“Flood Modelling of Imphal Valley using Hydrologic Engineering Centre-River Analysis System”

THESIS

Submitted to the

Jawaharlal Nehru Krishi Vishwa Vidyalaya
Jabalpur

In partial fulfillment of the requirement for
The Degree of

MASTER OF TECHNOLOGY

in

AGRICULTURAL ENGINEERING
(SOIL AND WATER ENGINEERING)

by

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2020

CERTIFICATE - I

This is to certify that the thesis entitled **"Flood Modelling of Imphal Valley using Hydrologic Engineering Centre-River Analysis System"** submitted in partial fulfilment of the requirement for the degree of **MASTER OF TECHNOLOGY in AGRICULTURAL ENGINEERING** in the **Department of Soil and Water Engineering** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Miss Hemam Henarita Devi** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.

All the assistance and help received during the course of the investigations has been acknowledged by her.

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This is to certify that the thesis entitled **“Flood Modelling of Imphal Valley using Hydrologic Engineering Centre-River Analysis System”** submitted by **Miss Hemam Henarita Devi** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirements for the degree of **MASTER OF TECHNOLOGY in AGRICULTURAL ENGINEERING** in the **Department of Soil and Water Engineering,** has been after evaluation, approved by the External Examiner and by the Student’s Advisory Committee after an oral examination on the same.

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I, **Hemam Henarita Devi** D/o **Shri Hemam Dijen Singh** certify the work embodied in thesis entitled **"Flood Modelling of Imphal Valley using Hydrologic Engineering Centre-River Analysis System"** is my own first hand bonafide work carried out by me under the guidance of **Dr. S. K. Pyasi** at Department of **Soil and Water Engineering**, College of Agricultural Engineering, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.) during 2018-19.

The matter embodied in the thesis has not been submitted for the award of any other degree/diploma. Due credit has been made to all the assistance and help.

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ACKNOWLEDGEMENT

First and foremost, I thank ‘Almighty God’ who has blessed me with the opportunity and strength to successfully complete this work.

It is a moment of great pleasure to put in record my heartfelt gratitude and indebtedness to honorable guide and chairman of my Advisory Committee Dr. S. K. Pyasi, Professor, Department of Soil and Water Engineering, JNKVV, Jabalpur for his able magnificent guidance, inspiration, constructive criticisms and encouragement during the course of investigations and preparation of the thesis.

I would like to express my sincere thanks and my gratitude to my co-advisor Dr. Ng. Romeji, Assistant Professor, Department of Civil Engineering, National Institute of Technology, Manipur and members of my advisory committee Dr. R. B. Singh, Professor, Department of Mathematic and Statistics, College of Agriculture, Jabalpur and Dr. R. N. Shrivastava, Associate Professor, Department of Soil and Water Engineering, College of Agricultural Engineering, Jabalpur for their helpful and constant guidance during the course of investigation.

I take the opportunity to thank Dr. P.K. Bisen, Hon'ble Vice Chancellor, JNKVV, Dr. D. Khare, Dean Faculty of Agriculture, JNKVV, Jabalpur, Dr. P.K. Mishra, Director, Research Services, JNKVV, Jabalpur, Dr. Abhishek Shukla, Directorate of Instructions, JNKVV, Jabalpur and Dr. R.K. Nema, Dean and Professor and Head, Department of Soil and Water Engineering, College of Agricultural Engineering, Jabalpur for their exuberant interest for submission of piece of research work.

I take this opportunity to thank Dr. M.K. Hardaha, Professor, Dr. M.K. Awasthi, Professor, Dr. S.K. Sharma, Professor, Dr. A.K. Bajpai, Associate Professor, Dr. Y.K. Tiwari, Associate Professor and Dr. M.L Sahu, Associate Professor of Department of Soil and Water Engneering, for their aspiring guidance and countless supervision throughout the research study.

I extend my sincere thanks to one and all of NIT Manipur PhD Research Scholars viz., I. Bidyasagar Singh, M. Bipinchandra, L. Chandramani Singh and PG Students/Project Staffs for their valuable support rendered for the completion of this research study.

I also attribute gratefulness to the various data sources: Indian Council of Agricultural Research (ICAR), Lamphelpat station, Imphal, Manipur for the hydro-met data provided; Directorate of Environment & Climate Change, Govt of Manipur, for the climatic data provided for various stations; Hydrological Investigation Circle, Water Resources Department, Govt of Manipur, for the important flood and river hydraulic data made available for the study.

I feel wordless to express my heartiest feelings towards my father Shri Hemam Dijen Singh and my mother Smt. Pukhram Binarani Devi and my younger sisters, Rupali Hemam and Deepali Hemam and also my grandparents Hemam Mangi and Hemam Momon for their unconditional love, care, blessings, appreciation and moral support.

I take it my pious duty in thanking my friend namely Rokozeno Chalie-u, for encouraging and supporting me and making me strong and positive in myself during the tough times.

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ABBREVIATIONS

HEC- RAS	:	Flood Modelling of Imphal Valley using Hydrologic Engineering centre-River Analysis System
GIS	:	Geographic information system
RS	:	Remote Sensing
LULC	:	Land Use and Land Cover
viz	:	namely

INTRODUCTION

Floods is broadly classified as riverine floods and urban floods, is increasingly becoming one of the most recurrent hydro-meteorological disasters in the globe. Flood inundation models are a valuable tool in mitigating increasing flood fatalities and losses as it provides an understanding of hydraulic modelling and floodplain dynamics, with a key focus on state-of-the-art remote sensing/geospatial data. This research study is motivated on how these models enable us to derive composite flood inundation maps for an urban sub-basin based on the above approach, which can support appropriate land use and urban planning, and contain new human settlements in flood prone areas. The methods to estimate and communicate uncertainty in urban flooding is however complex.

Among all the natural hazards of the world floods probably account for the greatest loss of life and highest degree of material damage. According to Abhas Jha and Jessica (2012), in 2010 alone, 178 million people were affected by floods and the total financial losses in the exceptional years such as 1998 and 2010 exceeded $40 billion. Even though flood is a natural phenomenon it becomes a hazard to the environment when it causes colossal loss to human lives and property. The total geographical area of the world that is covered by flood plain is about 3.5 %. Floods are divided into seven different types : periodic floods, flash floods, river floods, coastal floods, seasonal flood, tsunami floods and lake floods.

Over the past decades, there have been an increasing number of extreme rainfall and flood events occurring globally in relation to climate change, which paralyzes cities and result in serious social and economic consequences. In addition, small scale urban flooding occurs consecutively throughout the urbanized regions of the globe in relation to poor drainage. There is a growing need for proper storm water management to mitigate urban flood risk. In order to minimize the socio-economic impacts of flooding, solutions for preventing it consist of structural or non-structural measures Structural measures are costly whereas non-structural measures are financially more viable, focusing on prevention and conservation to give better harmony between the environment and urban areas along the river (Tucci, 2007).

Hydrodynamic models are efficient tools in the study of urban flooding and storm water management. Numerical simulations of urban floods are important when scientifically planning and designing urban drainage systems and providing efficient urban flood disaster control and management strategies. Although many models have been developed for river and coastal flooding, urban flooding models have not yet been adequately developed; this partly attributes to the complex flow processes in urban areas when inundation occurs. As there is a one dimensional (1D) flow property in sewer systems, the highly efficient one-dimensional (1D) model is the most commonly used tool to simulate the hydraulic performance of urban drainage systems. Although 2D models are more accurate and precise, the requirements of high-resolution data and computing resources poses a constraint.

Manipur is a small state located in a hilly terrain, covering an area of 22,327 square kilometres. The state lies at a latitude of 23°83'N – 25°68'N and a longitude of 93°03'E – 94°78'E. Annual rainfall varies from 933 mm to 2135 mm in the valley and up to 3148 mm in the hilly area and rainy season is quite long starting sometimes in the early part of May and continues up to the middle of October. Manipur Valley is traversed by the major rivers viz., **Imphal, Iril, Kongba, Thoubal, Sekmai, Nambul, Nambol, Khuga rivers, etc.** which either confluence or indirectly connect with the Imphal river to form the Manipur river from Ithai Barrage site onwards. The estimated catchment area of the Manipur river system is 6332 sq. Km.

Manipur is highly prone to natural disaster. Flood is a recurrent phenomenon in Manipur. In the year 2015 the state faced the worst flood in 200 years due to incessant rainfall in the past few days with water overflowed from of all main major rivers that wreaks havoc washing away connecting bridges, embankment breach cutting off many villages from the mainland. Worst affected districts are Bishnupur, Imphal East, Imphal West, Churachandpur, Thoubal and Chandel districts. Recent flood patterns have depicted the haphazard nature of rainfall events and the rise of degree of urban flooding in both spatial and temporal extents (Fig. 1.1). In order to avert this recurrent hydrological disaster, we need to develop a strategic plan by adopting appropriate methods/techniques/mathematical tools. Findings of this strategy for Imphal river basin and the Barak river basin may also be very useful for planning and rehabilitation of flood affected areas of Madhya Pradesh State.

With these in view following objectives is planned:

1. To analyze rainfall – runoff process of Imphal valley.
2. Application of HEC-RAS model for hydrological simulations.
3. To generate the flood inundation map of the study area using the simulated data

REVIEW OF LITERATURE

Flood has become a major threat to the people of Manipur as the water level of major rivers increased due to incessant rain and lack of proper drainage facility. Manipur has experienced major floods in the year 1966, 1974, 1980, 1984, 1985, 1986, 1989, 2002 and 2015. While the most devastating one occurred in the year 1989 which inundated almost all of the Imphal valley. The constant flooding of Imphal valley is due to several constraints such as increased urbanization, change in land use patterns, high intensity of rainfall in the hilly areas, heavy runoff and low infiltration. Many scientist and researchers have investigated on how to prevent and control the flooding. A brief work carried out in different parts of the world pertaining to the investigations has been described in this chapter under the following subheads.

2.1 Flood and its impacts

Flood is a natural process that can be defined as a body of water which rises to overflow land that is not normally submerged (Ward, 1978). It can be generated by many causes (and combinations thereof) that include: heavy rain, rapid snow/ice melt, glacial lake breaches, ice breakup, debris entrapment, dam breaks, levee breaches, landslide blockages and groundwater rises. The most common types of flood are storm surges, river floods and flash floods (Baldassare, 2012). The causes of floods can be broadly divided into physical, such as climatologically forces, and human influences such as vegetation clearing and urban development. The most common causes of floods are climate related, most especially rainfall. Prolonged rainfall events are the most common cause of flooding worldwide. These events are usually associated with several days, weeks or months long of continuous rainfall. Human impacts on river catchments influence flood behaviour. Land use changes in particular have a direct impact on the magnitude and behaviour of floods all over the world. Deforestation results in increased run-off and often a decrease in channel capacity due to increased sedimentation rates (Nott, 2006).

Borrows and De Bruin (2006) indicated that among natural catastrophes, flooding has claimed more lives than any other single natural hazard. In the decade 1986 to 1995, flooding accounted for 31% of the global economic loss from natural catastrophes and 55% of the casualties. Globally floods are increasingly among the most devastating natural disasters affecting human life than any other natural disasters. In 2010 alone, 178 million people were affected by floods and the total financial losses in the exceptional years such as 1998 and 2010 exceeded $40 billion. Destructive floods occurred along the Indus River basin in Pakistan in August 2010; in Queensland, Australia, South Africa, Sri Lanka and the Philippines in late 2010 and early 2011; along with mudslides, in the Serrana region of Brazil in January 2011; following the earthquake-induced tsunami on the north-east coast of Japan in March 2011; along the Mississippi River in mid-2011; as a consequence of Hurricane Irene on the US East Coast in August 2011; in Pakistan’s southern Sindh province in September 2011; and in large areas of Thailand, including Bangkok, in October and November 2011 (Jha *et al*., 2012). It is also reported that one sixth of the global population (one billion people); the majority of them among the world's being low income earners live in the potential path of a 1 in 100 year flood according to (DFID, 2012). The Indian region are subjected to some of the world’s most intense floods during the monsoon season due to the monsoonal climate with periodic high magnitude rainfall and the presence of mighty mountain ranges . The areas drained by the Himalayan river and its tributaries represent the most flood prone areas in India (Kale, 1998). The onset of the Indian Summer Monsoon (ISM) and its advance bring rain over different parts of India. ISM has inter-annual and intra-seasonal phases as onset and advance (mid-May to mid-July), peak rainfall (July to August) and withdrawal (mid-September to mid-October). In addition, latent heat source shifts over northern India due to shifting of Intertropical Convergence Zone (ITCZ), which generally stays between 20° and 30°N during the peak monsoon (July–August). The onset and advance phase is often accompanied by one or more transient disturbances. Their movements not only advance the monsoon isochrones to different parts of India, but are accompanied by heavy rainfall in the vicinity of monsoon transients during this phase. Frequency and duration of rainstorms over the monsoon region exhibit increasing trends. During 1951–2015, an increase from 4 to 8 rainstorms per year and from 12 to 27 rainstorm days per season have been observed suggesting a substantial increase in the risk of large-scale floods during ISM in India (Ray *et al*., 2019). As per the information published by different government agencies, flood prone area in India has been increasing dramatically. As reported by Central Water Commission (CWC) under Ministry of Water Resources, government of India, the annual average area affected by floods is 7.563 million ha based on data for the period 1953 to 2000, with variability ranging from 1.46 million ha in 1965 to 17.5 million ha in 1978. On an average, floods have affected about 33 million persons between 1953-2000. There is every possibility that this figure may increase due to population growth. The National Flood Commission (1980) has reported that the total flood prone area of India was 34 million ha (Mohapatra and Singh, 2003).

Flood is influenced by various factors - rainfall, river-flow and tidal-surge, topography, measure of floodcontrol, and alterations due to infrastructural. Some floods grow and discharge gradually, while others can develop in just a few minutes and recede quickly such as flash flood. Flood events are happening for the last many years and centuries but urban floods are getting studied moderately of late (Brown, 2011). Urban flooding is caused by heavy rainfall overwhelming drainage capacity. It already has large economic and social impacts. These are very likely to increase if no changes are made to the management of urban drainage. Urban floods are a great disturbance of daily life in the city. Roads can be blocked; people can’t go to work or to schools. The economic damages are high but the number of casualties is usually very limited, because of the nature of the flood. The water slowly rises on the city streets. When the city is on flat terrain the flow speed is low and you can still see people driving through it. The water rises relatively slow and the water level usually does not reach life endangering heights (Aggarwal, 2014). Urban flooding may then lead to flash flood with little or no warning when an intense rainfall burst occurs, causing a large amount of rain within a brief period which is more devastating. Urbanization in developing countries doubled from less than 25% in 1970 to more than 50% in 2006 and urbanization increases flood risk by up to 3 times, peak flows result in flooding very quickly due to faster flow times (Rafiq *et al*., 2016).

Developments encroach floodplains, obstructing floodways and causing loss of natural flood storage. Continued development and redevelopment to higher density land uses by high land costs. The proportion of impermeable ground in existing developments is increasing as people build patios and pave over front gardens. Increased impervious areas such as roads, roofs and paving, due to increasing development densities means more run-offs (Singh and Singh, 2011). Climate models predict that winter rainfall will increase by 20-30% by the 2080s. Such an increase could lead to a much larger (up to 200%) increase in flood risk. Poor natural drainage, chocking of drainage system, extreme climate events and development in river flood plain are the main causes of the urban flooding (Rafiq *et al*., 2016). Urban flooding can be reduced with measures like: maintaining existing drainage channels, providing alternative drainage paths (may be underground), control of solid waste entering the drainage systems, providing porous pavements to allow infiltration of rainwater, etc. (Ranger, 2011). Jha et al. (2012) presented that over the recent years, there has been an increase in attention to improve flash flood warnings in India and GCM predictions of climate change show an increase in extreme precipitation events, which may lead to more severe flash flooding. The authors also concluded that more areas will be prone to flash flooding as a result of increased urbanization

2.2 Hydrodynamic simulation software

Hydrodynamic models are the most widely used tools to simulate detailed flood dynamics. They can be directly linked to hydrological models and river models to provide flood risk mapping, flood forecasting and scenario analysis. Unlike emperical models, the input of hydrodynamic models can be manipulated/ perturbed to investigate the impact of changes in initial conditions, boundary conditions, or topographic input to account for augmentation/destruction of hydraulic features/structures (Teng *et al*., 2017). Over the past century, two groups of approaches have attracted the most attention and are the subject of ongoing research: empirical methods such as measurements, surveys, remote sensing and statistical models evolved from these data-based methods and hydrodynamic models (Schumann et al., 2009; Smith, 1997). Flood mapping commonly uses 1D and 2D hydraulic mathematical models (conceptual or empirical) to represent the hydraulic phenomena that determine water-levels (1D and 2D) and the area flooded These hydraulic models can also be coupled to hydrological models and to atmospheric models, to give a complete conceptual representation of all the processes involved (Monte *et al*., 2015). The simplest representation of floodplain flow is to treat the flow as one-dimensional along the centre line of the river channel (Brunner, 2016). The 2D models represent floodplain flow as a two-dimensional field with the assumption that the third dimension e water depth - is shallow in comparison to the other two dimensions (Roberts *et al*., 2015). 2D hydrodynamic models are perhaps the most widely used models in flood extent mapping and flood risk estimation studies. There has now been much assessment of the capability of the 2D models. Neelz and Pender (2009) have given a comprehensive review of 2D hydraulic modelling packages and, based on the review, a benchmarking study has been carried out to compare the performance of some commonly used 2D models (Neelz and Pender, 2010). More recently a later set of 2D models was reviewed and compared once again (Neelz and Pender, 2013) and confirmed that 2D models are capable of adequately predicting those variables, including velocity, flood extent and water level, upon which flood risk management decisions are based. For the most accurate modelling of each flood scenario, the most powerful tools should be used. Normally, 1-D modelling is practiced in order to reach practical results with low computational cost. However, in areas with mild terrain, this rather simplified approach can produce misleading results. Furthermore, additional complications are inserted into the modelling process, if there are obstacles in the computational field (e.g. buildings, bridges etc.). Therefore, in the areas of mild terrain, and particularly in built-up areas, a more comprehensive modelling approach should be adopted, e.g. 2-D and possibly 3-D models (Abderrezzak et al., 2008). Several packages are already available for 2-D flood modelling. The most popular of them are MIKE 21, CCHE2D, TELEMAC-2D, ISIS-2d, SOBEK, TUFLOW, RiverFLO2D, and Infoworks-2D (Tsakiris, 2014). For the last two decades advancement in the field of remote sensing and geographic information system (GIS) have greatly facilitated the operation of flood mapping and flood risk assessment. It is evident that GIS has a great role to play in natural hazard management because natural hazards are multi dimensional and the spatial component is inherent (Coppock, 1995). The main advantage of using GIS for flood management is that it not only generates a visualization of flooding but also creates potential to further analyze this product to estimate probable damage due to flood (Hausmann et al., 1998; Clark, 1998).

Smith (1997) reviews the application of remote sensing for detecting river inundation, stage and discharge. Since then, the focus in this direction is shifting from flood boundary delineation to risk and damage assessment. Therefore, there is a need to review the current literature with a holistic view of dealing with various prospects and constraints of using the technology of remote sensing and GIS in flood management. In the initial stages of satellite remote sensing the data available was from Landsat Multi Spectral Scanner (MSS) with 80 m resolution. The pioneering investigations in the field of application of remote sensing in flood mitigation were predominantly concentrated on the flood prone regions of USA. MSS data were used to deal with the flood affected areas in Iowa (Hallberg et al., 1973; Rango et al.,1974), Arizona (Morrison et al., 1973), and Mississippi River basin (Deutsch et al., 1973; Deutsch et al., 1974; Rango et al., 1974; McGinnis et al., 1975; Morrison et al., 1976). MSS APPLICATION OF REMOTE SENSING IN FLOOD MANAGEMENT 285 band 7 (0.8–1.1 µm) has been found particularly suitable for distinguishing water or moist soil from dry surface due to strong absorption of water in the near infrared range of the spectrum (Smith, 1997). From the early 1980s, Landsat Thematic Mapper (TM) imageries with 30 m resolution became the prime source of data for monitoring floods and delineating the boundary of inundation. Special attention was given to dealing with monsoon flooding in the developing countries like West Africa (Berg et al., 1983), India (Bhavsar, 1983) and Thailand (Ruangsiri et al., 1984). During later stages SPOT multi spectral imageries, were also used for flood delineation with the similar assumption that water has very low reflectance in the near infrared portion of the spectra. SPOT imageries, for example, were used along with a DEM for delineation of monsoon flood in Bangladesh (Brouder, 1994).

The existence of cloud cover appears as the single most important impediment to capture the progress of floods in bad weather condition (Rango et al., 1977). . The development of microwave remote sensing, particularly radar imageries, solve the problem because the radar pulse can penetrate cloud cover. Currently the most common approach to flood management is to use synthetic aperture radar (SAR) imagery and optical remote sensing imagery simultaneously in one project (Chen et al., 1999). Rejesk (1993) introduces three different methods for hazard zoning. His first method describes a binary model which evaluates whether the hazard is present or not in a particular raster cell. The second method involves ranking different locations of an area depending upon the intensity of the hazard present. In the last approach some 'hazard' values have been assigned to each of the raster cells based on the results of a multivariate model which were built up on a host of variables related to river flooding and associated hazards. Islam et al. (2001) conducted the most innovative, simple and cost effective study regarding flood hazard management by assessing the flood depth from NOAA AVHRR imageries simply by the tonal difference of the flood water.

The coupling of hydrological and hydraulic models has been a valuable tool in flood studies (Ballesteros et al., 2011; Bonnifait et al., 2009; Grimaldi et al., 2013; Paz et al., 2011; Sarhadi; Soltani; Modarres, 2012; Suriya; Mudgal, 2012), because it enables future scenarios to be simulated from limited input data. Moreover, this coupling combined with additional data and modelling procedures, such as remote-sensing (Bates et al., 2006; Chormanski et al., 2011; Raber et al., 2007) and Geographical

Information Systems (GIS) (CASAS et al., 2006), adds greatly to the optimization and display of results. Hydraulic modelling requires information that adequately represents flooded areas, including (a) data or estimates of flows upstream of the reach of interest (Sarhadi; Soltani; Modarres, 2012) and (b) good quality data on regional topography and bathymetry (Horritt; Bates, 2001; Nicholas; Walling, 1997). Lack of adequate topographic and bathymetric data can cause problems for the description of flooded areas given by the hydraulic model (Hardy; Bates; Anderson, 1999; Horritt; Bates; Mattinson, 2006; Sanders, 2007), because the channel bed and morphology of the region adjacent to the water-course are inadequately represented.

2. 3 Flood modelling studies in India

Romeji *et. al*. (2019) carried out a comprehensive study on the persistent and chronic urban flooding in Guwahati city (one of the most worst affected urban flood zones in India), using an integrated hydrologic–hydraulic model application aided by geospatial and ground survey inputs. The author(s) has effectively advocated the development of a refined urban topographic database (sub-metre contours) in the form a hybrid digital elevation model (DEM) of 0.25 to 1.0 m spatial resolution built upon CARTOSAT-1 stereo derived DEM and DGPS Real Time Kinematic (RTK) ground survey data conglomeration. HEC-HMS was effectively used to derive the flood flow hydrographs and drainage channel flow routing, which were consecutively applied as the boundary conditions in the DHI MIKE-FLOOD hydraulic model environment. The author(s) selected specific flood zones using Z-base flood points and carried out flood inundation simulations in real-time environment with building footprints, drainages/sewers, etc imposed on the urban bathymetry grid layer. It was established that the computed flood runoff peak values and runoff hydrographs followed the magnitude and spatial extent of flooding in Guwahati urban catchment (peak flows as high as 120 m^3/s have been generated in short durations of 3 to 6 hours, exceeding the discharge capacities of major drainage channels as Bharalu, Bahini, Amchang Nallas, etc in Guwahati urban catchment). Further the author(s) concluded that parcels of Rajgarh, Anil Nagar, Nabin Nagar localities in Guwahati city and its bye-lanes suffer from perpetual flooding and were classed as high to very high flood prone zones, where floods have occurred with daily total rainfall peaks ranging between 80 mm to 400 mm (analysis of storm records 2000 - 2014). Nandurkar et al. (2017) used HEC-RAS model to estimate the flood depths in Pune city for various rainfall conditions in 2016 monsoon. The estimated water depths at various locations in Pune city indicate moderate flooding in isolated pockets of the city. The study concluded that GIS/HEC-RAS provides important set of tools integrating the geospatial data for predicting urban flood and further of assessing vulnerability of the urban areas. Sunilkumar and Vargheese (2017) used the HEC RAS model and HEC HMS model to developed a flood inundation map and a flood hydrograph of the Mangalam River Basin and concluded that created map using HEC RAS serve as an information guide for various activities like flood mitigation. Sania and Prashant (2015) reviewed the application of HEC RAS in flood prediction and flood control in India and concluded that HEC-RAS is a advance software which is easy to use and powerful in determining water surface profile. It gives flood warning and prevent from flooding and inundation maps created by HEC-RAS are useful for various emergency plan of action. Agnihotri et al. (2011) examined the over-flooded cross-sections of Tapi River and modified that cross-section using geospatial technologies. The study helps to prepare plan for flood mitigation in Surat city and controlling flood over Tapti River. HECRAS software and ArcGIS software was used for preparation of flood inundation map. Tiwari et al. (2012) estimated the bridge scour for the Ganges road bridge using HEC RAS and it is then compared with Lacey’s formula. Comparative study carried out for different angles of attack and restricted flow condition near the bridge site concluded that more realistic results are obtained by HEC-RAS model as it considers more related factors as angle of attack, bed conditions, shape of piers, flow concentrations, flow depth and Froude No. as against discharge intensity and silt factor considered in case of Lacey’s equation. Timbadiya et al. (2011) aimed at determining values of Manning’s roughness coefficients for upper and lower reaches of the lower Tapi River for simulation of flood. The requirement of multiple channel roughness coefficients along the river was done through simulation of flood, using HEC-RAS, for the years 1998 and 2003. Vijay et al. (2009) presented hydrodynamic simulation of the river Yamuna under different designated flood flows to delineate the land availability under existing and modified riverbed geometry including channel dredging and riverbed dressing. Parhi et al. used HEC-RAS to calibrate the channel roughness coefficient along the river Mahanadi, Odisha. The study concluded that mannnig’s "n” value of 0.032 gives best result for Khairrmal to Munduli reach of the Mahanadi river. The calibrated model, in terms of channel roughness, was used to simulate the flood for year 2006 in the same river reach. The performance of the calibrated and validated HEC-RAS based model is tested using Nash and Sutcliffe efficiency. Vijay et al. (2007) describes a hydrodynamic model called River Cad that provides the flood levels and land availability at various cross – sections in order to assess the limitation and evaluate the possibilities for riverbed development. Doiphode and Ravindra (2012) simulate flows through natural channels based on the concepts of hydraulic flood routing model, with time-varying roughness. The authors solved Saint Venant's equation using the quasi-steady dynamic wave and full dynamic wave theory. Husain et al. (2018) describes the development and application of a hydrodynamic model based on HEC-RAS modeling system developed by the Hydrologic Engineering Centre at United States Army Corps of Engineers for the simulation of floods in the Delhi segment of River Yamuna. The HEC-RAS model was first calibrated and validated and then applied for the simulation of historical floods of 2010 and 2013. The study concluded that concluded that the results presented herein could provide valuable aid to policy makers in formulating mitigation strategies to counteract the adverse impacts of flooding in the Yamuna River basin. Sravani and Balaji (2013) used the combination of SWAT, HEC-RAS and GIS models to provide a method for modelling and visualizing the spatial distribution of the Thamiraparani River Basin response for a given storm event in terms of flood inundation area. The hydrologic analysis from this study shows that SWAT model could be used to get a reasonable estimate of the hydrology with minimal calibration and the study also demonstrated the usefulness of these models as exploratory tools for identifying critical sections of the reach for detailed analysis. Prabeer Kumar Parhi (2018) estimated the levels of peak floods at different locations of Mahanadi River reach between Hirakuddam and Naraj considering 25 years return period and 36 cross sections using Gumbel’s extreme value distribution and HEC-RAS model. The results of the study showed that out at 23 sections, heightening of embankment spanning from a minimum of 0.11 m to a maximum of 10.63 m in the left bank and from 0.09 m to a maximum of 9.94 m for the right bank is needed to effectively minimize the flood hazard of the Mahanadi River system. Pathan et al. (2019) applied the methodology of flood modeling using Arc GIS and HEC GeoRAS software to Purna River, Navsari district, Gujarat, India . Satellite, topographic, contour map, hydraulic and hydrologic data were used for flood modeling. The study concluded that with GIS technology combine with the computed model the flood mitigation is very beneficial for disaster management after mapping the extent of the flood. Sandhyarekha and Shivapur (2017) successfully modelled and mapped the watershed area of the Krishna basin using the HEC-RAS hydraulic model showing the flooded areas along the part of Krishna basin. The authors concluded that HEC-RAS model coupled with remotely sensed data (DEM) is vital in geospatial analysis of the hydrologic cycle including inundation mapping, watershed and flood plain delineation. Rakesh and Chandranath (2005) screened data of 13 stream flow gauging sites of the North Brahmaputra region of India using the discordancy measure (Di)(Di) and tested homogeneity of the region employing the L-moments based heterogeneity measure (H) and conducted a flood frequency analysis Zope *et al*. (2016) investigated the impact of land use–land cover change and urbanization on floods for an urban catchment of the Oshiwara River in Mumbai using HEC-GeoHMS and HEC-HMS models concluded that the flood inundation area is increased by 5.61% for the 100-year return period and 6.04% for the 10-year return period. Mandal and Chakrabarty (2016) developed a simulation model of surface runoff in upper Teesta basin using HEC-RAS and HEC-HMS by integrating meteorological and morphological data in the geospatial environment and the authors concluded that the model can be applied in other flash flood prone area of the world for early warning and rescue operation. Rao et al. (2014) carried out hydrological and hydraulic simulation study in the Mandakini River using space based inputs to quantify the causes of the flash floods and their impact on recent floods in the Kedarnath area, Uttarkhand. The study reveals quantitative parameters of the disaster which was due to an integrated effect of high rainfall intensity, sudden breach of Chorabari lake and very steep topography. Kumar and Sumangala (2015) generated flood inundation maps using DEMs (ASTER), flood modeling using hydrodynamic models and compared with the flood extent maps derived from RADARSAT SAR satellite images for September 2003 flood event of Puri District, Orissa, India. The author concluded that integration of GIS and hydrodynamic modeling is an efficient way to predict and map the flood areas.

MATERIALS AND METHODS

The present study entitled **“Flood Modelling of Imphal Valley using Hydrologic Engineering centre-River Analysis System”** was conducted during the year of 2019 at RS and GIS laboratory, National Institute of Technology, Manipur. Different materials and methodologies were used during the course of evaluation.

3.1 Study Area:

Imphal valley is a palaeo-lake basin formed by filling up of an ancient Lake which once covered the whole valley. Imphal is located at 24°49′& 24° 82′ North latitude and 93°57′& 93°95′ East latitude in extreme eastern India with an average elevation of 786 meters (2,579 ft.). Imphal River, Nambul River and Kongba River flow through Imphal city in a North-South direction and have numerous tributaries running through the town. The topography of Manipur has significant influence on the population growth pattern in the Imphal city. Major growth in Imphal has taken place towards the south along the highways. The growth along the north, east and northwest has been restricted by hills. The land use/land cover patterns of the state have been classified into five categories, namely Settlement, agricultural land, forest, water bodies and others. The last category of others includes rivers/streams, roads, water logged areas converted to new agricultural land, and etc. There is sharp differences in land use patterns between the valley districts and the hill districts. In the valley districts, settlements account for more than ten per cent of the irrespective areas, whereas for the hill settlements account for less than one per cent of the area. Agricultural land in the valley is more than 40 per cent of the land area.

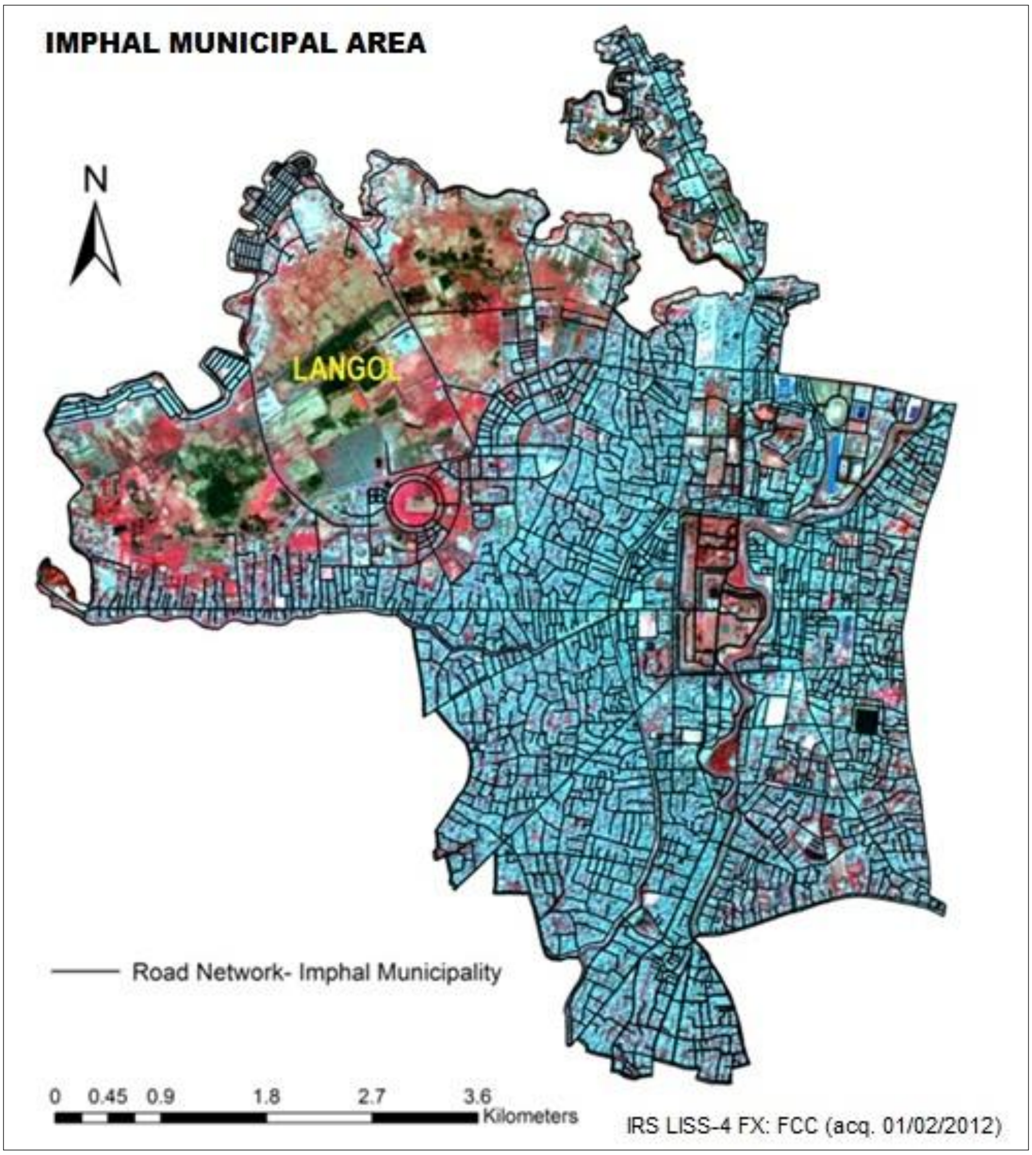

Fig. 3.1. Imphal Urban and its municipal boundary (source: IRIS project, NESAC)

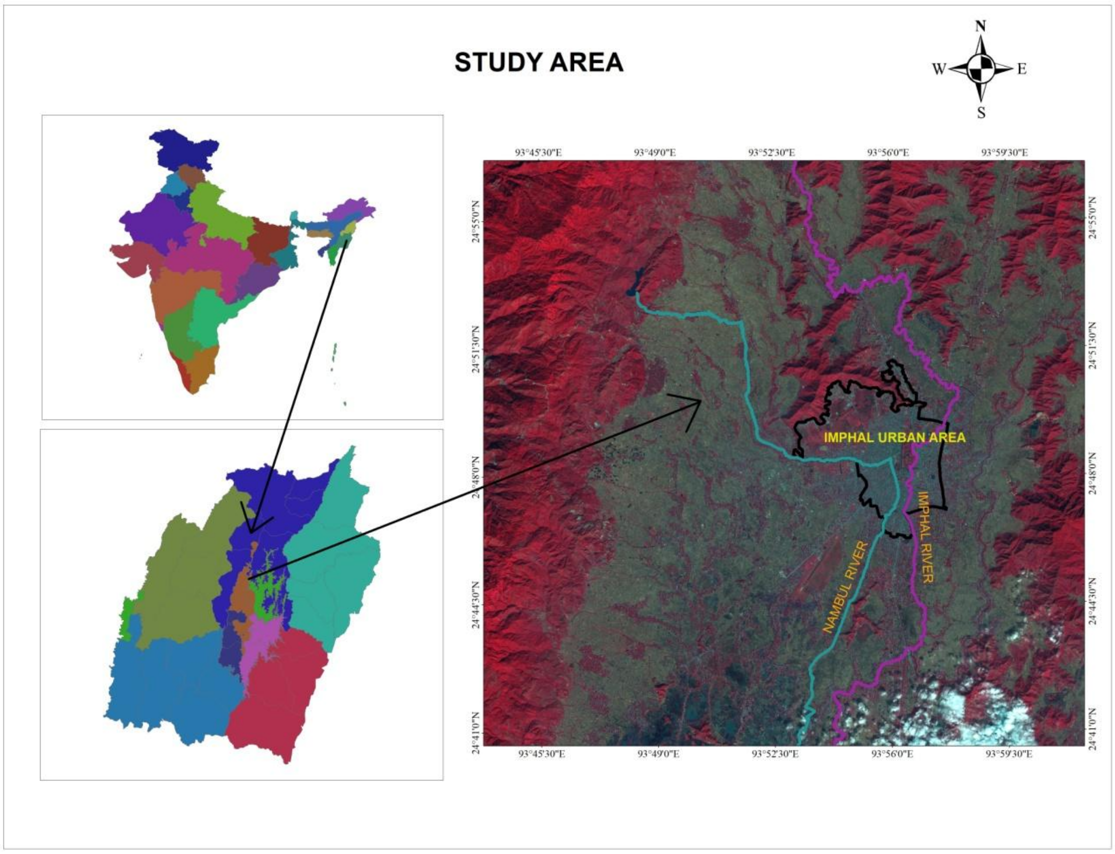

Fig 3. 2. Study Area Map

Imphal river basin and the Barak river basin are the two most important river basin of Manipur. During monsoon, floods and flash floods are the most common natural hazard faced by the state and Imphal city due to heavy reduction in surface water storage structures as a result of urbanization and change in land-use pattern. Recent urbanization activities have converted major portions of the sink area of the drainage system of Imphal urban into a fill region, which has drastically affected the hydrological regime of this sub-catchment. Imphal urban witness's intermittent flash floods and inundation since the disruption in its wetland composure, notably the floods in the monsoon months of 2002, 2011 and 2015 caused severe flood inundation. Though not as catastrophic as the floods in upper Assam region or Arunachal Pradesh, the prolonged water logging in this urban pocket may be classified as an urban disaster which needs to be resolute using a methodical approach. Summary of recorded flood events in Manipur is presented in Table 1.

Table 3. 1 Historical Flood record of Imphal valley

Year	Remarks
July-August 1989	Flood occurred in Manipur Valley at its devastating worst. Altogether 361 localities were inundated. Breached of embankment took place at 40 places. 7 lakhs of people were affected and 97,500 hectares of paddy fields were damaged . The magnitude of the flood was severe.
14th October 1992	Due to the incessant rainfall in the upper catchment area of the major rivers of Manipur Valley, water level of all the rivers rose rapidly. Serious breaches took place at 4 different place. The flood was of moderate magnitude.
September 1997	Flood occurred in Manipur Valley. All the rivers flowing through Manipur Valley were rising rapidly from 25th September 1997. Breaches of embankments took place at four different places of Nambul River. Due to the flood, damage caused to houses rose upto 4965 numbers. The flood was of high magnitude.
July-August 1998	Flood occurred in the Valley in July 1998 affecting some areas of Iroisemba. In August, breach of river embankment took place at one place of Wangjing River . Magnitude of the flood was low.
September 1999	There was incessant rainfall from 24th August to 3rd September 1999. The flood mainly affected the southern parts of the Valley. Not less than 7,300 houses and 15,300 hectares of paddy fields are affected. The flood was of moderate magnitude
September 2000	Flood occurred in Manipur Valley. Breaches of river embankment take place at 30 different places. Not less than 2,400 houses and 7,800 hectares of paddy field were affected. Breaches of river embankment take place at 11 places of Thoubal River. The flood was of moderate magnitude.
June-July 2001	Flood of low magnitude occurred in some parts of Manipur Valley. On 7th June breach of embankment of Nambol River took place at Nambol, Kongkham inundating Kongkham, Sabal Leikai, Maibam and Naorem. On 1st July Nambul River overflowed, inundating Uripok and Khwairamband Bazar
August 2002	Severe flood was occurred in Manipur valley. Breach of embankment took place at 59 places. Due to incessant rain in the catchments, all the rivers flowing in and around Imphal, Thoubal and Bishnupur districts were rising from August 11, 2002. On August 13, 2002, the water levels in all major rivers/streams in Manipur valley were rising alarmingly crossing the R.F.L on the same day. About 10,000 houses and 20,000 hectares of paddy fields were affected.

Year	Remarks
August 2015	Manipur is battling with the worst flood in 200 years due to incessant rainfall in the past few days with water overflowed from of all main major rivers that wreaks havoc washing away connecting bridges, embankment breach cutting off many villages from the mainland. Worst affected districts are Bishnupur, Imphal East, Imphal West, Churachandpur, Thoubal and Chandel districts
May and June 2017	The State experienced massive flood starting from 30th June, 2017 due to heavy incessant rains and caused extensive damages to dwelling houses, paddy fields, standing crops, infrastructure etc.

Fig 3.3 File photo of Imphal urban flooding caused by the Nambul river © 02/07/2017

Fig. 3.4 Nambul river at high flows recently in early Monsoon (2017) at Naoremthong

Fig. 3.5 Imphal river at high flows recently in early Monsoon (2017) near Ithai

3. 2 Tools and Packages:

3. 2. 1 ArcGIS 10. 2. 2

Arc GIS is a geographical information system for working with maps and geographic information maintained by the Environmental Systems Research Institute (ESRI). It is used for handling and analyzing geographic information by visualizing geographical statistics through layer building maps like climate data or trade flows. Arc GIS creates maps that require categories organized as layers. Each layer is registered spatially so that when they are overlaid on top of one another, the program lines them up properly to create a complex data map. The base layer is almost always a geographical map, pulled out of a range of sources depending upon the visualisation needed.

Arc GIS consists of the following windows desktop software:

- Arc Reader for view and query maps created with the other ArcGIS products
- Arc GIS Pro, works in 2D and 3D for cartography and visualization, and includes Artificial Intelligence
- Arc GIS Desktop has four fundamental applications:
    - ArcMap, for viewing and editing spatial data in two dimensions and creating two dimensional maps;
    - ArcScene, for viewing and editing three dimensional spatial data in local projected view;
    - ArcGlobe, for displaying large, global 3D datasets;
    - ArcCatalog, for GIS data management and manipulation tasks

All the pre processing works such as extracting the geometric data, Manning roughness data needed for the modelling and maps elaboration are carried out in ArcGIS with the help of HEC- geoRAS extension

3. 2. 2 HEC- GeoRAS

HEC – GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface. The interface allows the preparation of geometric data for import into HEC- RAS and process simulation results exported from HEC- RAS. It is developed using ArcGIS Desktop and ArcGIS Spatial Analyst and 3D Analyst extentions. The geodatabase design supports analysis of spatial data for hydraulic modelling and floodpain mapping

GeoRAS uses ArcGIS Desktop to develop spatial data input for HEC-RAS models from digital terrain models an dother GIS datasets. After the model results are calculated in HEC- RAS, they can be post processed in GeoRAS, then the floodplain depths and extents can be mapped together with other relevant spatial results such as modeled velocity distribution and sediment transport. It employs the divide and conquer approach to mapping extremely large terrain datasets. The geographic framework for hydraulic analysis, combined with public assets such as roads, freeways, shelter locations, and evacuation routes, aides in protecting lives and properties in the event of flooding.

3. 2. 3 HEC - RAS

Hydrologic Engineering Centre River Analysis System (HEC – RAS) is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program was developed by the **United States Army Corps of Engineers** in order to manage the rivers, harbors, and other pubic works under their jurisdiction. It was released in public in 1995. It includes numerous data entry capabilities, hydraulic analysis components, data storage and management capabilities, and graphing and reporting capabilities.

HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities.

The HEC-RAS system will ultimately contain three 1-dimensional hydraulic analysis components for:

(1) Steady flow water surface profile computations;

(2) unsteady flow simulation;

(3) Movable boundary sediment transport computations.

Currently steady and unsteady flows are available and sediment transport is under development. A key element is that all three components will use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed; including bridge scour computations, uniform flow computations, stable channel design, and sediment transport capacity.

3.2.3.1 HEC-RAS Theory

HEC-RAS is a one-dimensional steady flow hydraulic model designed to aid hydraulic engineers in channel flow analysis and floodplain determination. The results of the model can be applied in floodplain management and flood insurance studies. If you recall from hydraulics, steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario, and is called the direct step method. The basic computational procedure is based on an iterative solution of the energy equation, which states that the total energy (H) at any given location along the stream is the sum of potential energy (Z + Y) and kinetic energy (V2/2g). The change in energy between two cross-sections is called head loss (hL). The energy equation parameters are illustrated in the figure 2 :

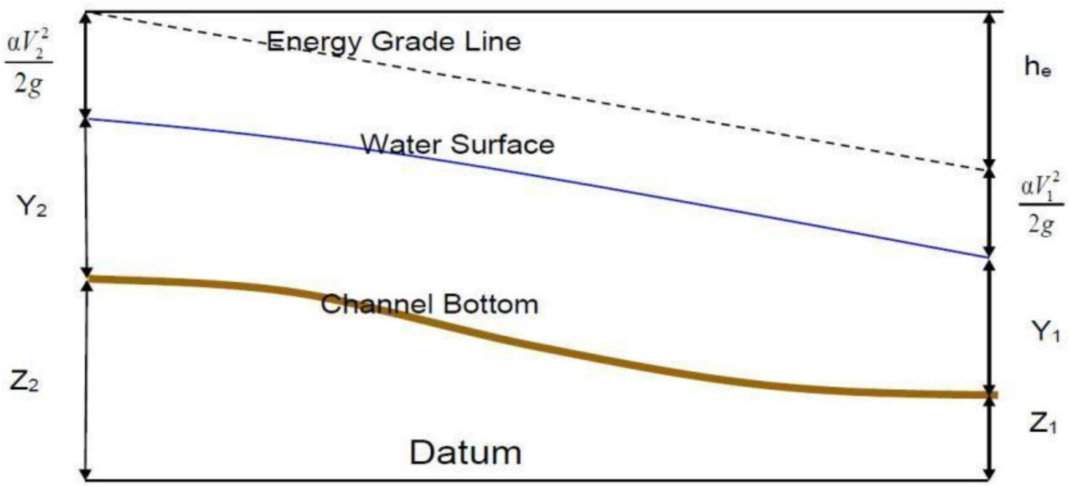

Figure 3.6 Representation of terms in the energy equation

Given the flow and water surface elevation at one cross-section, the goal of the direct step method is to compute the water surface elevation at the adjacent cross-section. Whether the computations proceed from upstream to downstream or vice versa, depend on the flow regime. The dimensionless Froude number (Fr) is used to characterize flow regime, where:

- Fr < 1 denotes Subcritical flow
- Fr > 1 denotes Supercritical flow
- Fr = 1 denotes Critical flow

For a subcritical flow scenario, which is very common in natural and man-made channels, direct step computations would begin at the downstream end of the reach, and progress upstream between adjacent cross-sections. For supercritical flow, the computations would begin at the upstream end of the reach and proceed downstream.

The Energy equation is written as follows:

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad \textbf{(1)}$$

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)

a_1, a_2 = velocity weighting coefficients

g = gravitational acceleration h_e = energy head loss

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-values change) as the basis for subdivision (Figure 6). Conveyance is calculated within each subdivision from the following form of Manning's equation (based on English units):

$$Q = KS_f^{\frac{1}{2}} \tag{2}$$

$$K = \frac{1.486}{n} AR^{\frac{2}{3}} \tag{3}$$

Where: K = conveyance for subdivision

n = Manning's roughness coefficient for subdivision

A = flow area for subdivision

R = hydraulic radius for subdivision (area / wetted perimeter)

S_f = slope of the energy grade line

The program sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and the right overbank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right).

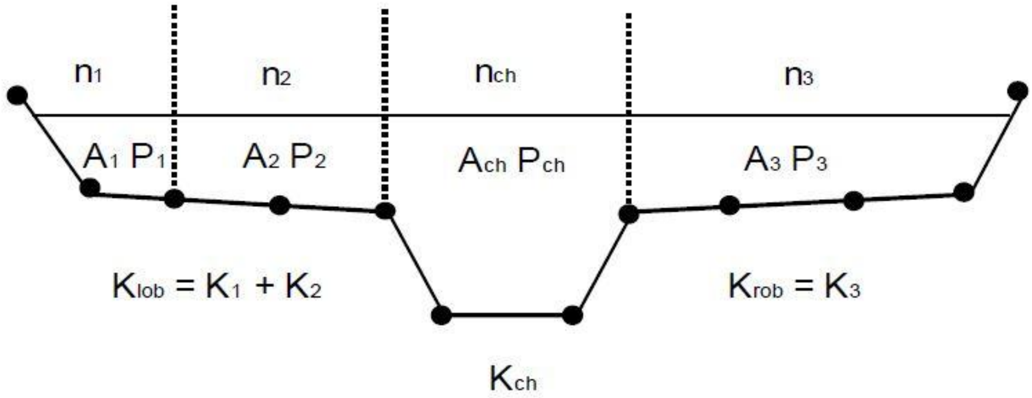

Figure 3.7 HEC-RAS Default Conveyance Subdivision Method

Whenever the water surface passes through critical depth, the energy equation is not considered to be applicable. The energy equation is only applicable to gradually varied flow situations, and the transition from subcritical to supercritical or supercritical to subcritical is a rapidly varying flow situation. There are several instances when the transition from subcritical to supercritical and supercritical to subcritical flow can occur. These include significant changes in channel slope, bridge constrictions, drop structures and weirs, and stream junctions. In some of these instances empirical equations can be used (such as at drop structures and weirs), while at others it is necessary to apply the momentum equation in order to obtain an answer. Within HEC-RAS, the momentum equation can be applied for the following specific problems: the occurrence of a hydraulic jump; low flow hydraulics at bridges; and stream junctions. In order to understand how the momentum equation is being used to solve each of the three problems, a derivation of the momentum equation is shown here.

The momentum equation is derived from Newton's second law of motion:

Force = Mass x Acceleration (change in momentum)

$$\Sigma F_x = ma \quad \textbf{(4)}$$

$$P_2 - P_1 + W_x - F_f = Q\rho\Delta V_x \quad \textbf{(5)}$$

Where: P = Hydrologic pressure force at locations 1 and 2.

W_x = Force due to the weight of water in the X direction.

F_x = Force due to external friction losses.

Q = Discharge

ρ = Density of water

ΔV = Change on velocity from 2 to 1, in the X direction.

Flow is assumed to be steady because time dependant terms are not included in the energy equation (Equation 2). Flow is assumed to be gradually varied because Equation 2 is based on the premise that a hydrostatic pressure distribution exists at each cross section. At locations where the flow is rapidly varied, the program switches to the momentum equation or other empirical equations. Flow is assumed to be one-dimensional because Equation 3 is based on the premise that the total energy head is the same for all points in a cross section.

3. 3 Hydrologic Modelling Datasets:

3.3.1 Spatial Data

3. 3. 1 .1 Digital Elevation Model (DEM)

The DEM is a digital file consisting of terrain elevations for ground positions at regularly spaced intervals. It is a fundamental dataset for development of geometrical data model for import in HEC RAS model. This dataset is useful in hydrological modeling, hydraulic modeling, and flood hazard map generation. The DEM used was ALOS PALSAR of cell size 12.5 resample to 10m. In a DEM, each cell has a value corresponding to its elevation (z-values at regularly spaced intervals). The DEM files contain the elevation of the terrain over a specified area, usually at a fixed grid interval over the “Bare Earth”. The intervals between each of the grid points will always be referenced to some geographical coordinate system (latitude and longitude or UTM (Universal Transverse Mercator) coordinate systems (Easting and Northing). For a more detailed information, it is necessary that grid points of a DEM data file are closer together. If the grid spacing is small the details of the peaks and valleys in the terrain will be modeled better than when the grid intervals are very large.

3.3.3.2 Multispectral Satellite Imagery (MX):

Sentinel-2 is a satellite designed specifically to deliver a wealth of data and imagery and was launched as a part of the European

Commission's Copernicus program on June 23, 2015. The satellite was developed and operated by European Space Agency (ESA). It systematically acquires optical imagery at high spatial resolution of 10m to 60m over land and coastal waters in the visible, near infrared (VNIR), and short-wave infrared (SWIR) spectral zones, including 13 spectral channels, which ensures the capture of differences in vegetation state, including temporal changes, and also minimizes impact on the quality of atmospheric photography. It is making a step change in the way we manage our environment, understand and tackle the effects of climate change and safeguard everyday lives. The combination of high resolution, novel spectral capabilities, a swath width of 290 km and frequent revisit times provides unprecedented views of Earth. The mission is based on a constellation of two identical satellites Sentinel 2A and Sentinel 2B. The two satellites cover all Earth’s land surfaces, large islands, inland and coastal waters every five days at the equator. The mission provides information for agricultural and forestry practices and for helping manage food security. Satellite images obtain from Sentinel 2 can be used to determine various plant indices such as leaf area chlorophyll and water content indexes.

Sentinel-2 image is a useful tool for flood hazard mapping and helps in mapping changes in land cover and to monitor the world’s forests. It also provides information on pollution in lakes and coastal waters. Images of floods, volcanic eruptions and landslides obtain from Sentinel 2 contribute to disaster mapping and help humanitarian relief efforts. The multi spectral imagery used was of 10 m resolution and it gives an idea of the extent of flood in Imphal valley.

3.3.3 Land Use Land Cover

Land Use/Land Cover data refers to data that is a result of classifying raw satellite data into "land use and land cover" (LULC) categories based on the return value of the satellite image. The classification process of LULC is very labour intensive. The term land use and land cover are often use together and is interchangeable but each term has its own unique meaning. Land cover refers to the surface cover on the ground like vegetation, urban infrastructure, water, base soil whereas land use refers to the purpose the land serves. LULC provides information of various land uses and cover types, such as urban, forested, shrub land, agriculture, etc. LULC map are most commonly in a raster or grid data structure and each cell have a value that corresponds to a certain classification. LULC of the study area was created in ArcGIS based on the image processing algorithm Supervised Maximum Likelihood Classification. In the maximum likelihood classification each cell is assign to one of the classes represented in the signature file. The LULC of the study area was classified into five different classes and the five different classes are build ups, water bodies, agriculture, vegetation and open soil.

3.4 Hydro-meteorological Data :

3. 4. 1 Rainfall Data (ICAR)

The rainfall data of the study area for the year 2017 was collected from the Agro- Met Weather Station located at the ICAR Research Complex NEH Region, Manipur Centre, Lamphelpat. The reading was collected twice daily at 0600 hrs and 1130 hrs. Agrometeorological station is a derivative station that uses advanced remote data acquisition unit.and records the rainfall and other weather conditions of a particular area. Agro- Met is geared with multi- parameter weather sensors and it simultaneously measures wind speed and direction, air temperature, air humidity, air pressure, rain amount, duration and intensity, solar radiation and sunshine duration. The station obtains the data from the sensor via SMS or Satellite network. The device helps in disaster management through timely and accurate data monitoring. The station is equipped with one unit of the following components:

- Advanced Remote Data- Acquisation Unit
- Multi- parameter sensor
- Rain gauge sensor
- Soil moisture and temperature sensor
- Unit 15 W Solar Panel
- Mechanical mountings and sensor housing

Table 3.2 Rainfall data for the year 2017

Months	Temp (^{0}C)		R Humid (%)		Wind Direc (Deg.)		Wind	C C (Okta)		Rainfall	Sunshine
	Max.	Min.	700h	1300h	700h	1300h	Speed (km/hr)	700h	1300h	(mm)	(hrs)
Jan	23.3	6.0	89.3	42.2	184.1	219.7	2.7	0.8	1.3	3.7	6.0
Feb	24.7	8.6	86.3	41.5	221.1	262.1	4.1	0.8	1.2	19.4	7.9
Mar	24.0	11.7	83.9	52.0	182.9	263.2	4.7	3.2	4.1	250.6	5.3
Apr	25.8	17.4	85.0	68.5	161.5	219.5	4.6	4.3	4.9	273.3	5.3
May	28.9	19.8	85.0	62.6	144.5	248.5	4.2	4.8	3.9	230.9	6.0
Jun	29.0	22.3	91.9	73.4	172.8	223.8	0.0	5.8	5.4	319.8	3.7
Jul	29.0	22.6	92.8	76.1	143.9	219.4	0.0	7.0	6.0	396.8	3.0
Aug	29.1	22.3	93.9	78.4	178.4	223.1	0.0	6.8	6.5	219.3	2.9
Sept	29.1	21.8	93.6	76.0	164.7	234.3	0.0	6.5	5.0	359.2	4.3
Oct	28.1	19.4	92.5	69.7	81.6	230.2	0.0	6.1	4.6	242.6	4.8
Nov	26.6	13.5	93.3	58.8	93.8	193.2	0.0	2.8	2.3	7.5	8.2
Dec	22.4	9.7	93.8	58.8	82.9	233.4	0.0	2.5	1.8	116.3	6.4

3. 5 Methodology :

3.5. 1 Overview

The process of flood inundation mapping is an essential component of flood risk management because flood inundation provides accurate geospatial information about the extent of floods and when it is coupled with a geographical information system, helps decision makers extract other useful information to assess the risk related to floods such as human loss, financial damages and environmental degradation. Several methods are available to obtain the spatial extent of flood. For any flood modelling detail knowledge of the field, background investigation, data aquisation and model development is necessary. Background investigations includes obtaining a detailed history of flood events of the study area and reviewing previous reports.

The Hydrological Modelling is done by using ArcGIS 10.2.2 with HEC-GeoRAS extension and HEC-RAS version 5.0. 6 by understanding the basic functions in HEC-GeoRAS for pre- and/or post-processing of GIS data and HEC-RAS results for flood inundation mapping using ArcGIS. The essential dataset required for HEC RAS is the terrain data or DEM, aerial image, Manning's roughness coefficient and flow data. LULC map was created to define the Manning's roughness coefficient on the cross sections. The study area was classified into five land cover categories: buid ups, water body, agriculture, vegetation, open soil and roughness coefficients were assigned to each land cover category.

After extraction of geometric data, roughness coefficient data was performed in ArcGIS by HEC GeoRAS extension tools the GIS processed data is imported to HEC RAS. In HEC RAS unsteady state flow simulations were performed, entering the flow data at the upstream cross section of the reach assigning the boundary condition as normal. Once the unsteady state flow simulation in HEC-RAS model was complete, output data was exported to GIS. In ArcGIS the HEC GeoRAS extension uses the output data to create the flood inundation map.

3. 5. 2 Methods

The development of the present flood model integrates HEC RAS river hydraulic model with GIS. HEC RAS was utilized as hydrodynamic model using HEC GeoRAS for linking to a GIS environment. The propose approach to the study can be broadly divided as the Pre processing of data or RAS Geometric data creation, model execution and Post processing or Floop map creation .

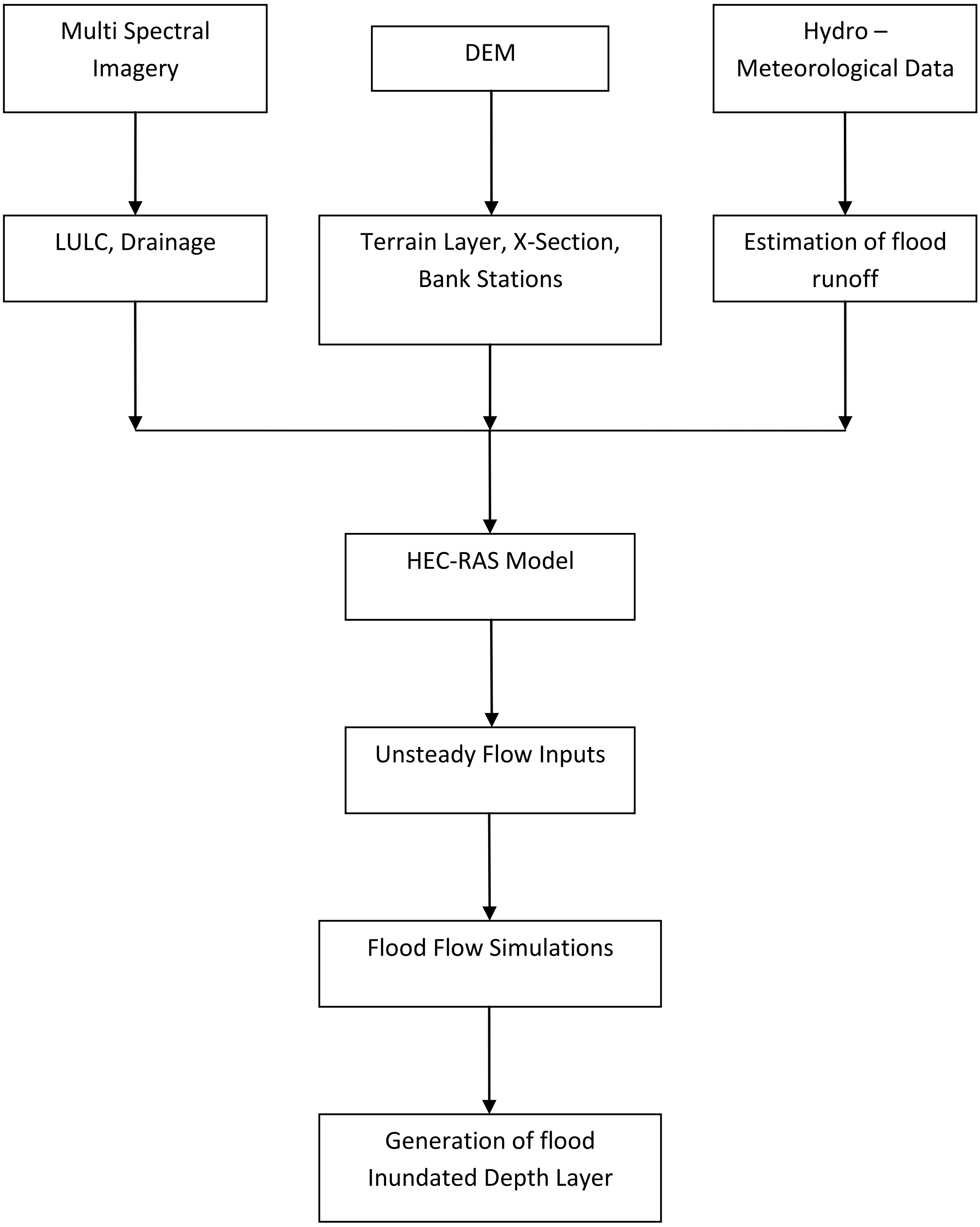

Fig. 3.8 Methodology Flow Chart

3.5.2.1 Pre processing of data or RAS Geometric data creation

Geometric data for import to HEC RAS model is created by making corrections in the acquired data. The data for import into the model is prepared in the GIS platform with help of HEC GeoRAS extension. First the DEM was converted to TIN format by using the 3D analyst toolbox. Pre processing mainly comprises of correction of satellite remote sensing data, tabulations of the hydro-meteorological data, and generations of various input layers. The input layers are LULC and other geometric data such as river centreline, river banks, flow paths, river cross- sections which were created using the TIN data as the base map in HEC GeoRAS and delineated the geometric data by using the editor tool in Arc GIS. The layers are resampled to 10 m spatial resolution so that when they are overlaid on top of one another, the program lines them up properly to create a complex map. The detailed procedure is given as under

Setting up Analysis Environment for HEC-GeoRAS

The first step is to add a base map to the project file. With the help of the HEC-GeoRAS extension a New Map is added to create a new data frame. A new data frame is added to the ArcMap table of contents. To create a geometry file, click on add button in ArcMap and add the Terrain data. All the data and data frame added must have the same coordinate.

HEC RAS has three main components: - (a) the geometry data which consists of a description of the size, shape, and connectivity of stream cross-sections; (b) the Flow data which contains discharge rates; and (c) the Plan data which contains information pertinent to the run specifications of the model, such as a description of the flow regime. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario. The basic computational procedure is based on an iterative solution of the energy equation (6) shown (Butler & Davies, 2004).

$$H = Z + \frac{P}{\rho g} + \frac{V2}{2g} \qquad \textbf{(6)}$$

Where H = Total Energy Head (m)

Z = Potential head (m)

p/ρg = Pressure head (m)

P = pressure (N/m^2)

ρg = Unit weight (N/m^3)

$V^2/2g$ = Kinetic (velocity) head (m)

V = Velocity of flow (m/s)

g = Acceleration due to gravity (m/s^2)

Creating RAS Layers

The geometry file for HEC-RAS must contain information on cross-sections, hydraulic structures, river banks and other physical attributes of river channels. The pre-processing of data involves creating these attributes in GIS, and then exporting them to the HEC-RAS geometry file. Each attribute in HEC GeoRAS is stored in a separate feature class called as RAS Layer. Empty GIS layers are created using the RAS geometry menu in the HEC GeoRAS toolbar before creating river attributes in GIS. After creating the RAS Layers a list of all the possible attributes were present in the in the HEC-RAS geometry file.the layers are then created by clicking on create all layers menu. HEC-GeoRAS then creates a geo-database in the same folder where the map document is saved and stores all the feature classes/RAS layers in this geo-database. The layers created are empty and needs to be populated depending on our project needs. After populating the layers then create a HEC-RAS geometry file.

Creating River Centerline

The river centreline establishes the river reach network for HEC-RAS. One feature for each reach was digitized following the centre of the river, and aligned in the direction of flow. For digitization the most upstream part of the Imphal river is zoomed in to see the main channel. The river centerline is created by editing the River feature class, and choosing river as the Target. Using the Sketch tool, the river centerline of Imphal river is digitized from upstream to downstream end and double click when it is done (do not double-click until we reach the end). After finishing digitizing the upper the river centerline of Imphal river, save edits, and stop editing.

After digitization of the reaches, the reaches must be given a specific name. The river and reach within a river in HEC-RAS must have a unique name.. unique name for the river and reach is assigned by clicking on Assign River Code/Reach Code button and activate it. Once again we made sure that the reaches created were connected, and populate the remaining attributes of the River feature class.

HydroID is a unique number for a given feature in a geo database. The River and Reach attributes contain unique names for rivers and reaches, respectively. The From Node and To Node attributes define the connectivity between reaches. ArcLength is the actual length of the reach in map units, and is equal to Shape_Length. In HEC-RAS, distances are represented using station numbers measured from downstream to upstream. For example, each river has a station number of zero at the downstream end, and is equal to the length of the river at the upstream end.

Creating River Banks

After creating the river centreline bank lines were created by drawing along the approximate location of the top-of-bank on both sides of all of the streams. In HEC-RAS the bank stations should be specified for each cross section. The GeoRAS utility determines where the bank station falls on each cross section by drawing in the bank lines that intersect the cross section. Flow lines were also delineated to approximate the flow paths of the centre of mass of the main channel, the left overbank and the right overbank. Bank lines are created mainly to distinguish the main channel from the overbank floodplain areas. The information about the bank locations iwere used to assign different properties for cross-sections. For example, in assigning Manning’s n value, overbank areas are assigned higher values of Manning’s n compared to the main channel to account for more roughness caused by vegetation. There is no specific guidelines for creating the river bank, they can be digitized either along the flow direction or against the flow direction, or may be continuous or broken. Eventhough no specific guidelines are given for digitizing the river bank we follow these steps to get a more consistent result; 1) start from the upstream end; 2) looking downstream, digitize the left bank first and then the right bank.

Creating Flowpaths

Flowpath lines are created almost the same way as the previous layers and it can be used to determine the downstream reach lengths between cross-sections in the main channel and over bank areas The flowpath layer consists of three types of lines: centreline, left overbank, and right over bank. The river centreline that we created earlier can be used as the flowpath centerline if it lie approximately in the centre of the main channel. In the RAS Geometry tool click on Create RAS Layers and choose Flow Path Centrelines. A message box appears that ask if you want to use the stream centerline to create the flowpath centerline, click yes on the message box. Confirm River for Stream Centreline and Flowpaths for Flow Path Centrelines, and click OK. The flowpaths are created using the sketch tool. The left and right flowpaths were digitized within the floodplain in the downstream direction. The left and right flowpaths were used to compute distances between cross-sections in the over bank areas. For consistency the left flowpath was first digitized along the downstream direction followed by the right flowpath for each reach. After digitizing, save the edits were saved and editing was stopped. After editing the flowpaths were labeled left or right accordingly by using the Assign Line Type button .

Creating Cross-sections

In HEC RAS the shape of the stream and its characteristics, such as roughness, expansion and contraction losses, and ineffective flow areas are defined by the cross sections. Cross sections are created by drawing the XS cutlines into the GIS perpendicular to the approximated flow lines.one of the key inputs in HEC RAS is cross section. Cross-section cutline creates a ground profile across channel flow by extracting the elevation data from the terrain. The intersection of XS cutlines with other RAS layers such as centreline and flow path lines helps in computing HEC-RAS attributes such as bank stations, downstream reach lengths and Manning's n. To produce a good representation of channel bed and floodplain creating adequate number of cross- sections is critical. In creating the cross section layers certain guidelines must be:

(1) Digitized the XS cutlines perpendicular to the direction of flow;

(2) The XS cutlines must span over the entire flood extent to be modelled; and

(3) Digitization of XS cutlines must be done from left to right looking in the downstream direction.

While digitizing a consistent spacing between cross-sections were maintained and it was also made sure that each cross sections were wide enough to cover the floodplain. In order to make sure that the cross sections were wide enough cross section profile tool was used. One cross-section each on the upstream and downstream was given if there was any structure such as bridge or culvert along the path of the river. Any Structures along the river was identified by using the aerial photograph. After digitizing the cross-sections, the edits were saved and editing was stopped to prevent further editing. Once the cross- sections are digitized, HEC-RAS attributes such as Reach/River name, station number along the centreline, bank stations and downstream reach lengths were added to the cross- section. All these HEC RAS attributes are based on the intersection of cross-sections with other layers, so make sure each cross-section intersects with the centreline and overbank flow paths to avoid any problem. The XS cutlines does not have any elevation information, they are 2 D lines.

Survey was conducted at five different locations along the river to calculate the cross- section. A total station theodolite was used for the survey. The different places where the survey was conducted is listed below:

1. Taothong
2. Iroisemba
3. Shamushang
4. Naoremthong
5. Sagolband Bijoygovinda

Table 3.3 Cross section and Elevation data

Station	Prism Height	Elevation	Northing	Easting	Height of Instrument
Taothong	2.08	729.512 m	2745210.479	588731.057	1.5 m
		731.537 m	2745224.420	588728.781	
Iroisemba	2.08	727.843 m	2744023.5	589613.5	1.5 m
		727.861 m	2744032.385	589613.414	
Shamushang	2.08	723.970 m	2743959.946	591625.715	1.5 m
		723.820 m	2743970.493	591628.249	
Naoremthong	2.08	722.580 m	2743859.693	592549.588	1.5 m
		721. 896 m	2743861.450	592541.354	
Sagobang Bijoygovinda	2.08	728.538 m	2743614.292	593203.472	1.5 m
		727.193 m	2743619.219	593204.548	

Fig. 3.9 Survey conducted at Iroisemba Confluence

Fig. 3.10 Survey conducted at Taothong

Assigning Manning's n to cross-sections

Manning's n values also known as roughness coefficients is the measurement of the resistance of flood flow in channels and floodplain. Manning's n has various applications in flood plain management, flood insurance studies and in the design of bridges and highways across the floodplain.

Manning's formula is given as:

$$\boldsymbol{V = \frac{1}{n} R^{2/3} S^{1/2}} \qquad \textbf{(6)}$$

Where:

V = mean velocity of the flow, in metres per second
R = hydraulic radius, in metres
S = slope of energy grade line, in metres per metre
n = Manning's roughness coefficient

Assigning Manning's n value is the last step and an important one performed before exporting the geometric file to HEC RAS. In the HEC RAS model the roughness for each cross section was defined by Manning's n value. Manning's roughness coefficient were assigned in two steps. The first step involves generation of Land Use and Land Cover layer throughout the watershed. The Sentinel 2 multi spectral imagery of 10 m resolution obtained from European Space Agency was used for generation of Land use and Land Cover layer. The LULC image claaification was done in ArcGIS using the maximum likelihood classification tool. Each land-use characteristic was assign an n-value based on published values for similar conditions (Chow, 1959; Barnes, 1967) and on engineering judgment and experience. Once the land-use was defined for the entire watershed, the representative n-values were assigned to the portion of each cross section that intersects the respective land-use area (defined in a polygon shape file in the GIS).. In HEC-GeoRAS the land use table have a descriptive field identifying landuse type, which is LU Code, and a field for corresponding Manning's n values. In addition, the land use polygons must be non multi-part features (a multipart feature has multiple geometries in the same feature). The second step involved entering the in-stream n-values. These n-values are based on field inspections and hydraulic properties and range from 0.015 for some of the concrete lined channels to 0.07 for the steep, streams with a lot of overhanging vegetation and debris.

Select the Manning's n Values layer from the RAS geometry and choose the extract n values option. In the dialogue box confirm LandUse for Land Use, choose n value for Manning Field, XSCutLines for XS Cut Lines, leave the default name Manning for XS Manning Table, and click OK. Manning' s n were then extracted automatically for each cross section depending on the intersection of cross-sections with landuse polygons.

Table 3. 4 Manning's n value

Class	Manning's n value
Build Ups	0.06
Water Bodies	0.036
Agriculture	0.04
Vegetation	0.02
Open Soil	0.030

Importing Geometry data into HEC-RAS

Before importing the geometry data to the HEC RAS model a thorough check on the GIS data to be exported is performed and made sure that the right data is being imported to HEC RAS. A manual data check is done on all the feature classes and made sure that all the attribute tables are populated correctly and no invalid numbers are populating any field. After verification of all the layers the geometric data was exported by clicking on the RAS Geometry and choosing the Export RASData option. A series of messages appears while exporting the geometric data. At the end two files of the format .xml and .sdf were created. The file with the format .sdf was then imported to HEC RAS.

After opening HEC RAS first the project was saved in the .prj format. Then by clicking on to the Geometric data editor and choosing the import geometry data option the geometric data was finally imported to HEC RAS.

A quality check on the imported data was done to prevent any erroneous data from entering the model.

3. 5. 2. 2 Model Execution/ Unsteady flow analysis

The geometry data exported from GIS needs some corrections before the flood analysis. Necessary corrections were made using the cross section editor in HEC RAS. The analysis environment was set up by delineating a specific flow area and entering the boundary conditions. Since the flow is unsteady boundary conditions were required at the farthest upstream and the downstream cross- section. Discharge of the particular time period under consideration was entered as the boundary condition for the upper reach. For the lower reach the boundary condition selected was normal depth. The data was then saved in the unsteady flow data editor. The unsteady flow analysis was initiated after the geometry and unsteady flow data were completed. In the main program window Unsteady Flow Analysis was selected under the Run menu. A plan was defined by selecting the geometry file and the unsteady flow file. The plan was saved as Imphal River plan. In the simulation time window a beginning and ending date and time for simulation was entered. The beginning date was set as 01/ 05/ 2017 and the ending date was set as 31/ 08/ 2017. The computation interval was set to 12 hrs. After filling up the necessary details the unsteady state analysis was performed in HEC RAS. Once the simulation is complete the output can be viewed from different tables and graph.

3. 5. 2. 3 Post Processing

Once the simulations in HEC-RAS model was complete, output data was exported and imported to GIS and analysed. Finally the inundation map was created in ArcGIS using RAS Mapper tool. In Arc Map the output SDF file is converted to XML file. To create the inundation map click on the RAS Mapper and open the post processing layer menu. In the post processing layer menu new analysis option is chosen and named Unsteady Flow. In the RAS GIS Export File the exported data from HEC RAS was put and single terrain type was chosen and Imphal_tin was put. An output directory was created and HEC- GeoRAS creates a geodatabase with the analysis name in the output directory. The rasterization size was given as default and clicked ok. By clicking on the RAS Mapper and choosing the Import RAS data option, a series of message was shown thus creating a bounding polygon defining the analysis extent of the inundation mapping. Again by clicking on RAS Mapping the inundation mapping option is chosen. This creates a surface with water surface elevation or a TIN. The underlying TIN (Imphal_tin) was substracted from the water surface TIN by converting the water surface TIN to a grid.

Again from the RAS Mapping tool the inundation mapping option was chosen and flood delineation using Rasters was selected then the desired profile was selected and executed. In this step the water surface TIN is converted to a grid and substracted from the dtmgrid. the area is divided into areas having positive results and negative results. The area having positive results means the water surface is higher than the terrain and it is the flooded area. All the area having positive results were converted to a polygon and this polygon is the inundation polygon.

RESULTS

This chapter describes the various results obtained after analysis of the various data within the limits of the objective of the study. This project was carried out to get a brief idea of the flood scenario in Imphal valley. The main aim of the project is to create a flood inundation map which can be use as a key tool in preventing future floods in the study area and also to aid in the management of the flood. The result of the present study have been presented under the following subheads:

4.1 Flow hydrograph

4. 2 Inundation depth Map

HEC RAS with it's HEC GeoRAS extension tool is a powerful yet easy to use tool and it aids in the development of flood inundation maps .HEC RAS software can also be used for determining water surface profiles in a wide variety of streams. HEC GeoRAS plays an important role in the modelling process. GeoRAS helps in the post processing of HEC RAS data into polygon shape file that define the extent of flooding for agiven flood. It also helps in data exchange between HEC RAS and ArcGIS. This data exchange between the two software is not possible without the help of the GeoRAS tool. Though not as catastrophic as the flooding of upper Assam region or Arunachal Pradesh, Imphal valley is prone to flooding and the city has been hit by many severe floods in the recent years causing damage to property and humans. In this study flood inundation map of imphal valley for the year 2017 is created to analyse the extent of flooding it cause. The flooding was mainly cause by overflowing of rivers . Most of the areas lying below the high flood level of Imphal rivers were mostly affected .

4.1. Flow Hydrograph

The flow hydrograph is generated using the daily rainfall data from 01 May 2017 to 31 August 2017 in the HEC RAS model. Flow hydrograph shows the rate of flow versus time past a specific point in a river or channel. The flow hydrograph is presented in Fig 6. The results show that the hydrograph design depends on several variables, such as precipitation, use and soil type, soil infiltration capacity, and the response time of the watershed to the same rainfall input, among others

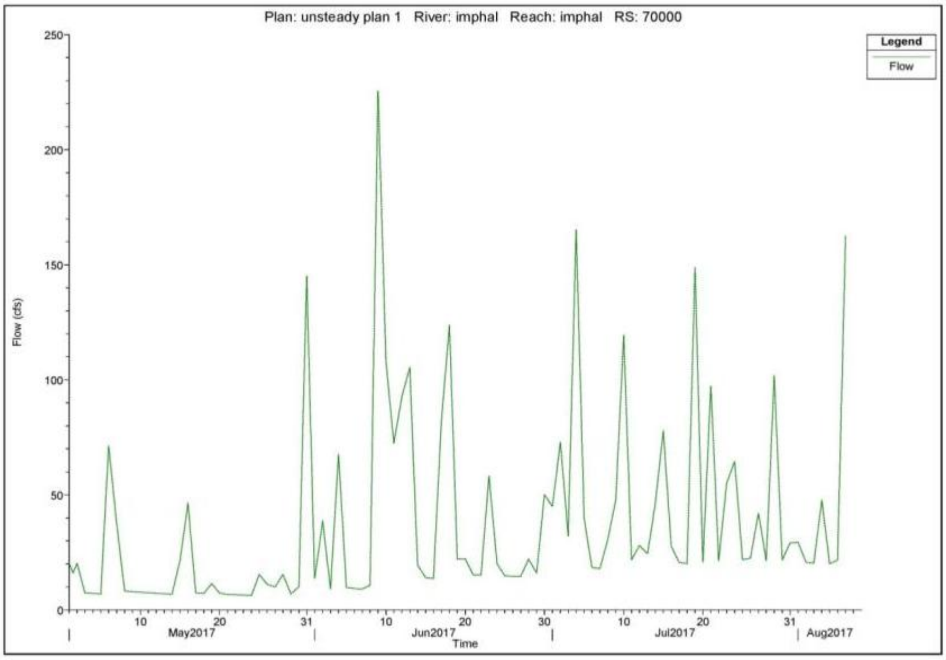

Fig. 4.1 Flow Hydrograph

.4. 2. Inundation depth map

The flood inundation map is generated using 10m spatial resolution of various input layers such as DEM as terrain parameter, LULC layer and precipitation data. These layers are futher processed in ArcGIS and simulation is carried out in HEC RAS. The inundation map so obtained is presented in Fig 4.2

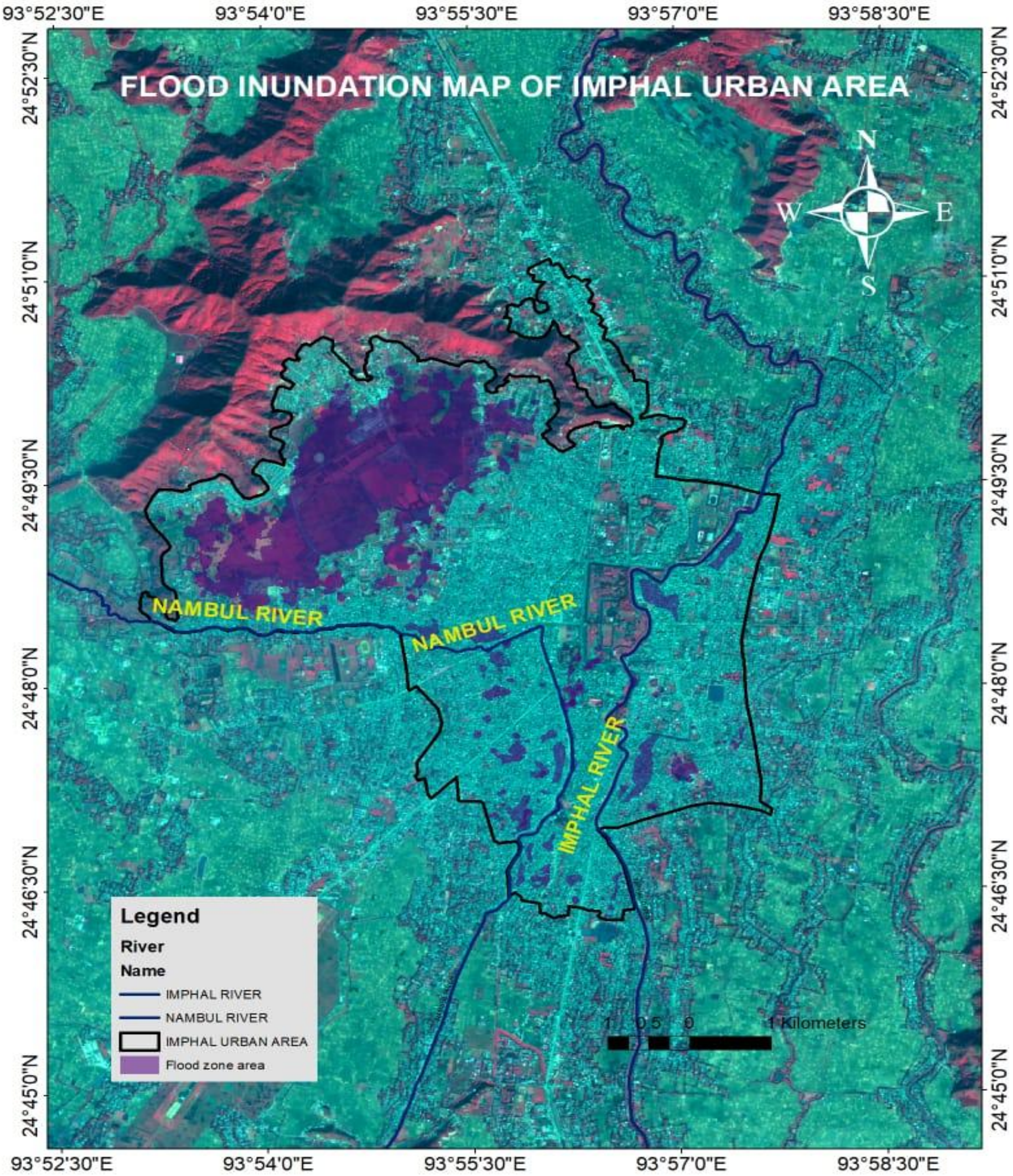

Fig 4. 2 Inundation map of Imphal Urban area

After the flood inundation map was created the quality of the inundation polygon was checked. Hydrological modeling (rainfall – runoff analysis) was successfully performed using HEC-RAS computer software version 5.0.6 after developing the basin model component using HEC GeoRAS in ArcGIS environment, populating the meteorological model and defining the control specifications, data was run while calibrating the parameters. The model output results were the quantified runoff floods that resulted from input rainfall data. From the above inundation map the extent of the flood can be understood. The inundation depth ranges from 0.01 to 2.649 m. The class wise inundated area is presented in table 4. 1. The total inundated area is 109. 338 and the LULC that is most affected is agriculture followed by build ups and the least affected LULC is the water bodies.

Table 4.1 LULC class-wise Inundated area (sq. km.)

CLASS	LULC	INUNDATED AREA
WATER BODIES	12. 94	4.0832
AGRICULTURE	78.3992	44.3465
BUILD UPS	65.8877	40.9568
VEGETATION	176.8588	4.215
BARE SOIL	178.6479	15.7365
TOTAL AREA	512.7348	109.338

The above table indicate that predominant disorderly use of riparian areas leaves most of the urban pockets of Imphal city vulnerable to flooding throughout the basin. Another flood-conducive factor is the lack of vegetated areas along the Imphal-Nambul River. The lack of riparian vegetation, as well as soil sealing due to uncontrolled and unplanned urbanisation of the municipalities, plagued by anthropogenic causes, increases the peak flow across most of the basin. Notably, the urban region lacks sink units (wetlands, reservoirs, lakes, etc) with the capacity to handle the expected flood volume. The expected reservoir volume is intended to dampen flood peaks and reduce downstream impacts of these events; thus, continuous monitoring during the rainy season is necessary for apposite flood warnings in Imphal urban region.

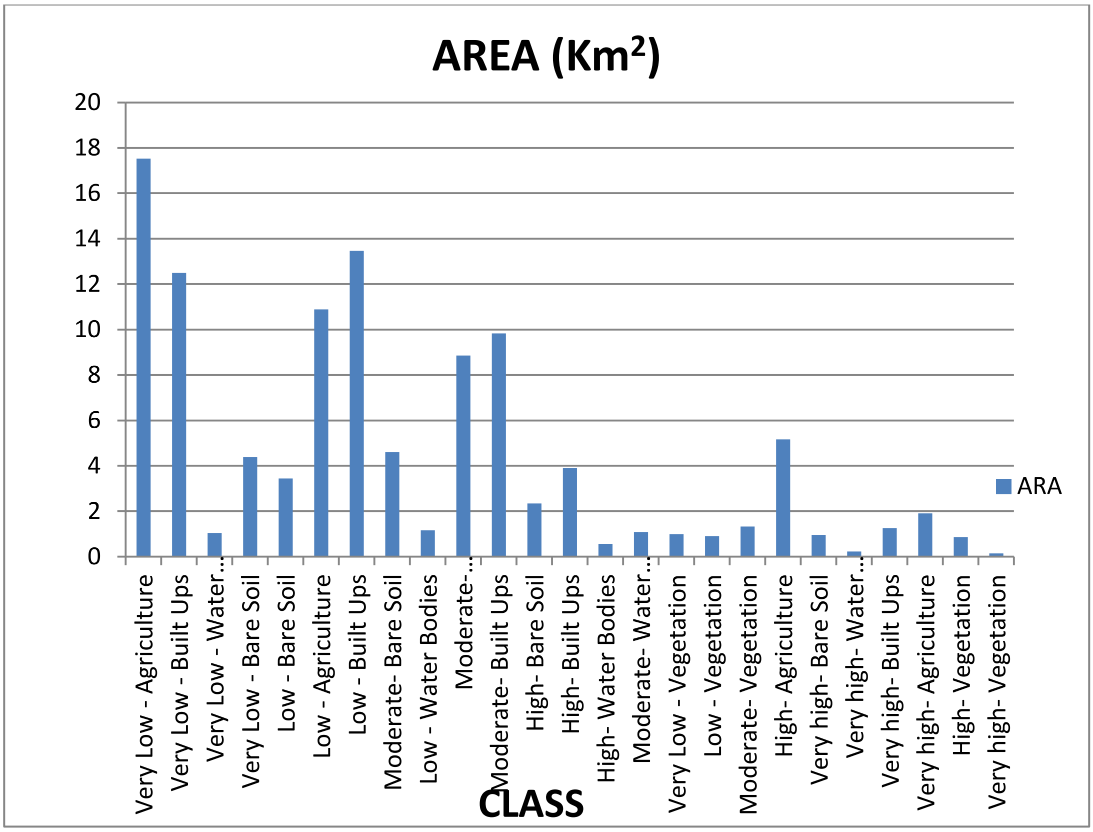

Fig. 4.3 Class-wise Inundated Area

Further, it can be observed that vegetation cover removal reduces the infiltration capacity and substantially increases the basin runoff coefficient (C), and riverbed sedimentation reduces the river hydraulic capacity. The combination of these two factors accelerates the water transport to the main course of the Imphal and Nambul rivers, causing flooding at several points where there are section bottlenecks or bed obstructions. The inundation map created has some errors since the high rise/ dikes in some parts of Imphal river and Nambul created were not considered during the simulation. During the grid layer creation the actual elevation of the embankment could not be incorporated because of insufficient data so there is some irregularities in the flood inundation map near the river banks. Manual editing was done to compensate the error.

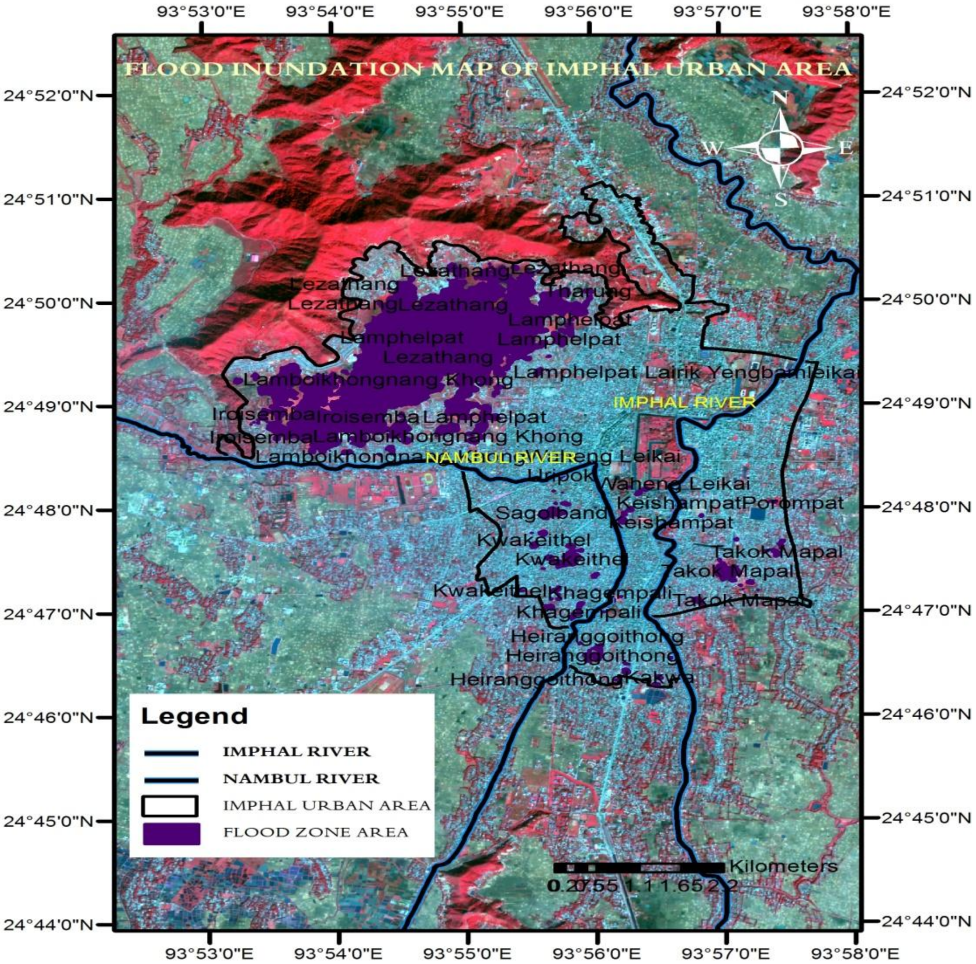

Fig 4. 4 Map of settlement area inundated

From figure 4.4 the areas that are frequently flooded are identified as Uripok, Langol, Kyamgei, Lamphelpat, Sagolband, Hapta, Minu thong. Most parts of Langol and Lamphelpat are submerged since these areas lie below the floodplain of Nambul river and these areas are normally area. wetland The imphal river meet the Kongba river at Kyamgei. Since there is stagnation point at this confluence the embankment of the Imphal river is destroyed and results in flooding of the nearby areas. It is observed that areas lying along the flood plain are most affected by flood. These inundated regions are mainly focused at the plain area of the catchment having low elevation. From table 4.1, the area covered by Agriculture class is 78.3992 sq. km. and the inundated area of the same class resulted from the analysis is found to be 40.9568 sq. km. of the total geographic area of the catchment.

And Built-ups class covered about 65. 887 sq. km. of which 40. 9568 sq. km. are inundated. Almost all of the cultivated areas are situated in low lying flood plain as the Imphal River is the main source of irrigation. Hence, the cultivated areas are most prone to be inundated it may result to the decreased in agricultural yield and hence ultimately affect the socio-economic condition of the state. From the result of this study, it is expected to help policy and decision makers to take up necessary preventive, mitigation and management measures.

SUMMARY, CONCLUSION AND SUGGESTION FOR FUTURE WORK

5.1 Summary

Flood is one of the greatest and most common forms of natural disaster that prevail in northeastern India. It is essential to properly understand, utilize and manage floods for taking up preventive measures and mitigation works to minimize the risk of flood and its ill effects, such as, damage to lives, properties, infrastructure and crops. Mapping of spatial inundation patterns during flood events is a must for environrnental management and disaster monitoring. A flood hazard map highlights the areas which are affected by or are vulnerable to flood. In this study the main emphasis is given on the assessment and flood inundation mapping of sub-watershed of Imphal River Basin of Manipur. Multispectral datasets Sentinel-2 imagery and Digital Elevation Models (DEM) from ASTER with 10 m resolutions, respectively, are used for producing flood inundation maps. Hydrologic Engineering Center's River analysis system (HEC-RAS) and RAS mapper are used to generate flood inundation map. The flood inundation map produced is limited to factors such as rainfall distribution, drainage density, land use, soil type, and slope. The weightage map is created by giving ranks and weights to these thematic maps. The hazard map thus prepared gives the total areas subjected to the hazards, as very low, low, moderate, high and very high risk zones. The flood inundation map so obtained may be utilized by land development planners as a part of an integrated approach to improve flood preparedness. The study area experiences repeated flash flood in recent years, has been selected and aims to improve future land developments and raise community awareness of the area. Based on the study carried out and analyzing the data following results were drawn.

- From the analysis of the inundation map the areas that are most flooded are the areas lying along the flood plain and the inundation depth ranges from 0.01 to 2.649 m.

- The total inundated area is 109. 338 and the LULC that is most affected is agriculture followed by build ups and the least affected LULC is the water bodies.
- Vegetation cover removal reduces the infiltration capacity and substantially increases the basin runoff coefficient (C), and riverbed sedimentation reduces the river hydraulic capacity. The combination of these two factors accelerates the water transport to the main course of the Imphal and Nambul rivers, causing flooding at several points.
- Further from the flood inundation map the areas the flooded areas are Uripok, Langol, Kyamgei, Lamphelpat, Sagolband, Hapta, Minu thong, Langol and Lamphelpat.

5.2 Conclusion

The integration of geospatial techniques and hydraulic modelling showed that it is possible to develop a reliable flood assessment in urban basins based on digital data, satellite imagery and an appropriate network of field observations. The hydraulic model satisfactorily represented the flood areas using 100-year return period in the Imphal urbane sub-basin of Imphal and Nambul rivers, and it could be a promising tool to support urban planning and a possible inception for flood early warning. The hydraulic model calibration was successful when relating the Manning coefficient and flood extents in urban centres. The calibration is a reliable method to check for other flood events. The results highlighted the vulnerability of the study area, especially heavily urbanised areas, to the occurrence of floods, which represent a serious risk to the safety of the population and infrastructure.

Considering the same flood event the value of the affected inundated area on the basis land-use classes is found to be more accurate in case of the model result with finer spatial resolution as compared to the coarser resolution. The model enabled us to run past and recent floodwaves and to analyse the effects of various interventions. Several model runs can be carried out investigating different flood situations and design alternatives. Due to various interventions in the flooplain or in case of their absence due to natural processes the discharge carrying capacity of Imphal river and its tributaries will further change in the coming years and decades. Consequently, the present calibration of the model should also be changed. The parameters of the model should be updated considering the effects of the new interventions and the results of the new river channel surveys. In order to achieve this goal, the database should be continuously revised and maintained.

Following conclusions can be drawn from the regional scale and local scale flood hazard assessment modelling studies implemented.

- The proposed regional scale methodology is simple, easy and inexpensive (free software and minimum amount of data requirement); yet it is very effective in terms of pinpointing the flood-prone locations in hydrological watersheds.
- The regional scale flood hazard assessment model can be operated both with small basins and relatively large basins.
- The local scale flood hazard assessment model implemented by use of HEC-RAS yielded precise results for the probable flood inundation areas for different return periods of flood occurrences.

5.3 Suggestion for further work

The methodology and the output of this study with HECRAS can be used for flood modelling at regional scale and also mapping areas susceptible to flooding.

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