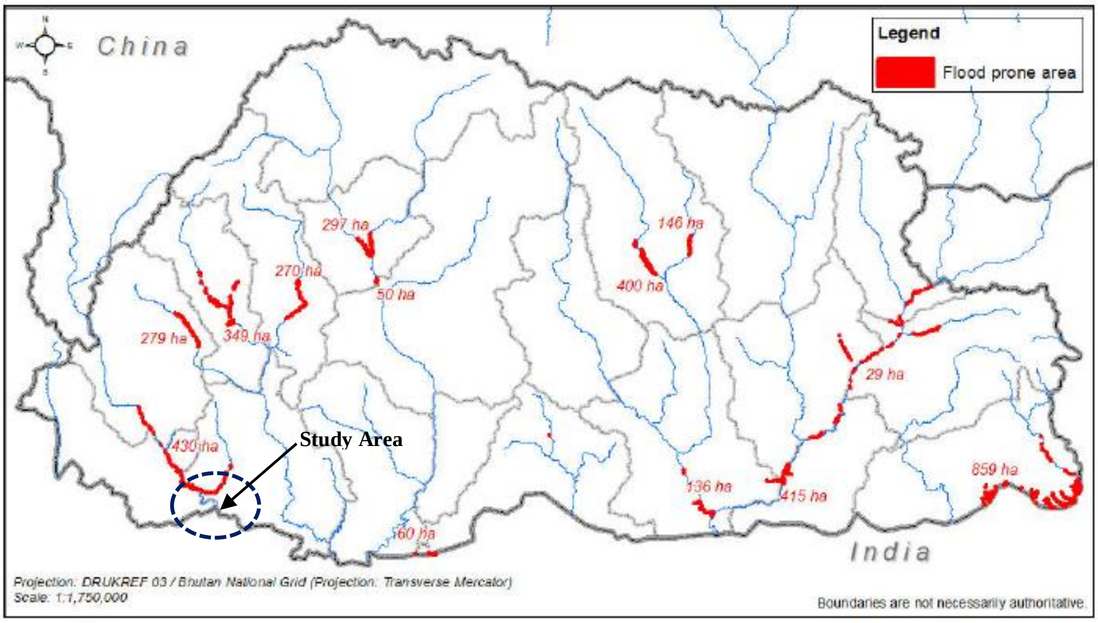

Figure 1 Map showing the river network prone to monsoon flooding (NEC 2016)

Bhutan has four major river systems, which are Drangmechu river, Puna-Tshangchu river (Sankosh), Wangchu river and the Amochu river. Each flows swiftly out of the Himalayas, southerly to join the Brahmaputra River in India. The total length of rivers, with their tributaries, in Bhutan is about 7,200Km approximately. All the rivers of Bhutan show marked characteristics of mountain streams flowing between high Rocky Mountains confining the channel in a narrow valley. As the gradient of the river falls remarkably, the streams rush tumultuously over beds of huge boulders and rock masses. None of these streams are navigable in the mountains or even in the plains. As the rivers flow towards the southern foothills, the transition from mountainous areas to flat plains typically occurs and is often accompanied by extensive flooding.

Phuntsholing is located in the southern belt of the country bordering the Indian town of Jaigoan, West Bengal. It has an altitude of 160m above the sea level with the total area of 16.80 Km^2 of which 24.30% of the total area is under forest cover. The rugged hill slopes surrounded by thick forests with numerous rivers and rivulets makes escape routes limited and the entire city extremely vulnerable in the event of landslides and floods (Thromde Disaster Management Plan, 2016). Phuntsholing area is the place where numerous rivers meet together before they drain to the plains of India. This region poses a number of flood and landslide-prone area making continuous challenges to economic/industrial/commercial infrastructure from the risk of flood hazard. The rivers that flow through the valley are Barsachu, Balujorachu, Omchu, Singyechu including the major river Amochu. The town is exposed to flash flood every monsoon seasons and experiences significant flooding disaster almost every year, occurred in 1993, 1996, 2000, 2009, 2015 and 2016 (PTDP, 2018). The Rivers and streams flow into the Indian Territory and hence experiences the similar flooding impact causing threat to India as well. The measures undertaken in Bhutan will also benefit the Indian state of Assam and west Bengal as the intervention measures will lessen the velocity of the rivers and sediment loads which would have occurred erosion of huge acres of land (PTDP, 2018).

Southern foothills are inhabited densely due to the increase in population and faster rate of economic development as landscapes are gentle, fertile and most suitable for agricultural farming. Likewise, the flood damages have also increased despite public investment in flood control measures. The heavy monsoon rainfall from June to August makes the communities highly susceptible to the risk of flooding and other climate induced disasters. Several streams and rivers expand massively during the rainfall season along with the surface runoff from the catchment area bring huge flow making the people, farmland and public infrastructures highly vulnerable to the hazard.

Therefore, the threat caused by flood can be prevented through better planning using the models of Geographic Information System (GIS) and remote sensing technology in order to change in future on urban floods. The models serve as information on expected flood magnitudes and frequencies that result in marking the areas subjected to flood (Tingsanchali, 2012). GIS is “cartographic representation tool facilitating the presentation of the results of hazard and vulnerability analysis in a given territory” (Kovacs et al., 2017). GIS using remote sensing technology is the recent key tool for monitoring flood, used for obtaining the flood images of the flood affected area. To mitigate flash floods disastrous effects, there is the need to have effective modeling to understand the problem. The software known as Hydrologic Engineering Centers Rivers Analysis System (HEC-RAS) is commonly used for generating flood inundation maps and images for ranges of applications. Hence, HEC-GeoRAS with GIS makes the structure of the model geometry and output of the post-processing very easily (Elkhrachy, 2018).

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance from the targeted area. With the advancements in the remote sensing and the Geographic Information Systems (GIS) technology, it allows researchers in carrying out quick damage assessment, early warning and real time monitoring of flood disasters (Khanna et al.). It can be also used for various purposes by downloading the real time satellite images to see the pre and post detection changes on the surface of earth. High temporal resolution played a vital role in Remote Sensing data for flood monitoring to encounter the cloud cover.

With the increasing availability of satellite images, well in advance of any flood occurring, satellites can help civil protection planners anticipate where a river would be most prone to burst its banks, and take action accordingly. Satellite data can provide highly detailed digital elevation models of areas at risk that can serve as the basis of computerised flood simulations. During a flood event near-real-time images are a management tool for authorities coping with the disaster. One of the biggest problems is obtaining a clear picture of the overall extent of the flood.

Wide area satellite images can show an entire flood within a single picture, with radar instruments especially well-suited for differentiating between waterlogged and dry land. A sequence of satellite images can show if the flood is growing or diminishing over time, and highlight further areas coming under threat of inundation. Simply comparing before and after images of the flooded region makes possible a rapid and authoritative damage assessment estimate, factoring in different land cover types to quantify the cost of the flood. However, due to the constrain of obtaining clear picture of real time satellite images of the overall extend of the flood, comparing for calibration with the simulated inundation flood extend were not possible in this study. The data from LULC 2016 were used to assess the impact of flood on the present city, while master plan of future city of Phuntsholing, developed by

Phuntsholing Township Development Project (PDTP) and Local Area Plan (LAP) prepared by Department of Human Settlement (DHS), Ministry of Works and Human Settlement (MoWHS) were used to find out the affected area of future city of study area.

Objectives of the Study

The objective of this study is to improve the current flood management by preparing different flood inundation mappings using series of discharge scenario in Amochu river basin. Therefore, specific objectives of this study are as listed below:

- To analyze flood frequency for different return periods.
- To generate flood inundation map in order to locate sites that are vulnerable to flooding.
- To find out the impact of flood to the settlements of present city and future city plan in the study area.

Outcome of the Study

- Maximum instantaneous peak discharge corresponding to different return period, relative to best flood frequency technique.
- The water surface elevations and Flood inundation map produced at different return period flood.
- Affected areas by flood in present and future city plan assessed.

Limitation

In the course of carrying out this research, it is likely to encounter some of the limitation as mention below:

1. The non-availability of a high resolution digital elevation model. A DEM5m data, resample from DEM12.5m spatial resolution Alos Palsar available freely from Alaska Satellite Facility website (JAXA/METI, 2015) will be used to facilitate the simulation in this study, which cannot reflect the current river bed form in DEM.

2. Due to the inadequate real time satellite images of overall flood extend of the study area, the images without cloud cover were not available during flood event. Thus, calibration of simulated flood extend with the real time satellite images is not possible in this study.
3. To get accurate and valid flood data, primary data such as rainfall and discharge data are very crucial, which will be one of the limitations in this project as it has only one gauging station in the main stream. Therefore, there are need to install a number of hydrological stations along the river basin in order to have appropriate flood inundation map.

Problem Statement

Phuntsholing city has been experiencing several disasters over the last 20 years. The major and the recurrent devastating hazards caused by the massive floods were in 2000, 2009 and 2016, that resulted in extensive damages to houses, government and private infrastructure (PTDP, 2018).

Phuntsholing city is one of the commercially trading centers of Bhutan which is located adjacent to the Amochu River. It holds over 80% of Bhutan's trade. It is the second most populated town in the country with expected rise of 5% per year despite of limited land availability. Due to the fast development and limited plain area, the city has been facing serious shortage of land for its expansion. Since it has limited land, there is housing crisis due to which many Bhutanese people reside in Indian border town Jaigaon.

Limited land is the main growth problem in Phuntsholing, confined by steep and unstable Himalayan foothill along with Amochu River and international border. The city has high potential of precipitation and is vulnerable to the flood damage due to overflow and erosion of riverbank. Flash flood is triggered by monsoon precipitation arising more frequently due to climate change. Major chunk of valuable flat land along the western region of the Phuntsholing city has been lost to uncontrolled river as a result of erosion and sedimentation by debris. The high monsoon flows have eroded vast areas of land, restricting the scope for growth and sustainability of the economy of the city. As such Phuntsholing city is planning to extend the town about 4.62 Km^2 (462 hectares) of riparian land of Amochu River to accommodate the expansion under the "Phuntsholing Township Development Project" (PTDP, 2018).

The Amochu River is one of the important rivers in Bhutan. It appears from Tangla in Tibet and passes the Chumbi valley where it flows through a narrow, deep bed bordered and reaches the duars plains in the south. As it reaches onto the plains, broaden to a width more than 1Km, which is exposed to several flash flood during every monsoon season, besides encountering significant devastating flooding in 1993, 1996, 2000, 2009, 2015 and 2016. It then joins Brahmaputra River after crossing Bhutan's territory. Even in winter, Amochu River still has a swift stream with the depth of approximately one meter. During heavy precipitation, the Amochu River tends to swell and overflow the river, flooding the entire town creating chaos to the settlements. Figure 2 shows some of the damages done by Amochu River during the time of 2016 flood events.

Therefore, there is a need to carry out flood inundation mapping so as to expedite policy makers and planners in the development of flood mitigation measures or manage natural risk for the future planning for the Phuntsholing city. Further, mapping of flash flood will also be beneficial for risk managers and disaster response or emergency services during the time of intense rainfall events. This study can also provide a baseline to study the requirement of flood insurance policy in the future, as the country has no such policy at the present. Further, the model develop can also be used for flood forecasting during different flood scenario.

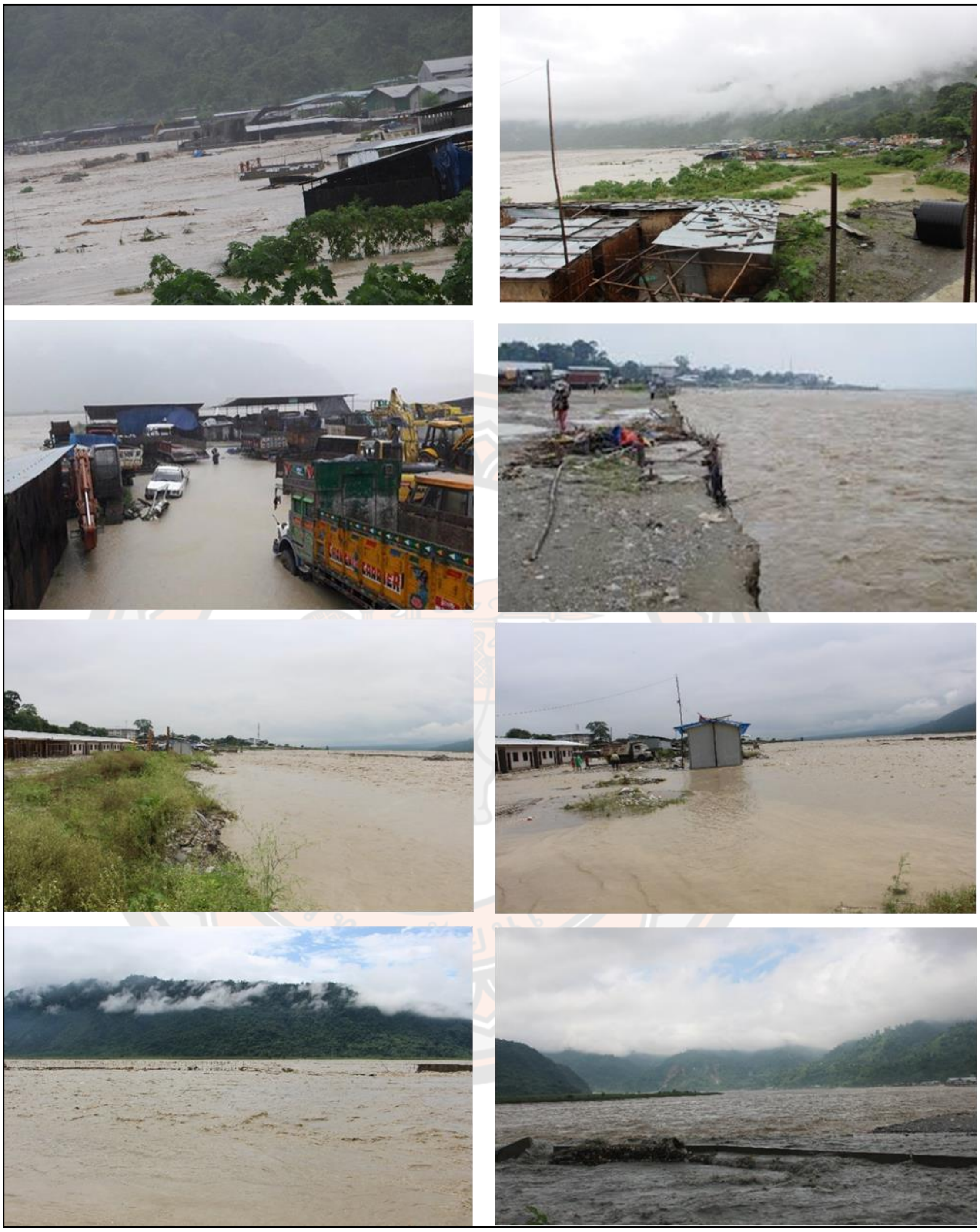

Figure 2 Flood inundation and lateral erosion of July 2016 flooding (CDCL, 2018)

CHAPTER II

LITERATRURE REVIEW

The following literatures are some of the literature review carried out by other researchers in flood modelling for disaster response, proper planning and development of the townships purposes using ArcGIS and HEC-RAS:

Concept of HEC-RAS model

HEC-RAS is a software developed by US Army Corps of Engineers used to simulate water surface profiles corresponding to different peak discharge (Hydraulic Engineering Center, 2016). It can perform one-dimensional steady, one and two dimensional unsteady flow hydraulic, sediment transport computation and water temperature modeling etc. It is one of the most capable approach used for generating flood plain map worldwide (Demir & Kisi, 2015; El-Naqa & Jaber, 2018).

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. In the steady flow simulation, HEC-RAS solves the energy equation to calculate the water surface profiles from one cross-section to another. The basic computational procedure is based on an iterative solution of the energy equation:

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

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 figure 3:

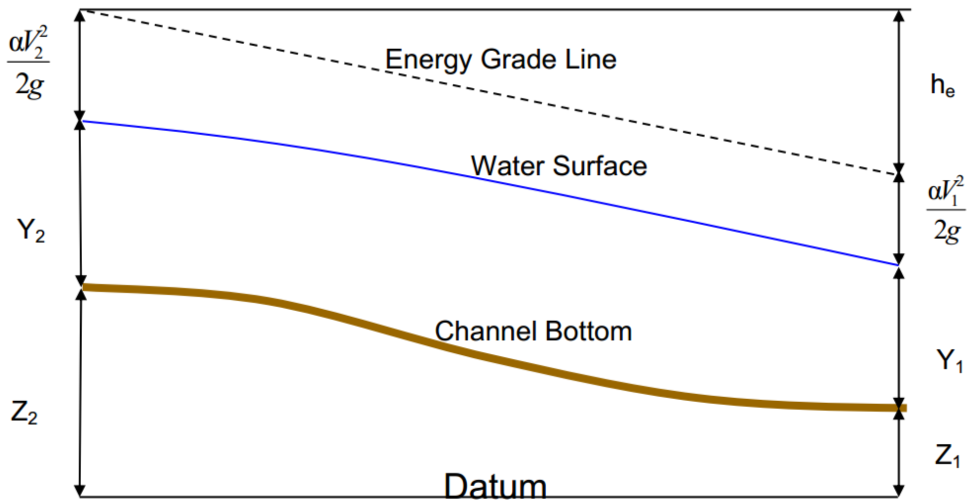

Figure 3 Representation of Term in the Energy Equation

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 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 4). 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)

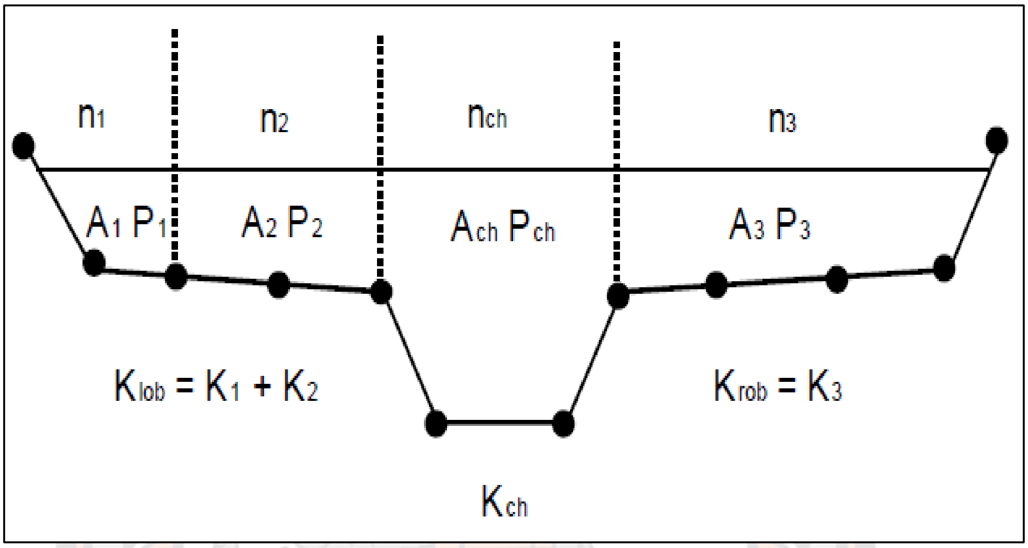

Figure 4 HEC-RAS Default Conveyance Subdivision Method

Source: (Hydraulic Engineering Center, 2016)

Flood Inundation mapping using HEC-RAS model

The study conducted by El-Naqa and Jaber (2018) on flood plain analysis used ArcGIS and HEC-RAS to prepare the geospatial information for the hydraulic model that results to get the flood plain mapping illustrating the floodplains, and the affected potential area. HEC-RAS sensitivity analysis model worked properly as the roughness parameter increased, average total velocity and Froude number decreased and ultimately, there was an increase in hydraulic depth and water surface elevation. The HEC-RAS software and its GIS extension HEC-GeoRAS was therefore well-suited for developing flood inundation maps for a variety of applications.

The finding of Getahun and Gebre (2015) on Flood Hazard Assessment and Mapping of Flood inundation area generated 12 Flood inundation mapping based on the observed peak flow data from the selected six gauging stations with 5% increased flow rate corresponding to 5, 10, 25, 50 and 100 years return periods using HEC-RAS. Flood hazard assessment was carried by delineating flood hazard zones using multi-criteria evaluation technique in GIS by overlaying weighted parameter such rainfall, slope, elevation, soil type, drainage density and land use etc. which directly influenced the flooding in the area. The hazard map indicated that downstream part of the basin was low-lying flat area (2103 Km^2 + 35406 Km^2) exposed to high and very high flood hazard zone. The main causes of flooding were found out to be the intense rainfall especially in the monsoon season.

As per Demir and Kisi (2015) flood hazard mapping was conducted to obtain flood hazard maps using GIS and HEC-RAS for floods corresponding to different return periods (10, 25, 50, 100, and 1000). By using HEC-GeoRAS in ArcGIS, spatial data such river center line, river reach, bank line, flow paths, cross section, stream network and other geometric information's were obtained and then were transferred to HEC-RAS to derive the flood. HEC-RAS (Hydrologic Engineering Center and River Analysis System) used energy equation for the calculation of water surface profile. This software allowed users to assigned manning's coefficient, boundary condition to individual cross section respectively in order to obtain water depth and mean velocity for the given cross section. Manning roughness coefficients of 0.022, 0.026, and 0.045 were used for concrete, bush-wooded, and woodland river banks and 0.03 was utilized for the river base.

Khattak et al. (2015) researched on floodplain mapping using HEC-RAS and ArcGIS found that HEC-RAS was used to analyze the channel flow and delineate the flood plain area as it can simulate water surface profiles corresponding to selected flood event and the effects of various obstructions such as culverts, bridges, structures in the overbank region and weirs. The detailed analysis report carried out in HEC-RAS showed the flood depth and discharge generated at each cross section which were mapped for 10, 50, 100, 200, 500, and 1000 year and 2010 floods. As a result, it was found that severity of the 2010 flood was very high as the water surface elevations produced were much higher than that produced by 100 year return-period flood. Result obtained was designated that more than 400% of the area is likely to be inundated under 100 year return period as compared to the normal flow of the river, where most of this area are found to be agriculture land. The results from this case study clearly indicated that HEC-RAS tool is a very ideal for the simulation of flood levels for a given flood.

According to Elkhrachy (2018) for inundation modelling, HEC-RAS and ArcGIS extension HEC-GeoRAS were used to prepare flood inundation mapping in steady flow conditions. However in this study, due to the missing hydrological data, the HEC-RAS model was not calibrated but used SAR image processing technique from Sentenil-1 satellite to detect the surface water area and compare that obtained results with HEC-RAS model. The four different methods had been used during SAR image processing to detect the water bodies like K-mean solution, Image difference solution, Otsu’s solution and Local adaptive solution. The result showed that Otsu’s solution method gave the biggest water area with 86.1% and image different solution method gave the smallest water area with only 16%. The result also found that the water surface extent from both results HEC-RAS and SAR images were compared and observed that water extend area overlapped by 52 – 86% for both used method.

Significant of DEM resolution

As per the study conducted by Kurniyaningrum et al. (2019) on sensitivity of flow depth inundation based on the micro-scale topography found that DEM resolution of 5m had the significant increase in the inundation extent and depths, appeared to be exceedingly large. This combined effect of flood depth and inundation area had drastically increased as well as the excess in flood extent. They expressed that LIDAR DEM of resolution 1m until 5m affected the propagation of a flood wave in a channel and surrounding floodplain which caused the geometrical properties of topography, impeding as well as accelerating the speed of the flow of water.

Impact of flood extends

According to Bennani et al. (2019) with regard to flood hazard mapping, the river flood inundated areas near to the river such as agriculture fields, building and road connecting from valley to city. Bhattarai et al. (2018) also found that in their study, the large percentage of prone area affected by the flood is an agricultural land due to the location near to river followed by water body and forest. Similar study by

Rahmati et al. (2015), found that the settlement and agriculture land are the most influential flooding affected areas due to proximity of the river. Rahmati et al. (2015) stated that the distance from river is one crucial factor for the impact of flood distribution and its magnitude. From the river, the distance ranges from 2000 to 3000m, there is low possibility of flooding while in the ranges between 200 to 500m and <500m, there is high probability of flooding which means the river from 0 to 1000m, specifies positive influence in flooding whereas areas more than 1000m have negative influence with regard to occurrence of the flood. Therefore, it clearly indicated that flooding occurs commonly to the river bank and less chances of hampering to the places far away from the rivers.

The river in certain regions are more vulnerable to flooding due to variation in altitudes (Bennani et al., 2019). An altitude plays an important role in flood magnitude since different elevations have different climate characteristics which cause the differences in vegetation and stability of the land (Rahmati et al., 2015). Bennani et al. (2019) stated that the magnitude of flood and water depth are significantly higher downstream than the magnitude and depth upstream. The flood extension in the upstream remain near to the main river bed while the extension in the downstream is intensely affected with tremendous extended flooded area because of the contribution of river flow from upstream.

The finding by Curebal et al. (2015) on flood analysis perceived that possible flow values of river and its range depends on the changes in precipitation characteristics of the region. It also declared that the morphology of city and flood plain directly impacts the flood distribution. Due to high morphological characteristics of the area, the volumetric flow rate is high with significant destruction of the vicinity of the area.

However, to obtain the precise result of flood frequency and magnitude, beside meteorological data, a high resolution and precise DEM is the prerequisite to prepare any flood hazard mapping (Curebal et al., 2015). The inundation area can be verified by comparing with actual flood area obtained from satellite images. This real flood event after the flooding can be used as the standard to comprehend the flood magnitudes and its characteristics. Therefore, study by Curebal et al. (2015) showed that the 500-year flood depth provided the minimum error (0.31) in the modelled area and this result directly supported the fit statistics.

CHAPTER III

METHODOLOGY

Study Area

Among the five major and five minor hydrological basin (Figure 5) in Bhutan, Phuntsholing city lies in the extreme downstream of the Amochu basin with the global positioning system (GPS) coordinate of 26° 51' 41.5080" N and 89° 23' 0.9528" E (NEC, 2016). It is located just near to Indian border, sharing border with Indian town Jaigoan, West Bangal. It is the second largest populated city next to capital Thimphu. It is the main commercial trading center of Bhutan and principle trading gateway with India, where all the goods imported from other countries enter Bhutan via road through it (Figure 6).

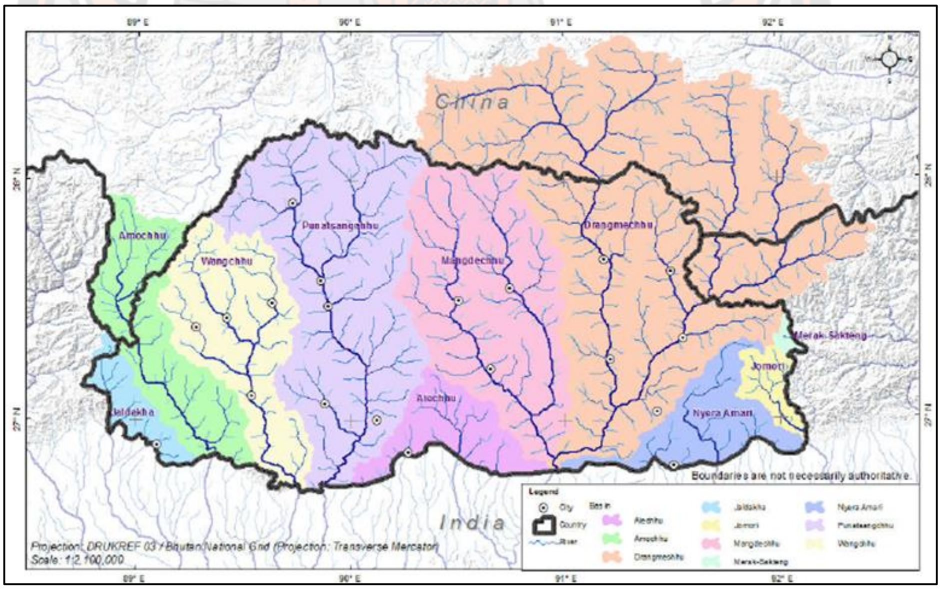

Figure 5 Hydrological Basins Map of Bhutan (NEC 2016)

It experiences heavy rainfall during monsoon season with heaviest average precipitation of 950mm and 850mm in June and August month respectively. The highest average temperature recorded is 32.5 degree Centigrade in June and lowest in January with 13.3 degree Centigrade (Thromde Disaster Management Plan, 2016).

It is also the town where most of the crucial economic/industrial/commercial infrastructures has been located, which faces continuous threats from hydro-meteorological hazards as many rivers converge through this area before flowing into the plains of India. Amochu River which flows very next to it poses the immediate threat to the settlements and properties during every monsoon season.

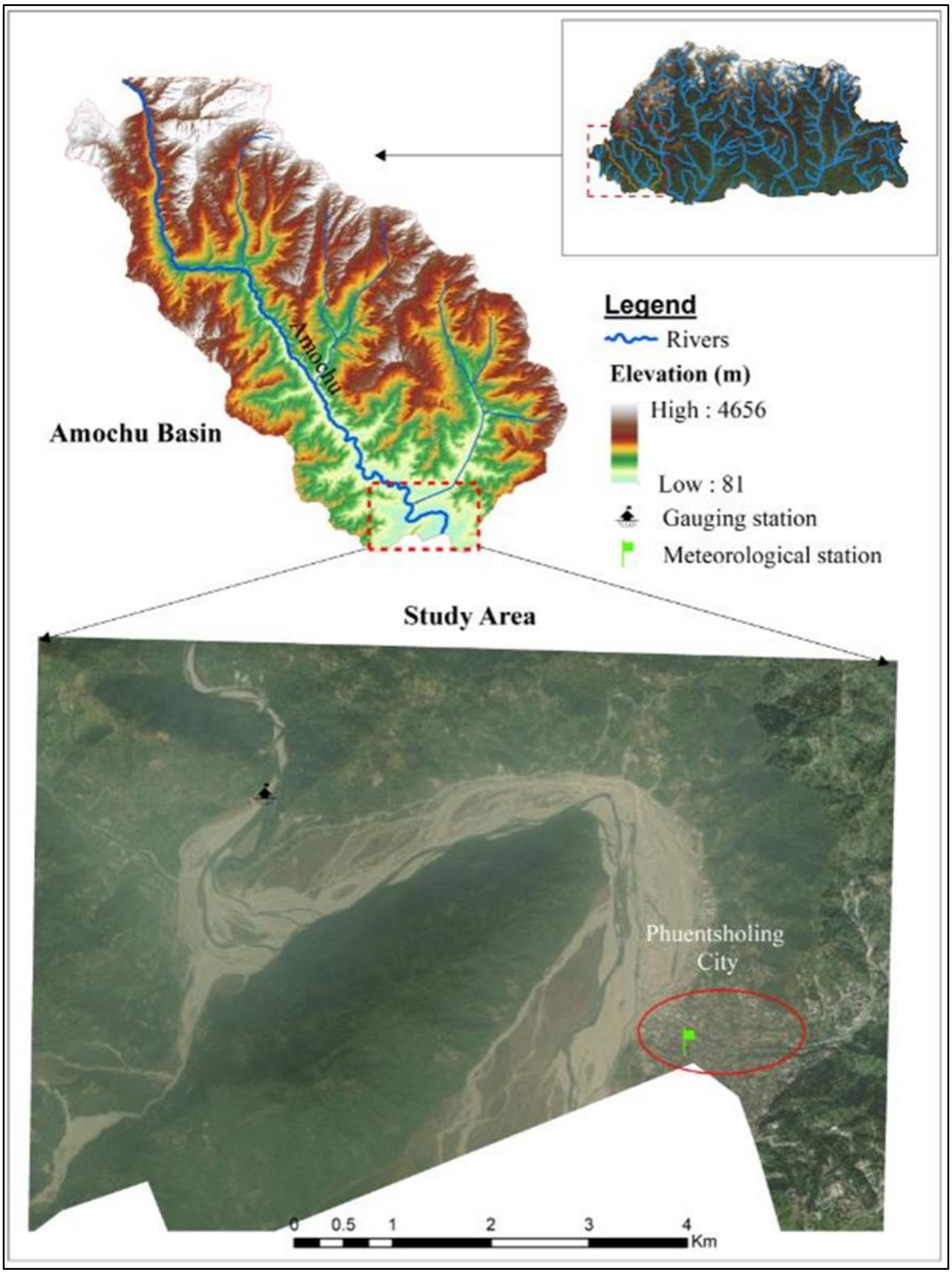

Figure 6 Map showing the Study Area

Master Plan zonation of Phuntsholing city

Due to the fast development of the Phuntsholing city and the limited plain area, the city has been facing serious shortage of land for its expansion. As such under Phuntsholing Township Development Project (PDTP), Phuntsholing city with the Department of Human Settlement (DHS), Ministry of Works and Human Settlement (MoWHS) is planning to extend or accommodate the expansion of the upcoming city by reclaiming the riparian land about 4.62 Km^2 (462 hectares) along the Amochu river bank.

Therefore, to build up the future city, the Phuntsholing Township Development Project (PTDP) has divided the proposed upcoming city into zone based to facilitate the development of the city into phase wise with the schedule to complete all zones by 2035. It is divided into four zones with the development of Zone A at first phase and then follow by other zones, Zone B, Zone C and Zone E in the subsequent phase accordingly (Figure 7). The LAP area will be develop by Department of Human Settlement under Ministry of Works and Human Settlements. All this Zones and LAP comprises of heavily modified with urban and semi urban rural environments utilities as detailed in Table 1 and 2 (CDCL & HCPDPM).

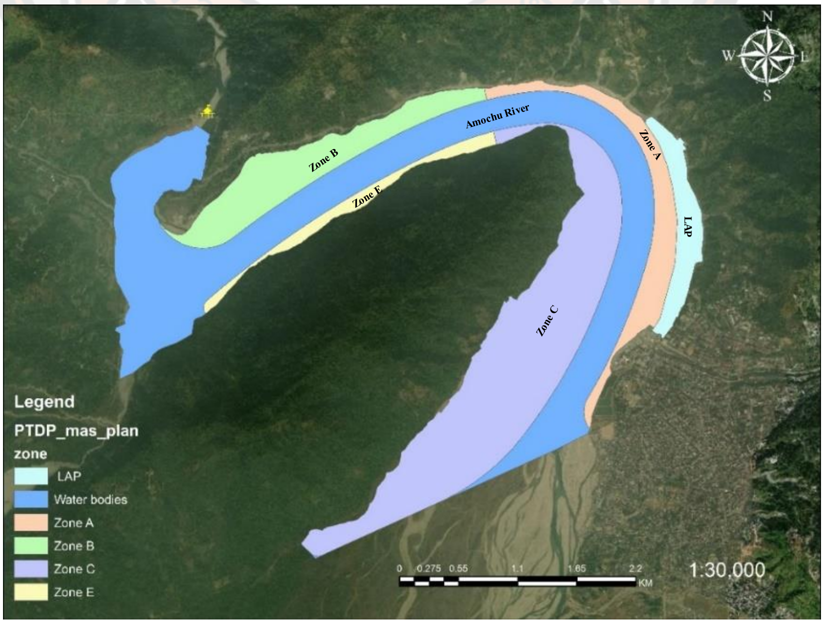

Figure 7 Proposed project master plan of Phuntsholing Township Development Project in zonal bases

Table 1 Description of Zonation and its uses.

Zonation	Precinct	Permissible Uses
Zone A	Public Utility precinct	Public Utility, Heliport.
	Civic Amenity & Social Infrastructure Precinct	Public Institutions, Mercantile-1&2.
	Central Area Precinct	Dwelling-2, Mercantile -1&2, Business, Hospitality-1&2, Public Institutional.
	Residential Mixed Use	Dwelling-1&2, Mercantile -1&2, Business, Religious.
	Riverfront Precinct	Dwelling-2, Mercantile-1&2, Business, Hospitality-1&2, Assembly 1&2.
	Main Street Precinct	Dwelling-1&2, Mercantile-1&2, Business, Religious, Educational-1, Institutional, Hospitality-1&2, Parks, Transport, Public Institutional.
	Green Precinct-1: Riverfront Green	Sports and Leisure, Parks, Transport, Temporary Use, Public Utility.
	Green Precinct-4: Neighborhood Park	Parks, Public Utility.
	Special Development Precinct-3: Business Park	Dwelling 1&2, Mercantile-1, 2&3, Business, Institutional, Religious, Hospitality-1&2, Parks, Industrial-1&2, Transport, Temporary Use, Institutional.
Zone B	Special Development Precinct-2: Hospitality	Dwelling-1&2, Mercantile-1, 2&3, Business, Assembly-1, 2&3, Institutional, Religious, Hospitality-1&2, Sports & Leisure, Parks, Temporary Use.
	Special Development Precinct-3: Business Park	Dwelling 1&2, Mercantile-1, 2&3, Business, Institutional, Religious, Hospitality-1&2, Parks, Industrial-1&2, Transport, Temporary Use, Institutional.
	Green Precinct-1: Riverfront Green	Sports and Leisure, Parks, Transport, Temporary Use, Public Utility.
Zone C	Public Utility precinct	Public Utility, Heliport.
	Residential Mixed Use	Dwelling-1&2, Mercantile-1&2, Business, Religious.
	Main Street Precinct	Dwelling-1&2, Mercantile-1&2, Business, Religious, Educational-1, Institutional, Hospitality-1&2, Parks, Transport, Public Institutional.

Table 1 Description of Zonation and its uses (Cont.)

Zonation	Precinct	Permissible Uses
Zone C	Riverfront Precinct	Dwelling-2, Mercantile-1&2, Business, Hospitality-1&2, Assembly 1&2.
	Central Area Precinct	Dwelling-2, Mercantile-1&2, Business, Hospitality-1&2, Public Institutional.
	Civic Amenity & Social Infrastructure Precinct	Public Institutions, Mercantile-1&2.
	Green Precinct-1: Riverfront Green	Sports and Leisure, Parks, Transport, Temporary Use, Public Utility.
	Green Precinct-2: Buffer & Forest Green	Parks, Public Utility.
	Green Precinct-3: Biodiversity Park	Parks, Public Utility, Mercantile-1, Urban Agriculture & Hospitality-1.
	Green Precinct-4: Neighborhood Park	Parks, Public Utility
	Special Development Precinct-1: Educational & Healthcare	Dwelling-1&2, Mercantile-1, Business, Hospitality, Assembly-1&3, Institutional, Religious, Sports & Leisure, Parks, Temporary use, Public Utilities.
	Special Development Precinct-2: Hospitality	Dwelling-1&2, Mercantile- 1, 2&3, Business, Assembly-1, 2&3, Institutional, Religious, Hospitality-1&2, Sports & Leisure, Parks, Temporary Use.
	Special Development Precinct-3: Business Park	Dwelling-1&2, Mercantile-1, 2&3, Business, Institutional, Religious, Hospitality-1&2, Parks, Industrial- 1&2, Transport, Temporary Use, Institutional.
	Special Development Precinct-4: Cultural Center	Assembly-3, Institutional, Hospitality-1&2, Sports & Leisure, Parks, Temporary Uses.
Zone E	Special Development Precinct-2: Hospitality	Dwelling-1&2, Mercantile- 1, 2&3, Business, Assembly-1, 2&3, Institutional, Religious, Hospitality-1&2, Sports & Leisure, Parks, Temporary Use.
	Special Development Precinct-3: Business Park	Dwelling-1&2, Mercantile-1, 2&3, Business, Institutional, Religious, Hospitality-1&2, Parks, Industrial- 1&2, Transport, Institutional, Temporary Use.
LAP	LAP Precinct	Urban Village-1, Services, National open green services, Green spaces system.

Table 2 Classification of permissible uses.

Use Classification	Uses
Dwelling-1	Dwelling-1 Detached dwelling unit, Semi-detached dwelling unit, Tenement, Cottage Industry, Pre-school, Farm House.
Dwelling-2	Apartment, Hostel.
Mercantile-1	Shop, Restaurant, Shopping Centre, Cafes, Bars, Coffee Shops.
Mercantile-2	Shopping Mall.
Mercantile-3	Wholesale, Agriculture Produce Market.
Business	Offices for Individuals, Corporate Offices, Call centers, Training Centers, Clinic, Fitness Centre, Nursing Home, Banks.
Educational-1	Preschools, Primary Schools, Secondary & Higher Secondary Schools.
Educational-2	College, Polytechnic, University.
Assembly-1	Community Hall, Banquet Hall.
Assembly-2	Theatre, Multiplex, Clubs.
Assembly-3	Convention Centre, Exhibition Hall, Auditorium, Planetarium, Stadium, Museum, Exhibition Halls.
Institutional	Research Centers, Hospital.
Religious	Temples, Church, Mosque, Gurudwara, Chorten, Prayer Wheel, Lhakhang, Mani Walls.
Hospitality-1	Bed and Breakfast, Guest House, Lodging & Boarding, Hotel, Motel, Serviced Apartments.
Hospitality-2	Hotel, Motel, Resorts, Serviced Apartment in Plots with area of $2000m^2$ or more.
Sports & Leisure	Sports Complex, Swimming Pool, Golf Course, Playfield, Camping Ground, Facility for water sports, Theme/Amusement Park, Aquarium, Zoo & Botanical Garden.
Parks	Gardens, Parks, Nursery, Green House, Play Fields.
Industrial -1	Auto Repair Workshop, Wood Workshop, Fabrication Workshops, Public-Garage, Assembly Unit, Farm Produce and Food Storage, Green Industries, Printing Press, Fuelling Station.
Industrial-2	Stone Cutting and Polishing, Slaughter House, Meat Processing Units, Leather Processing Units, Cold Storage, Fuelling Station.
Transport	Truck Terminal, Bus Terminal (by private enterprise).
Urban Agriculture	Horticulture, Dairy Development, Fisheries, Animal Rearing & Breeding, Natural Resource and Sanctuary, Tannery, Saw Mill, Agricultural Vocational Training.
Temporary Use	Fair, Circus, Exhibition, Seasonal Fruit/Vegetable/Flower Markets, Trade Fairs, Expos.

Table 2 Classification of permissible uses (Cont.)

Use Classification	Uses
Public Utility	Sub-station, Bus Station and Terminals, Fuelling Station, Parking, Multi-level Parking; Infrastructure for Water Supply, Purification Plant, Pumping Station, Electricity Sub-station; Drainage, Sanitation, Domestic Garbage Disposal Collection, Solid Waste, Transfer Station; Pumping Station, Electricity, Purification Plant, Fire Stations.
Public-Institutional	Post Office; Postal, Telegraph, and Communication Networks; Police Station, Fire Station, Government & Semi-government Medical Facility; Zonal Offices for Appropriate Authority, Public Library, Civic Centre, Offices for Government & Semi-government, Banks, Gymnasium, Sports Centre, Swimming Pool.

Data

Advanced Land Observatory Satellite - Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR) DEM 12.5m is resampled into DEM 5m spatial resolution to facilitate the simulation in the study. It was developed through Japan Aerospace Exploration Agency (JAXA) which is freely available for download from Alaska Satellite Facility website (JAXA/METI, 2015). The mission is to contribute the fields of mapping, land-coverage observation, disaster monitoring and resource surveying. Hydro-meteorological data were acquired from National Center for Hydrology and Meteorology (NCHM) office for Doyagang gauging station from 2006 to 2018. Topographical data and Land Use Land Cover map (LULC 2016) were acquired from National Land Commission (NLC) of Bhutan as this data are very essential in the production of the flood map (Figure 8). The Administrative map of the study area which defined the boundary of the region of study was obtained from the National Static Bureau (NSB) of Bhutan. Master plan of future city of the study area, developed by Phuntsholing Township Development Project (PTDP) and Local Area Plan (LAP) were obtained from Department of Human Settlement (DHS), Ministry of Works and Human Settlement (MoWHS), which are required at the final stage to compute the flood impact of the study area (Figure 7).

Requirement of all this essential data, sufficiently for the flood mapping is very important to prepare the Flood hazard and inundation map. The data used are of two categories, which are GIS data and meteorological data.

(a) GIS data

- The Administrative map of the study area which defined the boundary of the region.
- Digital Elevation Model (DEM 5m, resampled from 12.5m special resolution).
- Land used Land cover data (2016).
- Master plan of Phuntsholing Township Development Project (PTDP) and Local Area Plan (LAP) for future city of study area.

(b) Meteorological data and Hydrological Data

- Daily Rainfall (Since 1996 till 2018)
- Daily discharge (Since 2006 till 2018)

Rainfall data for Phuntsholing (Station 11150046) were available from 1996 and the discharge data for Doyagang gauging station (11210045) from 2006 onwards.

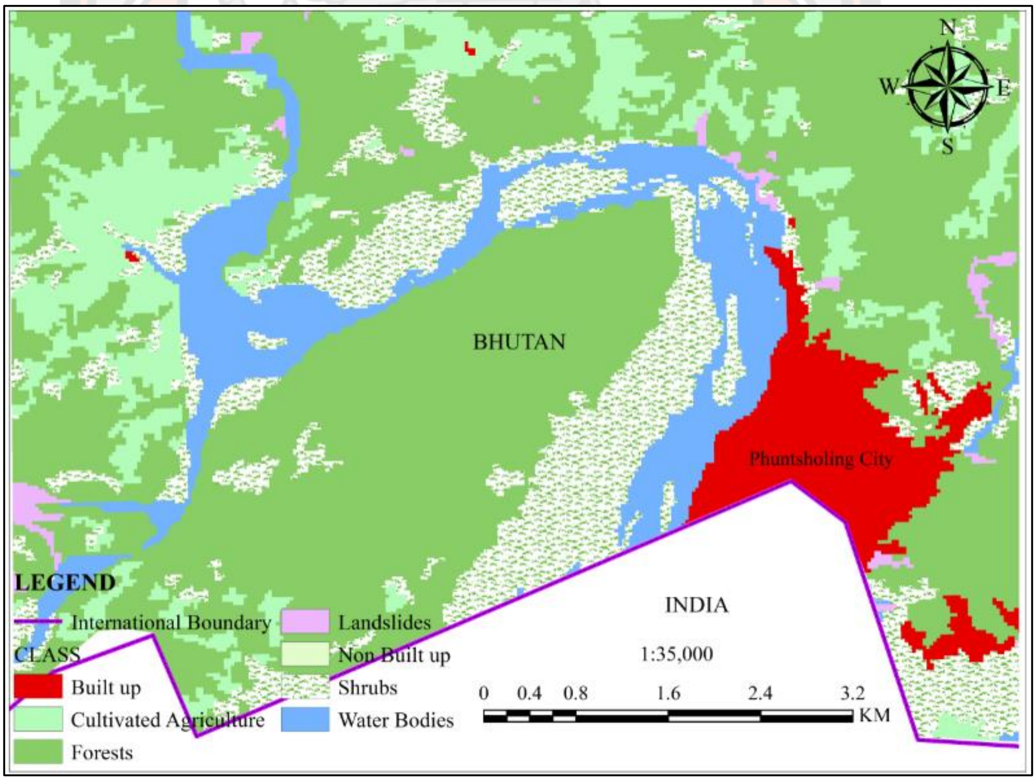

Figure 8 Land Use Land Cover map of a study area (LULC 2016)

Resampling of Digital Elevation Model (DEM)

DEM 12.5m resolution was converted to point vector format. This process will take center point of each pixel from 12.5m DEM assigned with respective elevation values. Elevation values in respective points are used to generate 5m resolution DEM with the help of spatial interpolation. In this case inverse distance weighted (IDW) interpolation technique was used. The IDW is a deterministic interpolation method where cell values are determined using a linear weighted combination of values of nearby sample points. Influence of sample points decreases with increase in distance away from the points (Gimond, 2019).

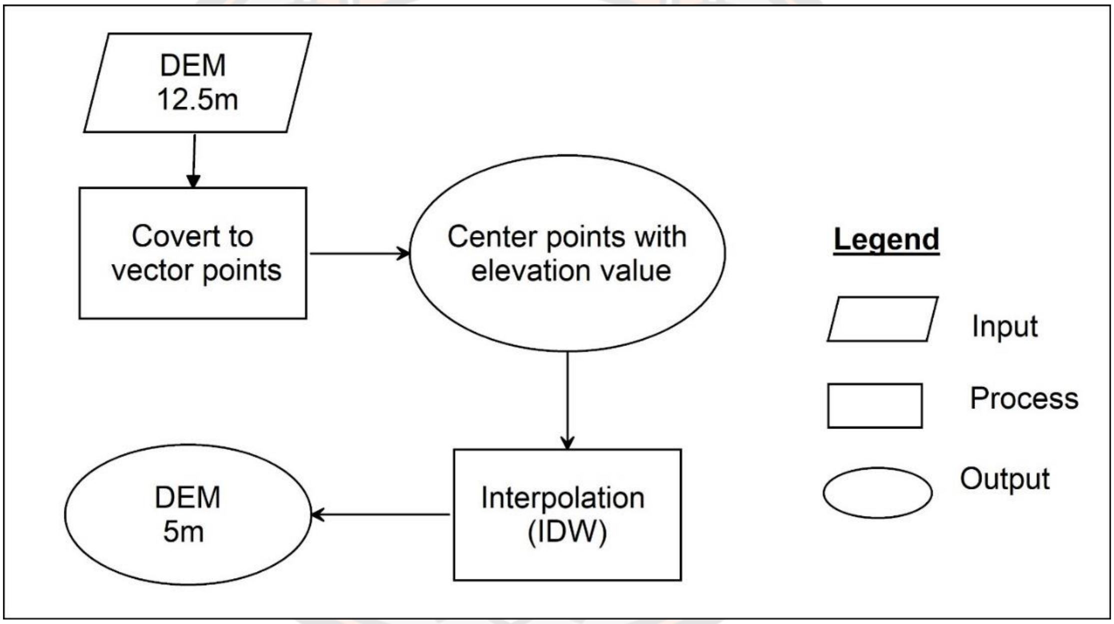

Figure 9 Resampling of 12.5m resolution DEM to 5m DEM using IWD technique

Methodology

The general methodology is to generate flood inundation map of the study area by processing the data in ARCGIS, HEC-GeoRAS and HEC-RAS tool as one dimensional flood model. The input data such as DEM5m, resample from DEM12.5 Alos Palsar, peak discharges for different return periods were obtained from flood frequency analysis and manning’s coefficient for mountainous stream were extracted with the information from land use land cover map using Chow (1959) criteria. Rainfall data from 1996 till 2018 were also available but only flow data from 2006 to

2018 (Table 3) were analyzed in this study to obtain the peak discharges for different return period. There is only one stream gauging station in this study area which is just located next to Amochu motorable bridge at the upstream.

Table 3 Annual instant maximum flows of Amochu River at Doyagang gauging station.

Sl No.	Year	Discharge (Q) (m^3/s)	Sl No.	Year	Discharge (Q) (m^3/s)
1	2006	598	8	2013	925
2	2007	1033	9	2014	1391
3	2008	1225	10	2015	901
4	2009	2557	11	2016	1408
5	2010	1021	12	2017	593
6	2011	390	13	2018	326
7	2012	1224			

The maximum flow data of 2 year, 5 year, 10 year, 25 year, 50 year, 100 year and 1000 year return period were mapped to get the inundation area by using Log Normal and Log-Pearson III flood frequency techniques, which was applied to 13 years maximum flow data of the gauging station. The flow chart model using ArcGIS, HEC-GeoRAS & HEC-RAS described about the procedures to extract flood inundation map as detailed in Figure 10: (a) DEM was prepared based on resampled DEM 5m resolution, (b) HEC-GeoRAS was used to prepared the geometric data of the study area, (c) Flood frequency analysis was used to derive the floods corresponding to different return periods obtain from observed discharge, (d) HEC-RAS model was conducted to perform detail analysis of the flow corresponding to different return period floods, (e) Result from HEC-RAS model was then analyzed in ArcGIS to get the Flood inundation map, (f) Flood plain map of different flood from peak flow data were generated. (g) Modelled flood plain map were overlaid with the present and future city plan in order to get the affected area of the study area. This method can also be apply to any river system for the mapping of floodplain.

Depending upon the types of channel, slope and land use land cover of the study area, flood model will be generated by using corresponding manning's n value in the HEC-RAS model (Jigme Tenzin, 2017).

The flood frequency analysis (FFA) were used to estimate the water surface profile and flood inundation extend under different flood intensities. There are four commonly used FFA distribution technique/methods like Log-Pearson Type III Distribution, Log Normal Distribution, Normal Distribution and Gumbel value Distribution were used in analyzing of flood data (Khattak et al., 2015). In this study, Log-Pearson type III (LP3) distribution and Log Normal technique were used to obtain the peak discharge of different return period, which were used as an input flow data in HEC-RAS model. After that, flood hazard map is generated by using Hydrologic Engineering Centers River Analysis System (HEC-RAS) as one dimensional flood model.

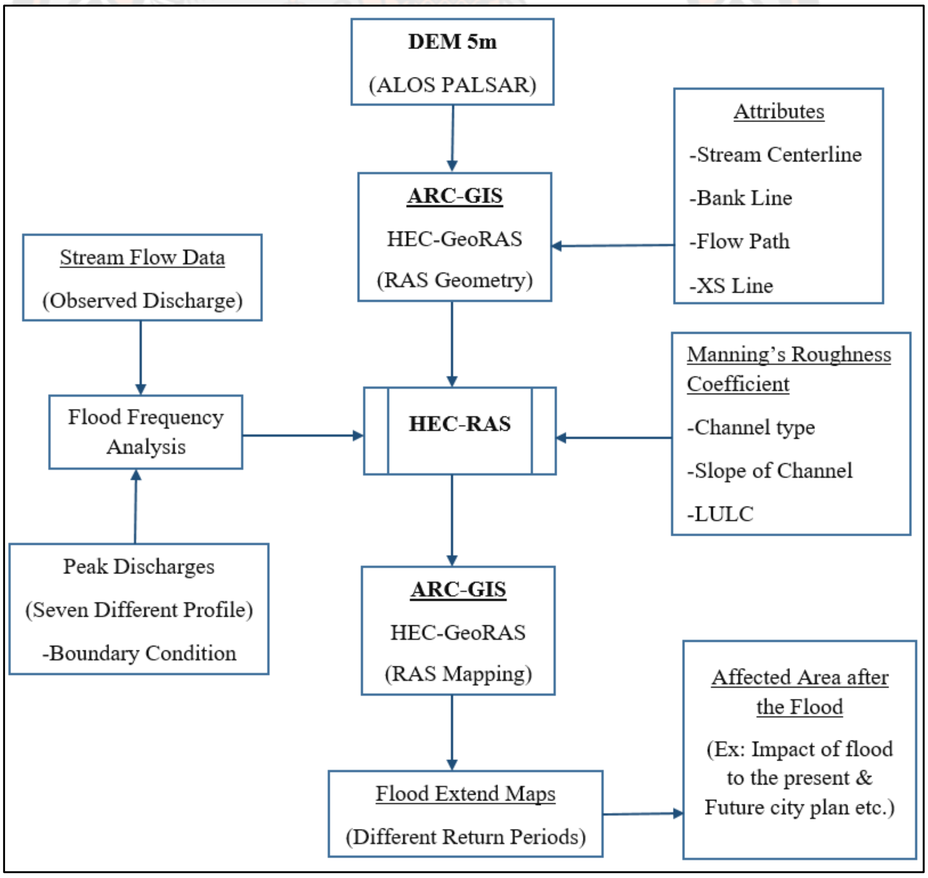

Figure 10 Flow chart showing the modeling using ARCGIS, HEC-GeoRAS & HEC-RAS

Flood Frequency Analysis

There is only one stream gauging station in this study area which is just located next to Amochu motorable bridge at the upstream with the flow data of 13 years from 2006 to 2018. Therefore, to predetermine the peak discharge for different return period, the observed flow data from the Doyagang gauging station were analyzed in the flood frequency method, which are used as an input flow data in HEC-RAS model to generate flood map for different return period.

The main objective of frequency analysis of hydrologic data is to associate recurrence frequencies of inundations through the use of probability distributions of extreme inundations (Te Chow et al., 1988). Flood frequency analysis is one of the main tools for estimating river discharge for a given return period. It involves the fittings of annual peak discharges over a period of observation into a probability model for the given catchment of the study area. Then the model parameters evolved from the flood frequency method are used to forecast the extreme events of large recurrence interval. The magnitude of an extreme event is inversely related to its frequency of occurrence, very severe events occurring less frequently than more moderate events (Te Chow et al., 1988). Authentic flood frequency estimates are very crucial for the flood plain management to defend the public, settlements by designing and locating the appropriate flood protection measures (Chikabvumbwa, 2019). Similarly, as per the Deraman et al. (2017), analysis of maximum annual peak discharge of different return periods is a basic tool for safe and economic planning and design of small dams, bridges and drainage work as well as for determining drainage coefficients.

Frequency analysis uses frequency factors to calculate the magnitudes of extreme events by the methods of 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. The statistical information such as mean values, standard deviations, skewness and recurrence intervals were calculated. These statistical data are then used to construct frequency distributions, interpreted in the graph and table that gives the various discharges as a function of recurrence interval or exceedance probability for different return periods of the study area (Deraman et al., 2017). Most conventional applied techniques for annual peak series to determine the peak discharge for different return periods are:

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

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

Among the four flood frequency techniques applied in this study for flood frequency analysis, Log Normal distribution and Log-Pearson III methods has been adopted to the get the peak discharge for different return period, which has been used as input flow data in HEC-RAS to get the inundation maps. Log Normal distribution gave the highest peak discharge for different return period, which better fits the model and nevertheless Log-Pearson III technique too has been used in this study to get the different inundation maps and compared the affected area of these two techniques, as in most of the researches carried out by other researcher found Log-Pearson III distribution has a well-known mathematical feature and yields correct results for most of the rivers (Curebal et al., 2015; Khattak et al., 2015).

Therefore, Peak discharged obtained from Log Normal distribution technique and Log-Pearson III flood extend of different returns period of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years and 1000 years has been used to map the flood extend of study area.

Hydrodynamic Model

HEC-GeoRAS is an extension of ArcGIS tool which was developed to process geographic data to be used in HEC-RAS module (Hydraulic Engineering Center, 2011). Digital Elevation model (DEM 5m) was used in producing triangular irregular network (TIN) for creating attributes by digitizing stream centerline, bank line, flow path, river cross-section and other geometry information using HEC-GeoRAS in GIS. After preparation of this RAS geometry information, RAS GIS import file is generated that can be used as input data for the HEC-RAS model. But before creating an import file we have to make sure that right layer is exported by verifying the layers in each tab in layer setup interface in RAS Geometry. Then after verifying all layers and tables, RAS Geometry file is ready to be exported to HEC-RAS model.

HEC-RAS is a software developed by US Army Corps of Engineers used to simulate water surface profiles corresponding to different peak discharge (Hydraulic Engineering Center, 2016). It can perform one-dimensional steady, one and two dimensional unsteady flow hydraulic, sediment transport computation and water temperature modeling etc. It is one of the most capable approach used for generating flood plain map worldwide (Demir & Kisi, 2015; El-Naqa & Jaber, 2018). It computed water surface profiles from one cross section to another by using energy equation (Figure 11). In this study, one-dimensional steady flow modeling was analyzed to get the flood inundation map.

The geometry data created in ArcGIS were imported to HEC-RAS and accordingly necessary correction were carried out to the bank line in aligned with the individual cross-section profile. This was performed by using graphical cross section editor selecting individual bank point moving either to the left or right until it is placed into its right location. HEC-RAS model used several input parameters such as river station number, left and right bank station, manning roughness coefficient value and reach length etc. at every cross section to depict elevation, shape and relative location along the stream (Figure 12). The manning roughness coefficient value (Table 4) were assigned in accordance with the Ven Te Chow for the mountainous stream as 0.04 for the bottom and 0.03 for the river bank in together with the information extracted from land use land cover map of the study area (Te Chow, 1959). The peak discharge for each return period from Doyagang gauging station were entered into the steady flow editor along with the boundary condition. There were four available external boundary condition types in the steady flow analysis where normal depth condition was used in this study as 0.005 at the downstream for all surface profiles. After assigning all the river geometry data, computation of steady flow analysis was carried out for subcritical flow regime in order to obtain the water depth, velocity and water surface elevation respectively in HEC-RAS. Figure 13 shows the output of a flood for different peak discharge after computing the steady flow.

Finally, the results from the HEC-RAS model were exported to ArcGIS in the form of RAS GIS export file through RAS mapping using HEC-GeoRAS tool. The file is converted to XML format from SDF file before flood plain inundation mapping was generated by performing water surface generation and flood plain delineation respectively (Hydraulic Engineering Center, 2011). Ultimately, Flood inundation map of study area is generated by converting the water surface TIN to GRID, which was subtracted from water surface grid. All the water surface grid cells after subtraction will have positives values which are commuted to polygons to obtain the final flood inundation maps (Merwade, 2016).

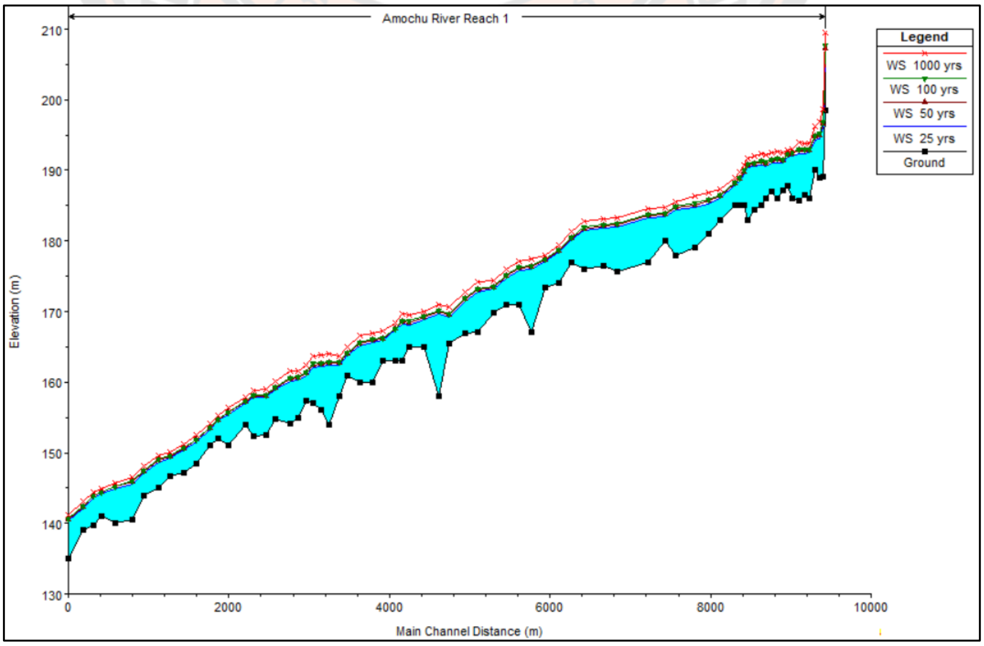

Figure 11 Water surface profile of different return period flood

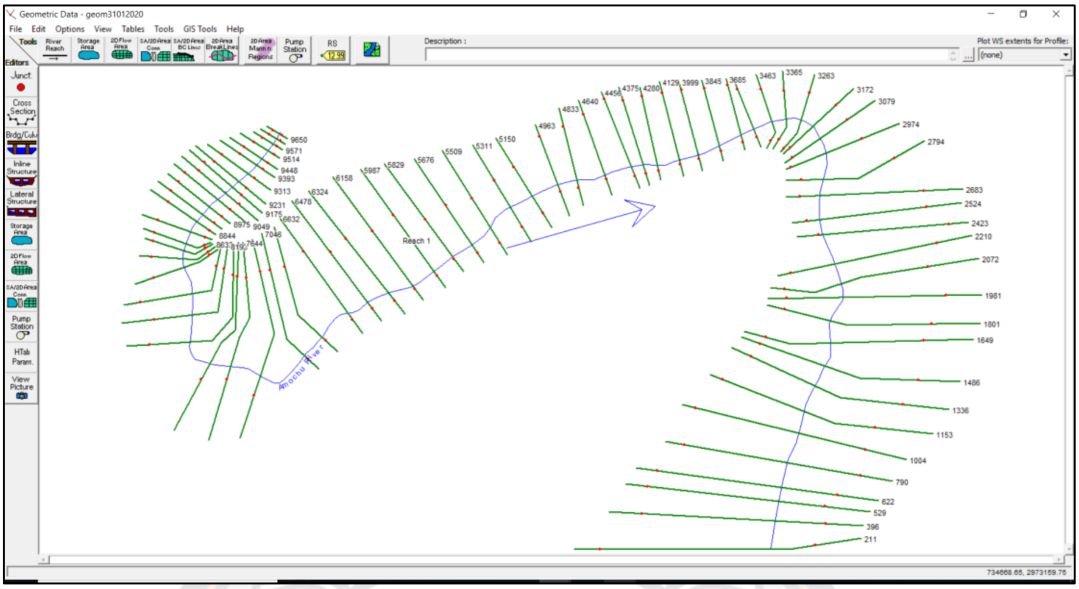

Figure 12 River geometry for the steady flow analysis

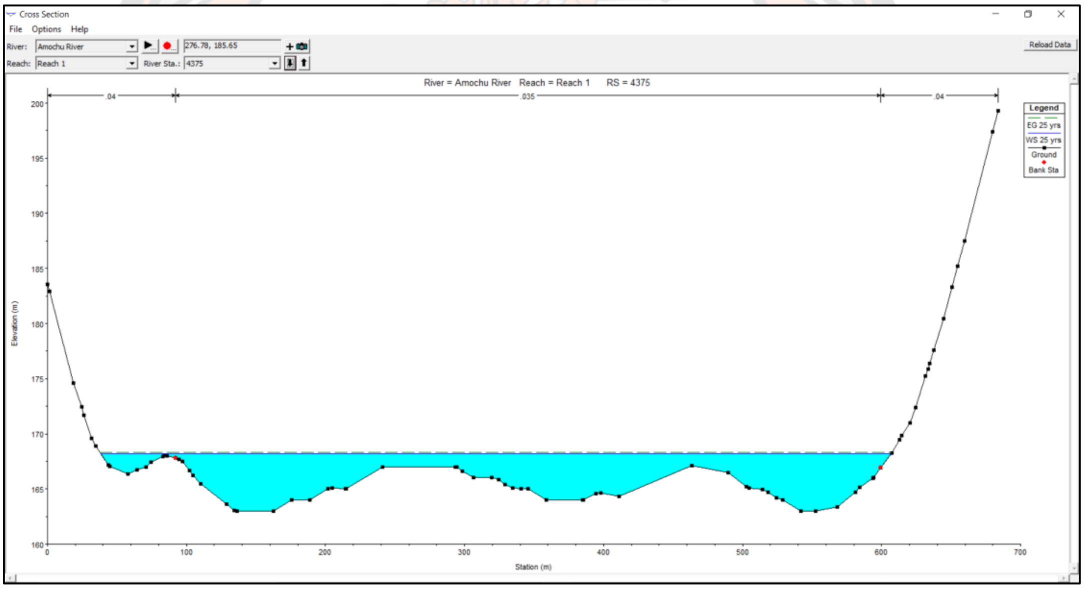

Figure 13 Graphical representation of cross section for steady flow

Table 4 Manning's n for Channels.

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at flood stage < 100 ft.)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
b. same as above, but more stones and weeds	0.03	0.035	0.04
c. clean, winding, some pools and shoals	0.033	0.04	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.05
e. same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. same as "d" with more stones	0.045	0.05	0.06
g. sluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.1	0.15
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
b. bottom: cobbles with large boulders	0.04	0.05	0.07
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.03	0.035
2. high grass	0.03	0.035	0.05
b. Cultivated areas			
1. no crop	0.02	0.03	0.04
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.03	0.04	0.05
c. Brush			
1. scattered brush, heavy weeds	0.035	0.05	0.07
2. light brush and trees, in winter	0.035	0.05	0.06
3. light brush and trees, in summer	0.04	0.06	0.08
4. medium to dense brush, in winter	0.045	0.07	0.11
5. medium to dense brush, in summer	0.07	0.1	0.16
d. Trees			
1. dense willows, summer, straight	0.11	0.15	0.2
2. cleared land with tree stumps, no sprouts	0.03	0.04	0.05
3. same as above, but with heavy growth of sprouts	0.05	0.06	0.08

Table 4 Manning's n for Channels (Cont.)

Type of Channel and Description	Minimum	Normal	Maximum
4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.08	0.1	0.12
5. Same as 4. with flood stage reaching branches	0.1	0.12	0.16
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.02
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.03
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.03
2. grass, some weeds	0.025	0.03	0.033
3. dense weeds or aquatic plants in deep channels	0.03	0.035	0.04
4. earth bottom and rubble sides	0.028	0.03	0.035
5. stony bottom and weedy banks	0.025	0.035	0.04
6. cobble bottom and clean sides	0.03	0.04	0.05
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.05	0.06
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.04
2. jagged and irregular	0.035	0.04	0.05
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.05	0.08	0.12
2. clean bottom, brush on sides	0.04	0.05	0.08
3. same as above, highest stage of flow	0.045	0.07	0.11
4. dense brush, high stage	0.08	0.1	0.14
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.01	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.01	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. un planed	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018

Table 4 Manning's n for Channels (Cont.)

Type of Channel and Description	Minimum	Normal	Maximum
5. lined with roofing paper	0.01	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	0.02
4. unfinished	0.014	0.017	0.02
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	0.02	-
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	0.02
2. random stone in mortar	0.017	0.02	0.024
3. cement rubble masonry, plastered	0.016	0.02	0.024
4. cement rubble masonry	0.02	0.025	0.03
5. dry rubble or riprap	0.02	0.03	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.02	0.025
2. random stone mortar	0.02	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	0.03
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	0.03	-	0.5

Source: (Chow, 1959)

CHAPTER IV

RESULTS

Flood Frequency Analysis

Flood frequency analysis is one of the main tools for estimating river discharge for a given return period. It used to forecast the design floods of large recurrence interval for the sites along a river by using four different techniques like Log-Pearson type III, Log Normal, Normal distribution and Gumbel distribution. These techniques involves using observed annual peak flow discharge data of 13 years from 2006 to 2018 from the Doyagang gauging station. Mean values, standard deviations, skewness and recurrence intervals were used to obtain the maximum discharge rate for different return periods using observed annual peak flow (Table 5). The discharge rate figures are then used to construct frequency distributions interpreted in the graph (Figure 14) that gives the various discharges as a function of recurrence interval or exceedance probability for different return periods of the study area (Deraman et al., 2017).

Table 5 Maximum instantaneous discharge for different return periods using FFA techniques for Doyagang gauging station.

FFA Techniques	Peak discharges for each return periods in m^3/sec						
	2 year	5 year	10 year	25 year	50 year	100 year	1000 year
LOG-PEARSON III	937.93	1476.54	1837.8	2296.66	2632.47	2957.06	3279.11
LOG NORMAL	911.19	1460.88	1869.58	2503.07	3029.54	3356.85	5151.67
NORMAL	1045.68	1531.08	1784.74	2084.8	2281.1	2386.59	2827.03
GUMBEL	950.98	1460.44	1797.75	2223.94	2540.11	2853.95	3890.97

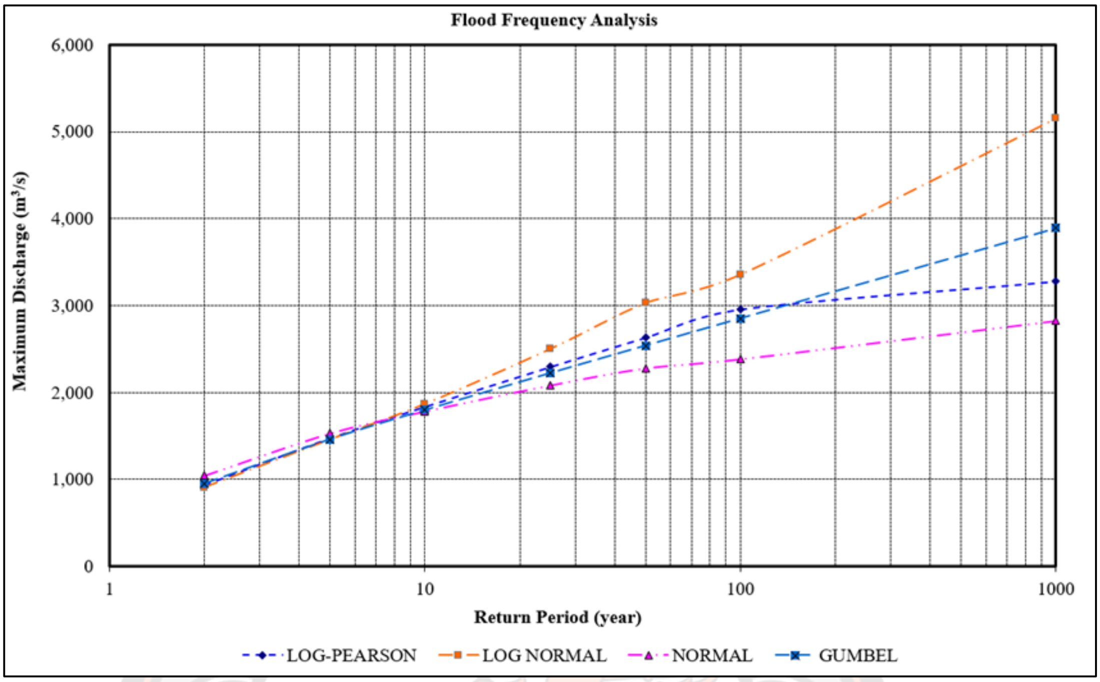

Figure 14 Comparison of flood by different flood frequency analysis technique

The assessment of flood discharges indicate that the peak discharge is increasing with increased in duration of return period. Among the different techniques from the result reflected in figure 13, the Log Normal distribution gave the highest discharges with the flow data used from the gauging station of Doyagang, which better fitted the model in this study area showing adequately satisfactory (Bennani et al., 2019). Log Normal is followed by Log-Pearson III, Normal and Gumbel distribution techniques.

Therefore, Log Normal distribution and Log-Pearson III methods has been used to the get the peak discharge for different return period, which has been used as input flow data in HECRAS to get the inundation maps. Log-Pearson III technique has been adopted in this study to get the different inundation maps and compared the affected area of these two techniques, as in most of the researches carried out by other researcher found Log-Pearson III distribution has a well-known mathematical feature and yields correct results for most of the rivers (Curebal et al., 2015; Khattak et al., 2015).

The annual instant maximum flow value of Amochu River at Doyagang gauging station measured from 2009 extreme flood event induced by cyclone Aila was 2557 m^3/sec. While comparing to the maximum peak discharge for different return periods, the 2009 flood event demonstrate that it corresponds to the 25 year return period carried out with Log Normal and 50 year by Log-Pearson III technique respectively (Curebal et al., 2015). As such, the peak discharge of those return periods which has equal or more than actual flow value of 2557 m^3/sec recorded at Doyagang gauging station were computed to derived the affected area of the study area (Table 7-10 & Figure 30-47).

Hydraulic Modeling of the Flood

Hydraulic modeling and determination of the flood extends in the study area during the extreme events are very beneficial for risk managers, disaster response or emergency services. Further, inundation mapping will also expedite policy makers and planners in the development of flood mitigation measures (structure and non-structural) or manage natural risk for the future planning in the Phuntsholing city. The model developed can also be used for flood forecasting during different flood scenario. Owing to all this references, hydraulic modeling is carried out with DEM 5m spatial resolution, resampled from Alos Palsar DEM 12.5m. One dimensional open channel steady flow model was run with HEC-RAS software using the determined geometric data and flow values of various recurrence intervals.

After determining the peak discharge as an input data in hydraulic modeling, flood inundation maps were generated corresponding to different return periods of 2 year, 5 year, 10 year, 25 year, 50 year, 100 year and 1000 year. The flood inundation maps for 7 different return period has been generated which shows the details of affected area and its depth to the present and future city of the study area. LULC 2016 was used to assess the affected area of the present city, while master plan of Phuntsholing Township Development Project (PTDP) and Local Area Plan (LAP) prepared by Ministry of Works and Human Settlement (MoWHS) were used to find out the affected area of future city of study area.

The maximum inundation depth values obtained as result of Log Normal technique were found to be 8.31, 8.86, 9.16, 9.61, 9.95, 10.13 and 11.62m, for 2 year, 5 year, 10 year, 25 year, 50 year, 100 year, and 1000 year flow data respectively.

Similarly, for Log-Pearson III, it was found to be 8.34, 8.87, 9.14, 9.47, 9.70, 9.90 and 10.09m for different recurrent return periods (Table 6).

When the results are assessed together, it is understood that there is not much significant difference between the depth value created by Log Normal and Log-Pearson III techniques, although we can observed little difference in depth value within the Log Normal created by 1000 year inundation water at 11.62m, and the depth value created by 100 year as 10.13m. This might be due to the resampled 5m DEM, which cannot reflect the current river bed form in DEM. However, the depth value created by 25 years in Log Normal and 50 year return period in Log-Pearson III, whose discharge data corresponds to the observed discharge data of 2009 extreme flood event of 2557 m^3/s remains quite satisfactory as there are not much significant difference comparing to actual depth value of 2009 at 8m to 9m observed in the field (Figure 15).

Table 6 Maximum inundation depth corresponding to flow data of different return period with respect to Log Normal & Log-Pearson III techniques.

Sl No.	Return Periods	FFA Techniques	
		Log Normal (m)	Log-Pearson III (m)
1	2 year	8.31	8.34
2	5 year	8.86	8.87
3	10 year	9.16	9.14
4	25 year	9.61	9.47
5	50 year	9.95	9.7
6	100 year	10.13	9.9
7	1000 year	11.62	10.09

Figure 15 Actual depth value of 2009 extreme flood event at 8m to 9m observed at Doyagang gauging station

The flood inundation map with respect to Log Normal and Log-Pearson III techniques were as depicted in Figure 16 to 29:

(a) Inundated map for different return periods with relative to Log Normal frequency technique:

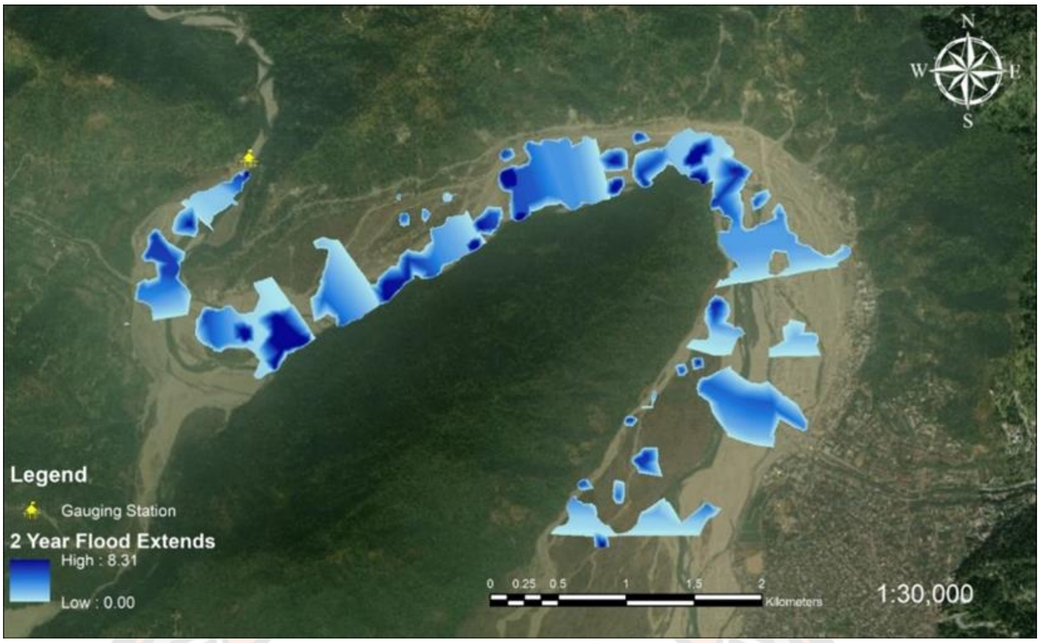

Figure 16 2-year flood extend for Amochu River in Phuntsholing City

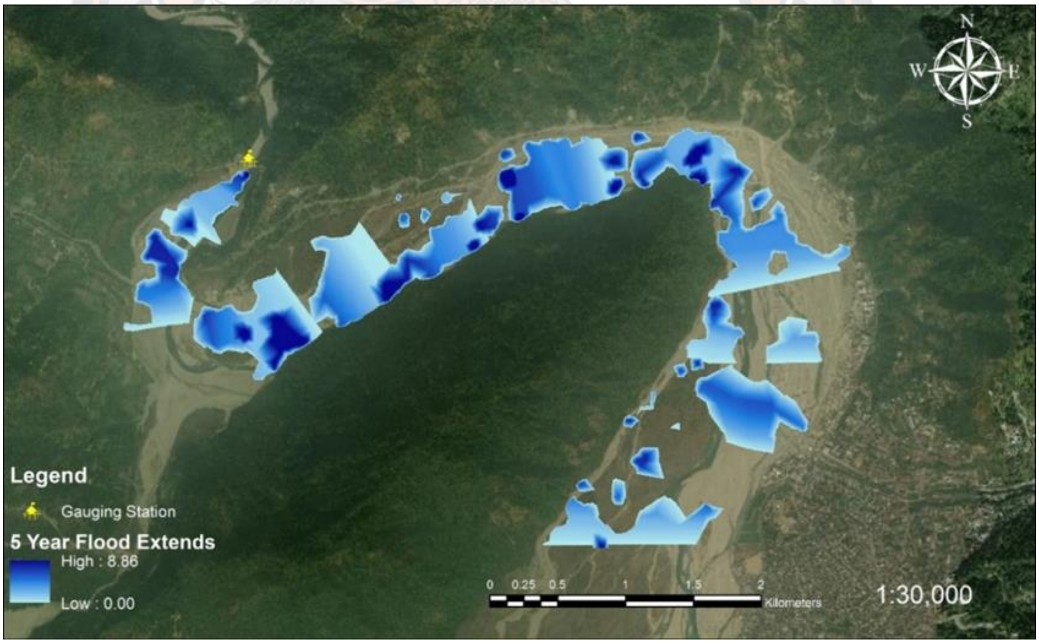

Figure 17 5-year flood extend for Amochu River in Phunstholing City

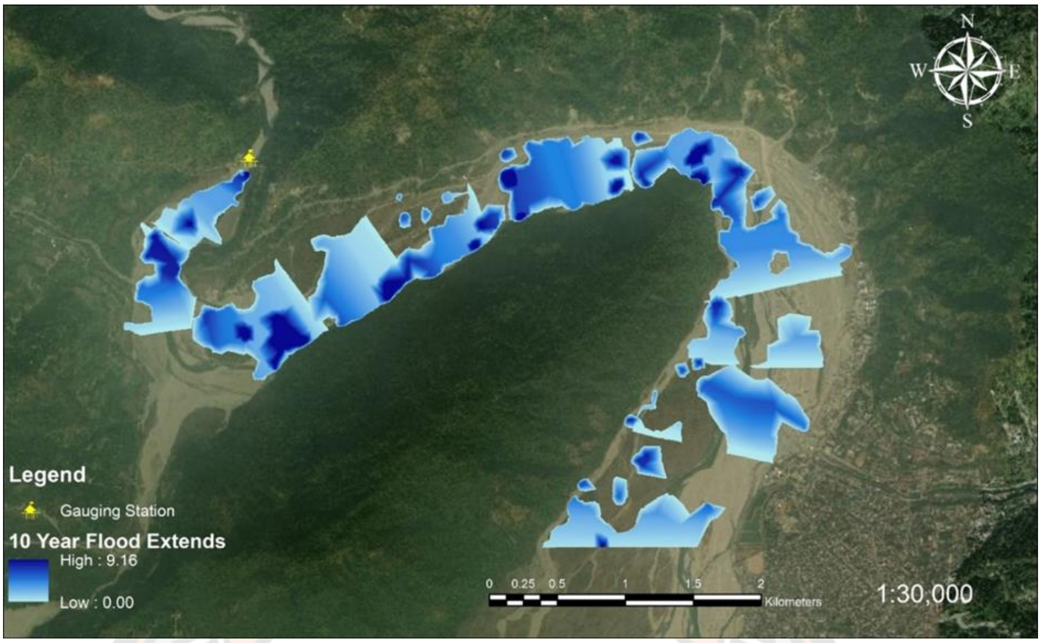

Figure 18 10-year flood extend for Amochu River in Phuntsholing City

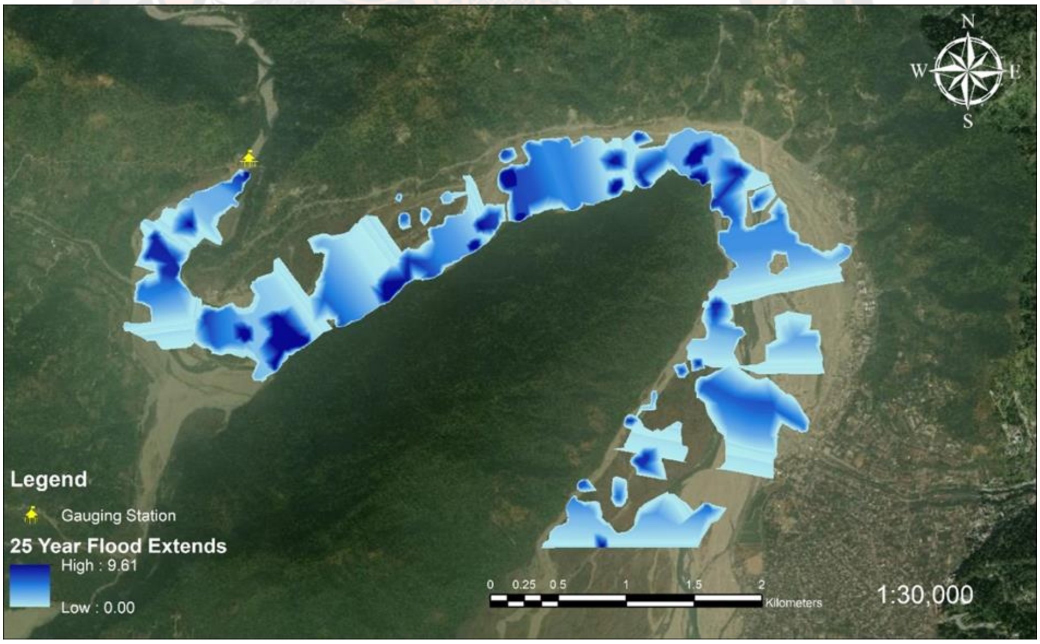

Figure 19 25-year flood extend for Amochu River in Phuntsholing City

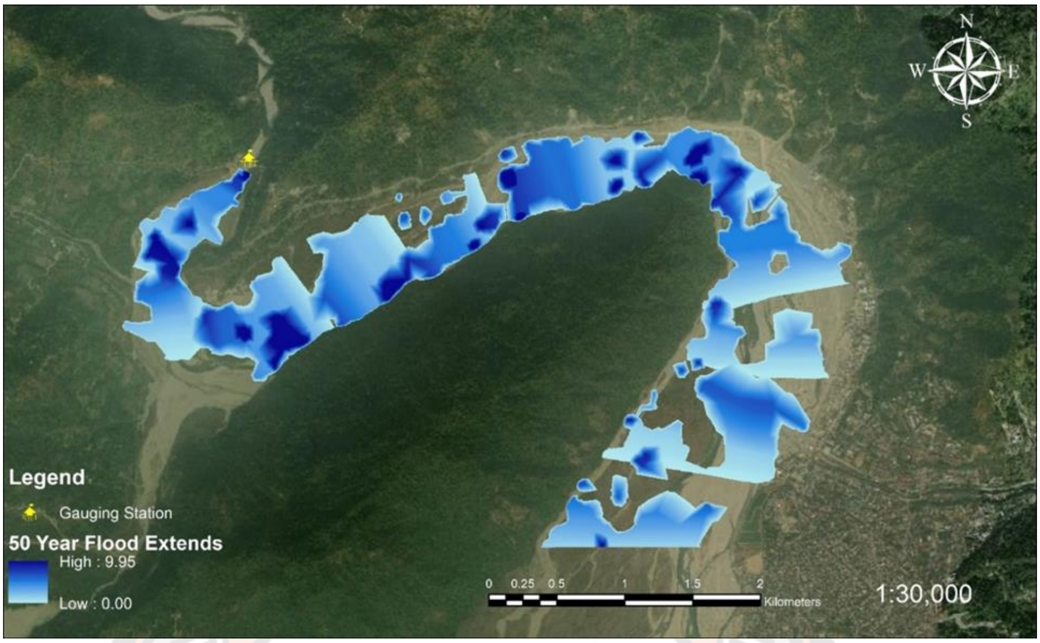

Figure 20 50-year flood extend for Amochu River in Phuntsholing City

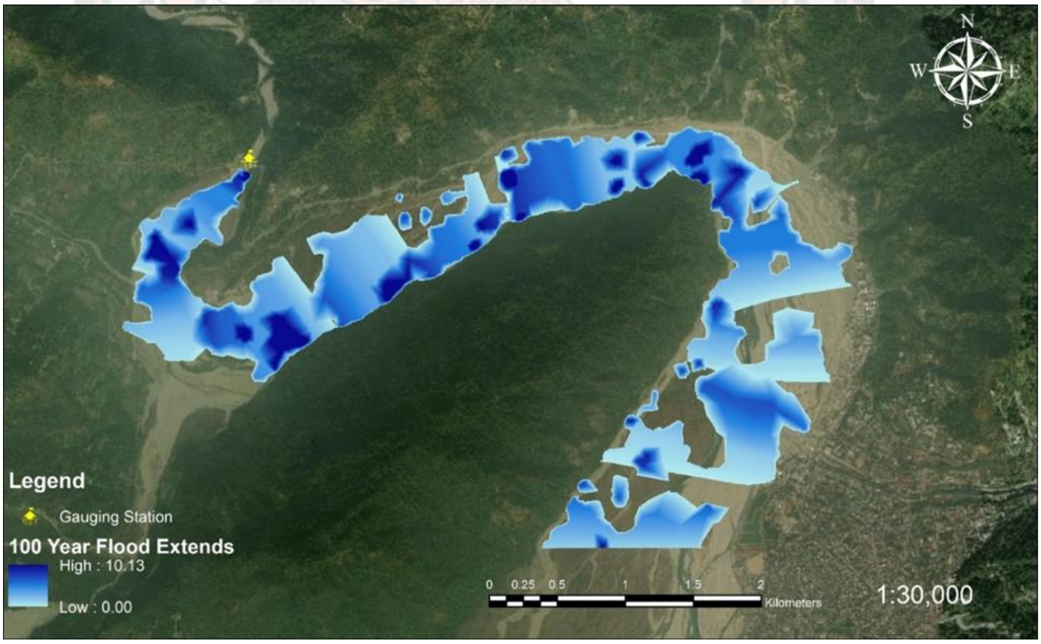

Figure 21 100-year flood extend for Amochu River in Phuntsholing City

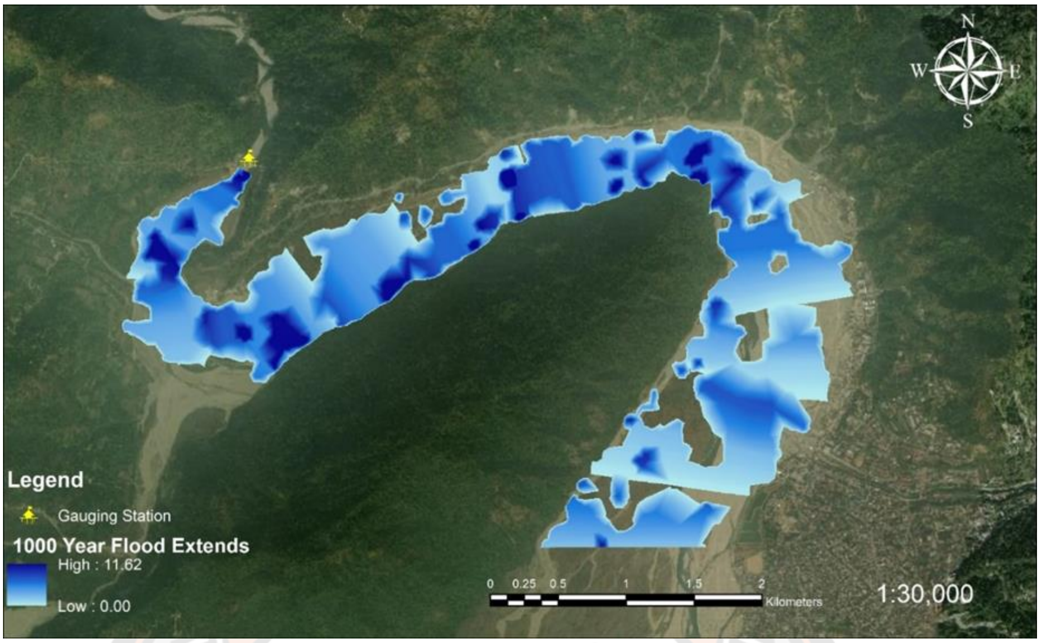

Figure 22 1000-year flood extend for Amochu River in Phuntsholing City

a) Inundated map for different return periods relative to Log-Pearson III frequency technique:

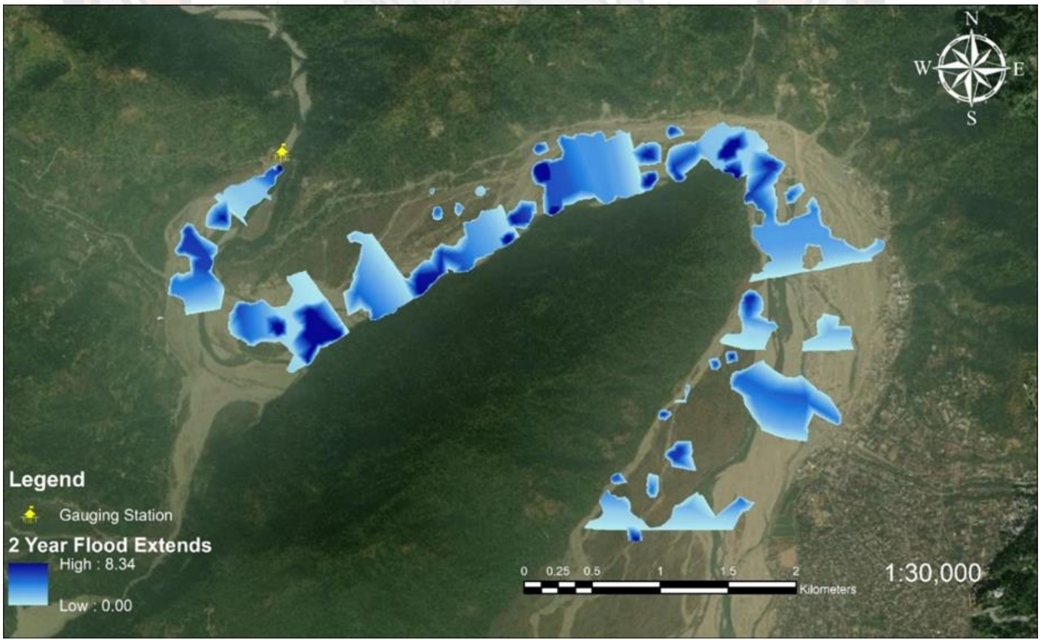

Figure 23 2-year flood extend for Amochu River in Phuntsholing City

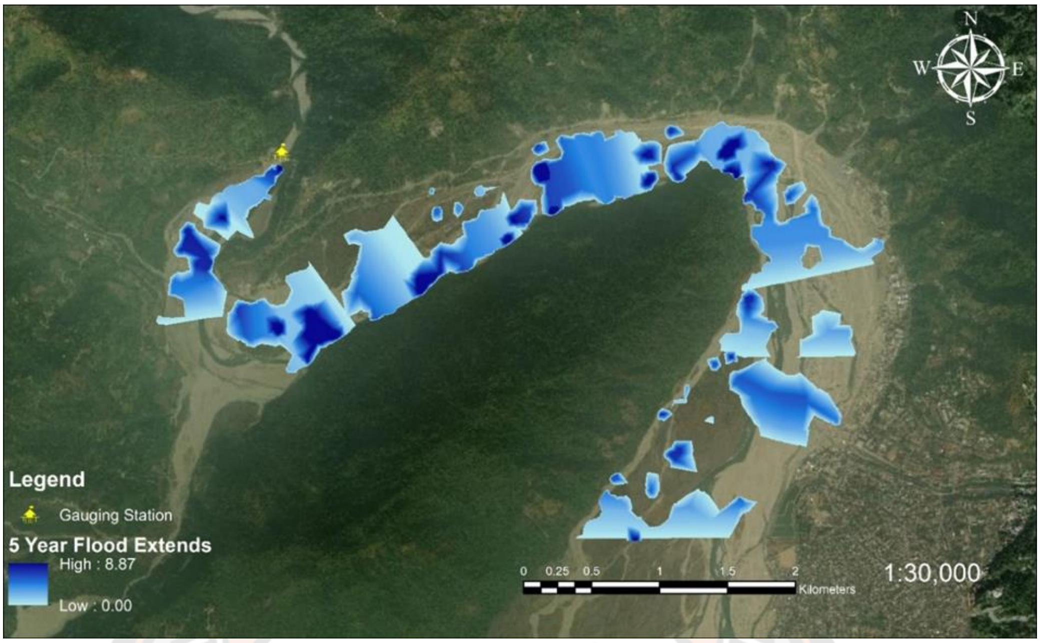

Figure 24 5-year flood extend for Amochu River in Phuntsholing City

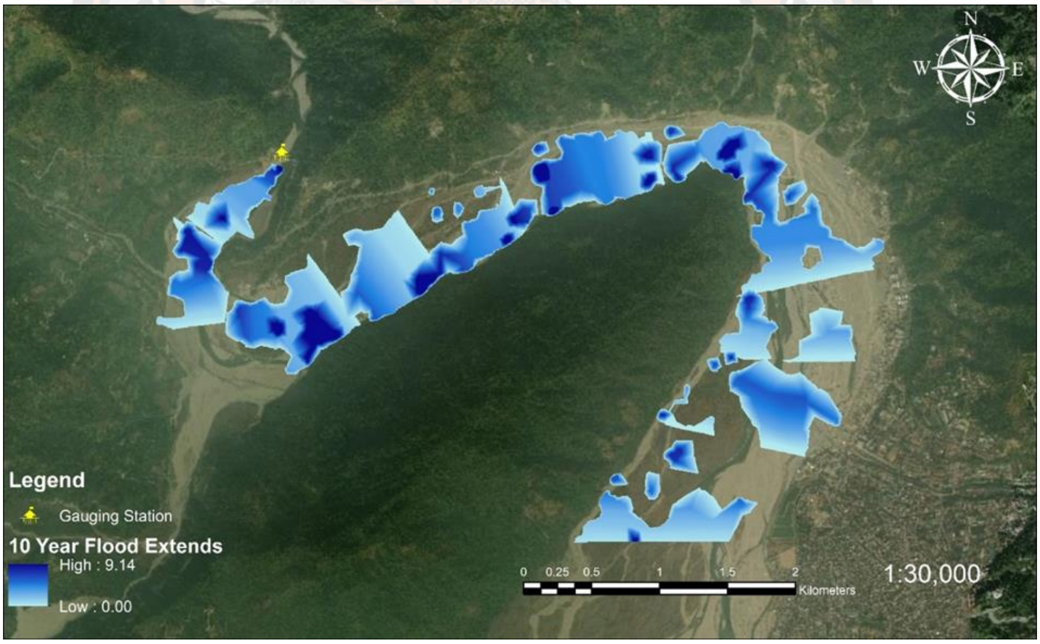

Figure 25 10-year flood extend for Amochu River in Phuntsholing City

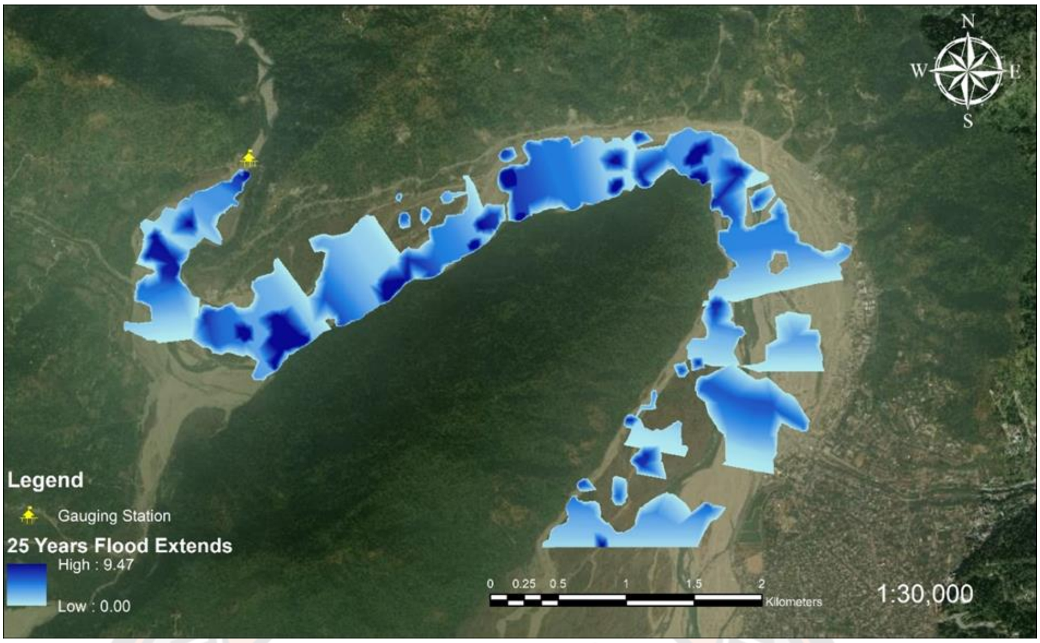

Figure 26 25-year flood extend for Amochu River in Phuntsholing City

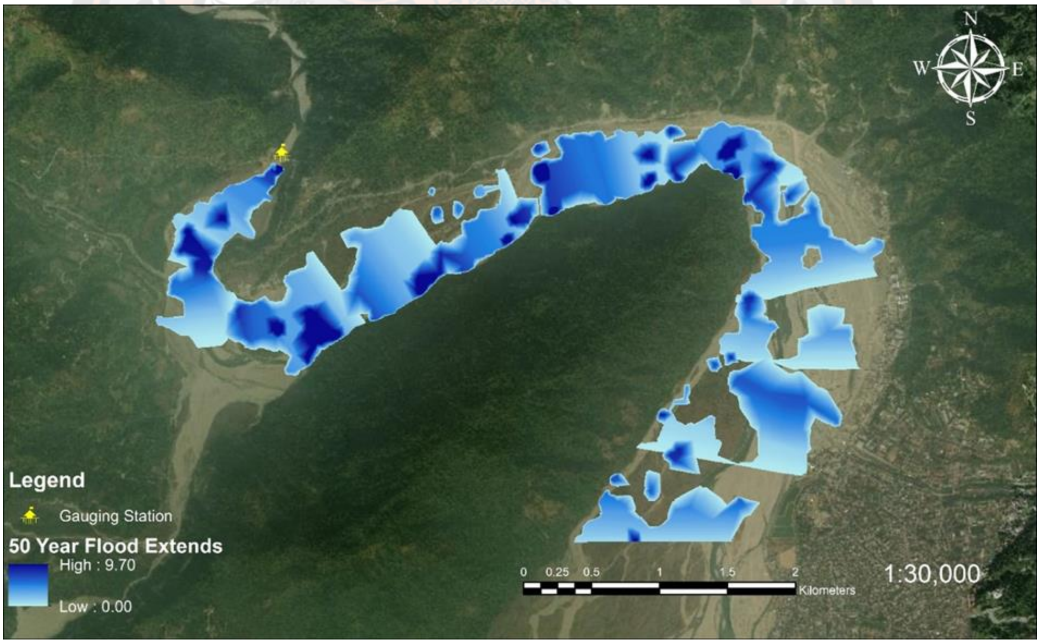

Figure 27 50-year flood extend for Amochu River in Phuntsholing City

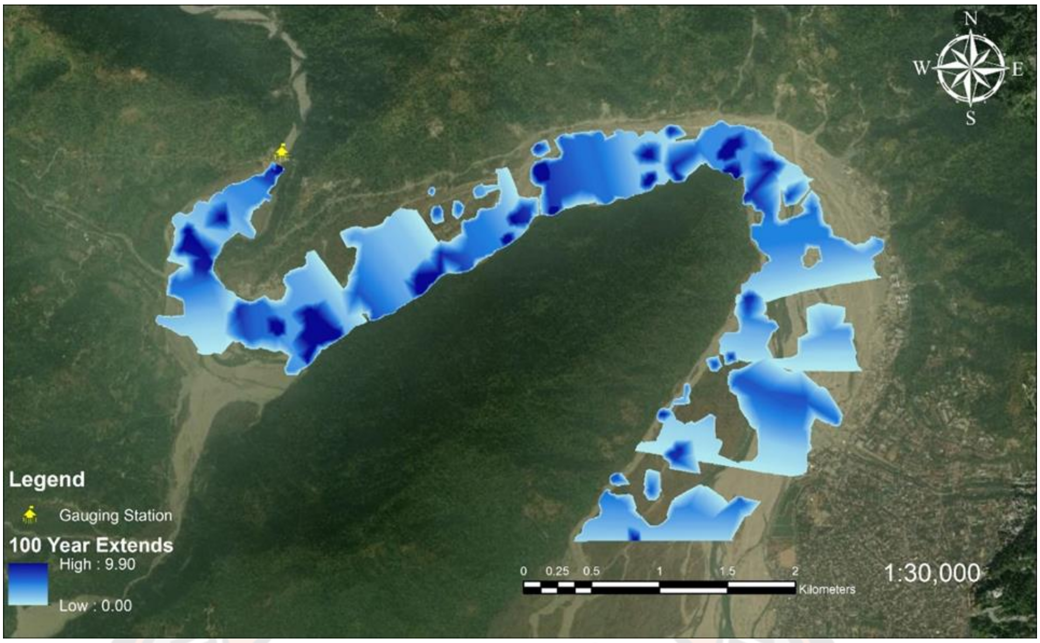

Figure 28 100-year flood extend for Amochu River in Phuntsholing City

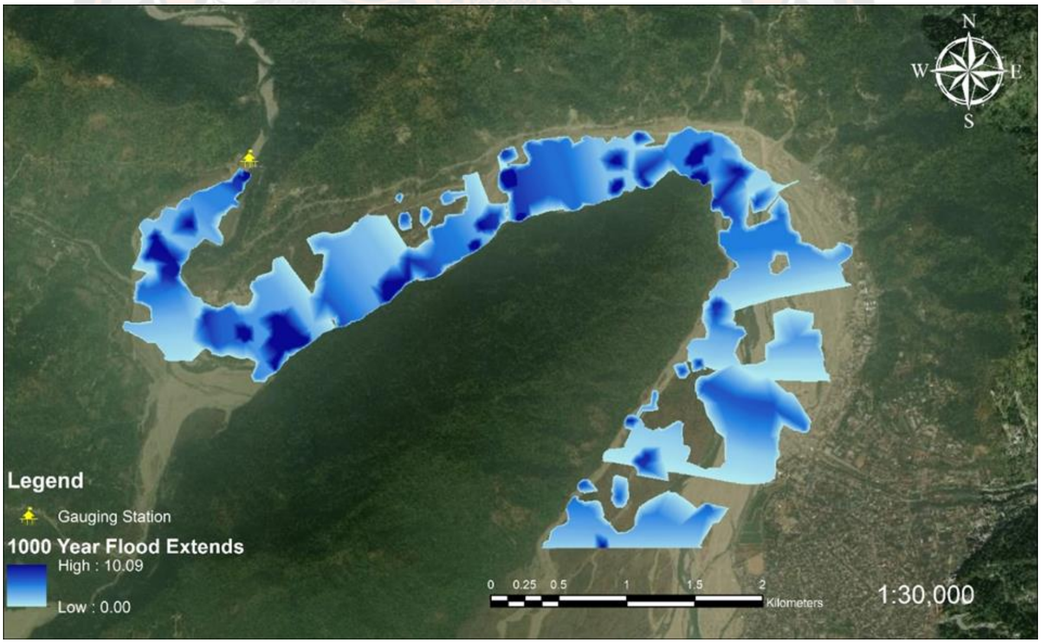

Figure 29 1000-year flood extend for Amochu River in Phuntsholing City

Impact of flood on the Present and future city of the study area

Impact of flood on the Present City

The result by Log-Pearson III technique using LULC 2016 map in the present Phuntsholing city represented the percentage of affected area by flood on land use type such as built up, agriculture, forest, shrubs and flood plain during the period of 50 years until the predicted years of 1000 (Figure 30 to 32). Log-Pearson III technique is used from 50 years onwards since the discharge rate of flood occurred in 2009 is equivalent to the discharge rate of 50 years.

The general result showed that in proximity of the river in present Phuntsholing city, flood plain and shrub regions will be expected to the most affected areas by flood and will remain the most affected regions in future as well, whereas the least affected areas by flood will be agriculture, built up and forest and will be remained as the least affected regions in future as well.

The affected area of the land use type by river flood in Phuntsholing city showed that in the 50 years of period, the highest affected area will the flood plain with 47.58% in total area of 4.63 Km^2 followed by shrubs area with 25.48% in area of 7.45 Km^2 and the least affected area will be agriculture area with 0.06% in total area of 6.11 Km^2, forest with 0.23% in 25.83 Km^2 and built up with 1.63% in 2.75 Km^2. Similarly, in 100 years, an affected area will be expected to be the highest at flood plain region with 49.35 % followed by shrubs area with 26.36%. The other three areas such as agriculture plot, forest and built up will be the least affected areas with 0.06%, 0.24% and 1.80% respectively. Likewise, over 1000 years, an affected area will be highest in the flood plain region with 50.85% followed by shrub area with 27.813% and the lowest affected area will be agriculture with 0.07%, forest with 0.25% and built up with 1.95% (Table 7 & Figure 33).

The trend showed that in the 50 years the affected area of flood plain is 47.58% which will expand by 1.77% in 100 years and by 1.5% in 1000 years. Similarly, in 50 years, the shrubs will be expected to be affected by flood with 25.48% which will be slowly extended by 0.88% in 100 years and 0.77% in 1000 years. Likewise, the affected areas of forest and built up will be 0.23% and 1.63% in

50 years which will slowly increase by 0.01% and 0.17% in 100 years and by 0.01% and 0.15% in 1000 years. However, the least affected area of agriculture by flood will remain same with 0.06% even after 50 years with very slightly increase by 0.01% in 1000 years.

Therefore, the major chunk of land affected is flood plain and shrubs, since these are located in riverine area which are highly prone to flood. They will remain as the major affected areas in future. Other land type i.e.; forest, built up and agriculture regions are located away from the river due to which the affected area by flood will be quite minimum.

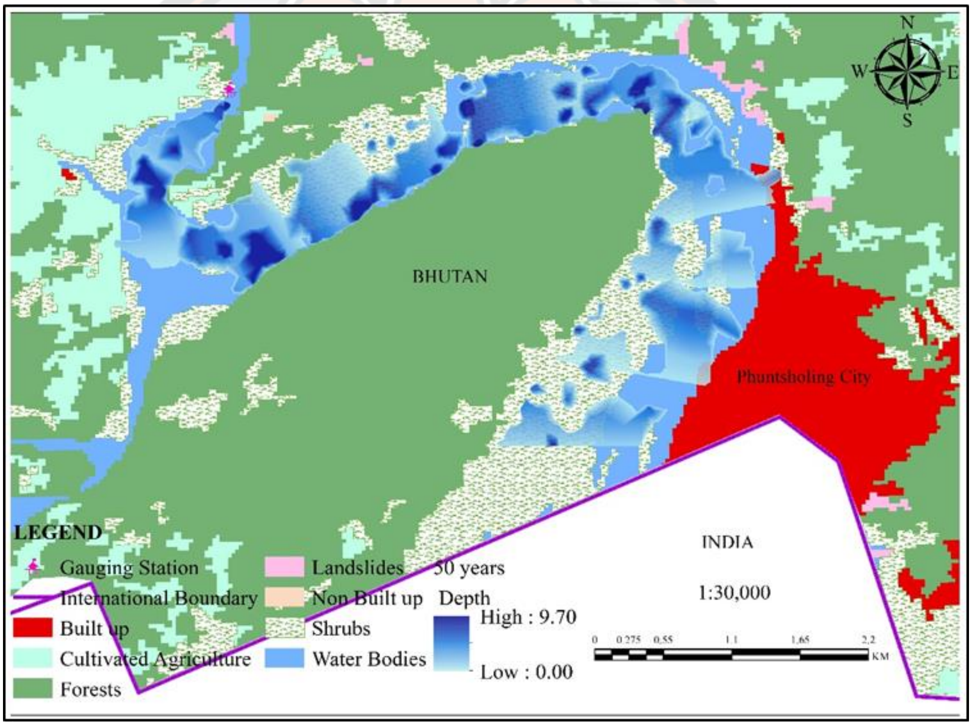

Figure 30 50-year flood effect on the of study area using LULC 2016

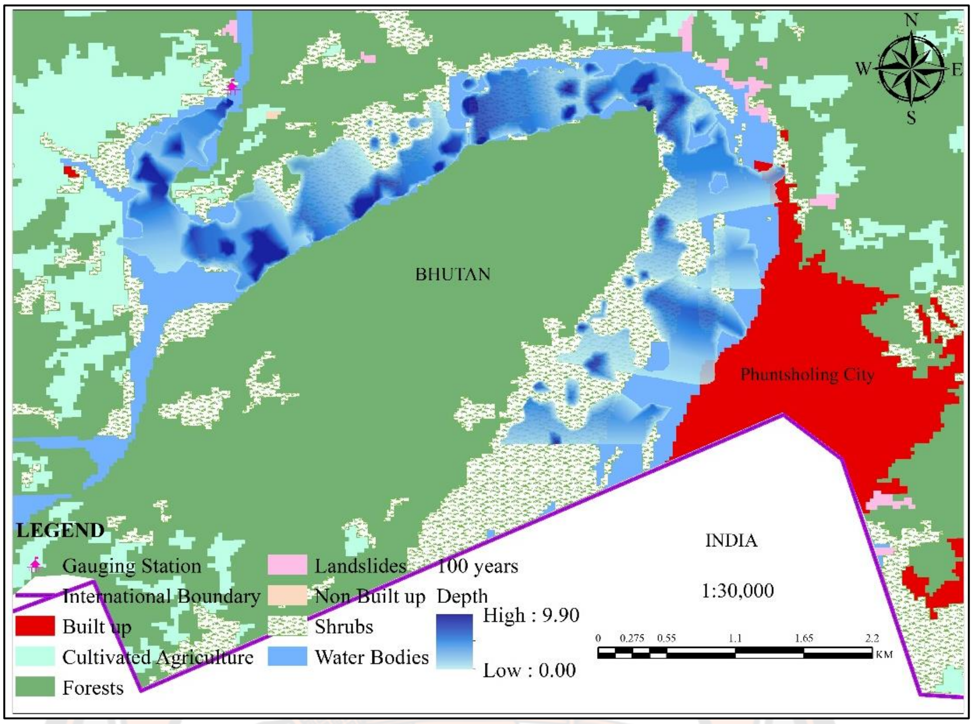

Figure 31 100-year flood effect on the of study area using LULC 2016

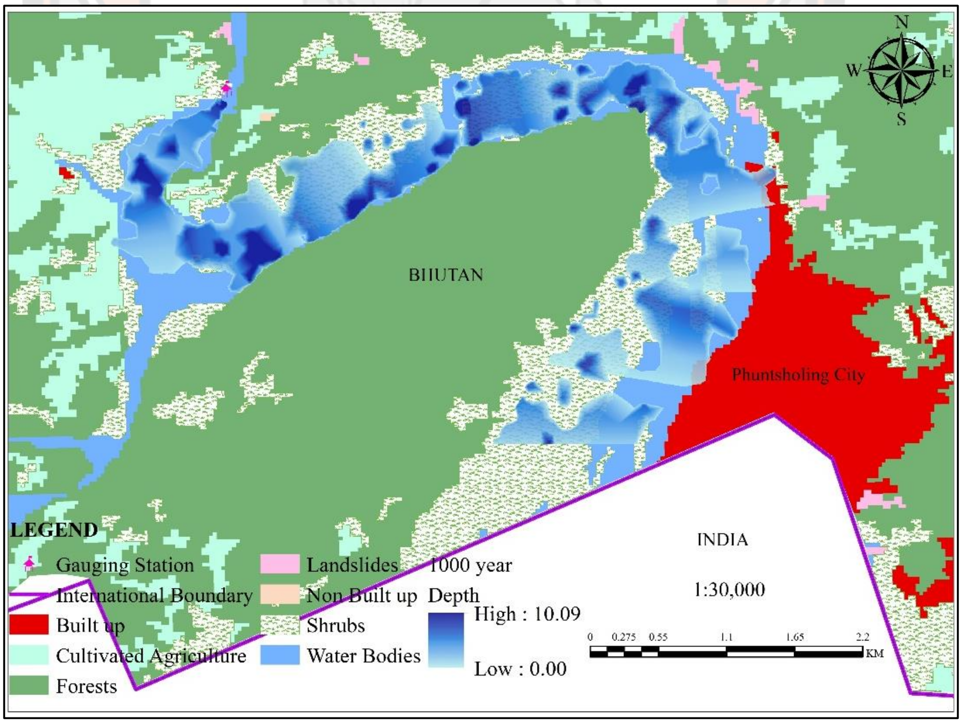

Figure 32 1000-year flood effect on the of study area using LULC 2016

Table 7 Impact of flood on the present city in Km^2 or (%) with relatives to Log-Pearson III technique for different return period peck discharge.

Land Use type	Total Area (Km^2)	Affected Area 50 year		Affected Area 100 year		Affected Area 1000 year	
		Km^2	%	Km^2	%	Km^2	%
Built up	2.75	0.045	1.63	0.05	1.8	0.053	1.95
Agriculture	6.11	0.003	0.06	0.004	0.06	0.004	0.07
Forests	25.83	0.058	0.23	0.062	0.24	0.066	0.25
Shrubs	7.45	1.898	25.48	1.964	26.36	2.021	27.13
Flood plain	4.63	2.203	47.58	2.285	49.35	2.355	50.85

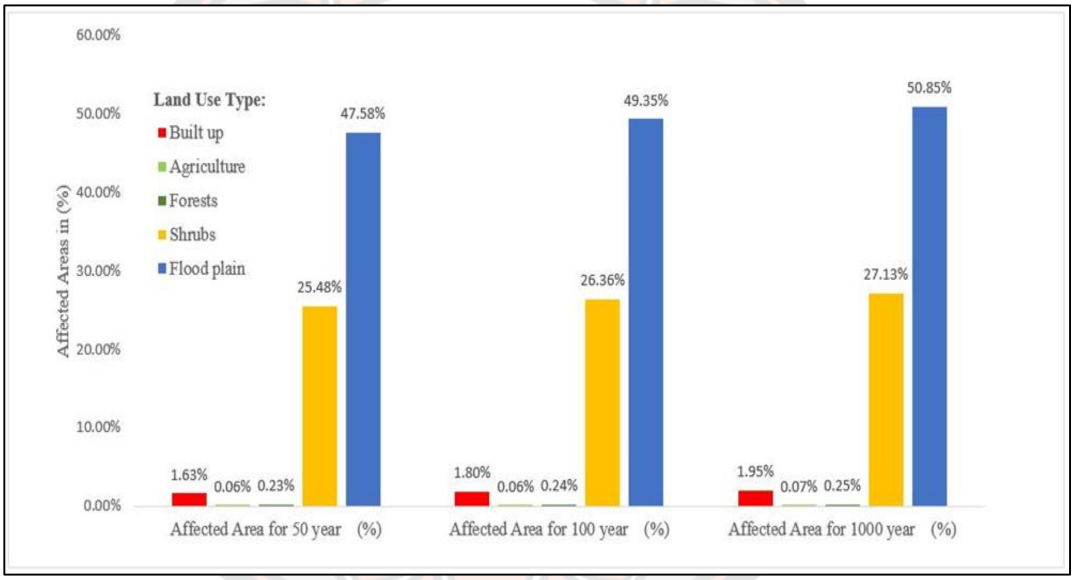

Figure 33 Graph showing the impact of flood on present city in percentage with relative to Log-Pearson III technique for different return period peak discharges

As per Log Normal technique, the land use type of the affected area of present Phuntsholing city is shown from 25 years until 1000 years. The reason for showing the affected areas of the land type from 25 years is that the discharge rate of 2009's flood is equivalent to the discharge rate of 25 years' flood. Thus, owing to the discharge rate, the forthcoming period has peak discharge more than 2009 flood is taken into account to predict the affected area in future by flood (Figure 34 to 37).

The overall data showed that the highest affected area by flood will be flood plain followed by shrub. These two regions will remain the most affected areas in future which will increase substantially with time. The minimum affected regions will be agriculture, forest and built up which are projected to increase slightly in future.

The maximum affected areas in 25 years are estimated to be flood plain and shrubs area with 46.55% and 24.88% and the least affected areas will be Agriculture field with 0.06%, forest land with 0.22% and built up with 1.47%. In 50 years, the major affected areas of flood plain and shrubs will noticeably enlarge to 49.67% and 26.53%, whereas the affected areas of forest and built up will slightly increase to 0.24% and 1.84% respectively, while the affected area of agriculture will remain same. As the year increases to 100 years, the affected areas of flood plain and shrubs also increase to 51.23% and 27.30%. As time reaches to 1000 years, the major affected areas of flood plain and shrubs will keep on expanding and reach to 58.02% and 30.51% (Table 8 & Figure 38).

From 25 years to 1000 years, the highest affected areas remain the flood plain and shrubs area. The data showed that over the years, the percentage figures for the affected areas of flood plain and shrubs will keep on increasing. In 25 years, the major affected area will be the flood plain with 46.55% which will incline to 49.67% in 50 years and continuously shoot up to 51.32% in 100 years and then in 1000 years, the figure will reach to 58.02%. The second most affected area remains shrubs with 24.88% in 25 years which will extend to 26.53% in 50 years, thereby it will keep increasing to 27.30% in 100 years and will grow the affected area upto 30.51%. The least affected areas in 25 years will be agriculture, forest and built up with 0.06%, 0.22% and 1.47% which will be gradually affected the least areas in 1000 years with 0.09%, 0.34 and 2.67% respectively.

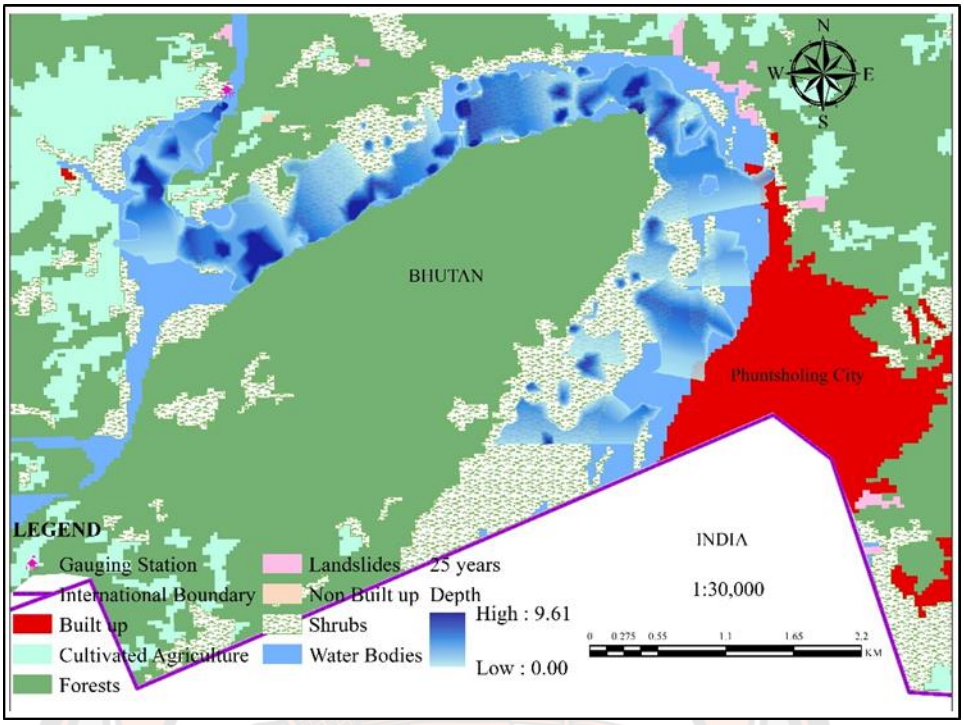

Figure 34 25-year flood effect on the study area using LULC 2016

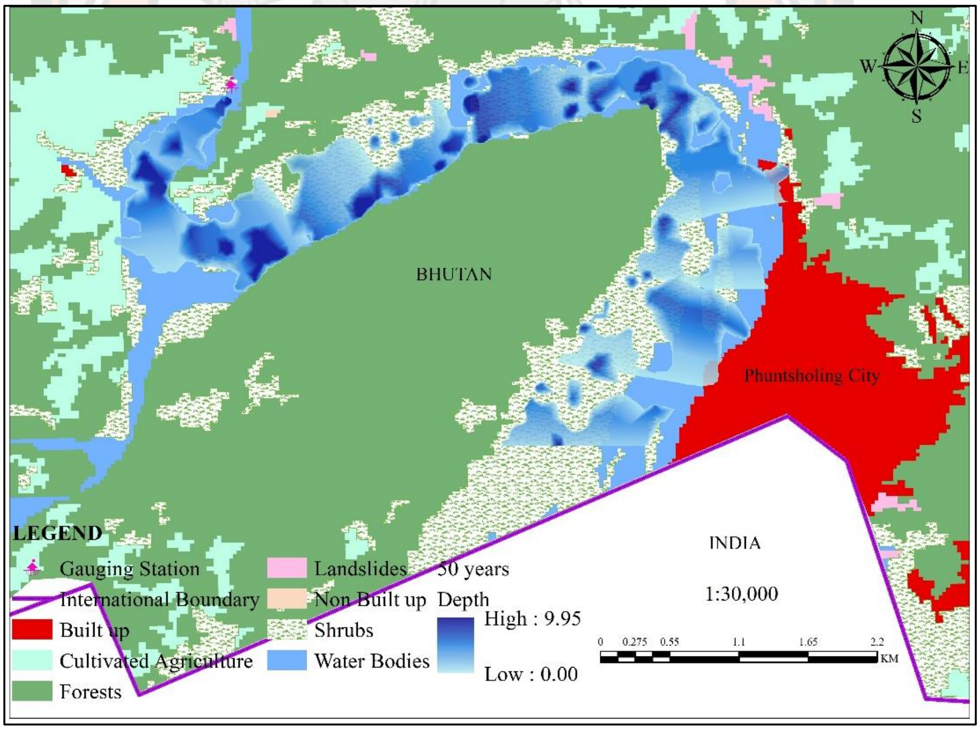

Figure 35 50-year flood effect on the study area using LULC 2016

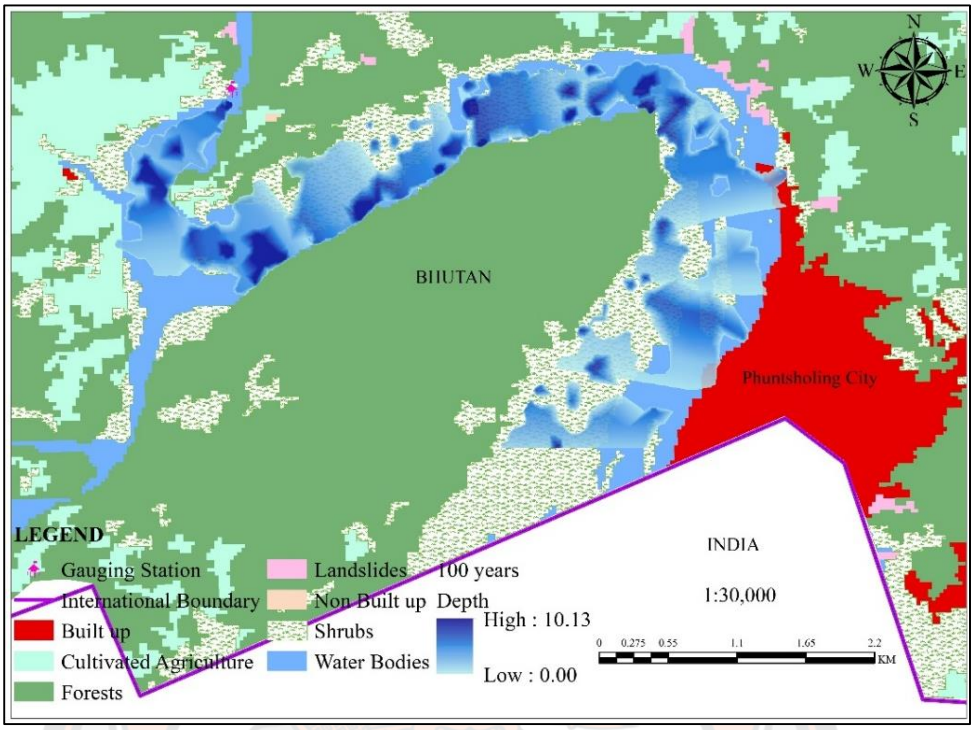

Figure 36 100-year flood effect on the study area using LULC 2016

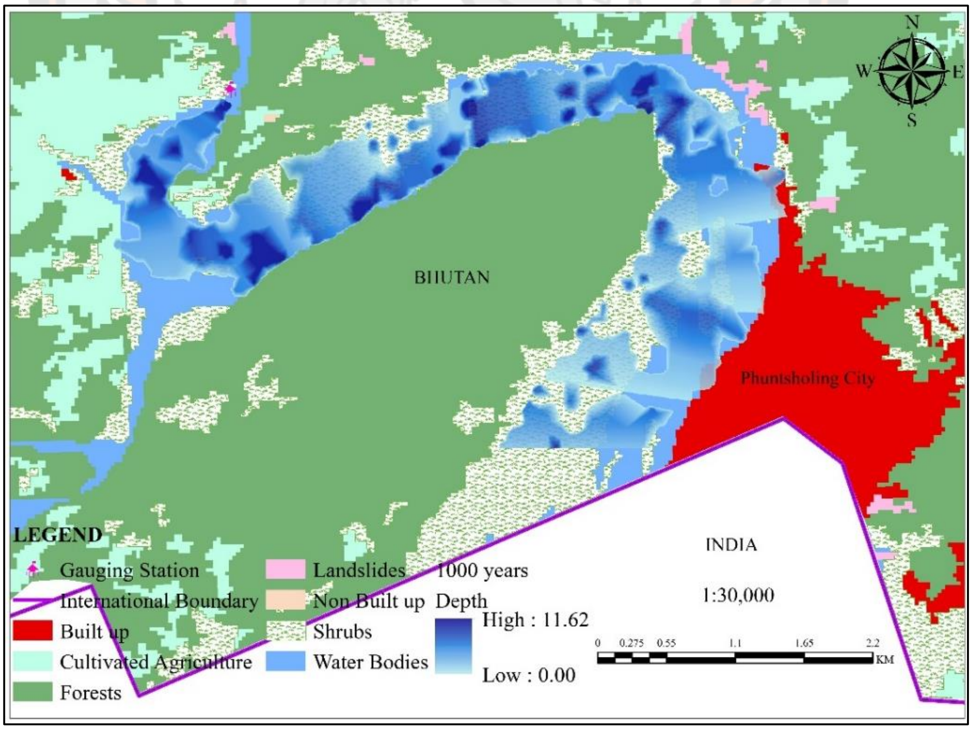

Figure 37 1000-year flood effect on the study area using LULC 2016

Table 8 Impact of flood on the present city in Km^2 or (%) with relatives to Log Normal technique for different return period peck discharge.

Land Use type	Total Area (Km^2)	Affected Area 25 year		Affected Area 50 year		Affected Area 100 year		Affected Area 1000 year	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%
Built up	2.75	0.04	1.47	0.05	1.84	0.054	1.98	0.073	2.67
Agriculture	6.11	0.003	0.06	0.004	0.06	0.004	0.07	0.005	0.09
Forests	25.83	0.057	0.22	0.063	0.24	0.067	0.26	0.088	0.34
Shrubs	7.45	1.854	24.88	1.977	26.53	2.034	27.3	2.273	30.51
Flood plain	4.63	2.155	46.55	2.3	49.67	2.372	51.23	2.686	58.02

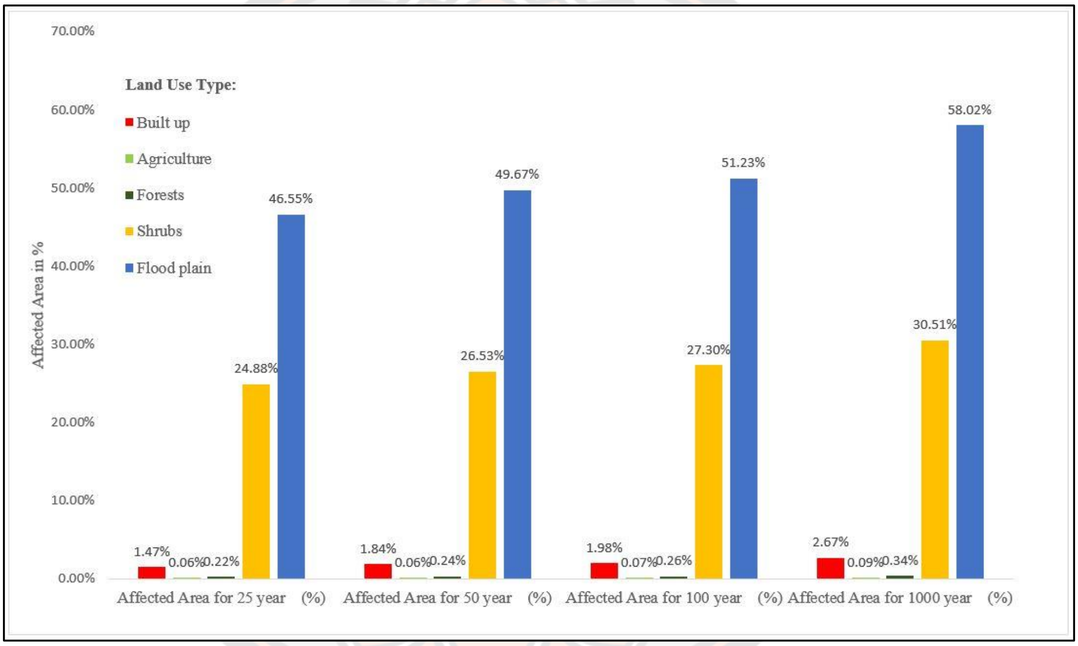

Figure 38 Graph showing the impact of flood on the present city in (%) with relative to Log Normal technique for different return period peak discharges

Impact of flood on the Future City

The result using Log-Pearson III technique from Phuntsholing Town Development project, depicted that the classified Zones will be projected to be affected by flood in upcoming city of Phuntsholing from 50 years until 1000 years. The overall finding showed that all the five classified zones will be affected with increase in percentage as the number of year’s increases (Figure 39 to 41).

In 50 years, the highest percentage of affected area will be Zone B with 52.58% in total area of 0.94 Km^2 followed by Zone E with 45.97% in area of 0.27 Km^2 and Zone C with 38.09% in area of 2.77 Km^2. The minimum affected area will be LAP with 12.50% in total area of 0.122 Km^2 and Zone A with 25.70% in area of 0.66 Km^2. In 100 years, the affected area of Zone B will likely to expand to 55.07%, Zone E with 46.75%, Zone C with 39.56%, Zone A with 27.98% and LAP with 13.72%. After 1000 years, there will be chances of expanding the affected area of Zone B with 57.50%, Zone E with 47.45% with, Zone C with 40.83%, Zone A with 30.50% and LAP with 14.91% (Table 9 & Figure 42).

The maximum affected Zone B, initially will be 52.58% which will increase significantly to 55.07% in 100 years and affected area will reach to 57.50% in 1000 years. Similarly, affected area by flood in Zone E and C in 50 years will be 45.97% and 38.09% which will extent to 46.75% and 39.56% in 100 years and 47.45% and 40.83% in 1000 respectively. In the similar manner, affected area of Zone A will be initially 25.70%, expected to expand 27.98% in 100 years and 30.50% in 1000 years. Likewise, the affected area of LAP in 50 years will be 12.50%, gradually increase to 13.72% in 100 years and 14.91% in 1000 years.

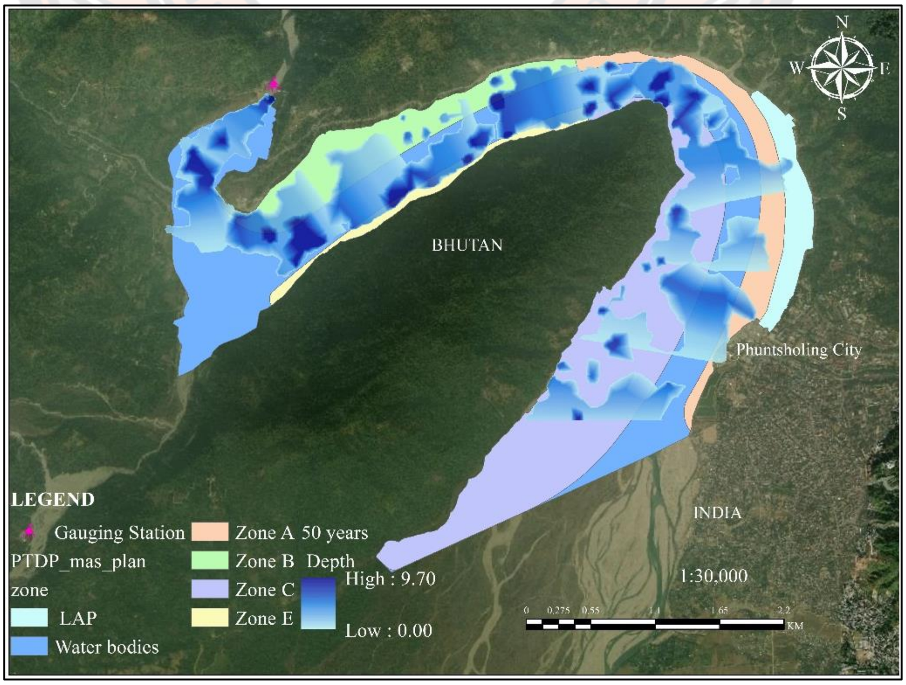

Figure 39 50-year flood effect on the study area using future city master plan

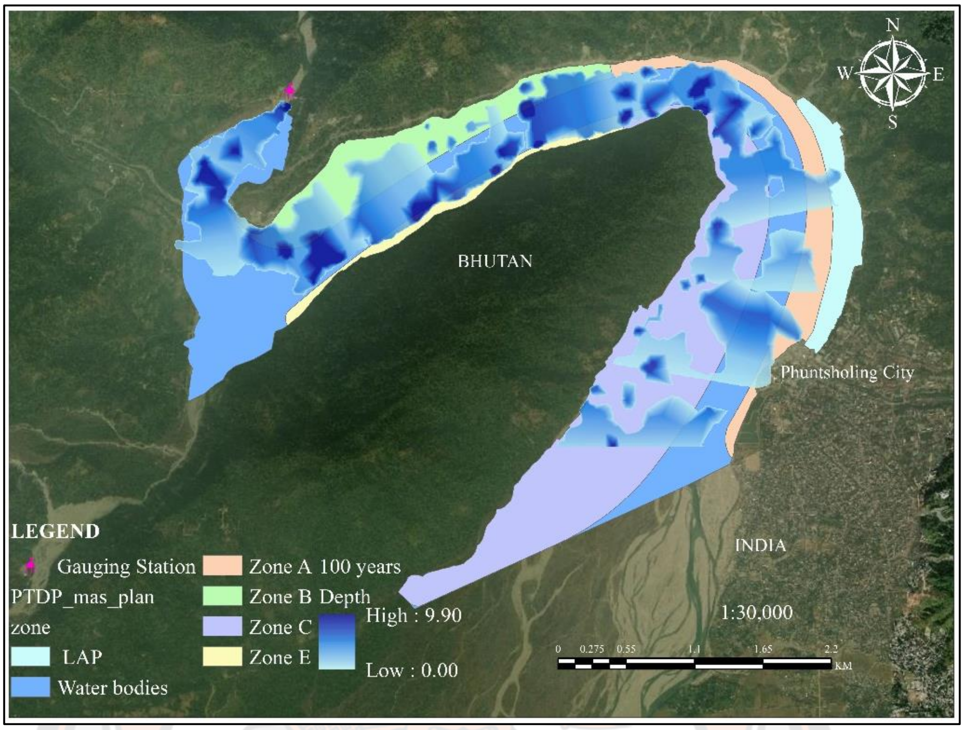

Figure 40 100-year flood effect on the study area using future city master plan

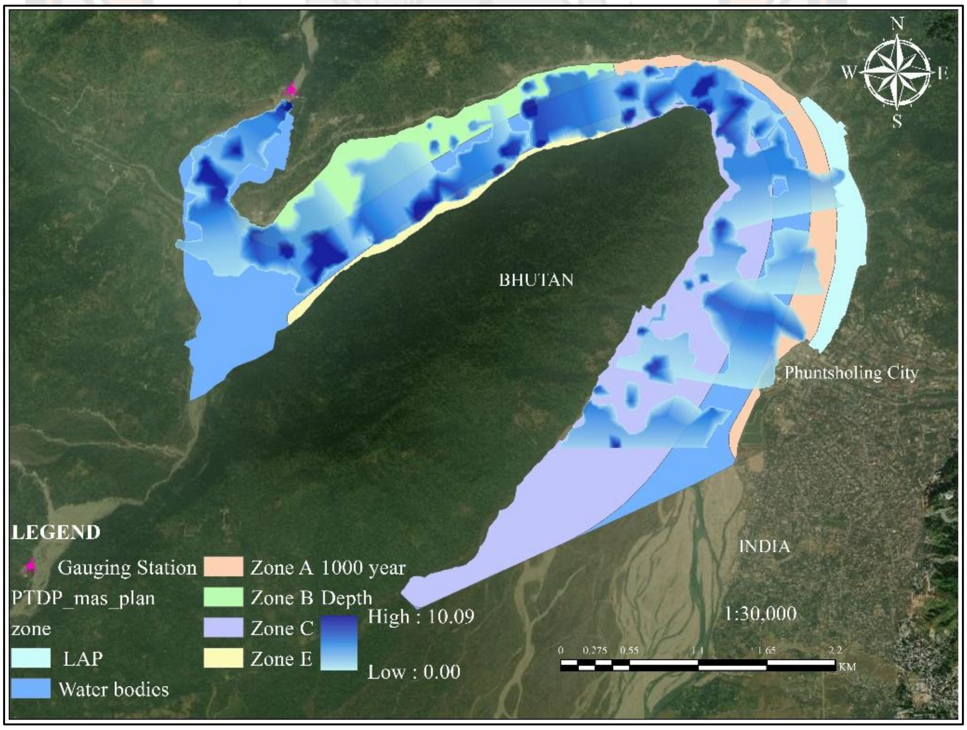

Figure 41 1000-year flood effect on the study area using future city master plan

Table 9 Impact of flood on the future city in Km^2 or (%) with relatives to Log-Pearson III technique for different return period peck discharge

Class	Total Area (Km^2)	Affected Area 50 year		Affected Area 100 year		Affected Area 1000 year	
		Km^2	%	Km^2	%	Km^2	%
Zone A	0.66	0.17	25.70	0.185	27.98	0.201	30.50
Zone B	0.94	0.494	52.58	0.518	55.07	0.54	57.50
Zone C	2.77	1.055	38.09	1.096	39.56	1.131	40.83
Zone E	0.27	0.124	45.97	0.126	46.75	0.128	47.45
LAP	0.122	0.015	12.50	0.017	13.72	0.018	14.91

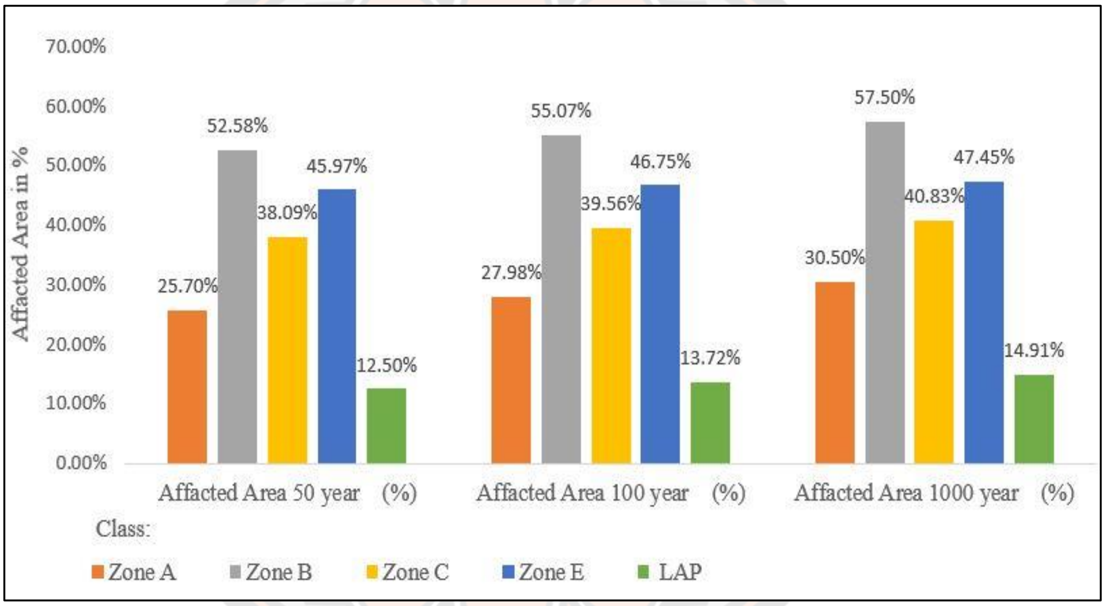

Figure 42 Graph showing the impact of flood on the futurt city in (%) with relative to Log-Pearson III technique for different return period peak discharges

The finding using Log Normal technique provided the information about the percentage of affected classified Zones by flood in the upcoming Phuntsholing city from 25 until 1000 years (Figure 43 to 46).

The overall result represented that the major percentage of affected area will be expected to be Zone B and Zone E followed by zone C and will keep on increasing the affected areas drastically in upcoming years. The minor affected area will be zone A and LAP and will increase as the upcoming future approaches.

The most affected area in 25 years will be Zone B with 51.41% followed by Zone E with 45.59% and Zone C with 36.84 %. However, the least affected area will be LAP with 12.16% and Zone A with 24.66% and. In 50 years, the affected area will be augmented to 55.60% in Zone B, 46.85% in Zone E, 39.83% in Zone C, 28.49% in Zone A and 13.95% in LAP. Similarly, the affected zones will be expected to expand continuously to 58.26% in Zone B, 47.71% in Zone E, 41.10% in Zone C, 31.12% in Zone A and 15.12% in LAP during 100 years. In the same manner, from 100 to 1000 years, the expansion of affected area will be continued from 58.26% to 69.53% in Zone B, 47.71% to 51.35% in Zone E, 41.10% to 46.88% in Zone C, 31.12% to 45.58% in Zone A and 15.12% to 22.01% in LAP (Table 10 & Figure 47).

The trend showed that during the period of 25 years, the major affected area by flood will be Zone B with 51.41%, Zone E with 45.59% and Zone C with 36.84%. In the same year, the minor affected will be Zone A with 24.66% and LAP with 12.16%. In 50 years, the affected area of Zone B will be drastically increased by 4.19%, Zone E by 1.26%, Zone C by 3.35%, Zone A by 3.88% and LAP by 1.79%. In 100 years, Zone B will be steadily increased by 2.66%, Zone E by 0.86%, Zone C by 1.27%, Zone A by 2.63% and LAP by 1.17%. When it reaches to 1000 years, the affect area of Zone B will be enlarged by 11.27%, Zone E by 3.64%, Zone C by 5.78%, Zone A by 14.46% and LAP by 6.89%.

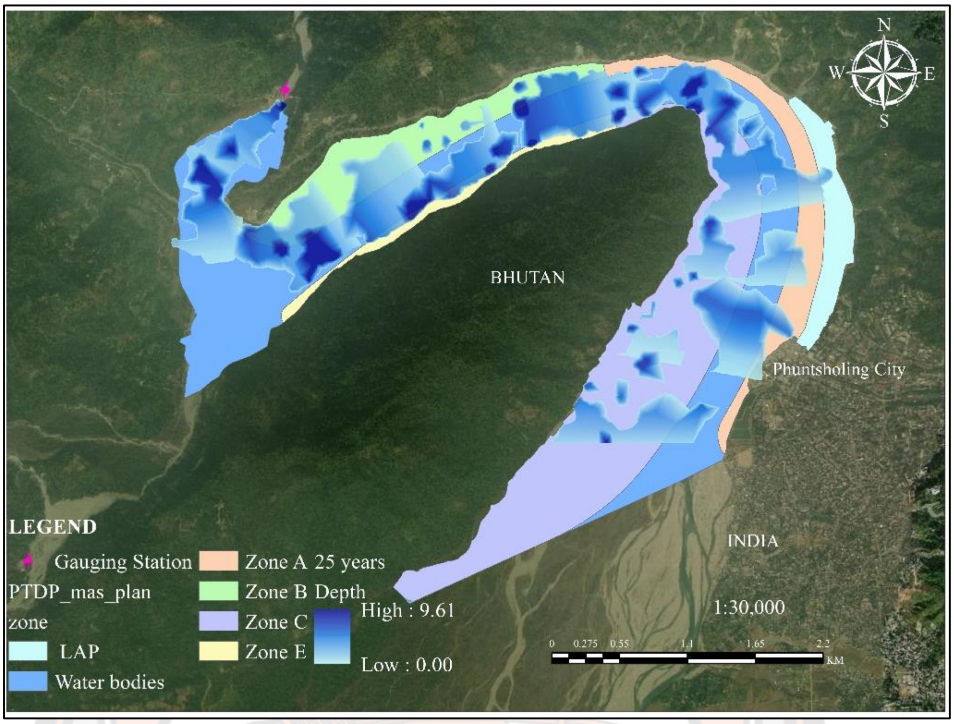

Figure 43 25-year flood effect on the study area using future city master plan

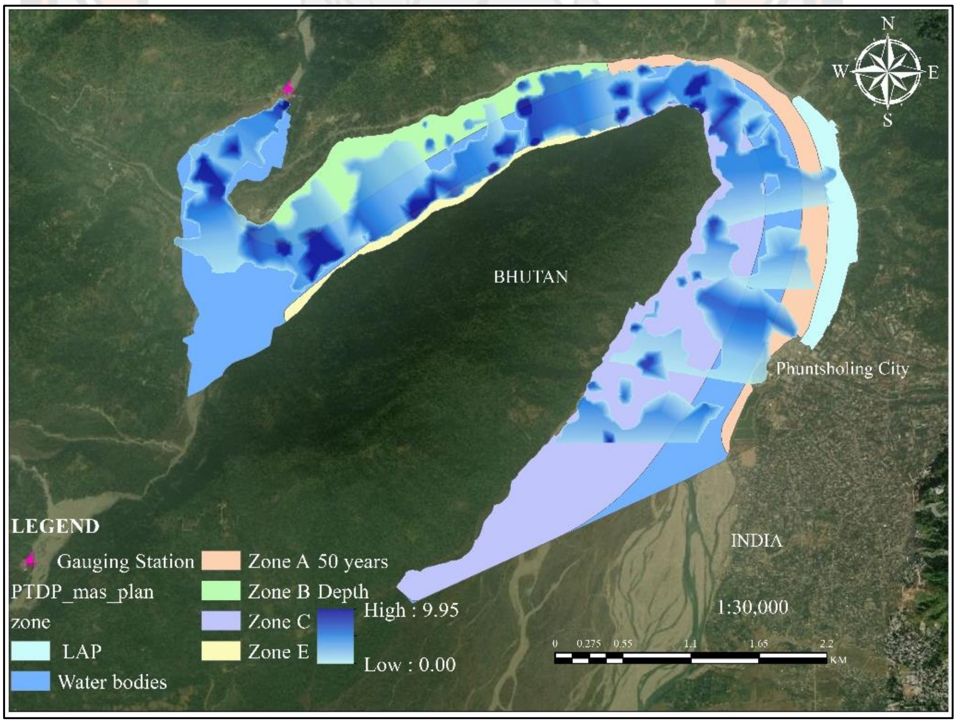

Figure 44 50-year flood effect on the study area using future city master plan

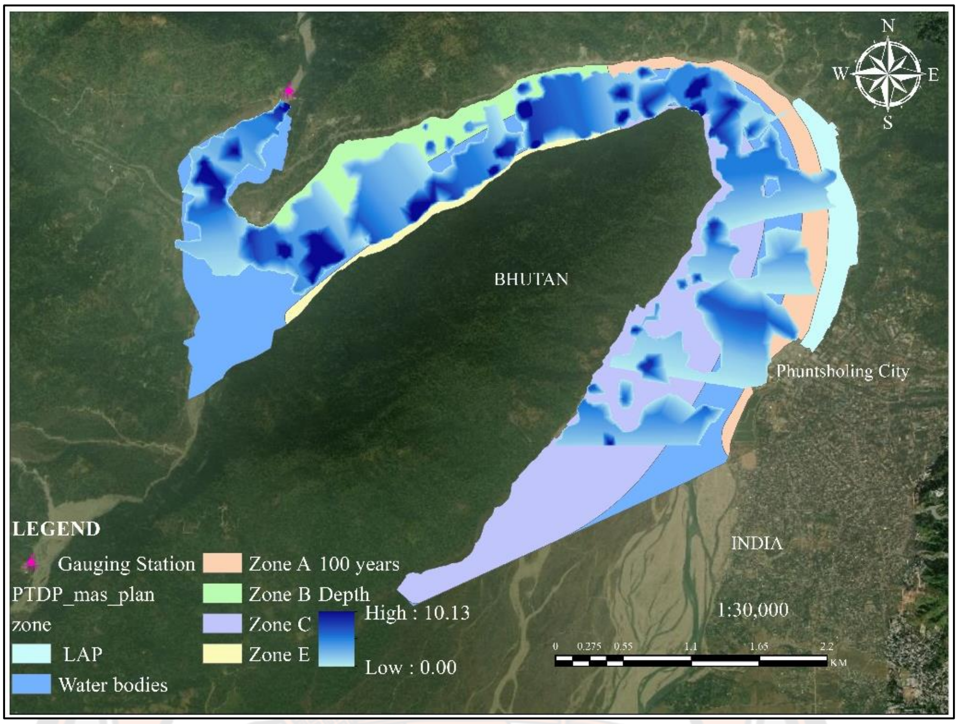

Figure 45 100-year flood effect on the study area using future city master plan

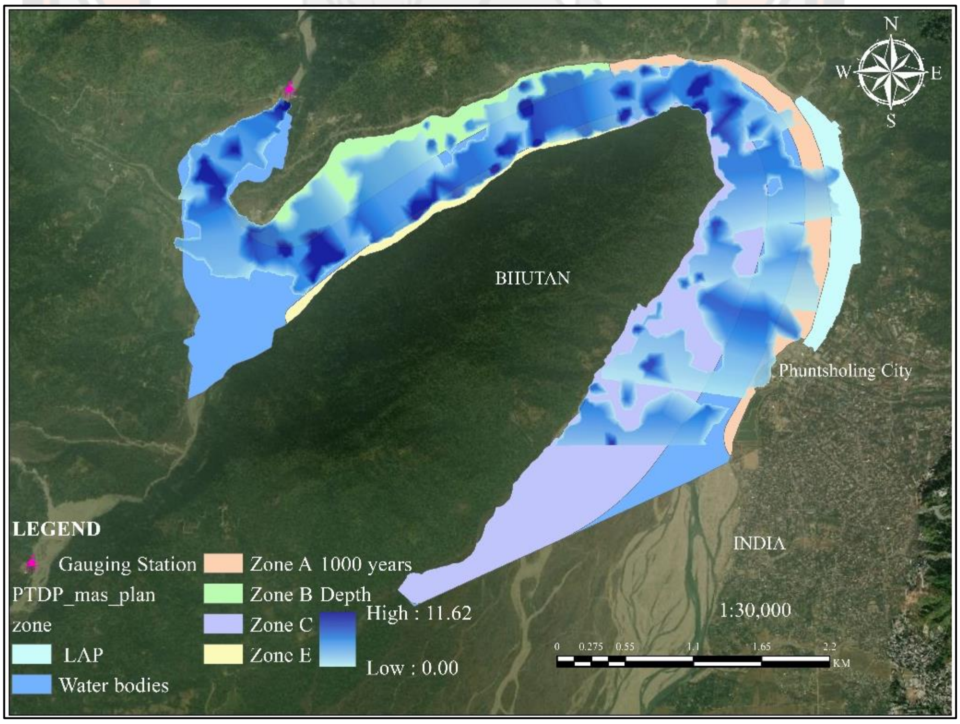

Figure 46 1000-year flood effect on the study area using future city master plan

Table 10 Impact of flood on the future city in Km^2 or (%) with relatives to Log Normal technique for different return period peck discharge.

Class	Total Area (Km^2)	Affected Area 25 year		Affected Area 50 year		Affected Area 100 year		Affected Area 1000 year	
		Km^2	%	Km^2	%	Km^2	%	Km^2	%
Zone A	0.66	0.163	24.66	0.188	28.49	0.205	31.12	0.301	45.58
Zone B	0.94	0.483	51.41	0.523	55.6	0.548	58.26	0.654	69.53
Zone C	2.77	1.021	36.84	1.103	39.83	1.139	41.1	1.298	46.88
Zone E	0.27	0.123	45.59	0.126	46.85	0.129	47.71	0.139	51.35
LAP	0.122	0.015	12.16	0.017	13.95	0.018	15.12	0.027	22.01

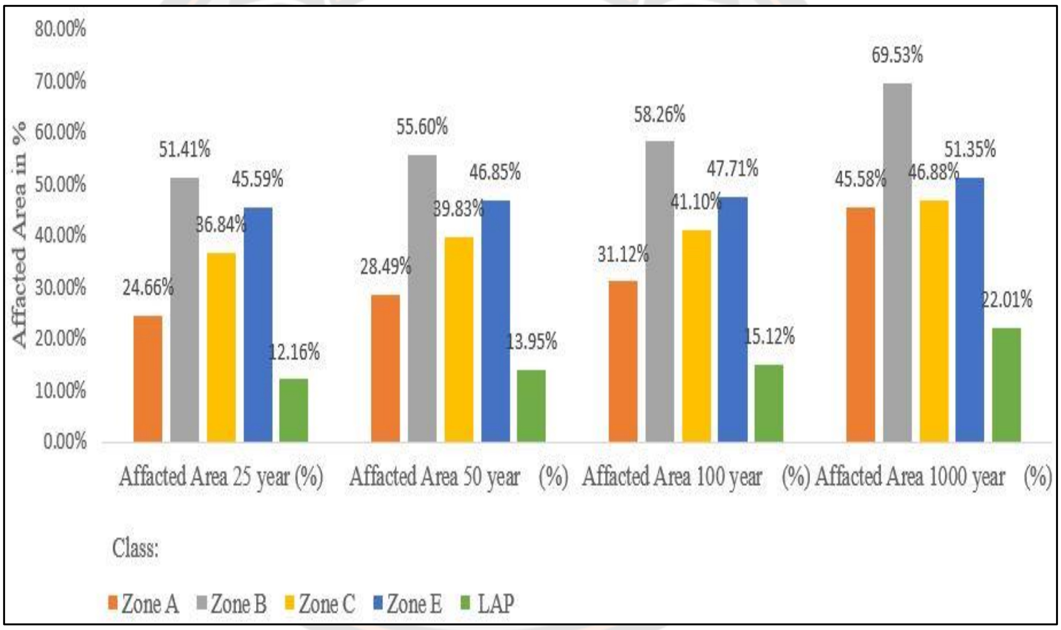

Figure 47 Graph showing the impact of flood on the future city in (%) with relative to Log Normal technique for different return period peak discharges

Comparison of the affected area of present Phuntsholing city by Log Normal and Log-Pearson III technique. In 2009, there was heavy flood occurred in present Phuntsholing city due to Cyclone Aila originated from the Bay of Bengal, which overflowed the nearby area damaging the infrastructure and settlements. The discharge rate of flood during that year was 2557 m^3/sec which had greater impact on the study area. Thus, the return period which has discharge rate equal or more than the discharge rate of 2009 flood event, computed with Log Normal and Log-Pearson III technique were compared to determine the flood impact on the study area. As a result, the discharge rate of 2009's flood event is found equivalent to the discharge rate (2503.70 m^3/sec) of Log Normal technique of 25 year return period and 50 years return period (2632.47m^3/sec) of Log-Pearson III technique.

Thus, the finding showed that the discharge rate of Log-Normal technique will have the heavy impact to the city with the rapid time period than the Log-Pearson III technique. Therefore, town planning in future should take into consideration the flood discharges of Log Normal techniques in the development of the appropriate flood mitigation measures in order to manage natural risk for the future planning of the study area.

CHAPTER V

DISUSSION AND CONCLUSION

Discussion

The study showed that the discharge rate of Amochu River using Log Normal from 2 years to 1000 years is 911.19 to 5151.67 m^3/sec with maximum inundation depth of 8.31 to 11.62m, while 8.34m to 10.09m deep for Log-Pearson III for discharge rate of 937.93 m^3/sec to 3279.11 m^3/sec respectively. Since Amochu River flows from higher elevation of 4656m to the lower elevation of 81m above sea level as given in figure 6, the discharge rate and depth are significantly high. When the results are assessed together, it was observed that there is not much difference between the depth value created by Log Normal and Log-Pearson III techniques, although we can observed little difference in depth value within the Log Normal created by 1000 year inundation water, 11.62m, and the depth value created by 100 year at 10.13m. This may be due to depth of the river was not very précised due to the resampled 5m DEM resolution was used, which did not extract the loop and corner of the depth of the river. However, the depth value created by 25 years in log Normal and 50 year return period in Log-Pearson III, whose discharge data corresponds to the observed discharge data of 2009 extreme flood event of 2557 m^3/sec remains quite satisfactory as there are not much significant difference comparing to actual depth value of 2009 at 8m to 9m (Figure 15).

As per the similar result found by Kurniyaningrum et al. (2019), that using high resolution 5m DEM, there will be significant increase in the inundation extent and depths. He also stated that LIDAR DEM of resolution 1m until 5m affected the propagation of a flood wave in a channel and surrounding floodplain which caused the geometrical properties of topography.

In this study, the major areas affected by floods on present city (using LULC 2016) with both Log-Pearson III (50 years until 1,000 years) and Log Normal technique from 25 years until 1,000 years will be the flood plain and shrub regions, since these areas are located at the proximity of Amochu river bank. The nature of

Amochu River is perennial and flows throughout the year. The flow of the river depends on the precipitation which is the seasonal bound and variation of flow volume depends on the dry and wet season (Wangdi & Lamichaney, 2018). The wet season commences from May till July with the onset of the south-west monsoon in June and the annual precipitation is 4018mm as of 2011 where average precipitation was 950mm during June. Since Phuntsholing is situated at an altitude of 160m above sea level and as per JICA map, River Amochu is located between 140 to 400msl which makes the entire town tremendously vulnerable to the floods (Thromde Disaster Management Plan, 2016). These affected areas are located at the plain area near the river with low lying altitude. Bennani et al. (2019) observed that due to difference in altitude, certain parts of the river are more prone to flooding. Curebal et al. (2015) perceived that the morphology of town and flood plain is the positive relationship that affects the distribution of flood water extent. Thus, the result represented the flood plain and shrubs area will have the highest vulnerability, whereas forest, built up and agriculture will have the least affected areas by flood since they are located far away from the river at slightly higher elevation. Similar result reported by Rahmati et al. (2015) that forest and rangeland showed the negligible impact in flooding, as the forest cover with vegetation can decrease the run-off and therefore reduce the flooding. Vegetated areas are less vulnerability to flooding because of infiltration capability and vegetation density (Rahmati et al., 2015). Rahmati et al. (2015) highlighted that one of the considering factors for city planning is the distance from the river which significantly impact on the flood spread and magnitude. He figured that distance of the river makes a significant different in inundating the areas whereby there is less possibility of flooding in river range of 2000 to 3000m and > 3000m, whereas there is high probability of flooding in the range < 500m, 500 to 1,000m and 1000 to 2000m.

Unlike Phuntsholing city, where area coverage of agriculture and forest plots are located little higher elevation and far away from the river, these regions are less prone to flood. However, in other countries, settlements and agriculture have the highest flood vulnerability since these places fall into the distance from the river from 0 to 1000m which have the positive influence in flooding, while the place away from 1,000m and faraway places has negative influence on flood (Rahmati et al., 2015).

Lenin Laikangbam (2019) found that areas lying along the flood plain are most affected by flood with the total area of 40.434 Km^2 of which 60.95% is found to be agricultural land and 16.16% is the build ups, located at the plain area of the catchment having low elevation. He also found that from 77.51 Km^2 of agricultural land, 24.65% is affected by flood and from 13.05% of built up, 6.53% is affected by flood. Bhattarai et al. (2018) assessed that the most prone area to be inundated by flood is the agriculture land with 47% to 49% followed by water body with 38% to 46% and forest with 3% to 10%. Similar result reported by Bennani et al. (2019) that due to the magnitude of flood occur different periods will affect buildings, road, agriculture and other land type nearby.

The Phuntsholing city has been facing serious shortage of land for its expansion, due to the fast development and limited plain area. Major chunk of valuable flat land along the western region of the Phuntsholing city has been lost to uncontrolled river as a result of erosion and sedimentation by debris. The high monsoon flows have eroded vast areas of land, restricting the scope for growth and sustainability of the economy of the city. As such Phuntsholing city is planning to extend the town about 4.62Km^2 (462 ha) of riparian land of Amochu River to accommodate the expansion under the "Phuntsholing Township Development Project" (PTDP, 2018).

Under the Phuntsholing Township Development Project (PTDP), Phuntsholing city and Department of Human Settlement (DHS), Ministry of Works and Human Settlement (MoWHS) has developed a future city master plan to extend or to accommodate the upcoming city by reclaiming the riparian land along the among river bank. This upcoming Phuntsholing city is divided into Zone based to facilitate the development of the city into phase wise. During the study, although most of the zones will be affected by the flood in the future, the highly affected Zone were found to be Zone B, Zone E, followed by Zone C and Zone A. These areas will be flood prone since these places are located at lower elevation just vicinity to the Amochu river (Figure 39-41 & 43-46). However, least affected will be LAP as it is located at the little higher elevation and away from the river. Similar study found by Bennani et al. (2019) that the extent of the flood and the water depths are much lower upstream than downstream of the river profile. Thus, the flood in upstream remains close to river bank while the affected area of the downstream keeps on extending due to the contribution of strong upstream water. This could be the reason that the affected areas of Zone B, Zone E, Zone C and Zone A will keep on extending as the year increases. Therefore, in future, to minimize the risk of flood, these Zones need to be protected using the most effective measures while planning for the settlements.

The comparative study of affected areas of land use type using Log Normal and Log-Pearson III technique were used for upcoming years. Based on the discharge rate of 2009's flood, the Log Normal method will have the high impact since the discharge rate of upcoming 25 years is equivalent in log normal to the discharge rate of Log Pearson III method of 50 years. Therefore, Policy maker, town planners or engineers in future needs to take into consideration the flood discharges of Log Normal techniques in the development of the appropriate flood mitigation measures to reduce the natural risk on the future planning for the Phuntsholing city as Log Normal technique will have the heavy impact to the city with the rapid time period than the Log-Pearson III technique.

Conclusion

A study on river flood modeling of Amochu river located in Phuntsholing city under Chukha District, Bhutan, was conducted to analyze flood frequency for different return periods, to generate flood inundation map to locate sites vulnerable to flooding and to find out the impact of flood to the settlements of present and future plan city in the study area. To examine affected land type by flood, Log Normal and Log-Pearson III techniques using the discharge rate of 2009 Amochu flood event were used for both existing and upcoming city plan. To obtain the flood inundation map, the one-dimensional model in HEC-RAS, ArcGIS for spatial data processing and HEC-GeoRAS as interface between HEC-RAS and GIS were used to comprehend the flood scenario. The Data such as DEM 5m spatial resolution (resampled from DEM 12.5m Alos Palsar), LULC 2016 and future city master plan were used in this study. LULC 2016 layer was used to assess the impact of flood in the present city, while master plan of future city of Phuntsholing prepared by PTDP and Ministry of Works and Human Settlement (MoWHS) were used to determine the affected areas by flood in the future city. The flood inundation maps for seven different return periods showed the details of affected area and the depth that indicated for both the present and future city by using the observed discharges data from the Doyagang gauging station solely located along the entire Amochu River.

The result found that in the current Phuntsholing city, the major vulnerable regions by flood will remain as the flood plain (46.55% to 58.02% from 25 year to 1000 years in Log Normal technique and 47.58% to 50.85% from 50 to 100 years in Log-Pearson III technique) and shrub areas (24.88% to 30.51% from 25 to 1000 years in Log Normal and 25.48% to 27.13% from 50 to 1000 years in Log-Pearson III technique) and the least affected areas will be agriculture (0.06% to 0.09% from 25 years to 1000 years in Log Normal and 0.06 to 0.07 from 50 to 1000 years in Log-Pearson III technique) and forest land (0.057% to 0.34% from 25 to 1000 years in Log Normal, 0.23 to 0.25% from 50 to 1000 year in Log-Pearson III). The study also found that in the upcoming city plan, Zone B (51.41% to 69.53% from 25 to1000 years in Log Normal and 52.58% to 57.50% from 50 to1000 years in Log-Pearson III) and Zone E (45.59% to 51.35% from 25 to1000 years in Log Normal 45.97% to 47.45% from 50 to 1000 years in Log-Pearson III) will be the most vulnerable zones to flood since these places are found to be located at vicinity of the river as well as to the downstream of the river, whereas Zone A (24.66% to 45.58% from 25-1000 years in Log Normal and 25.70% to 30.50% from 50 to1000 years in Log-Pearson III), LAP (12.16% to 22.01% from 25 to1000 years in Log Normal and12.50% to 14.91% from 50 to1000 years in Log-Pearson III technique) are less vulnerable since these places are located at little upstream and little farther away from the river. The study also found that the depth of the both present and upcoming city will be estimated to increase from 8.3m till 11.62m for 2 to 1000 years return period in Log Normal and 8.34m till 10.09m from 2 to 1000 years return period Log-Pearson III techniques.

Further, if city is to be extended along the riverine of Amochu River, extra discharges from the tributaries at the right banks has to be taken into account while mapping the flood. Therefore, this study imparts very useful preliminary information to the policy makers, urban planner or engineer’s further act upon sustainable flood mitigation measures in an efficient and effective way by reducing the risk to the settlements in the future. These findings are very useful tools for prediction of potential flooding areas and can be replicated to other parts of country for the better organization of a flood management plan.

Recommendations

From this study, the following recommendations are made to confront the future problem to flood and to carry the future studies in order to improve the accuracy of the study:

1. Acquired high resolution digital elevation model so as to get the accurate flood extend and depth of the study area.
2. Carry out calibration of simulated flood extend with the real time satellite images in the future to carry out validation with the inundation maps.
3. To get accurate and valid flood data, primary data such as rainfall and discharge data are very crucial, which is one of the limitations in this project as it has only one gauging station in the main stream. Therefore, there are need to install a number of hydrological stations along the river basin in order to have appropriate flood inundation map.
4. The flood inundation at the downstream is expected to increase by additional discharge from the two tributaries at the right side during the extreme monsoon season. But due to non-availability of discharge data, the discharge from these tributaries could not be taken into account. To get the discharge data, installation of individual gauging station is recommended which will be very helpful in achieving better inundation map in the future.
5. As land development and urbanization is going on in the study area, maps should be updated regularly by further complementing the study by analyzing flood risk in the flood inundation areas that has been analyzed in this study.

REFERENCES

Adhikari, K. (2015). *Modelling And Simulation Of Floods In Barsa River Near Pasakha* Climate Change, Environment and Development in Bhutan, Royal University of Bhutan (RUB), Thimphu, Bhutan.

Bennani, O., Tramblay, Y., Simon, G., Frédéric, L., & Saidi, M. E. M. (2019, 11/30). *Flood Hazard Mapping Using Two Digital Elevation Models: Application in a Semi-Arid Environment of Morocco*. *European Scientific Journal, 15*, 338-359. https://doi.org/10.19044/esj.2019.v15n33p338

Bhattarai, P., Prajwal, K., Tiwari, P., Lamichhane, N., Dhakal, P., Lamichhane, P., Panta, N., & Dahal, P. (2018). *Flood Inundation Mapping of Babai Basin using HEC-RAS & GIS*. https://doi.org/10.13140/RG.2.2.24401.99683

CDCL, & HCPDPM. *Amochu Land Development & Township Project* (Intergrated Detailed Project Report, Issue. C. D. C. Limited & H. D. P. M. P. Ltd.

Chikabvumbwa, S. (2019). *Rainfall Frequency Analysis using Gumbel Distribution*. https://doi.org/10.13140/RG.2.2.36593.12647

Curebal, I., Efe, R., Ozdemir, H., Soykan, A., & Sönmez, S. (2015, 05/29). GIS-based approach for flood analysis: case study of Keçidere flash flood event (Turkey). *Geocarto International*.

Demir, V., & Kisi, O. (2015). *Flood Hazard Mapping by Using Geographic Information System and Hydraulic Model: Mert River, Samsun, Turkey* [Research Article]. *Advances in Meteorology, 2016*, 1-9. https://doi.org/http://dx.doi.org/10.1155/2016/4891015

Deraman, W., Mutalib, N., & Mukhtar, N. (2017, 09/01). *Determination of return period for flood frequency analysis using normal and related distributions*. *Journal of Physics: Conference Series, 890*, 012162. https://doi.org/10.1088/1742-6596/890/1/012162

Donald W. Knight, & Shamseldin, A. Y. (2006). *River Basin Modelling For Flood Risk*

Mitigation. *Taylor & Francis/Balkema, The Netherlands*.

El-Naqa, A., & Jaber, M. (2018, 01/01). *Floodplain Analysis Using Arcgis, Hec-Georas And Hec-Ras In Attarat Um Al-Ghudran Oil Shale Concession Area, Jordan*. *Journal of Civil & Environmental Engineering*, *08*(05). https://doi.org/10.4172/2165-784x.1000323

Elkhrachy, I. (2018, February 01). *Assessment and Management Flash Flood in Najran Wady Using GIS and Remote Sensing* [Journal Article]. *Journal of the Indian Society of Remote Sensing*, *46*(2), 297-308. https://doi.org/10.1007/s12524-017-0670-1

Getahun, Y., & Gebre, S. (2015, 08/19). *Flood Hazard Assessment and Mapping of Flood Inundation Area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS Model*. *Civil & Environmental Engineering*.

Gimond, M. (2019). *Chapter 14 Spatial Interpolation*. Retrieved 11th April from https://mgimond.github.io/Spatial/spatial-interpolation.html

Hydraulic Engineering Center, U. A. C. o. E., California, USA. (2011). *HEC-GeoRAS - GIS tools for Support of HEC-RAS using ArcGIS, User's manual, Institute for water resources, CPD-83*. www.hec.usace.army.mil

Hydraulic Engineering Center, U. A. C. o. E., USA. (2016). *HEC-RAS River Analysis System, Hydraulic Reference Manual, Version 5.0, CPD 69*. https://www.hec.usace.army.mil/

JAXA/METI. (2015). *ALOS PALSAR_Radiometric_Terrain_Corrected_low_res; Includes Material © JAXA/METI 2007.* . Retrieved Accessed through ASF DAAC 11 November 2015, DOI: 10.5067/Z97HFCNKR6VA from

Jigme Tenzin, A. S. B. (2017). *Modeling of the Precipitation Induced Flash Flood in Sarpang, Bhutan Using Hec-RAS*. *Rasayan Journal of Chemistry*. https://doi.org/10.7324/rjc.2017.1021648

Khanna, R. K., Agrawal, C. K., & Kumar, P. *Remote Sensing And Gis Applications In Flood Management*.

Khattak, S., Anwar, F., Saeed, T. U., Sharif, M., Sheraz, K., & Ahmed, A. (2015, 11/06). Floodplain Mapping Using HEC-RAS and ArcGIS: A Case Study of Kabul River. *Arabian Journal for Science and Engineering, 41*. https://doi.org/10.1007/s13369-015-1915-3

Kovacs, Y., Doussin, N., & Gaussens, M. (2017). *Flood Risk And Cities In Developing Countries* 2492-2838).

Kurniyaningrum, E., Limantara, L. M., Suhartanto, E., & Sisinggih, D. (2019, 02/01). *Sensitivity of flow depth inundation based on the micro-scale topography in Krukut River, Jakarta, Indonesia*. *International Journal of Civil Engineering and Technology*, *10*, 697-706.

Lenin Laikangbam, C. L., Thangjam Somchand Singh. (2019). *Flood Hazard Zonation of Imphal River, Manipur, India, Using AWS Data. International Journal of Engineering and Advanced Technology (IJEAT), 8*(4th April 2019).

Merwade, V. (2016). *Tutorial on using HEC-GeoRAS with ArcGIS 10.x and HECRAS Modeling*.

NEC. (2016). *National Integrated Water Resources Management Plan*.

PTDP. (2018). *Phuentsholing Township Development Project (PTDP), Disaster And Climate Risk And Vulnerability Assessment*.

Rahman, S. U. (2014). *Impacts Of Flood On The Lives And Livelihoods Of People In Bangladesh: A Case Study Of A Village In Manikganj District* [Dissertation, BRAC University]. Dhaka, Bangladesh. http://hdl.handle.net/10361/3802

Rahmati, O., Pourghasemi, H., & Zeinivand, H. (2015, 06/09). *Flood susceptibility mapping using frequency ratio and weights-of-evidence models in the Golastan Province, Iran*. *Geocarto International*.

Te Chow, V. (1959). *Open-channel hydraulics*. McGraw-Hill.

Te Chow, V., Maidment, D. R., & Mays, L. W. (1988). *Applied Hydrology*. Tata McGraw-Hill Education. https://books.google.co.th/books?id=RRwidSsBJrEC

Teng, J., Jakeman, A. J., Vaze, J., Croke, B., Dutta, D., & Kim, S. (2017, 04/01). Flood inundation modelling: A review of methods, recent advances and uncertainty analysis. *90*, 201-216. https://doi.org/10.1016/j.envsoft.2017.01.006

Thromde Disaster Management Plan, T. A., Phuentsholing. (2016).

Tingsanchali, T. (2012). *Urban Flood Disaster Management*. *Procedia Engineering*, *32*, 25-37. https://doi.org/10.1016/j.proeng.2012.01.1233

Wangdi, K., & Lamichaney, M. (2018, 14th July). *Construction of Amochu Bridge on Samtse-Phuntsholing Highway*. *Kuensel* https://kuenselonline.com/construction-of-amochu-bridge-on-samtse-phuentsholing-highway/