

Rural Risk Assessment due to Flooding and Riverbank Erosion in Majuli, Assam, India

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*dedicated
to my parents.....*

ABSTRACT

The risk to the rural society of Majuli, located in the State of Assam, India, due to flooding and unrelenting riverbank erosion had been assessed using both conventional field survey method as well as non-conventional remote sensing technique. Flood inundated areas of Majuli were extracted using Radarsat-1 imageries of 21st July, 2004 and 17th September, 2010 covering the near peak flood of 2004 and end of a peak flood in 2010. To identify the flood susceptible areas, flood depths were calculated using ASTER GDEM of 30 m resolution and gauge station data of the respective dates and the whole area was divided into four classes- high flood, moderate flood, low flood and no flood. The study reveals that in 2004, most of the places in the central and south-western parts of the area were flooded and the flood depths in those areas were also high. It has been observed that the south-western part of Majuli, being located at the confluence zone of the river Brahmaputra and Subansiri, is highly susceptible to flooding as it was also got flooded at low flood level in 2010 and had high flood depths. The problem of flooding is acute along the river channel of Brahmaputra too. Along with the problem of flooding, the area is also associated with other flood induced hazards like riverbank erosion, embankment breach, road breach, sand casting etc. A (5 km x 5 km) grid-wise assessment of the riverbank erosion problem of the area shows that the villages that fall in grids 15, 16, 19, 20, 22, 28, 30, 31, 39, 53 and 56 are facing significant problems of riverbank erosion. The results were also validated using PGIS mapping in the area. From these analysis, it is found that the villages viz. Salmora, Sukhunamukh, Upper-Sonowal, Korotipar, Malowal Kalita, Ukhalchuk are continuously facing severe problems of riverbank erosion. From the study, the annual average rate of erosion in different time intervals are found as – 6.92 km²/yr. over 1972-2001, 2.47 km²/yr. over 2001-2004, 5.48 km²/yr. over 2004-2008 and 3.34 km²/yr. over 2008-2010. An empirical model was also tested in the study to calculate the erosion probability in the area and a correlation of 65% was found between the estimated and the predicted erosion probability values. From the elements at risk mapping and vulnerability analysis, the *Dakhipat Satra* and the *Bengenati Satra* are identified as highly vulnerable to flood hazard as their proximity to the river is increasing.

Keywords: Flood, Riverbank erosion, Erosion probability, Majuli, PGIS.

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1. INTRODUCTION

1.1. Background

1.1.1. Flood and Flood Risk

Among the most widespread natural disasters all over the world, flood is the one which is caused mainly due to heavy rainfall and damages human life and social developments (Kandiloti & Makropoulos, 2012). Based on its characteristics, flood is classified into four basic types - flash flood, standing flood, coastal flood due to storm surges and riverine flood. Of all these four types 'riverine flood' is the most difficult to control (Cuny, 1991). The Indian sub-continent, endowed with many natural water resources, suffers annually from flood events of various magnitudes. The north-eastern region alone generates one-third of the country's total run-off through the Brahmaputra and Barak river systems as their catchments receive high amount of rainfall (Wiebe, 2006). Being a vast country, the precipitation of India shows large spatial and temporal variations (Mohapatra & Singh, 2003; Sen, 2010); the spatial variation ranges from an average annual rainfall of more than 2800 mm in the Western Ghats, Andaman and Nicobar Islands, Assam and Meghalaya to about 300 mm in the western part of Rajasthan (rainwaterharvesting.org). The Brahmaputra river ranks fifth in the world in terms of discharge (Akhtar *et al.*, 2011) carrying a mean annual flood discharge of 48,160 m³/sec and sediment load of 400 million metric tons at Pandu, Assam (Goswami & Das, 2003). The monsoonal rain (May-October) contributes 82% of the Brahmaputra's mean annual flow at Pandu (Goswami, 1985). According to the Working Group on Flood Control Programme, set up by the Planning Commission for the 10th Five Year Plan of India, the country's total flood prone area is estimated as 45.64 M ha out of the total geographical area of 329 M ha (Ministry of Water Resources).

Flooding in the floodplains of Indian rivers is a recurring phenomenon and thereby not of much concern until and unless it is associated with some serious socio-economic consequences (Sen, 2010). Therefore, people perception is an important parameter for flood risk assessment. In the EU Floods Directive (2007/60/EC (COM 2007)), flood risk is defined as the "combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event" (EU, 2007). Flood inundation in the rural areas of the country is mostly associated with large scale loss in agricultural production, loss of livestock and sometimes loss of human lives too (Sen, 2010). Many historical records reveal that Majuli, the hub of 'Vaishnavite' monasteries, suffered from several large floods that had devastated the area causing extensive flood inundation and severe bank erosion. A catastrophic flood is reported to have occurred in 1735 ((Gait, 1905)in(Sarma & Phukan, 2004)).

1.1.2. Riverbank Erosion

Riverbank erosion is a significant problem worldwide and is associated with land loss and deposition of sediments along the river course. Land loss as a consequence of riverbank erosion not only threatens the existence of infrastructures or agricultural lands near to the riverbank but also poses threat to aquatic habitats and causes sedimentation downstream due to the generation of fine-grained sediments (Darby & Thorne, 1995). In India, most of the hydrological challenges are owed to the high sediment load of the rivers which ultimately results in riverbed aggradations, bank erosion and channel widening (Thakur *et al.*, 2012). Besides, riverbank erosion in the rivers of Brahmaputra-Barak and Ganga basin is also caused due to high flood discharge in the river, bed slope and composition of bed and bank materials. The land lost once due to riverbank erosion cannot be compensated by the riverine landmass that built-up by the river itself in due course of time. The severity of the problem can be well understood in case of Majuli, which was known as the largest inhabited river island of the world (Mohapatra & Singh, 2003).

1.2. Problem Statement

Majuli is an important cultural heritage site of Assam and is home to the 'Vaisnavite' monasteries, popularly known as 'Satras'(Sarma & Phukan, 2004). The area is situated at the bosom of the three river systems viz. the Subansiri, the Kherkatia suti (a spill channel of the river Brahmaputra which has been blocked few years back to stop the erosion problem) and the main Brahmaputra river. Geomorphologically, Majuli forms a part of the floodplains of Brahmaputra river and thereby continuously facing serious problems of flood hazard (due to the influence of SW monsoon) and riverbank erosion which has posed a threat to its rich cultural heritage and its existence as well (Kotoky et al. 2003). Different research works done at different time periods show that the average annual rate of erosion has been increasing at an alarming rate. However, no study has been carried out so far to assess the flood and erosion problems together and to identify the vulnerability of the different elements at risk. Therefore, this study attempts to assess the flood and erosion hazard of the area and vulnerability of the elements at risk i.e. agricultural lands and the 'Satras' due to the flood and riverbank erosion. The outcome of this study would help the decision makers to protect the area and its rich cultural heritage from engulfing of the river Brahmaputra.

1.3. Research Identification

This study aims to assess the flood and erosion susceptibility of the area and vulnerability of the elements at risk in the study area.

1.3.1. Research Objectives

- Flood susceptibility mapping.
- Riverbank erosion susceptibility mapping.
- Elements at risk ('Satras' and agricultural lands) mapping and vulnerability analysis.

1.3.2. Research Questions

- Which are the flood susceptible areas?
- What is the effectiveness of flood protection measures in the area?
- Which areas are susceptible to riverbank erosion?
- Which parameters are influencing the channel planform change?
- What is the annual rate of riverbank erosion?
- Which year has experienced highest amount of erosion and what is the reason behind it?
- Which elements are more vulnerable to flood hazard?
- How well the riverbank erosion can be predicted using an empirical model?

1.4. Structural Set-up of the Study

The whole study has been divided into the following chapters:

Chapter 1: This introductory chapter presents the background, problem statement, research objectives and the research questions.

Chapter 2: In this chapter, a review of the past literatures on relevant works has been carried out.

Chapter 3: This chapter describes the environmental setting, livelihoods, culture and heritage of the study area.

Chapter 4: This chapter dealt with the materials and methods used in the study.

Chapter 5: The chapter 4 presents the analysis and results of the study.

Chapter 6: In this chapter, a discussion has been carried out to answer the pre-defined research questions.

Chapter 7: This chapter constitutes a thesis conclusion based on the whole study and recommendations for further research in the context.

2. REVIEW OF LITERATURE

2.1. Fluvio-geomorphic processes and the origin of Majuli

The Brahmaputra, having a catchment area of 580,000 km², is one of the largest river systems of the world that flows through China (50.5%), India (33.6%), Bhutan (7.8%) and Bangladesh (8.1%) for a total distance of 2880 km. In India, it passes through a length of 278 km in the state of Arunachal Pradesh and 720 km in Assam (Akhtar *et al.*, 2011). With an average width of 8 km, the river Brahmaputra flows through the seismically unstable valley in Assam and occupies about one tenth of the valley. Being one of the active seismic regions of the world, the area witnessed two great earthquakes both of magnitude 8.7 in the years 1897 and 1950 which are among the most severe ones in the recorded earthquake history. Earthquakes of such magnitude not only resulted in devastation in the region but also have impacted the hydrologic regime of the same (Goswami, 1985; Goswami & Das, 2003). Due to such a large extent and complex geo-tectonic setting of this alluvial river system, the river Brahmaputra is associated with the problems of erosion-deposition of sediments, rapid bed aggradations, drainage congestions and flooding (Sarkar *et al.*, 2012).

On entering the Assam reach, Brahmaputra flows in a network of highly braided channels with the presence of numerous lateral and mid-channel bars and islands (Goswami, 1985). Most of these braided channels are transient in nature that get submerged during high monsoon flows and frequently change their geometry and location (Thakur *et al.*, 2012) with the rate of movements being as high as 2,600 ft./year. The rate of rise and fall of the river, the number and position of the major channels active during flood, the formation and movement of large bedforms, cohesion and variability in the composition of bank materials and intensity of bank slumping are identified as some of the major factors governing the bank line configuration and movement of the river Brahmaputra (Coleman, 1969). Majuli, once the largest inhabited river island of the world, was also formed by the action of such fluvial processes on the low-energy reach of the river Brahmaputra (Singh & Goswami, 2011). In a study mainly based on the historical reports and ancient literatures, Sarma & Phukan (2004) mentioned that in histories Majuli was referred as 'Majali', an assamese word, meaning a piece of land situated between two adjacent and parallel rivers. The study also reported that earlier, the river Brahmaputra, also known as Luit or Luit, used to flow to the north of Majuli and the river Dihing, one of Brahmaputra's major tributaries, flowed south of Majuli. Flowing to the south of Majuli, the Dihing received many other tributaries such as Dikhow, Jhanji, Bhogdoi, Dhanisri etc. and then finally met the Brahmaputra at a place called Lakhu. Later on, the Brahmaputra shifted its course towards south and joined the Dihing river at its present confluence point at Dihingmukh located about 190 km east of Lakhu. This shift in the river course resulted into the creation of the Majuli island. After the creation of the island, the flow of the Brahmaputra got divided into two anabranches – one flowing along the Brahmaputra or Luit to the north of Majuli, which is now known as the Kherkatia Suti and the

other directed to the south of Majuli through the Dihing channel. In due course of time, the flow in the Kherkatia suti gradually decreased and a major part of the discharge of Brahmaputra was diverted to flow through the Dihing river. Due to this natural diversion of the river flow, channel widening in the present course of Brahmaputra started causing unrelenting erosion in both the banks of the river (Sarma & Phukan, 2004).

2.2. Application of Remote Sensing and Geographic Information System (GIS) in Flood and Erosion Assessment

In the recent times, remote sensing and GIS techniques are proved to be very effective in flood and erosion studies. With the advancement of space technology, satellite imageries (both optical and microwave) are mainly used in the three phases of flood management – a) pre-flood (preparedness phase), b) on-flood (monitoring phase) and c) post-flood (damage assessment and mitigation phase). Different researchers in different parts of the world have used both optical and microwave remote sensing data for flood assessment in different time periods (Oberstadler *et al.*, 1997; Tholey *et al.*, 1997; Bates, 2004; Sanyal & Lu, 2005; Dhillon *et al.*, 2008). Tholey *et al.* (1997) studied the utility of satellite remote sensing data in flood management in combination with GIS. In this study, the authors demonstrated the applicability of a wide range of flood related information derived from remote sensing optical and radar data at different levels of flood management. Being passive in nature, optical systems can only operate effectively during daytime and good weather conditions (cloud free) while the SAR (Synthetic Aperture Radar) systems are active ones and can deliver weather independent day and night coverage. This property of the SAR systems make it often the only available tool for monitoring of the flood affected regions at a good temporal frequency (Tholey *et al.*, 1997).

Due to its ability to provide comprehensive, synoptic view of fairly large area at regular interval, remote sensing data integrated with GIS technique makes it an ideal tool for studying and monitoring river erosion and its bank line shifting (Sarkar *et al.*, 2012). Several studies have been done in this regard for some major rivers all over the world (Winterbottom & Gilvear, 2000; Mani *et al.*, 2003; Sankhua *et al.*, 2005; Beck, 2006; Dutta *et al.*, 2010; Akhtar *et al.*, 2011; Das *et al.*, 2012). Winterbottom & Gilvear (2000) incorporated both GIS technique and the influence of different geomorphic variables like river bank morphology, sediment type and floodplain vegetation on erosion rate to refine the Graf's model of riverbank erosion probability estimation. This study used aerial photographs of the river Tummel, Scotland to obtain high spatial resolution. The authors also remarked that satellite data accompanied with a good hydrological record could be used in Graf's model to determine highly accurate erosion probability predictions for large active river systems (Winterbottom & Gilvear, 2000). Thakur *et al.* (2012) carried out a study in the Ganga river, upstream of Farakka barrage using LANDSAT and IRS imageries to analyze the riverbank erosion hazard due to changes in the morphometric parameters like Sinuosity, Braidedness Index and percentage of the island area to the total river reach area (Thakur *et al.*, 2012). Another research work was carried out in the Brahmaputra river to quantify the actual bank erosion/deposition for a period of eighteen years (1990-2008) along the river in

its Indian reach for a stretch of around 620 km. using remote sensing and GIS. The study mapped the channel configuration of the river system on repetitive basis and also identified the stable and unstable reaches of the riverbanks and changes in the main channel. The research findings revealed that the Brahmaputra river that was flowing in south-westward direction upstream of Majuli took a sudden westward turn at Neamati, situated south of Majuli, during 1990-2008. This sudden westward turn of the river may be owed to the presence of relatively higher landform to the south of the river and the sub-surface east-west trending Jorhat Fault zone, located along the southern bank of the river in that reach (Sarkar et al., 2012).

2.2.1. Riverbank Erosion Assessment in Majuli

The problem of severe bank erosion in Majuli is well known and many researchers have investigated this problem at different times. Mani *et al.* (2003) observed the trends of riverbank erosion in a small part of Majuli, the area near Kaniajan village located in south Majuli. This study was carried out for a stretch of about 11 km and the erosion-deposition maps were prepared for the area using satellite data of 1991, 1997 and 1998. Erosion of the area was measured at various sections at 1 km interval and loss of 1900 ha of land was observed during 1991-1997 and 845 ha of land during 1997-1998 (Mani *et al.*, 2003).

Kotoky *et al.* (2003) studied the erosion problem of Majuli with the help of IRS imagery of 1998 and found a drastic decrease in the area of the island from 1245 km², as per the available historical records, to 577.65 km² in 1998. The study found that the rate of erosion in Majuli was 1.9 km²/yr. during 1920-98 (Kotoky *et al.*, 2003).

Another study carried out by Sarma & Phukan (2004) assessed the changes in the Majuli island during 20th century by superimposing the bank lines of 1917, 1966-72, 1996 and 2001 and subdividing the island into an array of twenty-six 5'latitude x 5'longitude blocks. The study found that the rate of bank line shift was not uniform throughout the island in time and space. Shifting of the bank line leading to erosion along the Brahmaputra was found to be dominant at the south bank with the maximum rate of retreat being 0.480 km./yr. and that leading to siltation was found to be confined mostly to the north bank due to the Subansiri river with the maximum rate of advance being 0.146 km./yr. According to the study, there is a continuous decrease in the area of Majuli from 751.31 km² in 1917 to 564.01 km² in 1966-1972, 453.76 km² in 1996 and 421.65 km² in 2001. The average annual rate of erosion was found as 1.77 km²/yr. from 1917 to 1972, 1.84 km²/yr. from 1972 to 1996 and 6.42 km²/yr. from 1996 to 2001 (Sarma & Phukan, 2004).

In a research work done by Sankhua *et al.* (2005), the authors deployed the use of remote sensing and artificial neural network (ANN) technique to study the erosion problem of the decaying island Majuli and suggested that the ANN model had a very good forecasting capability of the area loss due to the complex process of stream bank erosion. The study reported that the erosion problem of Majuli became significant only after 1950 earthquake and took a serious turn especially from 1954 onwards. This was due to the construction of erosion protection measures

in 1950 on the south bank of the river Brahmaputra in the Kokilamukh area, leaving the north bank unprotected. The authors also remarked that nothing substantial had been done to control the erosion problem of Majuli, except the construction of the embankments, a structural measure useful for temporary flood protection purpose only (Sankhua *et al.*, 2005).

3. STUDY AREA

3.1. Environmental Setting

Study area is located in Majuli, Assam, in the north-eastern part of India (Figure 3.1). Majuli, the nerve-centre of the Neo-Vaishnavite culture is situated between 26°45' N - 27°12' N latitude and 93°39' E - 94°35' E longitude. The area is bounded by the Brahmaputra river in the south, river Subansiri in the north-west and the Kherkatia Suti (an anabranch of the river Brahmaputra) in the north-east. In 1964, the mouth of the Kherkatia Suti was closed with the construction of a check dam across this spill channel (Hussain *et al.*, 1993). As envisaged from the IRS-P6 (LiSS III) imagery of 2010, this riverine landmass covers a total area of about 521.52 km². The mean height of the area is around 77.5 m above mean sea level (m.s.l.). Geologically, Majuli is a part of the great alluvial tract of the Brahmaputra river and geomorphologically, it forms a part of the Brahmaputra floodplains. Being an active floodplain, the area is characterized by the presence of numerous alluvial features including natural levees, crevasses, splay deposits, point bars, channel bars etc. (Singh & Goswami, 2011). Majuli is marked by the presence of around seventy *beels* (local name for small ponds, ox-bow lakes and swamps) that cover 14% of its total area (Bhaskar *et al.*, 2010). The climate of the area lies within the monsoon rainfall regime and receives an annual rainfall of about 2,150 mm. The temperature of Majuli, varies from 28° C to 33° C and relative humidity varies from 54% to 86% (Singh & Goswami, 2011).

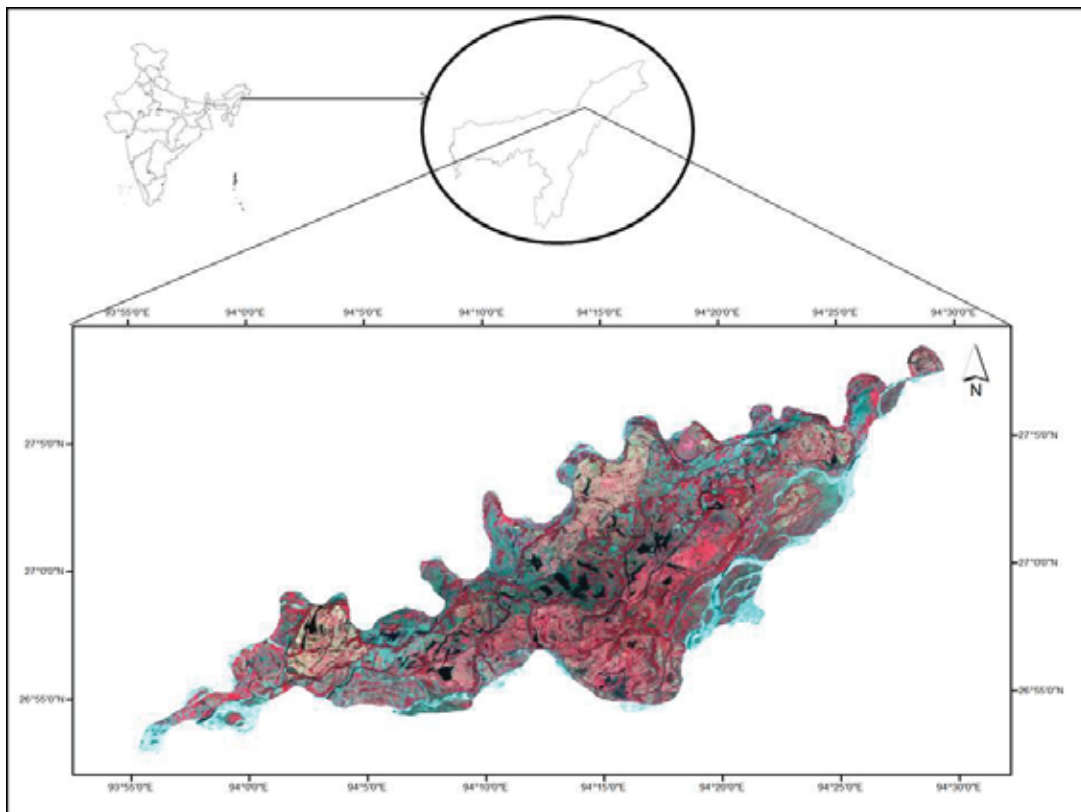


Figure 3.1: Location Map of the Study Area

The landmass Majuli is now a civil sub-division with its headquarter at Garmur and is a part of the Jorhat district in Assam. This civil sub-division of the Jorhat district is comprised of two development blocks – Namoni Majuli Development Block and Uzani Majuli Development Block and three Tehsils (Mauza) viz. Ahatguri, Kamalabari and Salmora. Of these three tehsils, the Ahatguri mauza has already been completely engulfed by the river Brahmaputra leaving many families homeless. According to the 2011 census, the population of Majuli is 1.68 lakhs of which 70% belongs to the tribal communities (Board, 2012).

3.1.1. Soil

Bank materials of the river Brahmaputra are mostly composed of varying proportions of fine sand and silt, with only occasional presence of minor amounts of clay (generally less than 5%) (Goswami, 1985). According to the sub-soil investigations carried out by the River Research Station at different locations of Majuli extending up to a depth of 30 m indicate that the area is mostly underlain by grey coloured, fine to medium sized, poorly graded sand covered by light grey coloured silt mixed with clay and/or fine sand of varying thickness ranging from 1.5 to about 12 m. However, there are few pockets like Salmora, Dakhinpat and Bessamora, located on the south-western part of Majuli bordering Brahmaputra river, where the soil is rich in inorganic clay content and the depth of clay rich horizon extends even beyond 15 m from the ground (Goswami, 2001; Singh & Goswami, 2011).

3.2. Livelihood and Culture

Being endowed with naturally fertile soil and plenty of water, agriculture plays the dominating role in the livelihood of the people of Majuli. Farmers grow more than hundred varieties of rice and many other crops like maize, black gram and various types of cereals, vegetables, fruits, sugarcane, cotton, jute, castor etc. The extraordinary pottery craft of Majuli is not only an age-old profession of the people but also an invaluable ingredient of its cultural life having immense archaeological significance. The facts that this craft has flourished through ages without using the potter's wheel and is traded through a traditional barter system make it a heritage of mankind that needs to be studied and preserved. Archaeologists have found in this form of pottery of Majuli a missing link between the Mohenjo-Daro and Harappa civilizations. Other occupations of the people include pisciculture, sericulture, horticulture, cattle farming, dairy, handloom, handicrafts (eg. - cane works, bamboo crafts) and boat making (Figure 3.2).

Majuli, characterized by the meeting and branching of numerous channels around alluvial sandbars, is a meeting ground of diverse cultural streams with an assortment of ethnic communities such as Mishings, Deoris, Kacharis, Koch Rajbangshis and sundry castes and creeds living peacefully and cohesively for hundreds of years. In the community lives of the people of Majuli, one can see a distinct mark of assimilation and synthesis of varied ethnic and cultural traditions fused with the dominant Satra culture. The famous 'Ras' festival of Majuli that is celebrated in the month of November attracts thousands of people and tourists every year (Goswami, 2001).

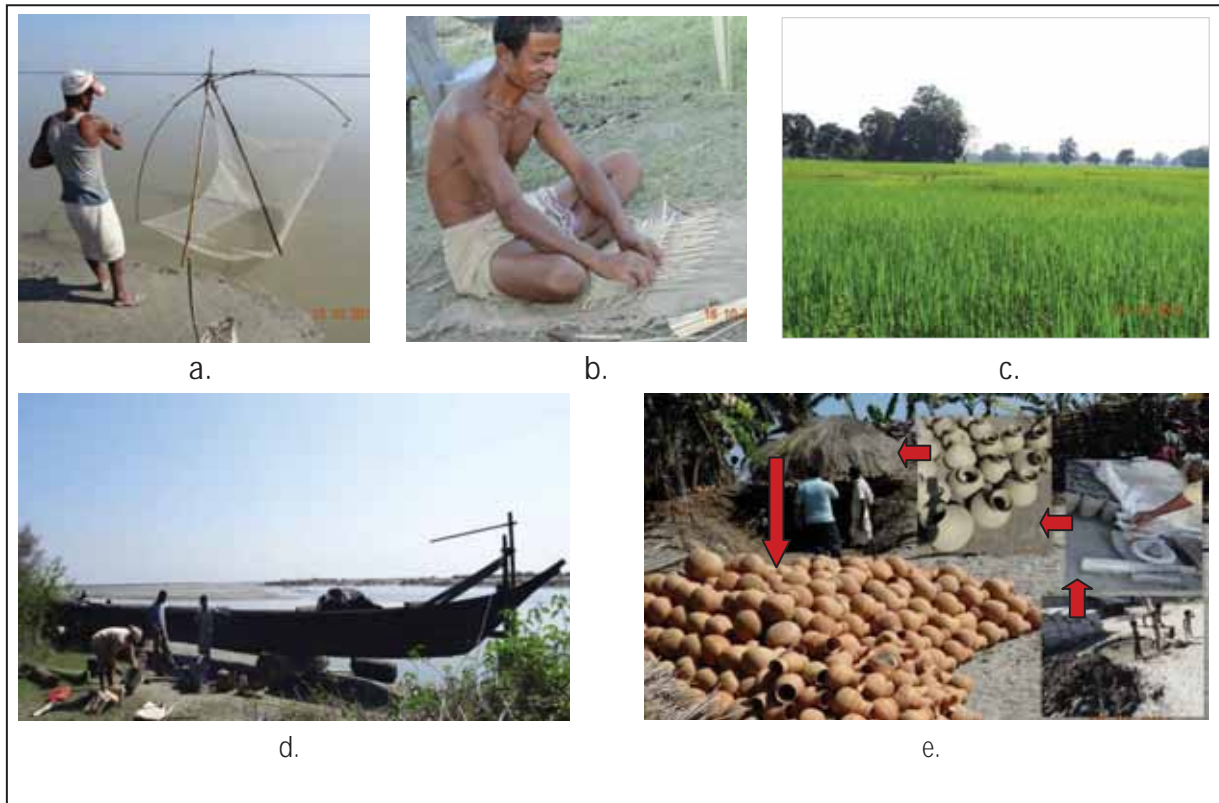


Figure 3.2: Livelihoods of Majuli (a. Fishing, b. Handicrafts, c. Agriculture, d. Boat making, e. Pottery making)

3.3. The *Satras*

One of the unique and important features of this riverine landmass is the presence of the 'Vaishnavite' monasteries, popularly known as the *Satras*. The *Satras* were founded by the great saint, poet litterateur and religious reformer Srimanta Sankardeva in the fifteenth century A.D. In Assam, around the unique system of these 'Vaishnavite' monasteries, the Neo-Vaishnavite culture has evolved over the last five hundred years. Earlier, as many as sixty five such *Satras* flourished with lakhs of 'Bhakats' (disciples) in Majuli and thousands of followers all over the state. These *Satras* not only have an impact on the religious and spiritual lives of the people but also have nurtured and preserved a rich tradition of art and craft like the Satriya dance – a classical dance form known worldwide, mask and boat making, pottery etc. Besides, many antiquities, manuscripts, coins etc. of great archaeological value are still preserved in the *Satras* (Goswami, 2001). Due to the engulfing of the river Brahmaputra and Subansiri, out of these sixty five *Satras* only twenty two are left at present. Among these twenty two, *Auniati*, *Dakhinpat*, *Garmur*, *Uttar Kamalabari*, *Natun Kamalabari*, *Chamaquri* and *Bengenati Satra* have still retained much of their past pride, position, tradition and glory and thereby become the nucleus of the Vaishnav religion and culture (Figure 3.3 a., b., c., d., e. and f.).



Figure 3.3: View of some of the historic *Satras* (a. Auniati Satra, b. Bhogpur Satra, c. Uttar Kamalabari Satra, d. Natun Kamalabari Satra, e. Dakhinpat Satra, f. Garmur Satra)

4. MATERIALS AND METHODS

4.1. Materials

The research work on the chosen topic has been carried out using both conventional or field survey method as well as non-conventional or remote sensing technique. Brief descriptions of the datasets used at different stages of the research are given below:

4.1.1. Survey of India (SOI) Toposheet

The Survey of India is the principal mapping agency of India. To delineate the boundary and the bank line of the rivers surrounding the study area SOI toposheets of 1972 at 1:50,000 scale with no.s 83F/9, 83F/13, 83I/4, 83I/8, 83J/1, 83J/5 were used.

4.1.2. LISS-III Imagery

The Linear Imaging Self Scanning Sensor (LISS) is an optical multi-spectral sensor that operates in four spectral bands; three are in the visible and near infra-red region and one in the short wave infra-red (SWIR) region. For the present study, IRS 1D and IRS P6 LISS-III imageries of 26/12/2001, 30/12/2004, 24/11/2008 and 06/01/2010 (Figure 4.1) having a spatial resolution of 23.5 m were used to extract the area of Majuli at different time periods and also to delineate the river bank lines over 2001 to 2010 thereby identifying the channel planform change during that period.

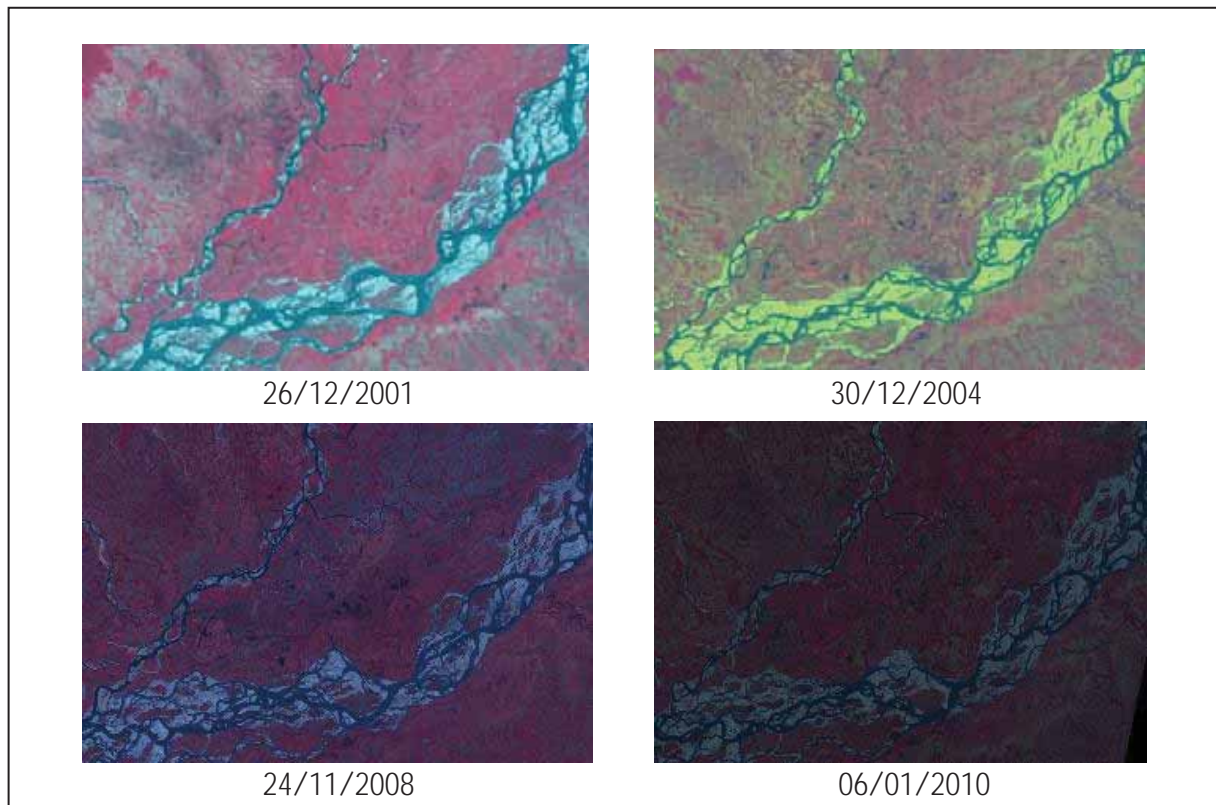


Figure 4.1: LISS-III imageries of the Study Area

4.1.3. Radarsat-1 Imagery

Radarsat-1 is a microwave satellite launched by the Canadian Space Agency in November, 1995 that uses SAR (Synthetic Aperture Radar) sensor. Being active in nature, SAR sensors are very effective in flood studies due to their all weather capabilities as during monsoon season optical images in most of the flood-prone areas are not useful due to high cloud cover. Therefore, to extract the flood inundation areas in the present study, Radarsat-1 imageries, operated in the C-band (ScanSAR Wide mode), with a spatial resolution of 50 m were used for the dates 21st July, 2004 and 17th September, 2010 (Figure 4.2).

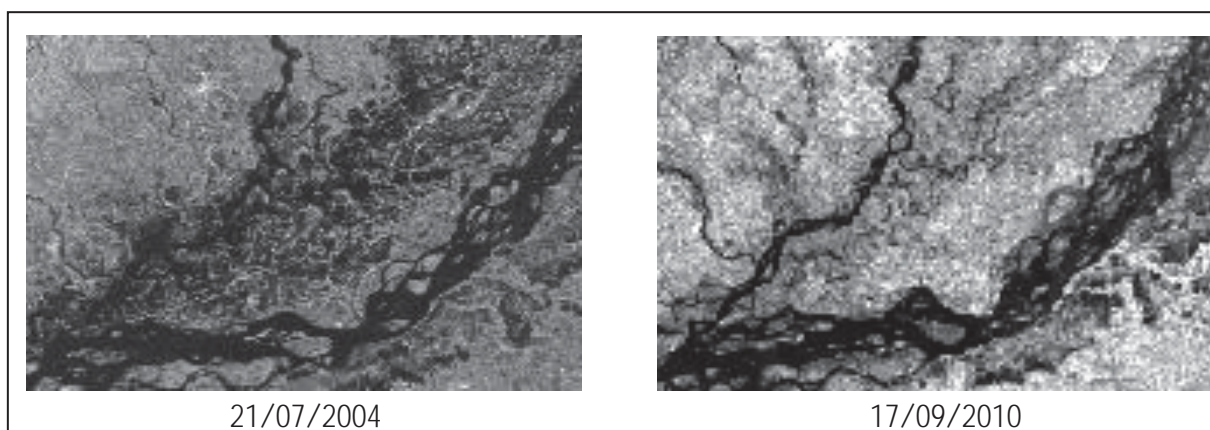


Figure 4.2: Radarsat-1 imageries of the Study Area

4.1.4. Google Imagery

To map the agricultural lands of the study area, high resolution Google imagery was used.

4.1.5. ASTER GDEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) is a joint project developed by the U.S. National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade and Industry (METI) to cover the land surface of the world (LPDAAC, 2013). In order to calculate the flood depth at different places of the study area ASTER GDEM version2 of 30m resolution was used in this study (Figure 4.13). The vertical accuracy of ASTER GDEM is 20m with 95% confidence (Fujisada *et al.*, 2005).

4.1.6. Hydrological Data

Hydrological data consisting of gauge station (Figure 4.14) data (for the period of 2004 and 2008 in case of Subansiri river and 2001-2010 in case of the Brahmaputra river) and flood discharge data of the Subansiri river (1988 - 2010) at Majuli were used to assess the flood characteristics of the study area.

4.1.7. Softwares used

- ArcGIS 10, 9.3
- Erdas Imagine 9.2
- Envi 4.3

- Google Earth Pro
- Global Mapper 13
- Python 2.7.3
- Statistica 7

4.1.8. Instrument used

Garmin GPS 12 was used in the study to locate the field survey points and also to map the historical *Satras*.

4.2. Methodology

The whole study can be divided into two major phases – flood assessment and riverbank erosion assessment for which two different methodologies (Figure 4.3 and Figure 4.4) were adopted.

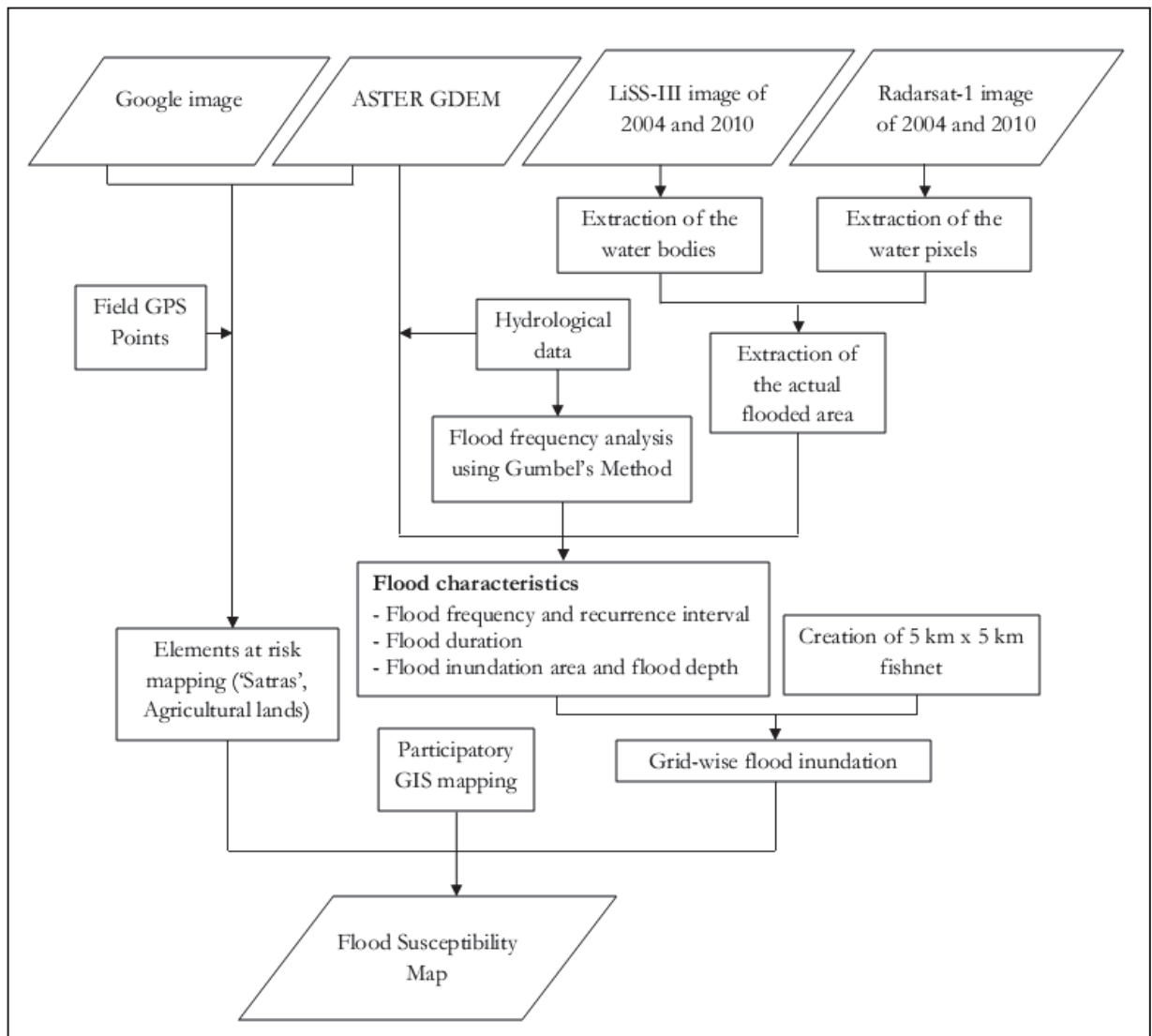


Figure 4.3: Methodology for Flood Assessment

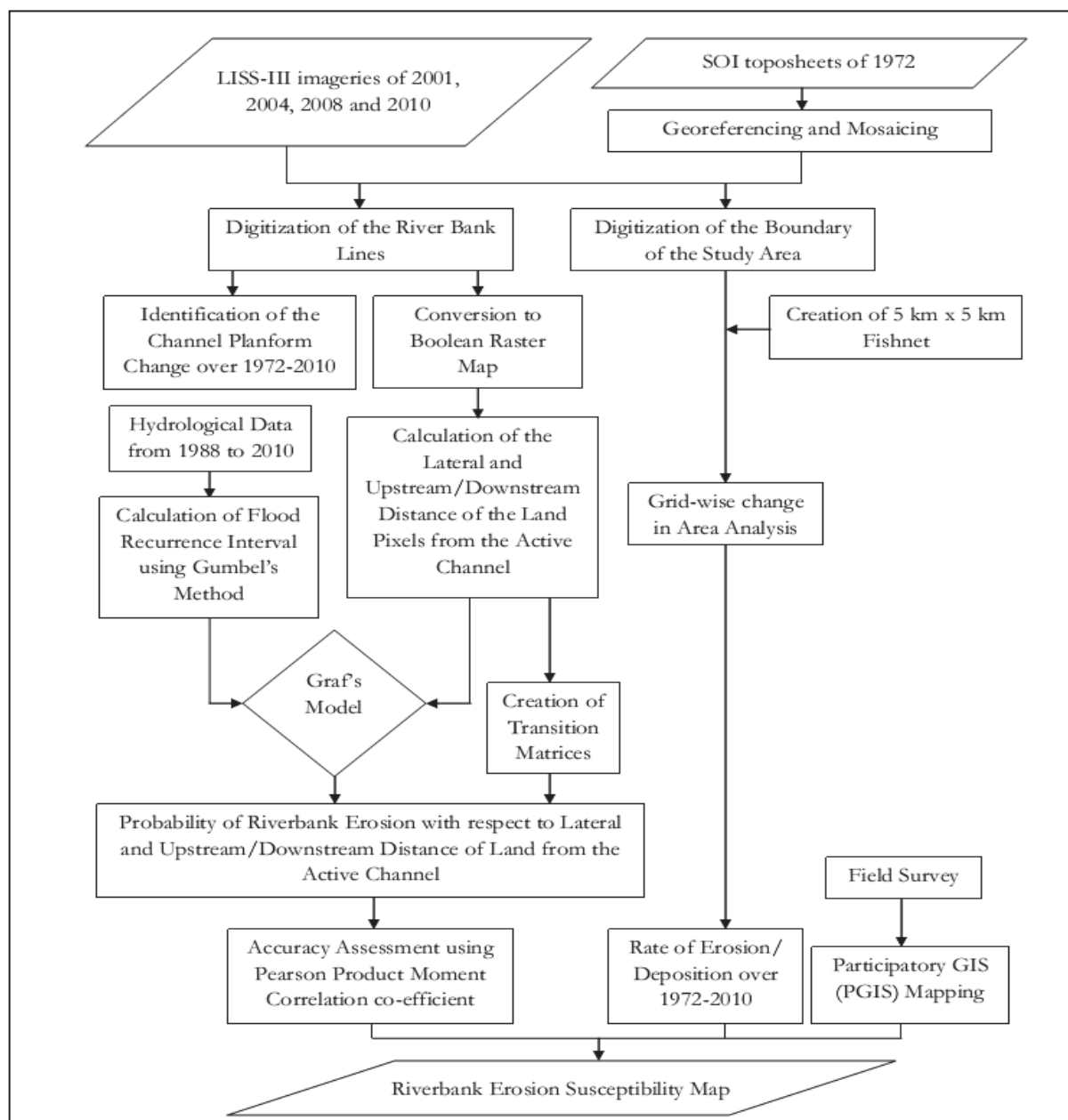


Figure 4.4: Methodology for Riverbank Erosion Assessment

4.2.1. Pre-processing of Datasets

After collecting, the SOI toposheets covering the study area were scanned and each of them was geo-referenced separately using Geographic Co-ordinate System in ArcGIS 9.3 with Root Mean Square (RMS) error less than 1. These geo-referenced toposheets were then extracted and mosaiced to a single image in Erdas and the co-ordinate system was transformed to Universal Transverse Mercator (UTM) Projection with World Geodetic System (WGS) 1984 datum and 46N zone using ArcGIS 9.3. All the LISS-III imageries were registered with the orthorectified Landsat-7 ETM+ imagery of 10th November, 2005 using image to image registration technique in Erdas. Due care was taken in image to image registration to keep the RMS error less than 1. Geocoding of the Radarsat-1 imageries of 2004 and 2010 were done using Envi 4.3.

4.2.2. Extraction of the Flooded Areas

The following algorithm (Figure 4.5) was used in Erdas Modeler to extract the flood inundation areas of Majuli in the two flood events i.e. 2004 and 2010 (IIRS, 2012).

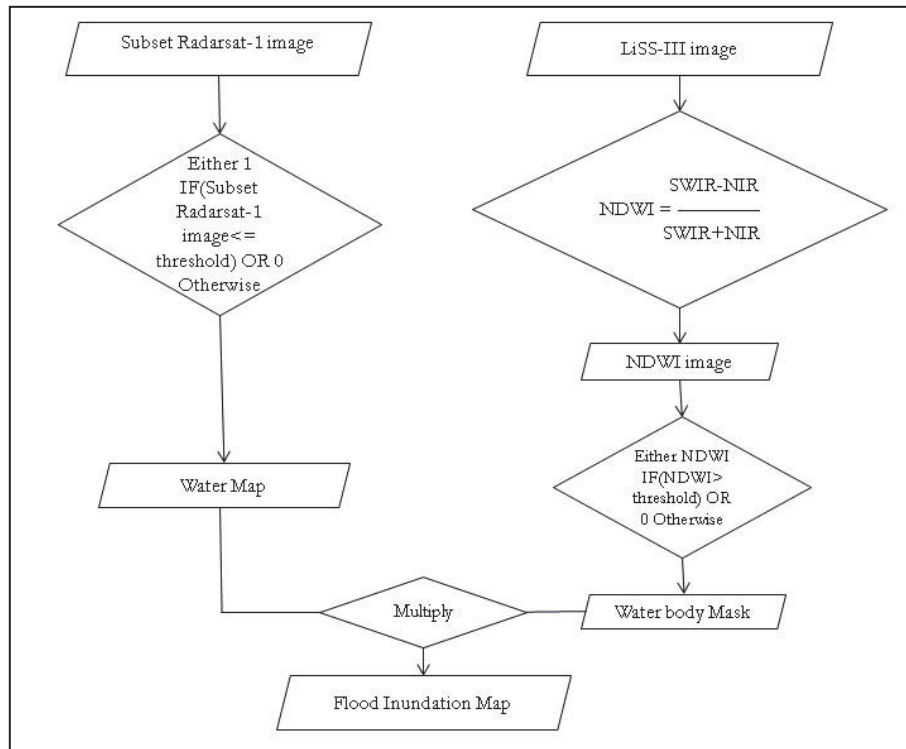


Figure 4.5: Algorithm used in Erdas Image to extract the flood inundated areas

4.2.2.1. Extraction of the water bodies from LISS-III imagery

Normalized Difference Water Index (NDWI) is a band ratio that helps in detecting the moisture content in soil and vegetation. In this study to extract the water bodies in the study area NDWI was used. The NDWI image from LISS-III imagery was prepared using the following formula (Sarkar *et al.*, 2012):

$$NDWI = \frac{SWIR-NIR}{SWIR+NIR} \quad [1]$$

The data type of the output image was set as 'float single'. In the NDWI image, the minimum possible NDWI value for the 2004 image was observed as -0.142 and that of the 2010 image was observed as -0.211. These minimum values of NDWI were used as the thresholds to extract the water bodies from the 2004 and 2010 LISS-III imageries. The models run in Erdas modeler for the years 2004 and 2010 are shown below (Figure 4.6 and 4.7)

4.2.2.2. Extraction of water pixels from Radarsat-1 imagery

The Radarsat-1 imageries were reprojected to the co-ordinate system same as of the LISS-III imageries and subset to the extent of the study area. Then the DB values for land and water were observed for both the imageries and a threshold value of 49 was set for 2004 imagery and that of

63 was set for 2010 to extract the water pixels. The models used to extract the water pixels for the two years are shown in the following figures (Figure 4.8 a. and b.). The output data type was set as 'unsigned 1 bit'.

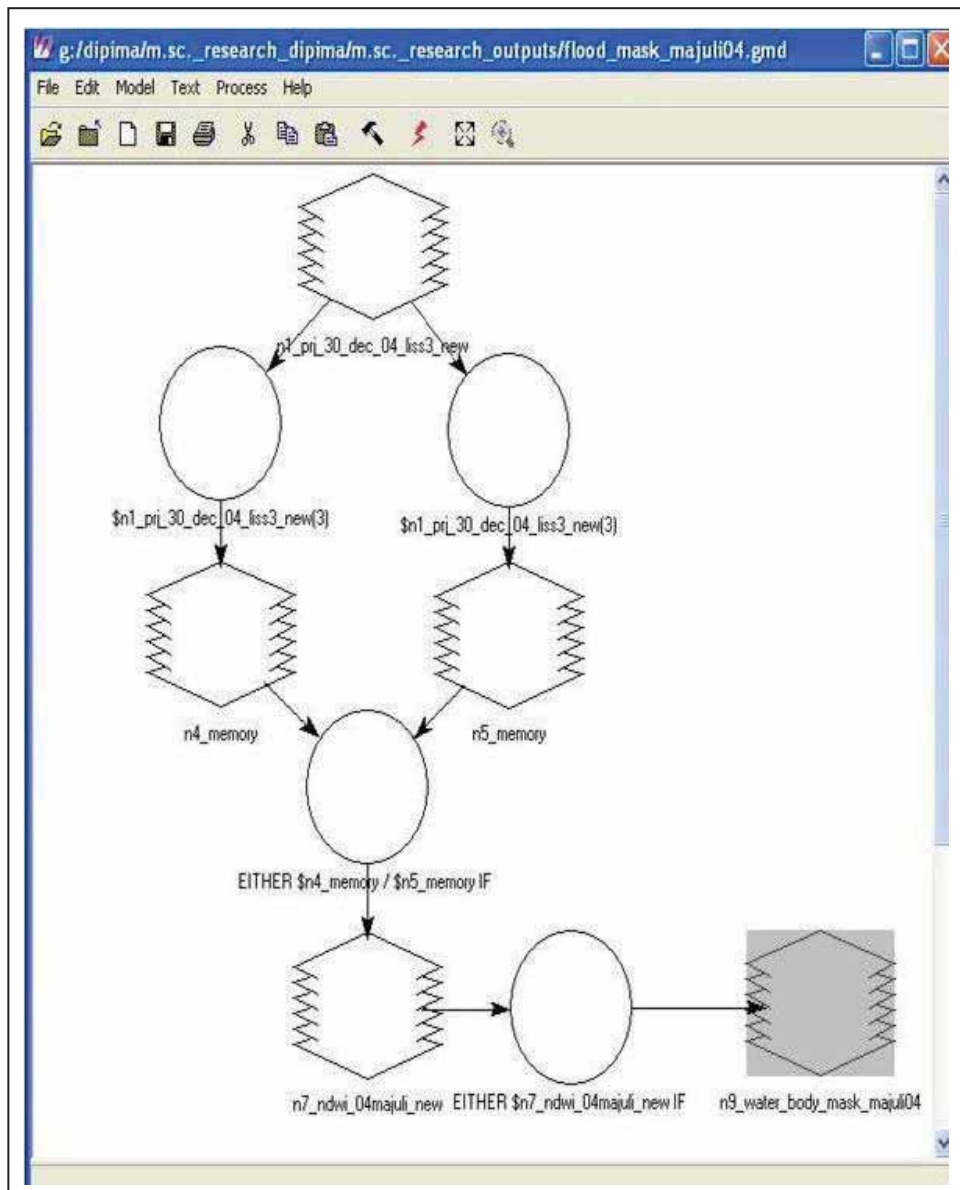


Figure 4.6: Model used in Erdas Modeler to extract the Water Bodies from LISS-III imagery, 2004

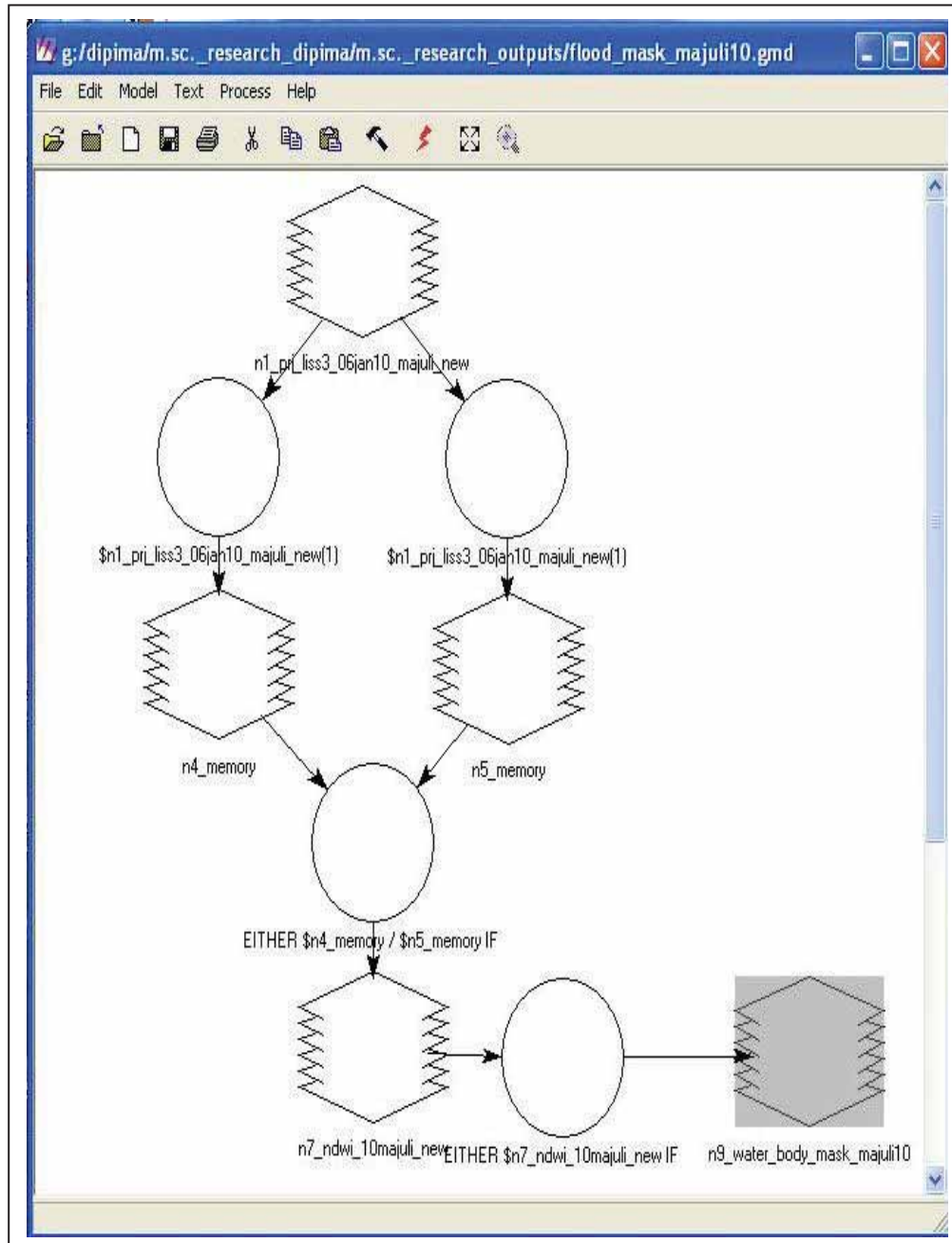
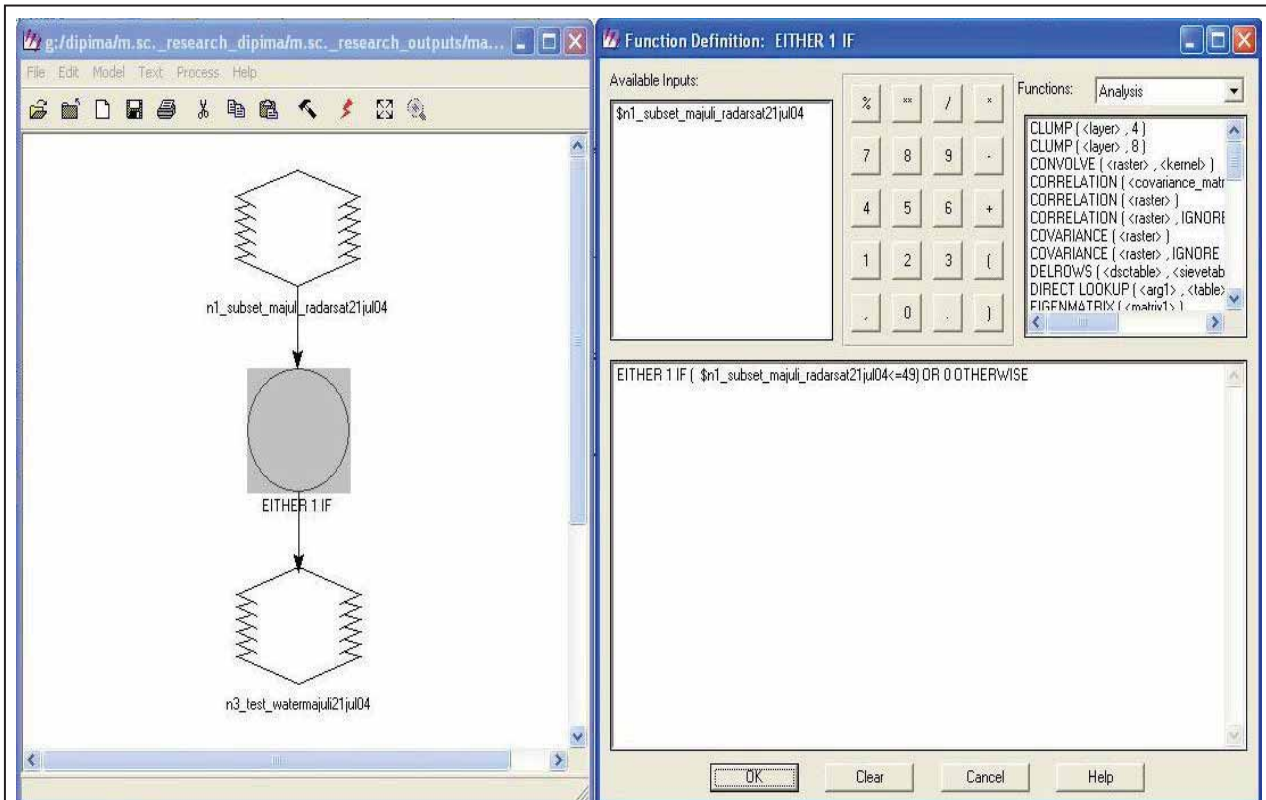
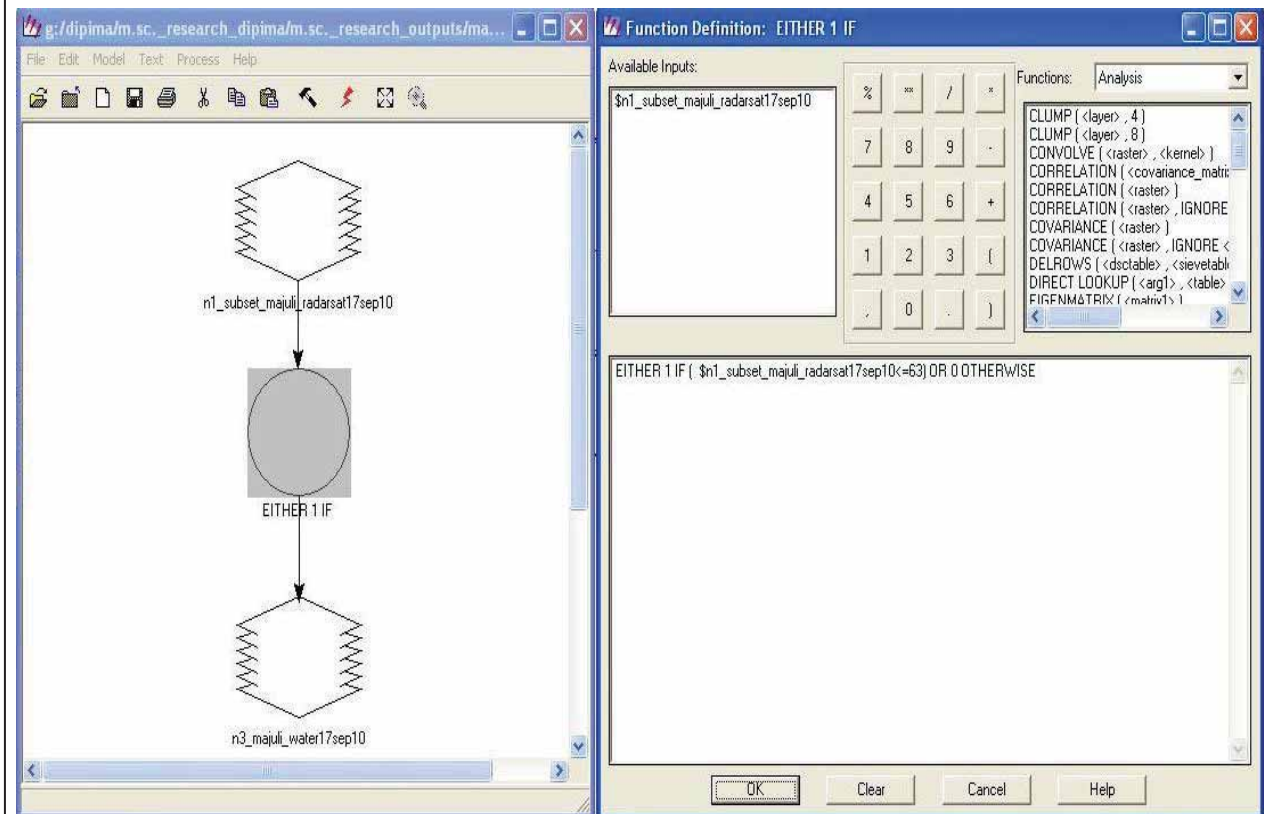


Figure 4.7: : Model used in Erdas Modeler to extract the Water Bodies from LISS-III imagery, 2010



a. 2004



b. 2010

Figure 4.8: Model used in Erdas Modeler to extract the water pixels from the Radarsat-1 imagery

4.2.2.3. Extraction of Flood Inundated area

To extract the actual flooded area, the water body maps generated from the LISS-III imagery of each year was multiplied with their respective water maps generated from the Radarsat-1 imagery. Figure 4.9 shows the model used for actual flood area extraction in Erdas (Figure 4.9).

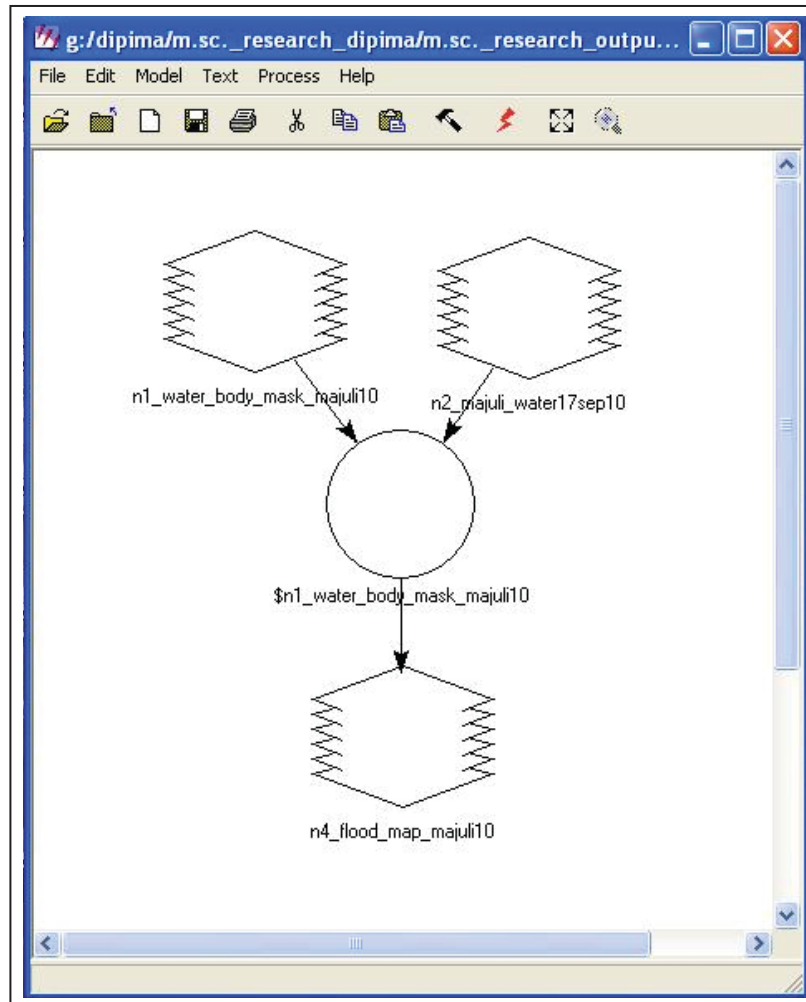


Figure 4.9: Model used in Erdas Modeler for Flood Inundation Area Extraction

4.2.3. Flood Depth Calculation

For flood depth calculation in the study area ASTER GDEM, flood inundation map and hydrological data were used. From the hydrological data (Annexure - I), the water level on 21st July, 2004 and 17th September, 2010 were recorded for the rivers Brahmaputra and Subansiri. However, for the year 2010 water level of the Subansiri river was not available.

To calculate the flood depth in 2004 due to the Subansiri river, the following condition was used (Figure 4.9):

EITHER CONDITIONAL {(DEM height ≤ 75) 3, (DEM height > 75 AND DEM height ≤ 82) 4, (DEM height > 82 AND DEM height ≤ 83.03) 5 } IF (Flood inundation map == 1) OR Flood inundation map OTHERWISE

To calculate the flood depth in 2004 due to the Brahmaputra river, the following condition was used:

EITHER CONDITIONAL { (DEM height<=75) 3, (DEM height>75 AND DEM height<=85) 4, (DEM height>85 AND DEM height<=86) 5 } IF (Flood inundation map==1) OR Flood inundation map OTHERWISE

To calculate the flood depth in 2010 due to the Brahmaputra river, the following condition was used:

EITHER CONDITIONAL { (DEM height<=75) 3, (DEM height>75 AND DEM height<=84) 4, (DEM height>84 AND DEM height<=85.24) 5 } IF (Flood inundation map==1) OR Flood inundation map OTHERWISE

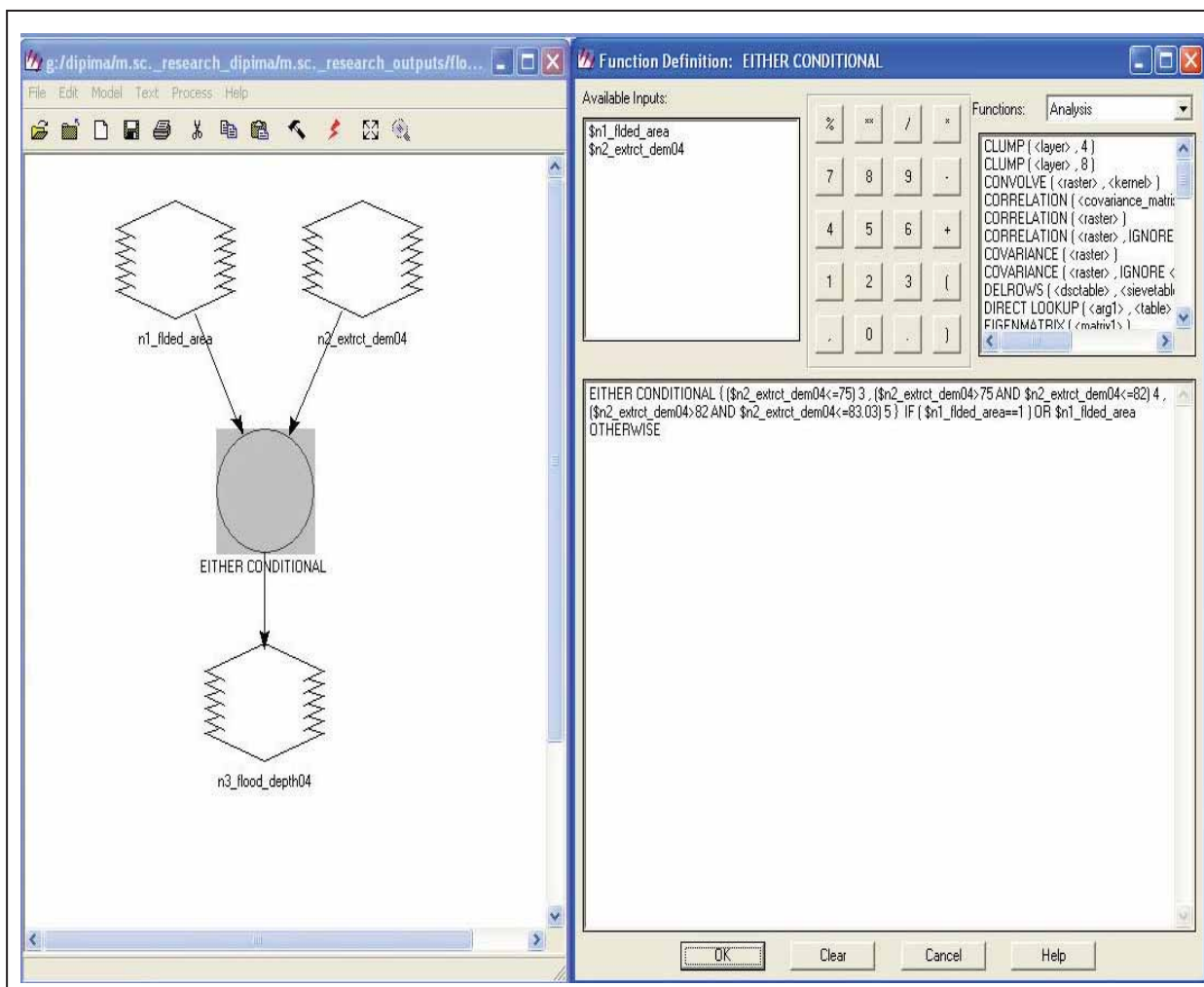


Figure 4.10: Model used for flood depth calculation

The conditions mentioned above means that if the area is flooded and if the terrain height is less than or equal to 75 m then the area is highly flooded as the flood depth in those areas is more than 8 m. Then if the area is flooded and if the terrain height is more than 75 m and less than or equal to 82 m (in case of Subansiri river in 2004) or more than 75 m and less than or equal to 85 m (in case of Brahmaputra river in 2004) or more than 75 m and less than or equal to 84 m (in

case of Brahmaputra river in 2010) then the area is moderately flooded as the flood depth in those areas ranges between 1- 11 m. Lastly, if the area is flooded and if the terrain height is more than 82 m and less than or equal to 83.03 m (in case of Subansiri river in 2004) or more than 85 m and less than or equal to 86 m (in case of Brahmaputra river in 2004) or more than 84 m and less than or equal to 85.24 m than the area is less flooded as the flood depth in those areas is less than 1m.

4.2.4. Flood frequency analysis

The annual maximum flood discharge data for the Subansiri river from 1988 to 2010 were arranged in the descending order and the plotting position recurrence interval T_p was then calculated using the Weibull formula (Subramanya, 2008):

$$T_p = \frac{N+1}{m} \quad [2]$$

where, m = order number, N = Number of years.

4.2.5. Identification of the channel planform change

From the pre-processed LISS-III imageries and SOI toposheet the river bank lines for the years 1972, 2001, 2004, 2008 and 2010 were digitized at 1:25000 scale with keeping the snapping tool on in ArcGIS 9.3 to overcome the digitization errors. These layers of the river bank lines were then overlaid on top of one another to identify the channel planform change over the years.

4.2.6. Calculation of Lateral and Upstream/ Downstream distance of the Land pixels from the Active Channel

The vector files of the river bank lines were converted to boolean raster files with the river having a value of '1' and the land having a value of '0' in ArcGIS 9.3 using the *Conversion* tool. The output pixel size of the raster files were set as 50 m. For the twenty five different defined distance classes of Graf's Model, different codes were written in Python 2.7.3. In the output images of different distance classes, the pixels satisfying the distance class had a value of '1' and the rest had value '0'. These images were then multiplied with the boolean maps of different years in ArcGIS 10 using the *Raster Calculator* tool to count the number of pixels eroded away between different intervals. In the resultant multiplied images, the pixels those got eroded had a value of '1' and the rest of the pixels had a value of '0'.

4.2.7. The Graf's Model

The Graf's model is an empirical model for riverbank erosion probability calculation. Graf (1984) developed this model based on the fact that the probability of any given cell to get eroded during a particular time period is dependent on its location with respect to the active channel and the magnitudes and frequencies of floods during that period. According to him, location of each cell relative to the active channel is most important in the lateral and upstream directions in case of meandering rivers. In his equation for erosion probability calculation, Graf had also accounted for the flood magnitude and frequency by calculating the sum of the recurrence intervals of the maximum annual flood discharges during the period of interest. Therefore, the probability that a given cell will get eroded in a specified time period is given as,

$$P_{i,j} = f(d_l, d_u, \sum_{t=1}^n r) \quad [3]$$

where, $P_{i,j}$ – probability of erosion ($0 \leq P_{i,j} \leq 1$) for a cell at co-ordinates i,j

f - a function

d_l - distance laterally across the floodplain from the cell to the nearest active channel

d_u - distance upstream along the floodplain to the nearest active channel

r – return interval of maximum annual flood

t – a year

n - number of years in the specified period

As in fluvial research distance terms have been shown to be related to magnitudes by power functions, therefore the form of function f is likely to be a multiple power function. Fluvial process and discharge measures are also commonly related by power functions, so that equation [3] can be reformed as,

$$P_{i,j} = a_0(d_l)^{b_1}(d_u)^{b_2}(\sum_{t=1}^n r)^{b_3} \quad [4]$$

where, $a_0, b_{1,2,3}$ are empirically derived constants based on historical bank erosion records.

Given empirically derived values for $P_{i,j}, d_l, d_u$ and r , equation [4] can be converted into its linear form as,

$$\log_{10} P_{i,j} = \log_{10} a_0 + b_1(\log_{10} d_l) + b_2(\log_{10} d_u) + b_3(\log_{10} \sum_{t=1}^n r) \quad [5]$$

The value of the constants can be determined using standard least squares techniques. Empirical values for ordered sets of $(P_{i,j}, d_l, d_u, \sum_{t=1}^n r)$ can be obtained from transition matrices (Graf, 1984).

4.2.7.1. Creation of transition matrix

With the count of the pixels in each distance class and the count of the pixels eroded away, that had been calculated above, six transition matrices were constructed for six different time periods i.e. 2001-2004, 2004-2008, 2008-2010, 2001-2008, 2001-2010 and 2004-2010. Each of these transition matrices consists of twenty five distance classes.

4.2.7.2. Erosion probability calculation

From the transition matrices, erosion probability for each distance class was estimated using the following formula:

$$P_{i,j} = \frac{C_e}{C} \quad [6]$$

where, C_e is the number of cells eroded in a particular distance class between the specified time period; C is the number of cells in the distance class. After getting all the values for the ordered sets $(P_{i,j}, d_l, d_u, \sum_{t=1}^n r)$ from the transition matrices, the values of the constants of equation [4] were calculated using multiple regression technique in Statistica 7 software. In multiple regression, equation [5] was used. After deriving the values of the constants, erosion probability for each distance class was predicted using equation [4].

4.2.8. Grid-wise flood and erosion assessment

In ArcGIS 9.3, a (5 km x 5 km) fishnet was created so that it covers the entire area of Majuli from 1972-2010. This fishnet was then converted into a polygon shapefile. To assess the flood inundation in each (5 km x 5 km) grid, the flood inundation map generated above was first converted into polygon file and then intersected with the (5 km x 5 km) fishnet polygon. Then the flood inundation area in each grid was calculated using *Calculate geometry* tool. The polygons of boundary layers of Majuli in different years were intersected with the (5 km x 5 km) fishnet polygon to calculate the area covered by landmass in each grid. The attribute table of each intersected file was then *joined* with each other to estimate the change in land area in each grid and thereby to estimate the rate of erosion/deposition at different time intervals.

4.2.9. Elements at risk mapping

For elements at risk mapping, two most important elements of the area i.e. the *Satras* and the agricultural lands were selected. To map the historically important *Satras*, GPS (Global Positioning System) point locations were collected with handheld Garmin GPS12 during the field survey. The agricultural lands of the study area were mapped using Google imagery of 1st December, 2009 through on-screen digitization in Google Earth Pro and then converted to shapefiles using Global Mapper 13.

4.2.10. Field activities

A field survey was carried out in the area during the month of October just after the big flood event of 2012. To assess the damage due to flood and riverbank erosion, a questionnaire was prepared (Annexure - II) and thirty three households were surveyed on random basis covering the entire study area. After the survey, the areas facing large-scale damage due to both flood and erosion were identified and subsequently Participatory GIS (PGIS) mapping was carried out in those areas viz. Haladhibari and Sonowal – Kachari village, Salmora village, Upper – Sonowal and Sukhunamukh village and Korotipar, Malowal Kalita and Ukhalchuk village (Figure 4.11 a., b., c. and d.) to see the channel migration over the period and to have an idea about the villages already engulfed by the rivers. Field GPS points were also collected for the active erosion areas, road breach and embankment breach points (Figure 4.12).



Figure 4.11: Participatory GIS mapping in the villages of Majuli



Figure 4.12: Field GPS points showing Erosion points, Embankment and Road breach points

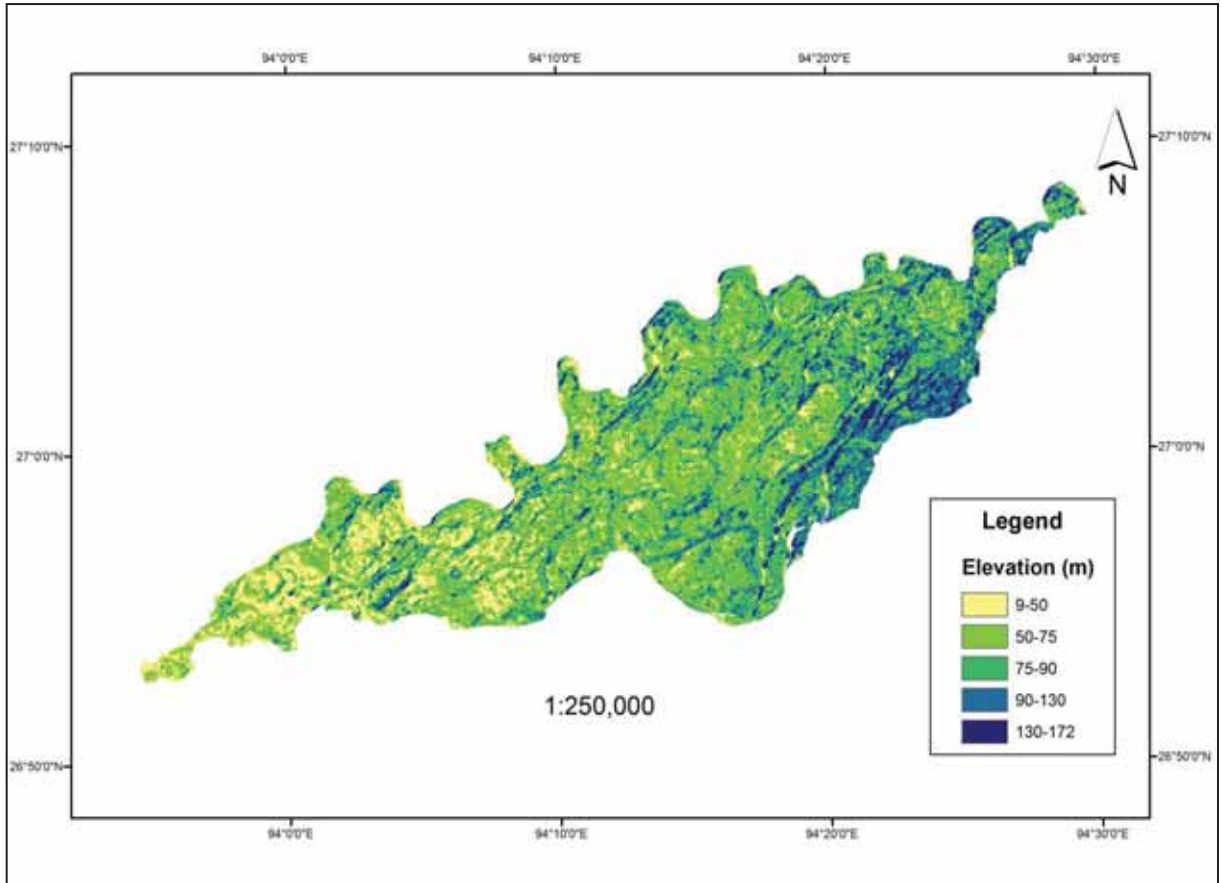


Figure 4.13: ASTER GDEM of Majuli

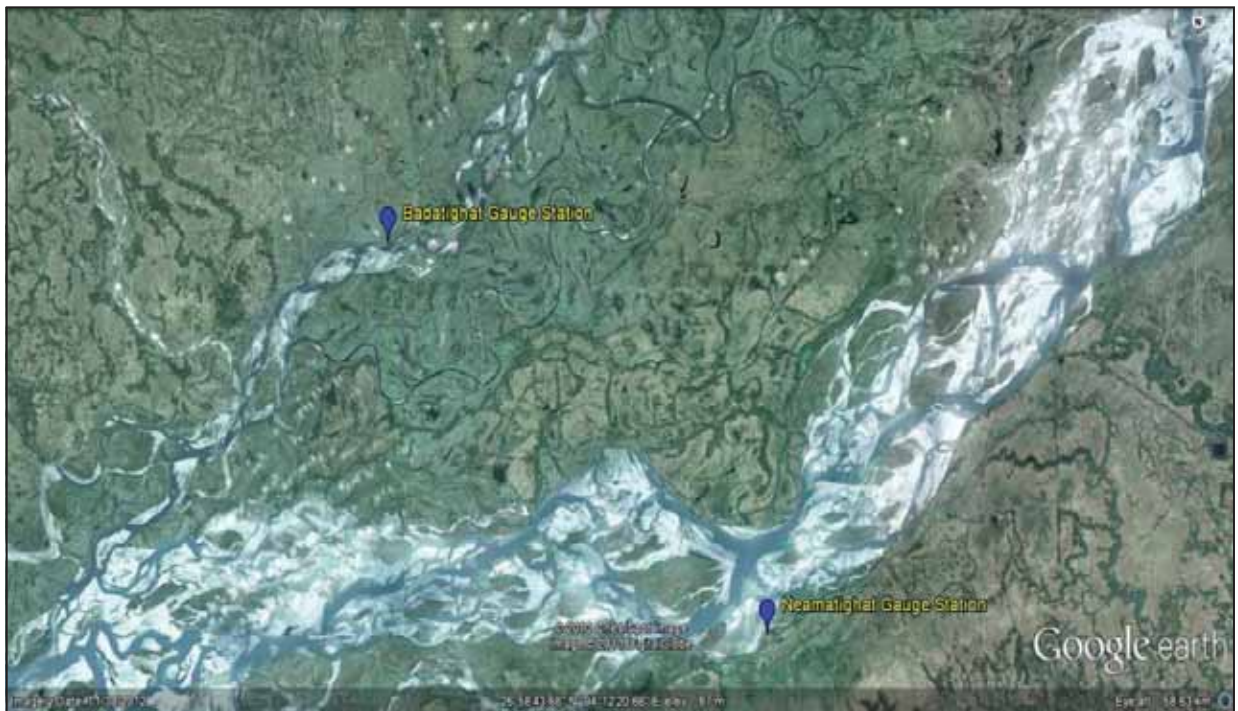


Figure 4.14: Location Map of the Gauge Station Sites

5. ANALYSIS AND RESULTS

5.1. Flood assessment

To assess the flood hazard in detail, flood inundation mapping was done using Radarsat-1 imageries covering the near peak flood period of 2004 and end of peak flood period of 2010 in Majuli and different flood characteristics like the flood depth, duration and frequency of flooding were studied.

5.1.1. Flood inundation

The flood inundated areas on 21st July, 2004 and 17th September, 2010 were extracted from the Radarsat-1 imageries following the methodology described in section 4.2.2. From the hydrological data (Annexure-I, Table 7.2, 7.4 and 7.5), it was observed that the water level of the river Brahmaputra on 21st July, 2004 was 85.83 m above mean sea level (m.s.l.) as recorded at the Neamatighat Station, Assam and that of the river Subansiri on the same day was 83.03 m above m.s.l. as recorded at the Badatighat station, Assam. The danger level of the Brahmaputra at Neamatighat is 85.04 m above m.s.l. and that of the Subansiri at Badatighat is 82.03 m above m.s.l. From these data, it is evident that on 21st July, 2004 both the rivers were flowing above the danger level. Figure 5.1 and 5.2 show the flood inundation extent on 21st July, 2004 and 17th September, 2010 respectively.

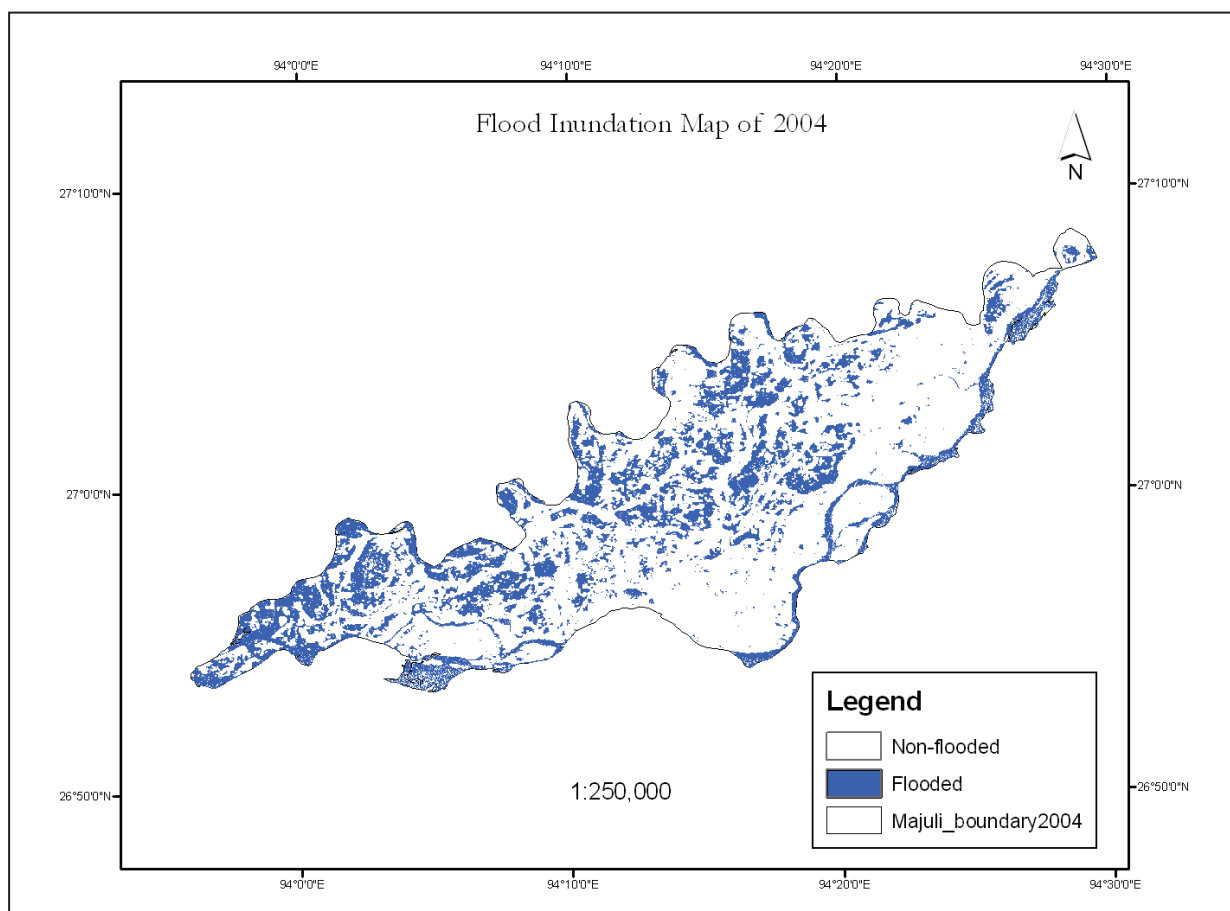


Figure 5.1 Flood Inundation on 21st July, 2004

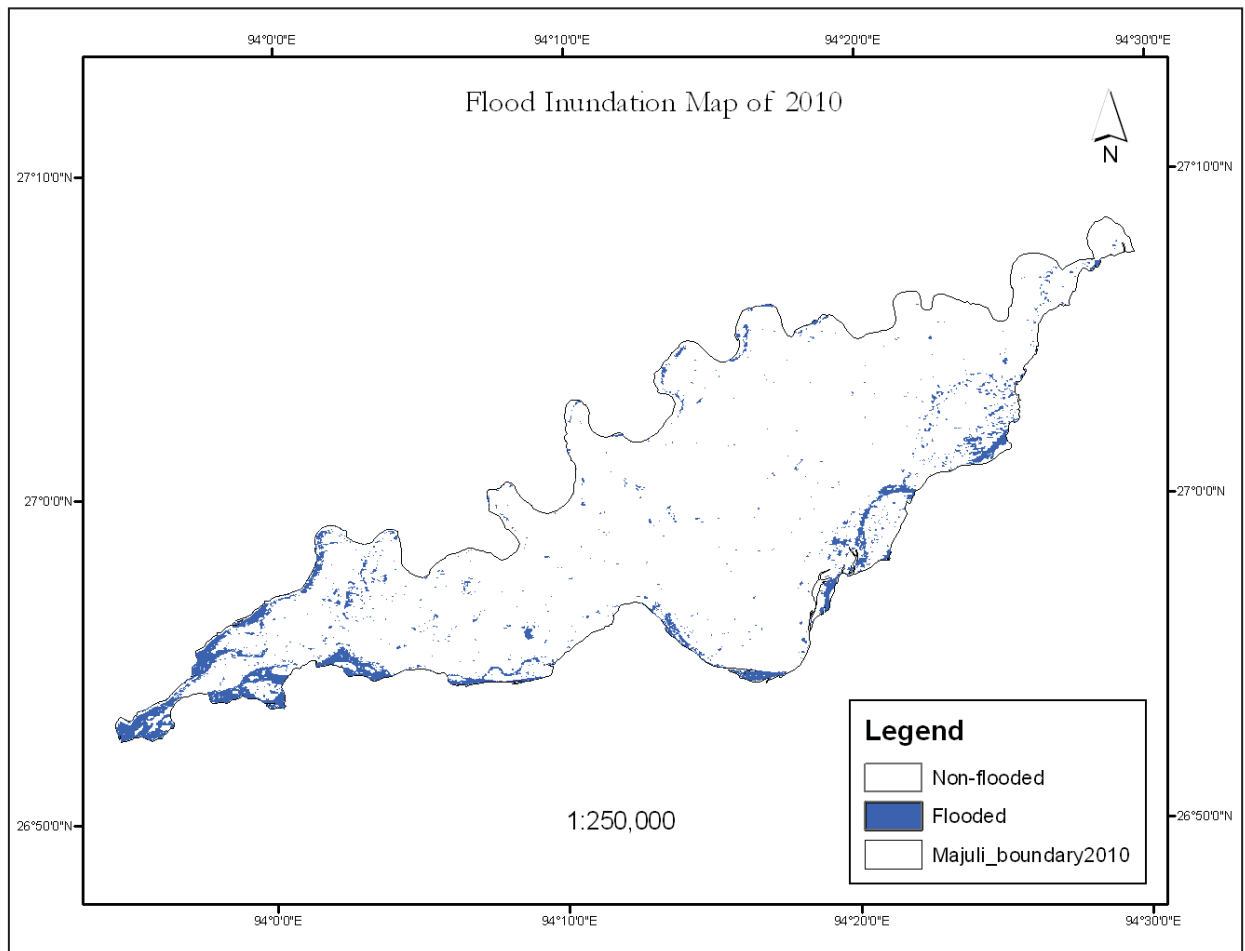


Figure 5.2: Flood Inundation on 17th September, 2010

On 17th September, 2010 the water level of the river Brahmaputra was recorded as 85.24 m above m.s.l. at Neamatighat Station, Assam which is 0.2 m above the danger level at that station. From the analysis it was found that on 21st July 2004, 146.47 km² of area was covered by flood water and that of 17th September, 2010 was 33.06 km². This high amount of inundation in 2004 is due to the high level of water in both the rivers.

5.1.2. Flood characteristics

5.1.2.1. Hydrological data analysis

Flood hydrographs are very effectively used in flood studies as it gives a visualization of the river response over a time period. Therefore to understand the flood characteristics of Majuli, flood hydrographs were prepared from the available data for the years 2001, 2004, 2008 and 2010 in case of the Brahmaputra river and for the years 2004 and 2008 in case of the Subansiri river (Figure 5.3 and 5.4). From Figure 5.3, it has been observed that over the period of 2001 - 2010, the year 2004 experienced some large flood events, the highest level of water in the Brahmaputra being more than 87 m above m.s.l. It is also evident from Figure 5.3 that in the year 2010, though the level of flood water is not very high, the duration of the flood events was much longer than

that of 2001, 2004 and 2008. Figure 5.4 depicts that the flood water level of 2004 was much higher than that of 2008 in the Subansiri river.

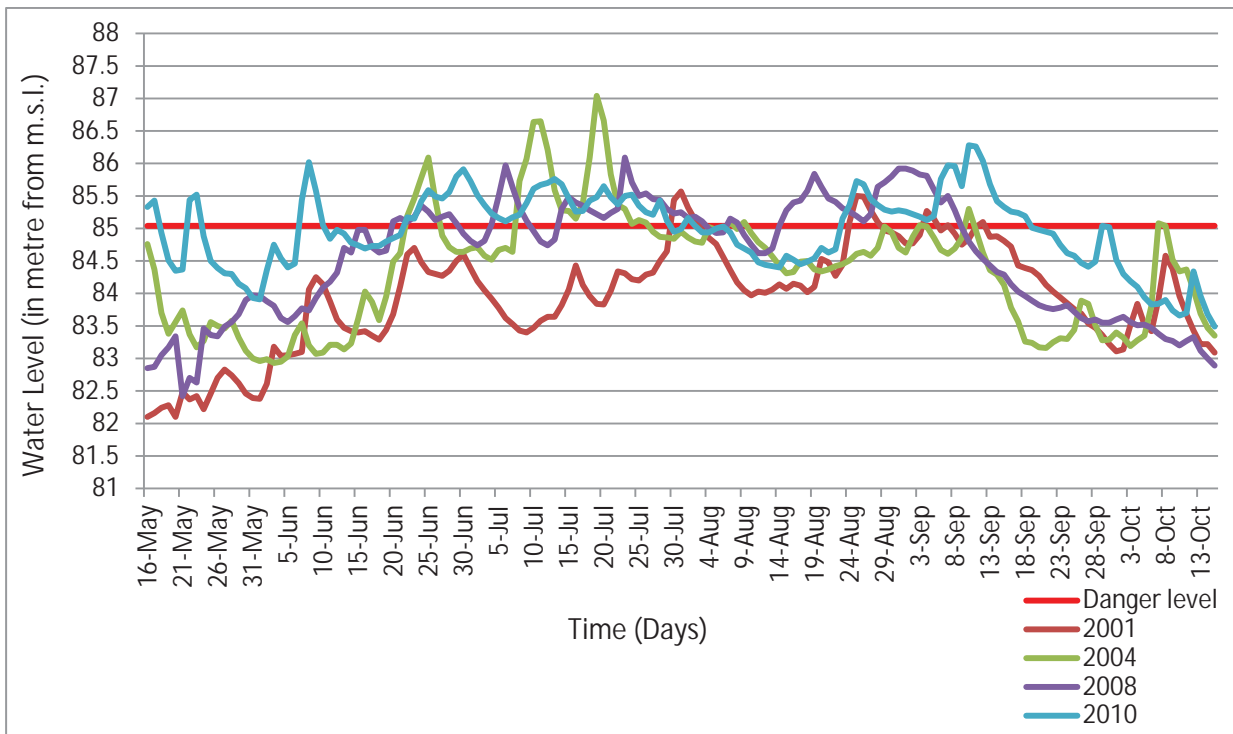


Figure 5.3: Flood Hydrographs for the Brahmaputra River

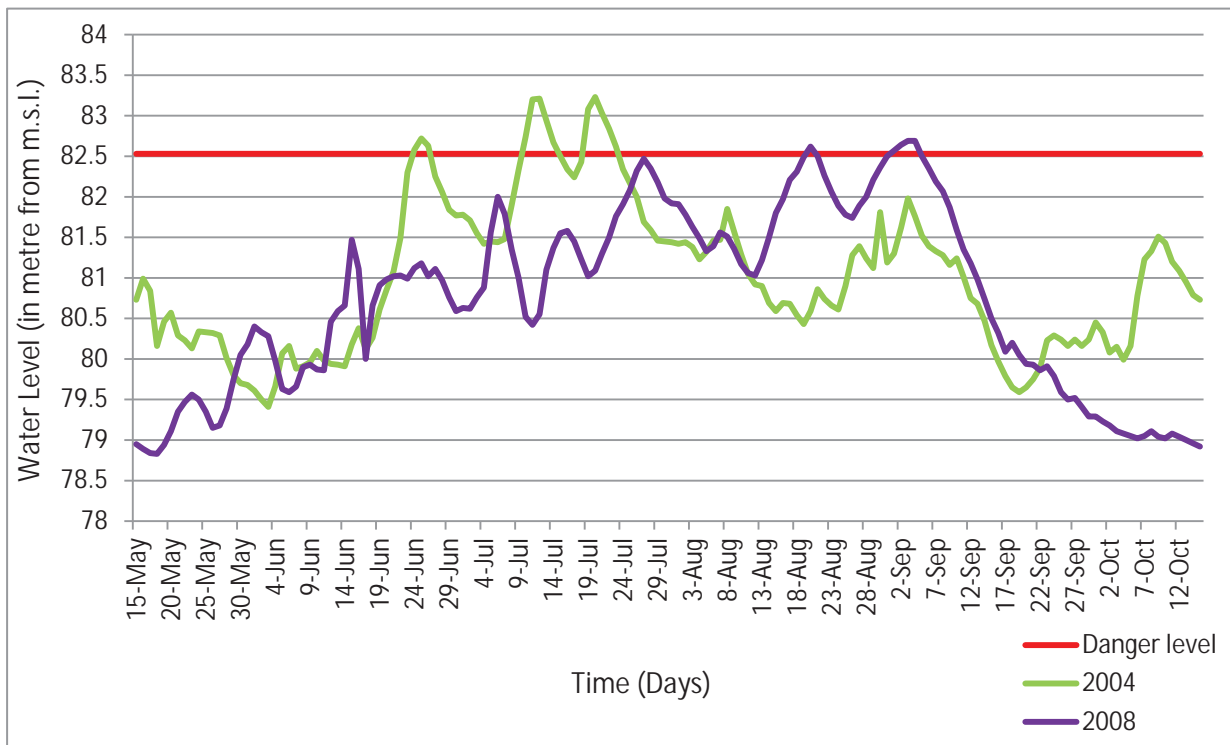


Figure 5.4: Flood Hydrographs for the Subansiri River

With the available flood discharge data of the Subansiri river, flood frequency analysis was also carried out to calculate the flood return period, T_p (equation [2], section 4.2.4) for the period of 1988 – 2010 (Table – 5.1).

Table 5.1 Calculation of T_p for the Subansiri river over 1988 - 2010

Order	Discharge (m ³ /s)	Return Period, T_p	Year
1	12358.04	24.00	1988
2	6808.9	12.00	1989
3	5133.91	8.00	2003
4	4711.84	6.00	2002
5	4631.44	4.80	1992
6	4529.49	4.00	1990
7	4395.34	3.43	2008
8	4235.88	3.00	2004
9	4234.33	2.67	2007
10	4218.55	2.40	2005
11	4006.73	2.18	2006
12	3978.26	2.00	1991
13	3857.8	1.85	1997
14	3850.93	1.71	2001
15	3685.41	1.60	1998
16	3596.82	1.50	1994
17	3558.75	1.41	1993
18	3489.84	1.33	1995
19	3457.05	1.26	1996
20	2445.06	1.20	2000
21	2066.69	1.14	1999
22	1937.72	1.09	2009
23	1935.79	1.04	2010

From the Table 5.1 it is observed that in 1988, the river Subansiri carried the highest amount of flood discharge which has return period of 24 years.

5.1.2.2. Flood Depth

Flood depths at different places of the study area were calculated using ASTER GDEM and the flood inundation maps of 2004 and 2010 and water level data of the river Brahmaputra and Subansiri on 21st July, 2004 and 17th September, 2010. On the basis of the flood depth, the whole area was classified into four classes – high flood, moderate flood, low flood and no flood (Figure 5.5, 5.6 and 5.7).

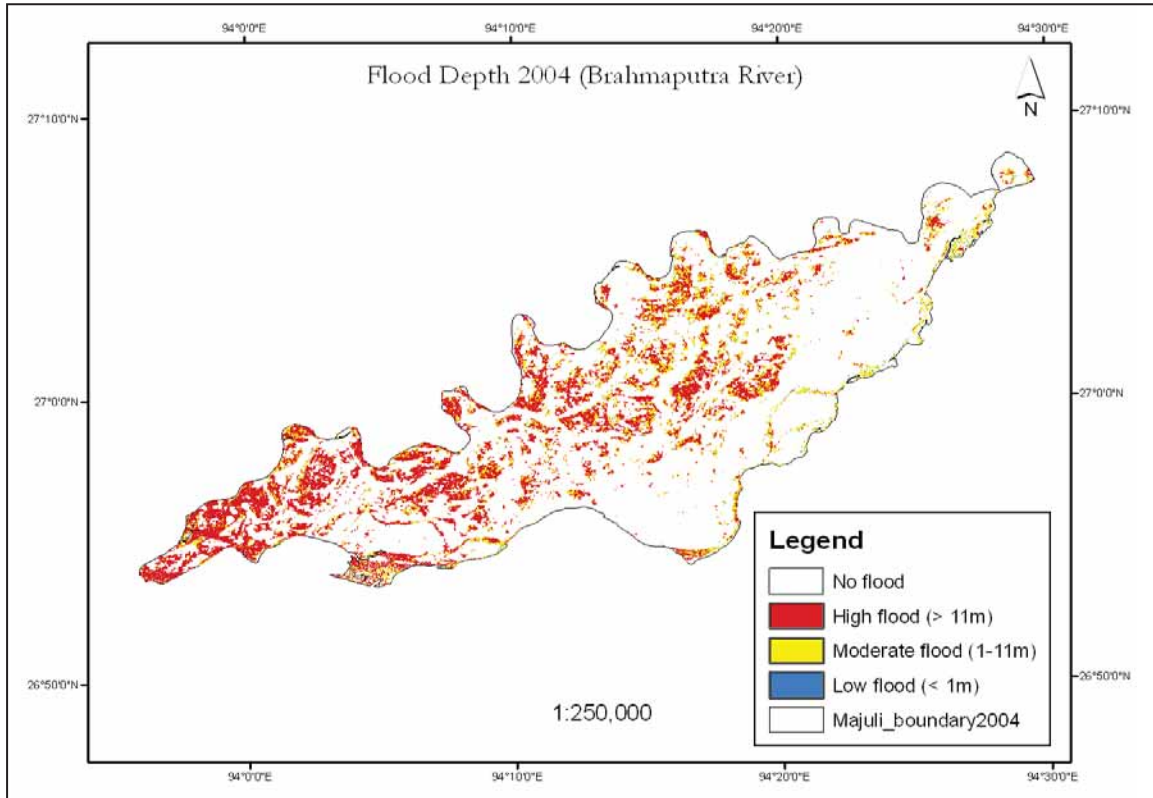


Figure 5.5: Flood depth on 21st July, 2004 due to the Brahmaputra river

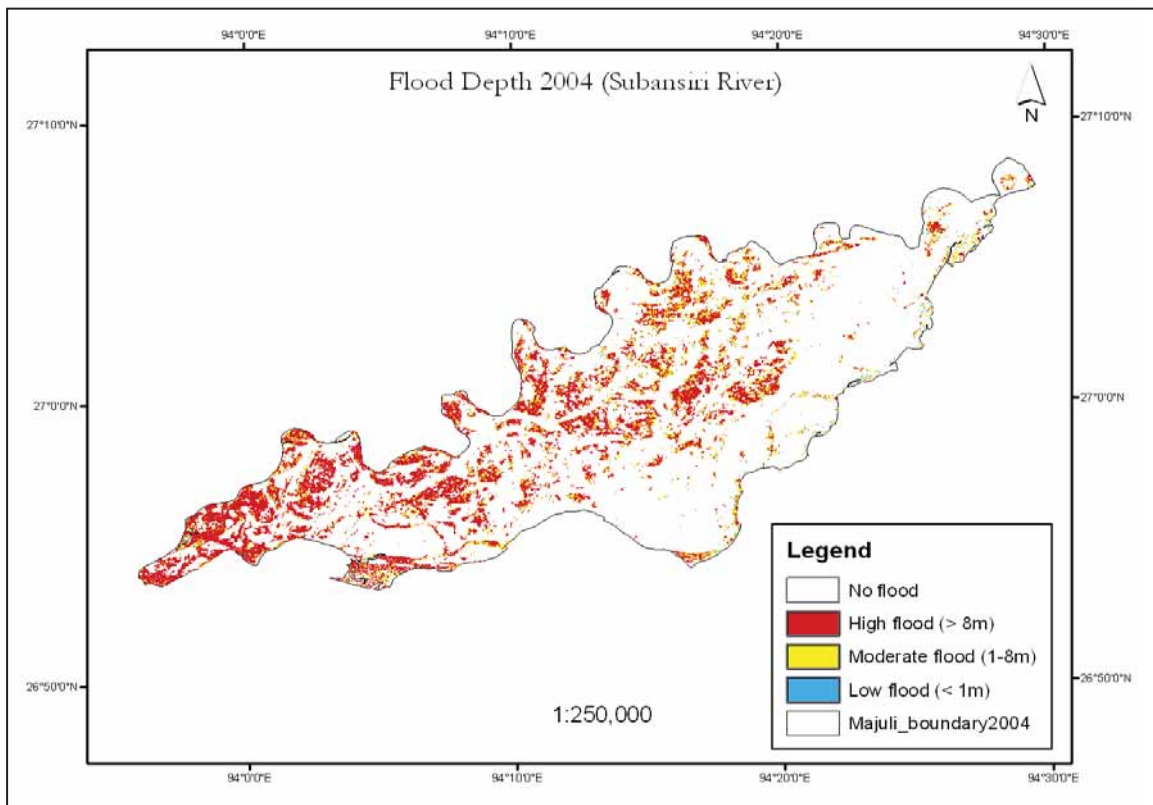


Figure 5.6: Flood depth on 21st July, 2004 due to the Subansiri river

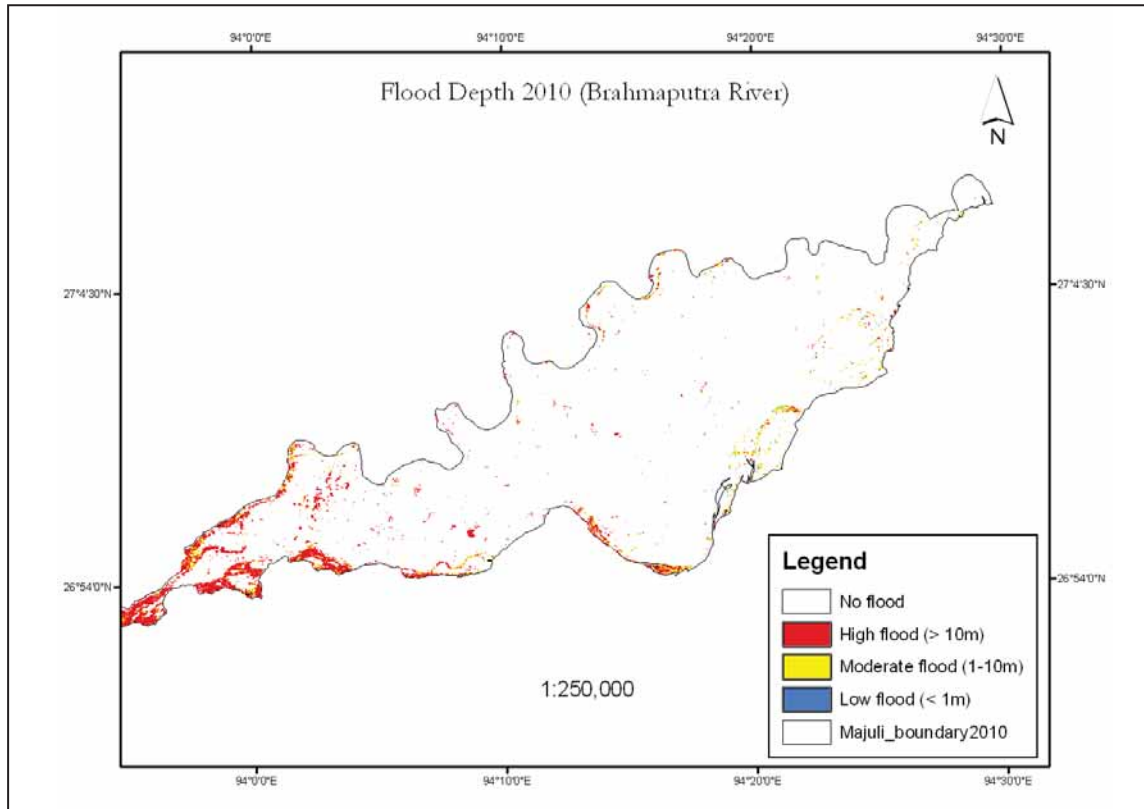


Figure 5.7: Flood depth on 17th September, 2010 due to the Brahmaputra river

From the flood depth maps it is observed that in 2004, most of the areas were under high flood water i.e. more than 8 m. In 2010, though the flood water level was not very high, the areas near to the confluence zone of the river Brahmaputra and Subansiri were highly flooded.

5.2. Riverbank erosion assessment

Riverbank erosion results due to the lateral movements of the river bank lines. Therefore, to assess the riverbank erosion it is necessary to study the channel planform change over time.

5.2.1. Channel planform change

To study the channel planform change over 1972 to 2010, the river bank lines at different years were overlaid on top of each other (Figure 5.8). From Figure 5.8 it is observed that most of the changes in the river bank lines took place at the confluence zone of the river Brahmaputra and Subansiri. A huge amount of land has been eroded away by both the rivers at the confluence zone over 1972 -2010. Besides the erosion at the confluence zone, active processes are also significant at the southern and south-western part of Majuli.

5.2.2. Change in area over 1972-2010

To point out the areas facing acute erosion problem, (5 km x 5 km) grid was constructed and the change in area at each grid was calculated by intersecting this grid file with the boundaries of the area in different years (Figure 5.9, Figure 5.10).

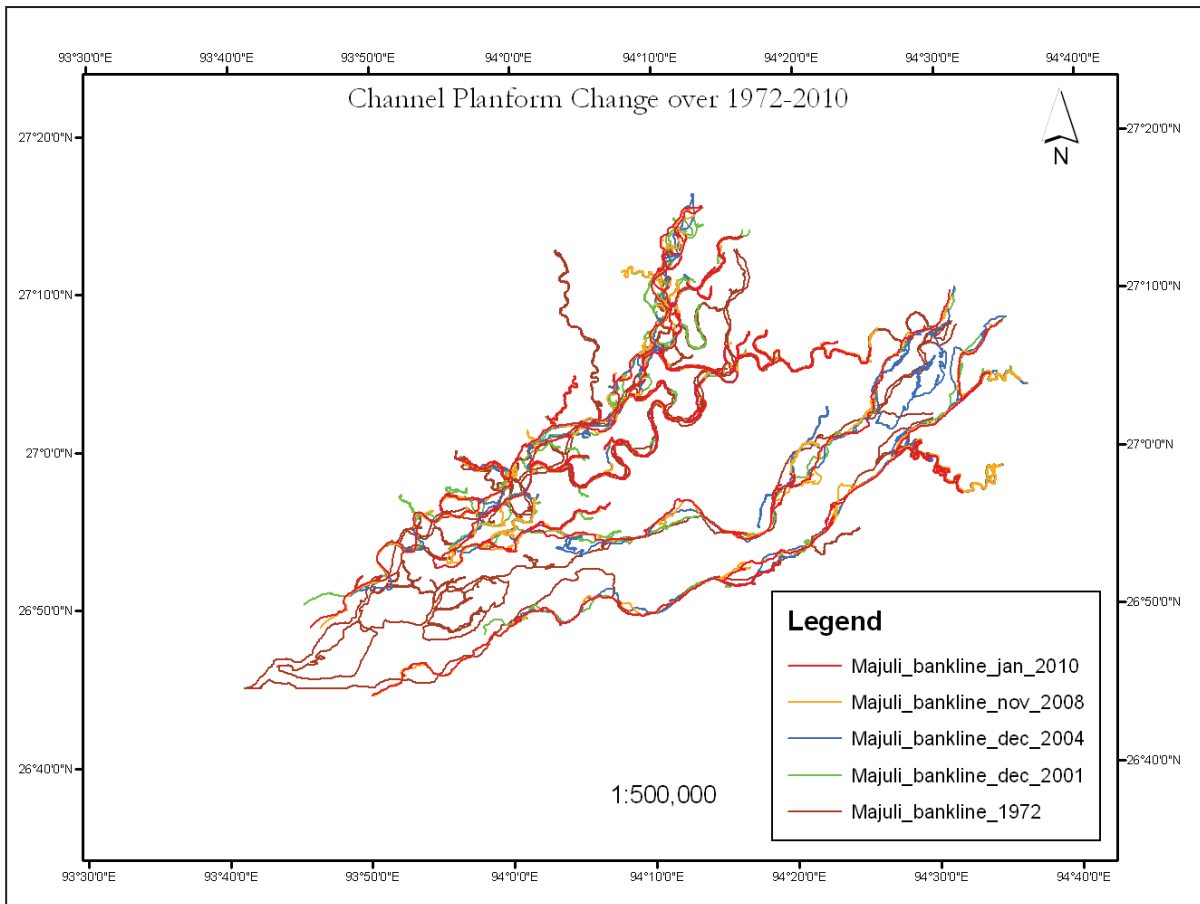


Figure 5.8: Channel Planform change over 1972 - 2010

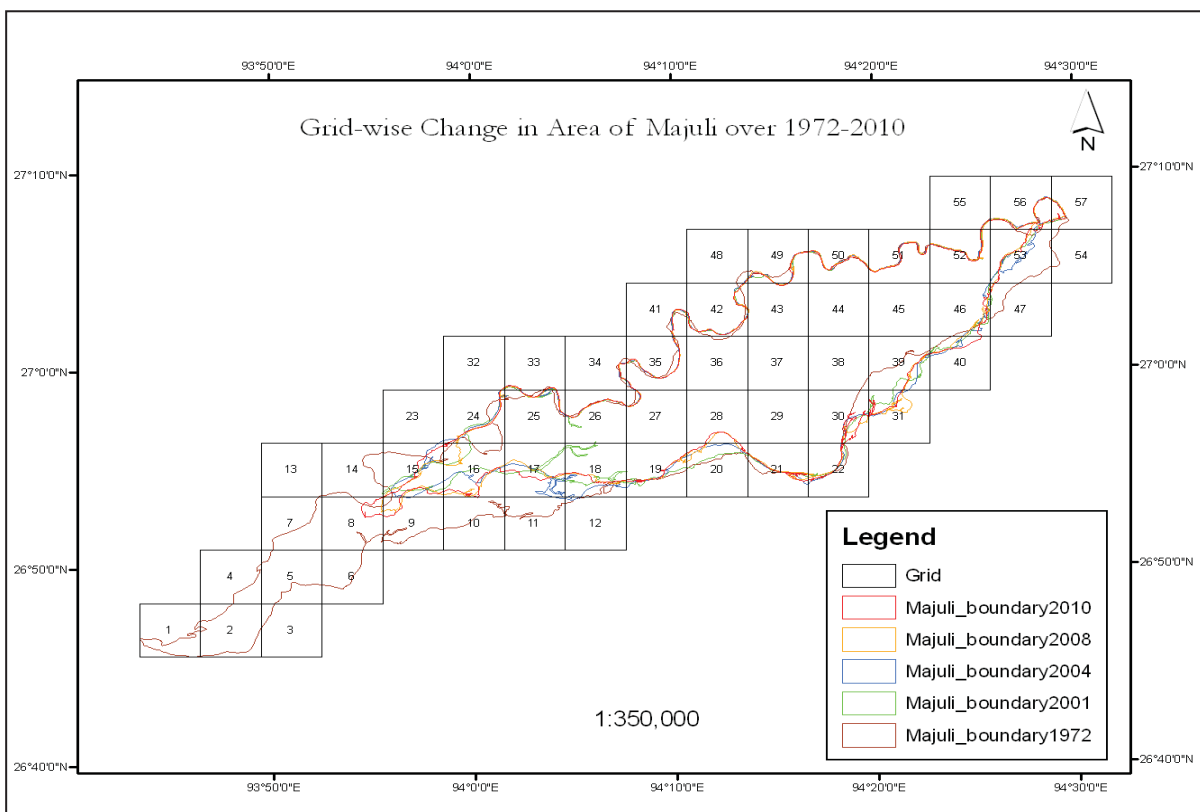


Figure 5.9: Grid-wise Change in Area of Majuli over 1972 - 2010

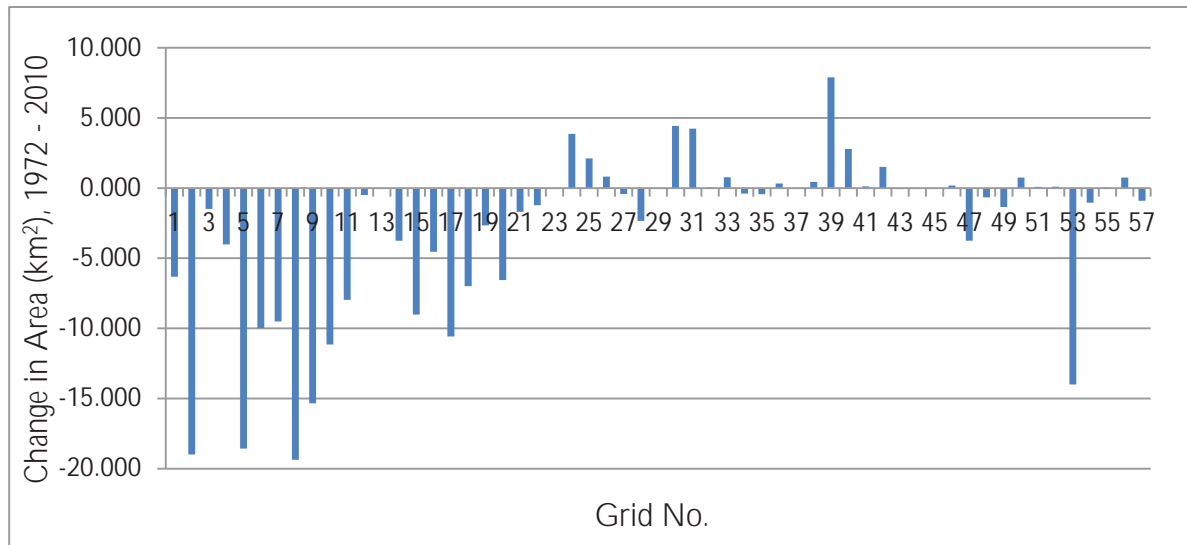


Figure 5.10: Grid-wise Change in Land Area (in km²) over 1972 -2010

From Figure 5.10, it is evident that the grids numbering 1 to 22, 27, 28, 34, 35, 47, 48, 49, 53, 54 and 57 were facing the problem of erosion over 1972 – 2010. The negative values of the change in area describe the erosion in the grids while the positive values describe the deposition. It is also observed from the analysis of the data regarding the change in land area in each grid over different time periods (Table 5.2), that the land area contained in the grids 1 to 7, 10, 13 and 54 had been completely engulfed by the two rivers over 1972-2001. However, some amount of deposition is also associated with few grids.

Table 5.2 Grid-wise change in land area (in km²) over different time periods

Grid No.	Change in Area (km ²) 1972-2001	Change in Area (km ²) 2001-2004	Change in Area (km ²) 2004-2008	Change in Area (km ²) 2008-2010	Change in Area (km ²) 1972-2010
1	-6.311	0.000	0.000	0.000	-6.311
2	-18.987	0.000	0.000	0.000	-18.987
3	-1.488	0.000	0.000	0.000	-1.488
4	-4.014	0.000	0.000	0.000	-4.014
5	-18.563	0.000	0.000	0.000	-18.563
6	-9.978	0.000	0.000	0.000	-9.978
7	-9.502	0.000	0.000	0.000	-9.502
8	-21.408	0.000	0.092	1.947	-19.369
9	-17.616	0.035	1.840	0.406	-15.337
10	-11.154	0.000	0.000	0.000	-11.154
11	-7.968	0.094	-0.094	0.000	-7.968
12	-0.493	0.194	-0.194	0.000	-0.493
13	-0.018	0.000	0.000	0.000	-0.018
14	-3.757	-0.001	0.000	0.005	-3.753
15	-11.036	2.269	-2.490	2.245	-9.012

16	-12.793	4.588	2.128	1.534	-4.544
17	-11.518	1.122	-2.522	2.340	-10.578
18	-6.030	4.777	-5.105	-0.630	-6.989
19	-0.513	-0.866	-0.481	-0.800	-2.660
20	-1.043	-4.132	-0.300	-1.084	-6.560
21	-1.820	0.797	-0.181	-0.480	-1.685
22	-1.108	0.578	-0.827	0.130	-1.228
23	0.000	0.056	-0.056	0.000	0.000
24	3.526	0.508	-0.921	0.750	3.863
25	1.583	-0.069	0.039	0.561	2.114
26	0.160	-0.108	-0.041	0.810	0.821
27	-0.445	-0.021	-0.058	0.093	-0.431
28	0.000	0.000	-1.663	-0.679	-2.342
29	0.000	0.000	0.000	0.000	0.000
30	3.707	-0.834	1.991	-0.438	4.426
31	2.436	2.269	1.655	-2.127	4.234
32	0.015	0.008	-0.008	0.037	0.053
33	0.229	0.019	-0.004	0.529	0.773
34	-0.375	0.035	-0.026	-0.026	-0.391
35	-0.579	-0.031	-0.123	0.292	-0.442
36	0.331	0.000	0.000	0.000	0.331
37	0.000	0.000	0.000	0.000	0.000
38	0.447	0.000	0.000	0.000	0.447
39	8.593	1.126	-1.537	-0.286	7.896
40	1.557	0.905	-0.791	1.117	2.788
41	0.046	-0.028	-0.027	0.135	0.125
42	1.760	-0.102	-0.267	0.126	1.518
43	-0.100	-0.032	-0.074	0.132	-0.074
44	0.000	0.000	0.000	0.000	0.000
45	0.000	0.000	0.000	0.000	0.000
46	-0.003	-0.538	-0.133	0.856	0.182
47	-3.770	-0.069	0.109	-0.022	-3.752
48	-0.670	-0.004	-0.009	0.024	-0.660
49	-1.979	0.340	-0.040	0.334	-1.345
50	0.498	-0.153	0.013	0.393	0.751
51	0.037	-0.166	-0.051	0.262	0.083
52	0.059	-0.030	-0.156	0.222	0.095
53	-13.634	3.056	-3.310	-0.111	-14.000
54	-1.039	0.000	0.000	0.000	-1.039
55	-0.042	0.053	-0.091	0.136	0.056
56	0.801	-0.144	-0.297	0.391	0.751
57	-0.804	-0.092	-0.030	0.025	-0.901

5.3. Grid-wise comparison between flood and riverbank erosion

To identify the areas facing both the problems of flooding and riverbank erosion, the same grid of (5 km x 5 km) was intersected with the flood inundation maps of 2004 and 2010 (Figure 5.11 and 5.12) and a plot was drawn to visualize the area of inundation in each grid during both the flood events of 2004 and 2010 (Figure 5.13). Another plot was drawn between the flood inundation of 2004 and the amount of erosion/ deposition over 2004 – 2008 (Figure 5.14). From the Figures 5.11, 5.12 and 5.13, it is observed that the grids 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 28, 30, 31, 39, 40, 46, 49, 50 and 53 got flooded during both the flood events of 2004 and 2010, the level of flood inundation being much higher in 2004. It is also observed from Figure 5.13 that in the grid 36, the area inundated due to the flood event of 2004 is more than 10 km².

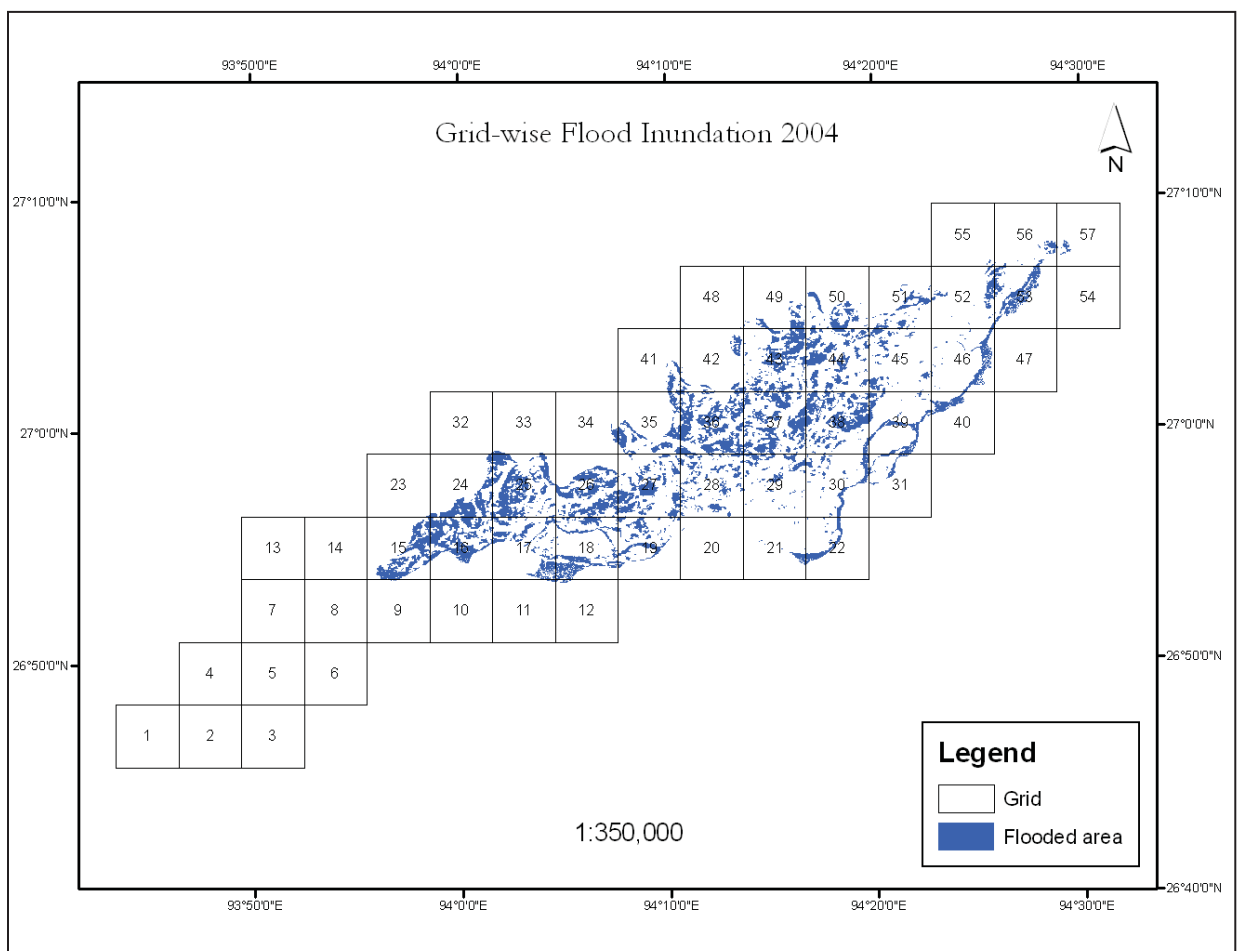


Figure 5.11: Grid-wise Flood Inundation Map of 2004

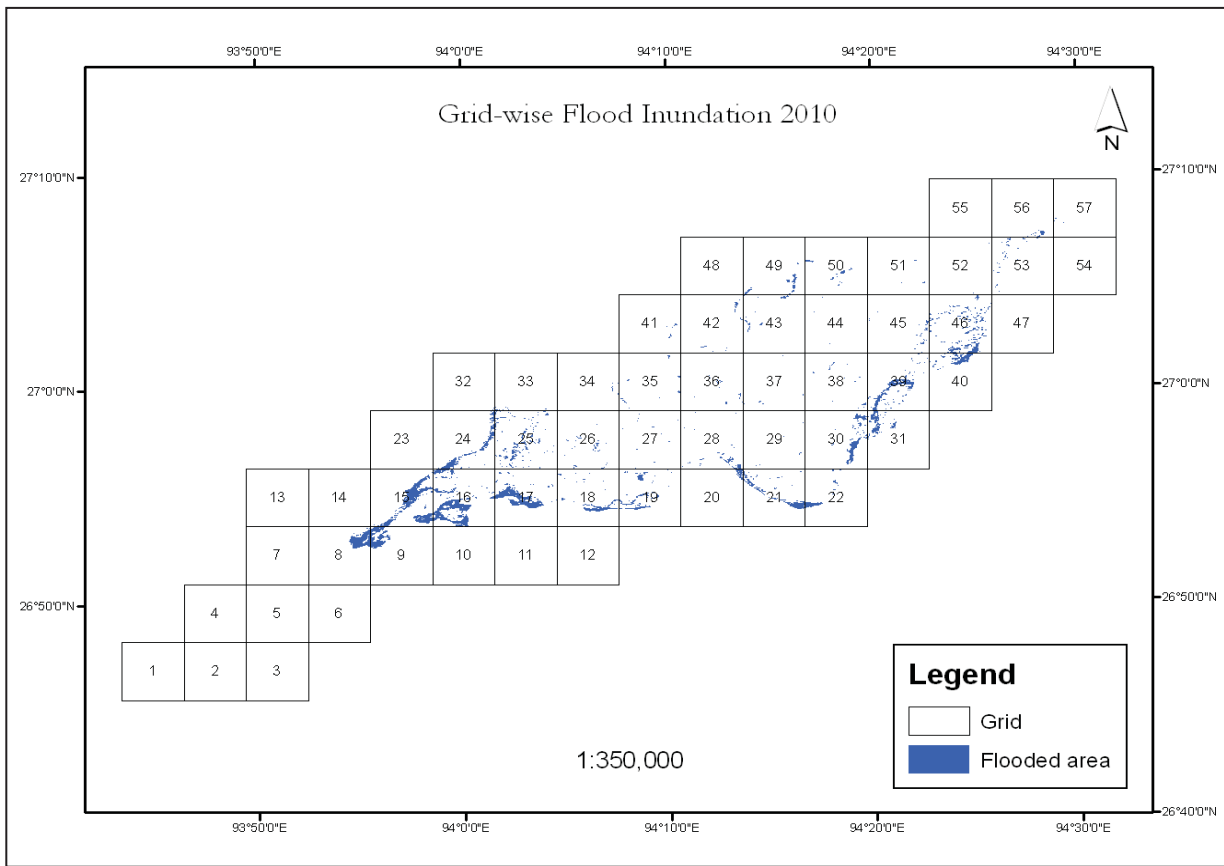


Figure 5.12: Grid-wise Flood Inundation Map of 2010

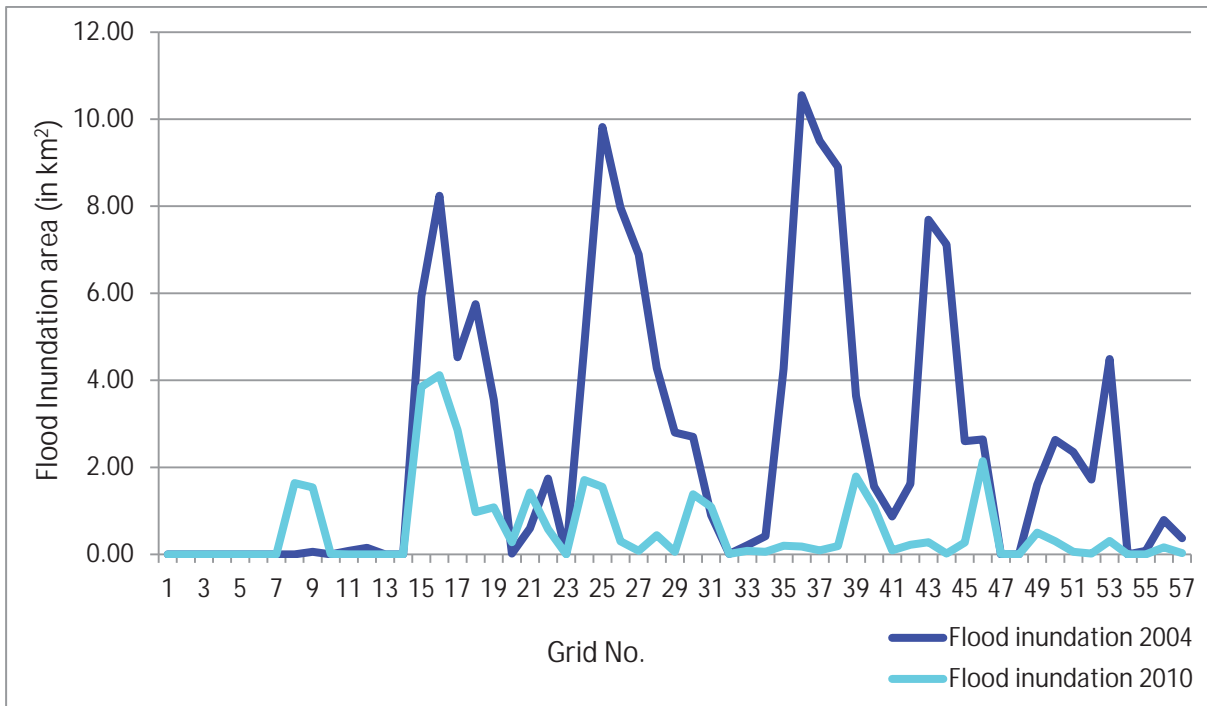


Figure 5.13: Grid-wise Flood Inundation Area (in km²) in 2004 and 2010

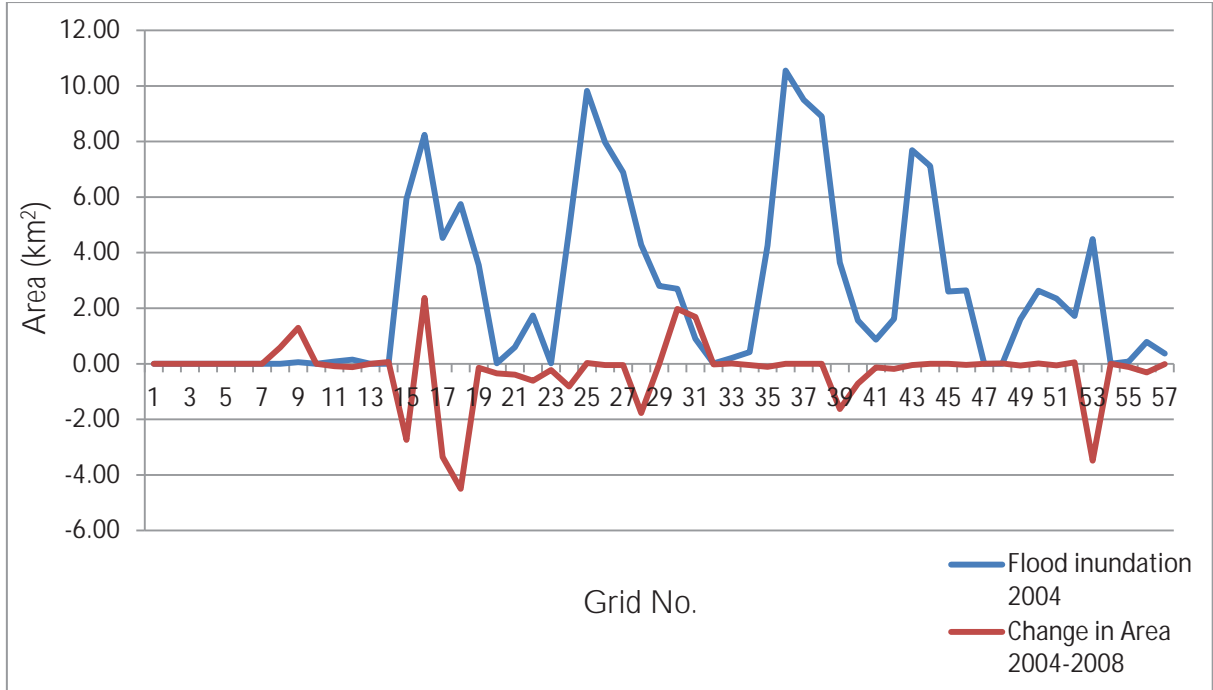


Figure 5.14: Grid-wise comparison between Flood 2004 and Change in Area over 2004-2008

From Figure 5.14 it is apparent that the grids 15, 18, 22, 24, 28, 39, 40 and 53 faced acute problems of both flooding and erosion during 2004 to 2008.

5.4. Riverbank erosion probability

To calculate the erosion probability in the area, Graf’s model was used which is an empirical method. In order to define the empirically derived constants of Graf’s equation (equation [3], section 4.2.7), first the number of pixels in each distance class was calculated (Figure 5.15). Then the number of eroded pixels for each distance class was calculated by multiplying the each distance class map with the boolean maps of different years (Figure 5.16). From the count of the land pixels present and eroded in each distance class, six transition matrices were constructed (Table 5.3, 5.4, 5.5, 5.6, 5.7 and 5.8). In these transition matrices, the value of ‘C’ represents the number of land pixels present in the specific distance class in the first year while the value of ‘C_e’ represents the number of land pixels eroded during the specified period. From the transition matrices 150 ordered sets of $(P_{i,j}, d_l, d_u, \sum_{t=1}^n r)$ were produced which were then used to solve the equation [5] (section 4.2.7) using multiple regression technique in Statistica 7 software. From the solution of equation [5] (section 4.2.7), the constants of the equation [4] (section 4.2.7) were derived with co-efficient of determination, r^2 of 0.43. Thus, the derived equation for riverbank erosion probability calculation is:

$$P_{i,j} = 5.201(d_l)^{-0.286}(d_{u,d})^{-0.299}(\sum_{t=1}^n r)^{0.024} \quad [7]$$

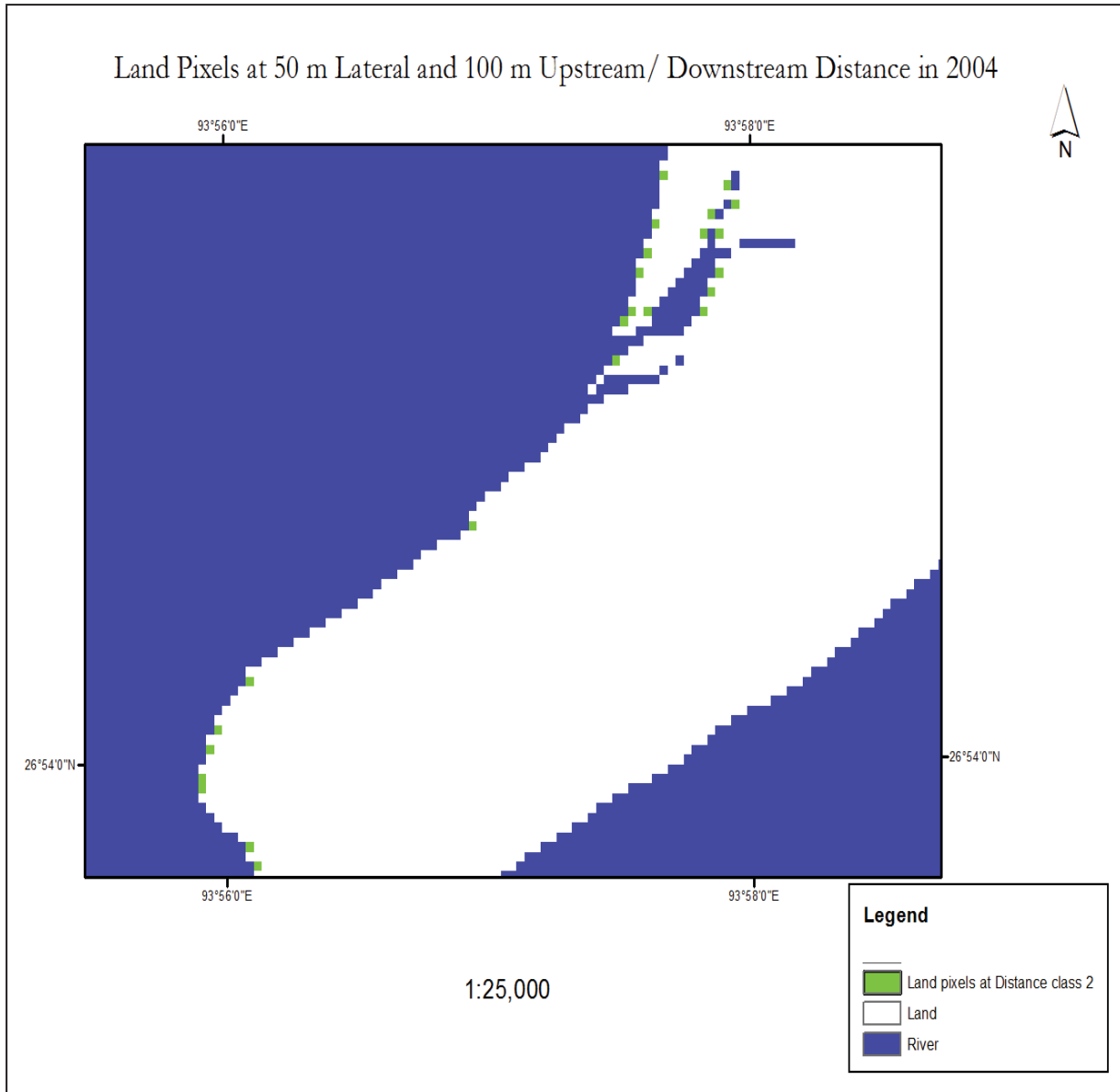


Figure 5.15: Land Pixels present in the Distance Class 2 (50 m Lateral and 100 m Upstream/Downstream 2004) in a part of Majuli

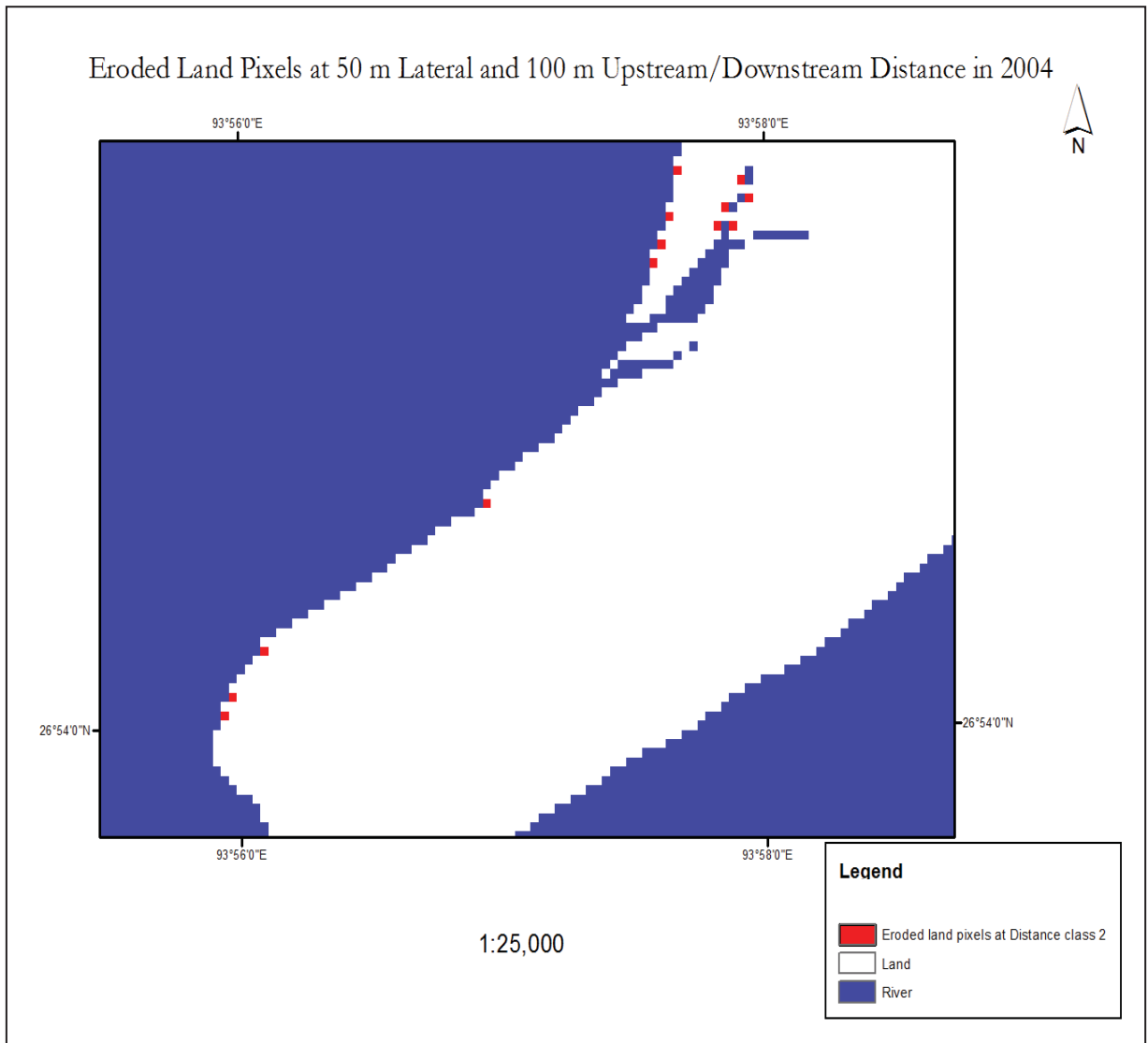


Figure 5.16: Eroded Land Pixels at Distance Class 2 during 2004 - 2008

Table 5.3 Transition Matrix for the period 2001 – 2004 ($\sum_{t=1}^4 r = 16$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1710	434	144	43	23
	C _e	561	122	45	14	5
	P _{ij}	0.33	0.28	0.31	0.33	0.22
100	C	657	686	214	65	33
	C _e	198	168	52	16	7
	P _{ij}	0.3	0.24	0.24	0.25	0.21
200	C	225	358	295	78	22
	C _e	68	91	51	15	3
	P _{ij}	0.3	0.25	0.17	0.19	0.14
500	C	38	57	70	105	13
	C _e	11	8	10	5	1
	P _{ij}	0.29	0.14	0.14	0.05	0.08
1000	C	15	22	25	31	51
	C _e	4	3	2	1	4
	P _{ij}	0.27	0.14	0.08	0.03	0.08

Table 5.4 Transition Matrix for the Period 2004 – 2008 ($\sum_{t=1}^5 r = 10$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1990	512	197	51	29
	C _e	954	217	99	28	15
	P _{ij}	0.48	0.42	0.5	0.55	0.52
100	C	753	793	263	78	33
	C _e	339	295	83	35	8
	P _{ij}	0.45	0.37	0.32	0.45	0.24
200	C	199	412	324	114	32
	C _e	97	164	101	32	9
	P _{ij}	0.49	0.4	0.31	0.28	0.28
500	C	45	49	68	97	23
	C _e	25	18	21	18	2
	P _{ij}	0.56	0.37	0.31	0.19	0.09
1000	C	21	23	19	35	49
	C _e	9	9	3	4	1
	P _{ij}	0.43	0.39	0.16	0.11	0.02

Table 5.5 Transition Matrix for the Period 2008 – 2010 ($\sum_{t=1}^3 r = 5$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1955	556	199	40	30
	C _e	688	171	57	13	6
	P _{ij}	0.35	0.31	0.29	0.33	0.2
100	C	724	777	285	79	42
	C _e	262	160	59	11	6
	P _{ij}	0.36	0.21	0.21	0.14	0.14
200	C	222	372	327	94	23
	C _e	81	90	46	12	3
	P _{ij}	0.36	0.24	0.14	0.13	0.13
500	C	39	57	71	115	27
	C _e	12	17	7	7	2
	P _{ij}	0.31	0.3	0.1	0.06	0.07
1000	C	20	29	28	42	34
	C _e	10	6	3	3	0
	P _{ij}	0.5	0.21	0.11	0.07	-

Table 5.6 Transition Matrix for the Period 2001 – 2008 ($\sum_{t=1}^8 r = 26$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1710	434	144	43	23
	C _e	746	187	69	19	12
	P _{ij}	0.44	0.43	0.48	0.44	0.52
100	C	657	686	214	65	33
	C _e	242	213	73	18	10
	P _{ij}	0.37	0.31	0.34	0.28	0.3
200	C	225	358	295	78	22
	C _e	89	114	67	15	3
	P _{ij}	0.4	0.32	0.23	0.19	0.14
500	C	38	57	70	105	13
	C _e	11	19	18	9	1
	P _{ij}	0.29	0.33	0.26	0.09	0.08
1000	C	15	22	25	31	51
	C _e	5	3	7	2	3
	P _{ij}	0.33	0.14	0.28	0.06	0.06

Table 5.7 Transition Matrix for the Period 2001-1010 ($\sum_{t=1}^{10} r = 31$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1710	434	144	43	23
	C _e	702	166	48	16	11
	P _{ij}	0.41	0.38	0.33	0.37	0.48
100	C	657	686	214	65	33
	C _e	238	199	65	16	9
	P _{ij}	0.36	0.29	0.3	0.25	0.27
200	C	225	358	295	78	22
	C _e	87	97	45	17	3
	P _{ij}	0.39	0.27	0.15	0.22	0.14
500	C	38	57	70	105	13
	C _e	15	19	14	7	1
	P _{ij}	0.39	0.33	0.2	0.07	0.08
1000	C	15	22	25	31	51
	C _e	5	5	7	1	4
	P _{ij}	0.33	0.23	0.28	0.03	0.08

Table 5.8 Transition Matrix for the Period 2004 – 2010 ($\sum_{t=1}^7 r = 15$)

Lateral Distance (m)	Statistic	Upstream/ Downstream Distance (m)				
		50	100	200	500	1000
50	C	1990	512	197	51	29
	C _e	934	199	85	20	12
	P _{ij}	0.47	0.39	0.43	0.39	0.41
100	C	753	793	263	78	33
	C _e	374	283	81	25	10
	P _{ij}	0.5	0.36	0.31	0.32	0.3
200	C	199	412	324	114	32
	C _e	97	158	84	26	4
	P _{ij}	0.49	0.38	0.26	0.23	0.13
500	C	45	49	68	97	23
	C _e	25	17	20	14	2
	P _{ij}	0.56	0.35	0.29	0.14	0.09
1000	C	21	23	19	35	49
	C _e	15	10	3	3	0
	P _{ij}	0.71	0.43	0.16	0.09	-

5.4.1. Accuracy Assessment of the Model

Using equation [7] (section 5.4), the probability of erosion for each distance classes in different time periods were predicted. To assess the accuracy of the model, correlation between the predicted and the estimated probability of erosion for each distance class was calculated using Pearson Product Moment Correlation Co-efficient (Annexure - II). The correlation between the predicted and estimated probability was found as 65%.

6. DISCUSSION

To assess the risk to the rural society of Majuli due to flood and riverbank erosion, a detailed analysis on these two problems was carried out in this study. A set of research questions were defined prior to the onset of the study to have a full understanding of the problems in the area. In this chapter, the results obtained in the previous chapter are discussed to answer the pre-defined research questions.

6.1. Flood Susceptibility

Research Question 1: Which are the flood susceptible areas?

➤ To answer this question, flood inundation mapping was done for the two periods i.e. on 21st July, 2004 and 17th September, 2010 covering the flood period in the area along with flood depth and flood frequency analysis. To identify the problem areas, a (5 km x 5 km) grid based analysis was also carried out. Being a floodplain of the Brahmaputra basin, the whole area is susceptible to flood hazard. However, from the two flood inundation maps (Figure 5.1 and 5.2), it is evident that the Namoni Majuli (lower part of Majuli), being located at the confluence zone of the river Brahmaputra and the Subansiri river, is highly susceptible to flood hazard. A few meters of rise in water level of the river above danger level may cause large-scale inundation in these areas. For instance, it is relevant to discuss that on 17th September, 2010 the water level of Brahmaputra was only 0.2 m above the danger level when the Namoni Majuli region got inundated. Besides, the problem of flooding is acute in the central part of the area and also along the river channel of Brahmaputra. The flood depth analysis for the two dates depicts that the depth of flood water in the areas near to the confluence zone is also very high i.e. more than 8m (Figure 5.5, 5.6 and 5.7). The flood frequency analysis of the gauge station data for both the rivers (Figure 5.3 and 5.4) and the field survey (Annexure – IV, Table 7.9) reveals that during the rainy season (May – October.), the area experiences more than two flood events every year that lasts for about 5-7 days. From the grid based analysis of flood inundation, it is observed that the land area contained in the grids 15, 16, 17, 18, 19, 21, 22, 24, 25, 26, 28, 30, 31, 39, 40, 46, 49, 50 and 53 got flooded during both the flood events of 2004 and 2010 and the level of flood inundation was much higher in 2004 than in 2010 (Figure 5.11, 5.12 and 5.13). It is also observed from Figure 5.13 that in the grid 36, the area inundated due to the flood event of 2004 is more than 10 km².

Research Question 2: What is the effectiveness of flood protection measures in the area?

➤ In order to protect Majuli from severe flood due to spilling of the Brahmaputra river in the upper reaches of the area after 1950 earthquake, several structural measures such as damming across the Kherkatia Suti, dykes, embankments, bunds etc. were constructed (Annexure - V). To study the effectiveness of these protective measures, field study was carried out just after the big flood event of 2012, in the month of October. During the survey, breaches at several places in

the embankments, spurs and roads were noticed (Figure 6.1). A Participatory GIS Mapping (Figure 6.2) was also carried out during the field survey and it was found that the main reason for large extent of flood inundation in 2012 (Figure 6.3) was the breach in the Tekeliphuta embankment near Haladhibari. This embankment had breached two times during the two large flood events of June and September, 2012. Due to this breaching in the embankment, deposition of a huge amount of sand (sand casting) was also observed during the survey in the Haladhibari and Sonowal Kachari villages that caused damage to a large amount of agricultural land and also to the houses and properties of the villagers (Figure 6.4).

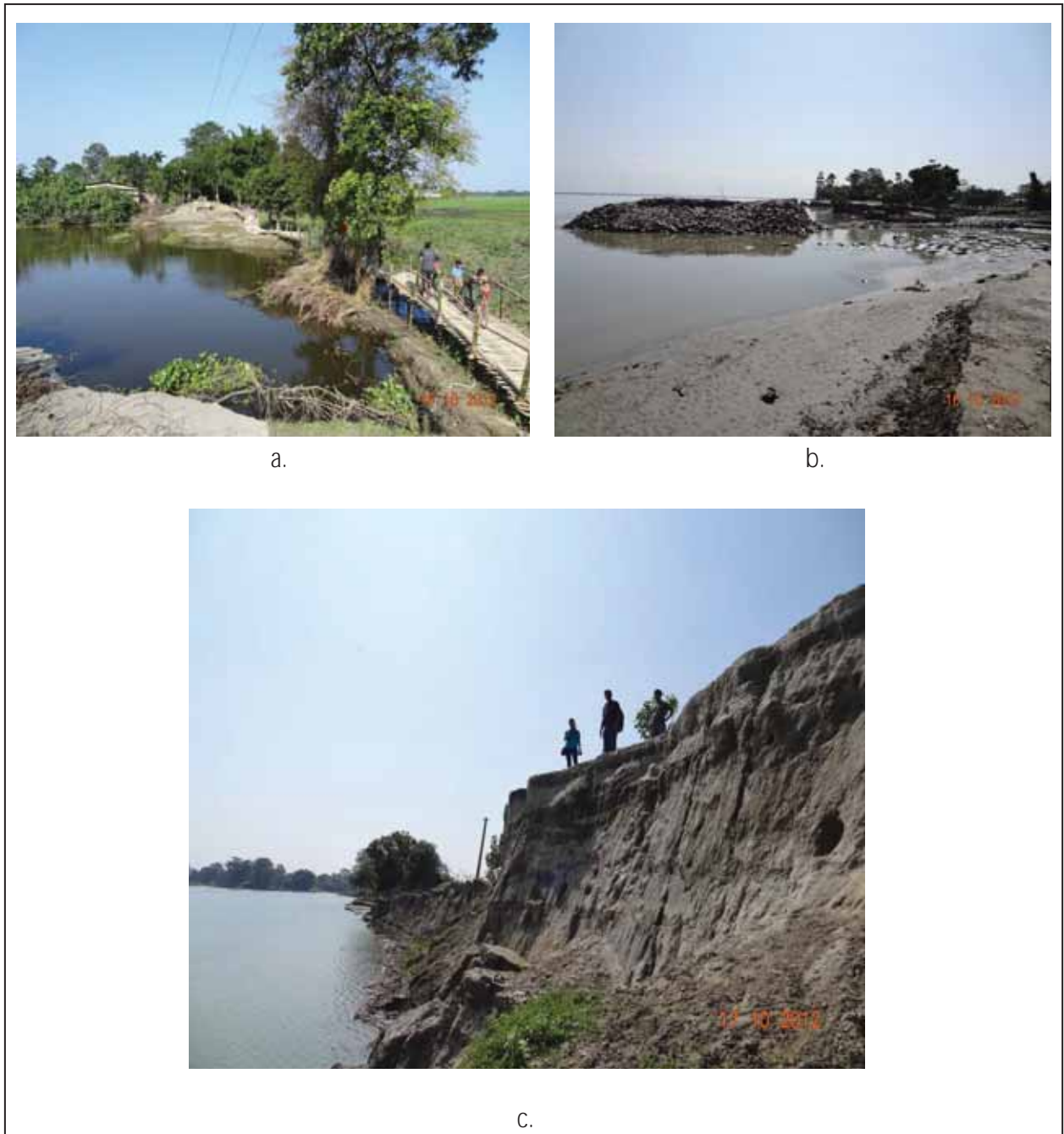


Figure 6.1: Breaches due to flood in a. Road, b. Spur, c. Embankment



Figure 6.2: Embankment breach near Haladhibari during Flood 2012

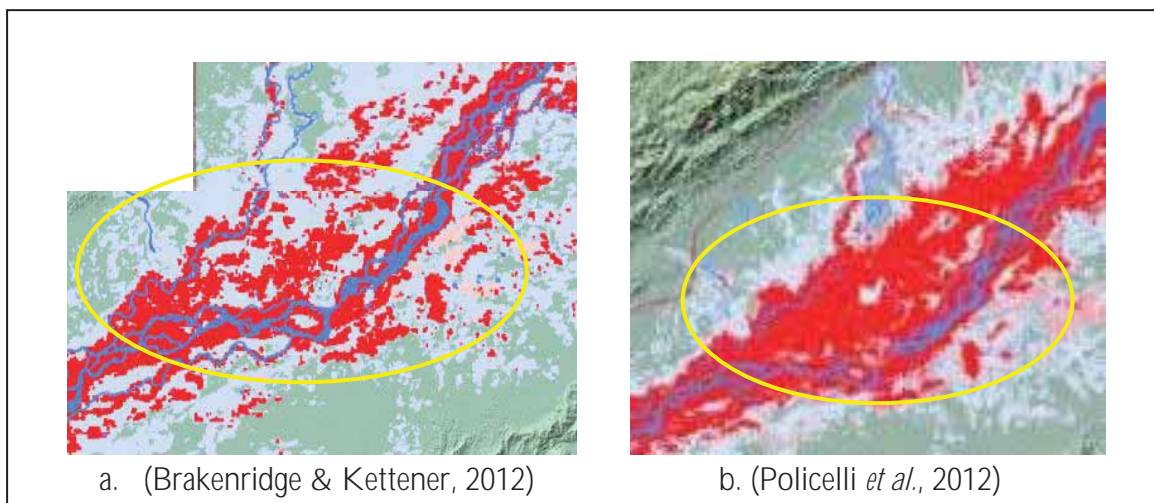


Figure 6.3: Flood Inundation extent of Majuli during Flood Events of 2012 (a. June 23 – July 2, b. 17th – 26th September)



Figure 6.4: Sand Casting in the Sonowal - Kachari Village

From the field survey, it had been marked that the problem of flooding due to natural overflow of river water in the area is not of much concern unless and until it is aggravated by its consequences of embankment or road breaching.

6.2. Riverbank Erosion Susceptibility

Research Question 3: Which areas are susceptible to riverbank erosion?

- To answer this question, thorough analysis of the river planform change was done using (5 km x 5 km) grid over 1972 – 2010. To validate the analysis of the results, PGIS mapping was also carried out during field survey (Figure 6.5). From Figure 6.5, it is apparent that the village Salmora, Sukhunamukh, Upper – Sonowal, Korotipar, Malowal Kalita, Ukhalchuk villages are continuously facing severe problems of riverbank erosion. Besides these, the other villages that fall in grids 15, 16, 19, 20, 22, 28, 30, 31, 39, 53 and 56 are also facing significant problems of riverbank erosion.

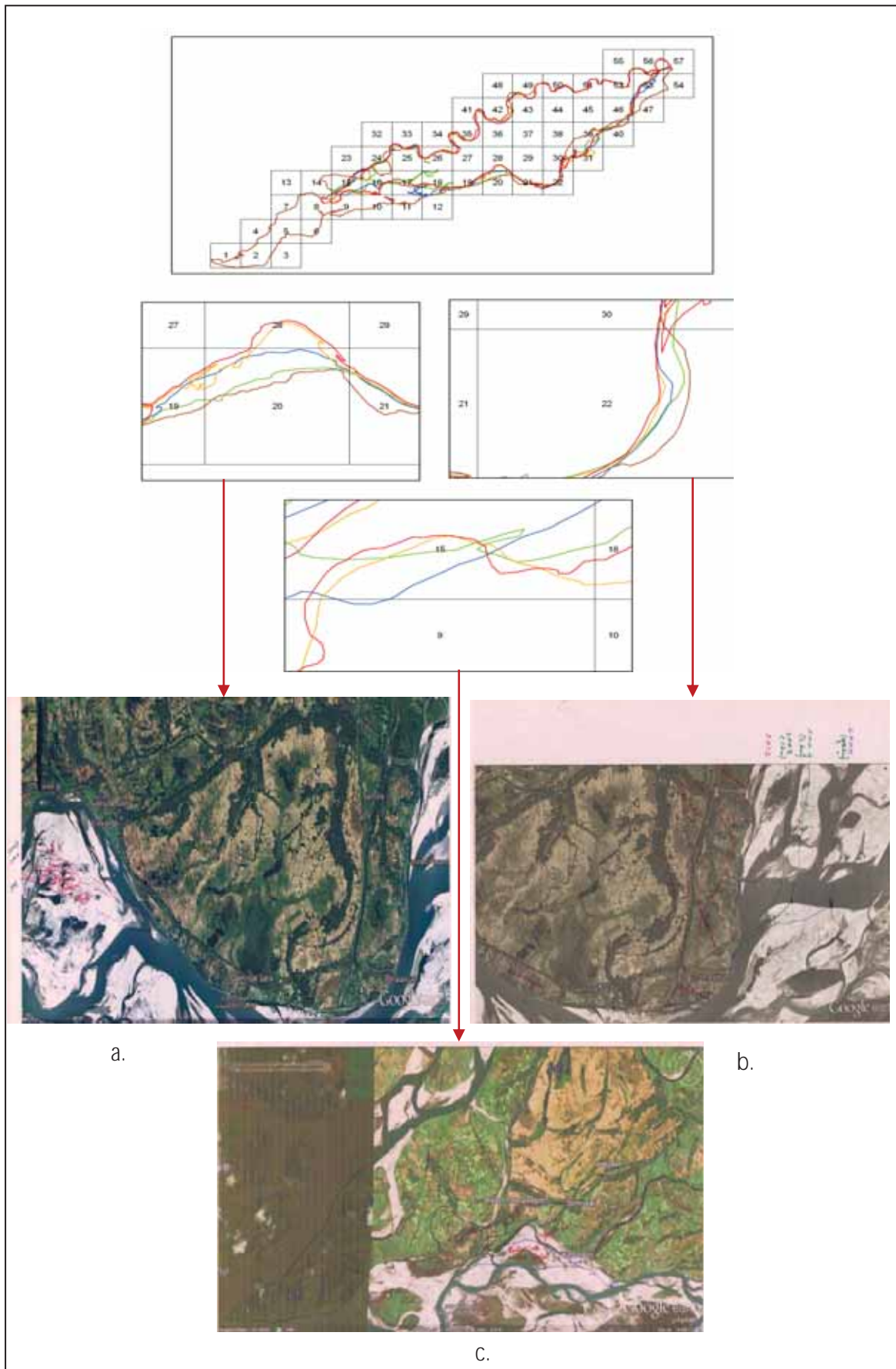


Figure 6.5: Areas affected due to Riverbank erosion (a. Salmora village, b. Upper – Sonowal and Sukhunamukh village, c. Korotipar, Malowal Kalita and Ukhalchuk village)

Research Question 4: Which parameters are influencing the channel planform change?

➤ From the detailed analysis of the problems in the area, it is observed that near to the areas severely affected by riverbank erosion such as Salmora, Sukhunamukh, Sumoimari etc. there is a bottle-neck zone in the river (Figure 5.8). Formation of this bottle-neck zone may be owed to construction of some structural measures in both side of the riverbank in that region (Figure 6.6). Besides, from Figure 5.14 it is observed that there is a close relation between the occurrences of a big flood event with subsequent riverbank erosion. Closing of the mouth of the Kherkatia Suti might also be a cause of increasing bank erosion in the area. This is because, once the Kherkatia Suti was a spill channel of the river Brahmaputra that used to carry the excess water during flood season. But due to the construction of the dam across this spill channel in 1965 – 66 as a part of protection measures, the whole of the flood water is now forced to move along the main channel of the river Brahmaputra.

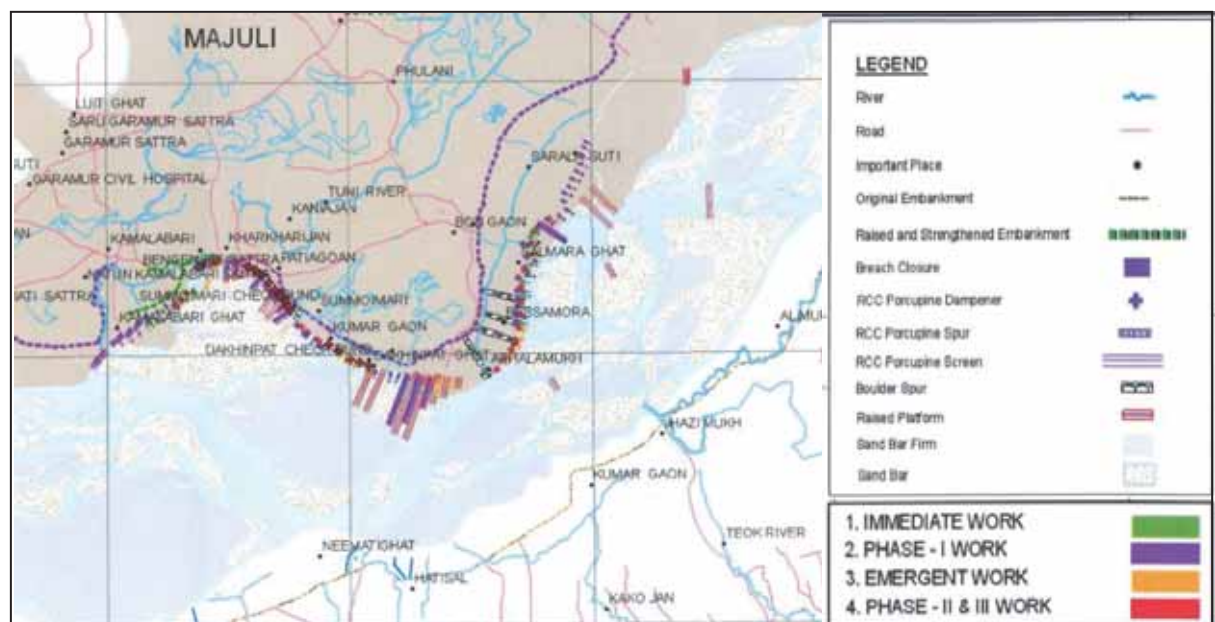


Figure 6.6: Protection works carried out in Majuli till March,2012 (Board, 2012)

Research Question 5: What is the annual rate of riverbank erosion?

➤ From the grid-based analysis of riverbank erosion, the amount of area eroded in different time periods and the annual average rate of erosion was calculated. The annual average rate of erosion in different time intervals are found as – 6.92 km²/ yr. over 1972-2001, 2.47 km²/yr. over 2001-2004, 5.48 km²/yr. over 2004-2008 and 3.34 km²/yr. over 2008-2010.

Research Question 6: Which year has experienced highest amount of erosion and what is the reason behind this?

➤ This question can be answered with the help of Figure 6.7 (Figure 6.7). From the figure it is evident that during 2004 – 2008 the rate of erosion in most of the grids is higher than that in 2001 – 2004 and 2008 – 2010. From Figure 5.14, the occurrence of the large flood event in 2004

can be regarded as one of the main reasons behind this high amount of erosion during 2004 – 2008.

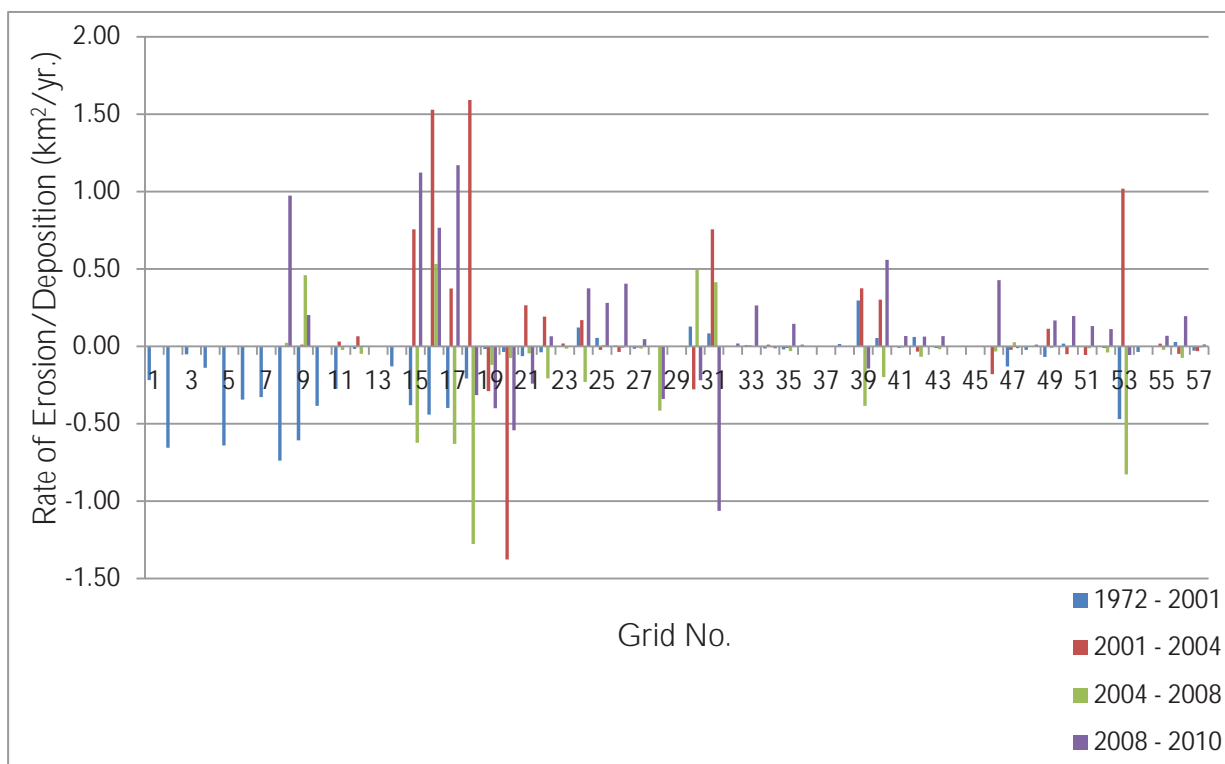


Figure 6.7: Grid-wise rate of Erosion/ Deposition (km²/yr.) in different time intervals

Research Question 7: Which elements are more vulnerable to flood hazard?

➤ The elements at risk i.e. the *Satras* and the agricultural lands of the area are mapped (Figure 6.8 and 6.9) and a field survey was carried out to assess the vulnerability of these elements. From Figure 6.9 it can be remarked that due to unrelenting bank erosion in the southern part of Majuli, most of the historically important *Satras* are becoming vulnerable to flood hazard as their proximity to river is increasing. In this regard, the vulnerability of the *Dakhinpat Satra* and the *Bengenati Satra* is very high. However, both these *Satras* are protected by an embankment. But at any case of embankment breach near this area, both the *Satras* will be at high risk of flood hazard. From the field survey it is observed that most of the agricultural lands are vulnerable to flood hazard, as high flood water remains stagnant in the fields for about 15-30 days. However, in places where flood is associated embankment breach the flood water remains stagnant in the fields for about 3 – 4 months.

Research Question 8: How well the riverbank erosion can be predicted using an empirical model?

➤ The Graf's model was used to calculate the riverbank erosion probability in Majuli. Using this model 65% of correlation was found between the estimated and predicted erosion probability values. This low value of correlation may be due to the quality of the flood discharge data as for the model input the flood discharge data of the Subansiri river is used due to the unavailability of discharge data for the Brahmaputra during the specified period and most of the erosion in the area is caused by the river Brahmaputra. Another reason for not getting very good

result from the model may also be the use of short-term hydrological data. Graf (1984) remarked that at least 50 years of hydrological records are desirable for the model input covering few large events (Graf, 1984). Besides, there might be some other factors influencing riverbank erosion which are not considered in the model like bank materials, presence or absence of protection measures, vegetation cover, geology, soil type etc.

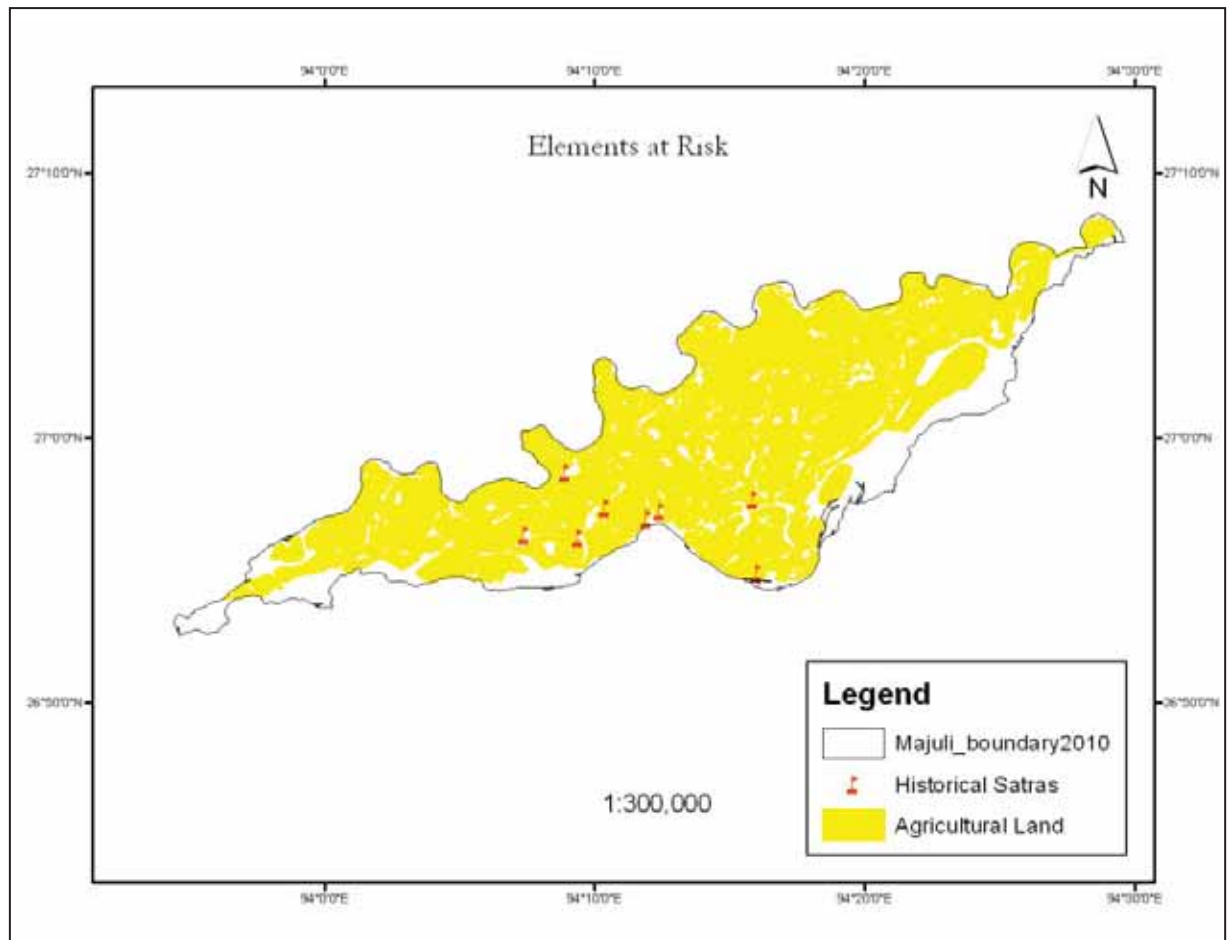


Figure 6.8: Elements at risk of the study area



Figure 6.9: Location map of the historically important *Satras*

7. CONCLUSION AND RECOMMENDATIONS

7.1. Conclusion

The Brahmaputra basin in India frequently suffers from different types of water induced hazards like flood, flash flood, river-bank erosion and sand casting (deposition of high amounts of sand by flood water) (Das *et al.*, 2009). Being located on the floodplains of Brahmaputra, Majuli too is not an exception. After thorough analysis of the results and field survey, it can be concluded that the problem of flood and riverbank erosion in the area is of serious concern. The area has experienced several large flood events in the years 1962, 1983, 1984, 1988, 1998, 2004, 2008 and 2012 among which 1998 and 2012 are the largest. Though there is no any loss of lives reported due to flooding in the area, a huge loss of livestock and agricultural production are associated with each flood event. Along with the problem of flooding, the area is also facing some other subsequent problems like embankment breach, road breach and sand casting. From the interactions with the stakeholders of the area, it has been revealed that in most of the places flooding due to river overflow is not of much concern as river water normally goes down within 2-3 days. But when the flooding is caused due to embankment breach or road breach, the problem is more acute as the flood water remains stagnant at a place for long time (Figure 7.1). The flood water entering the villages due to breach in the embankments also has a great force and thereby causes large-scale damages to houses and properties.



Figure 7.1: House under flood water due to road breach

From the study, it is observed that there is a continuous change in the area of Majuli due to active processes of erosion and deposition (Figure 7.2). The total area of Majuli in 1972 was 685.29 km², in 2001 510.51 km², in 2004 525.92 km², in 2008 511.88 km² and in 2010 521.52 km². However, the deposition is not a permanent process and gets eroded during high flood events. The erosion problem is more acute after the flood events in most of the places, the main cause being over-steepening of the bank materials due to the deposition of high amounts of sediments during the flood (Sankhua *et al.*, 2005).



Figure 7.2: Active riverbank erosion process at Salmora

The study findings therefore emphasize on an urgent need to develop an effective spatial plan considering all the aspects of flood and riverbank erosion to protect this heritage site from further engulfing by the two river systems.

7.2. Recommendations

Future investigations on this research theme can be focused on the following issues:

- Incorporation of other factors influencing the riverbank erosion in the study area for improvement of the erosion probability results of the Graf's model.
- Experiments on the empirical model can also be done using some other distance classes.
- Similar studies are also possible in different parts of the Indian rivers sensitive to flood and riverbank erosion.
- The effectiveness of the empirical model can also be studied in different parts of the world supported with good hydrological data.

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ANNEXURES

Annexure – I: Gauge Station Data

Table 7.1 Gauge Station Data for the Brahmaputra River near Majuli for the year 2001

Station: Neamatighat	2001					
	Danger Level: 85.04 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	82.38	84.39	85.32	84.77	83.11
2	–	82.61	84.19	85.13	84.77	83.14
3	–	83.18	84.05	84.97	84.9	83.51
4	–	83.04	83.92	84.85	85.27	83.84
5	–	83.05	83.78	84.76	85.15	83.52
6	–	83.07	83.62	84.56	84.97	83.42
7	–	83.1	83.53	84.36	85.05	83.91
8	–	84.06	83.43	84.17	84.92	84.58
9	–	84.25	83.4	84.05	84.75	84.38
10	–	84.14	83.47	83.97	84.84	83.96
11	–	83.88	83.58	84.03	85.02	83.68
12	–	83.6	83.64	84.01	85.1	83.43
13	–	83.47	83.64	84.06	84.87	83.22
14	–	83.42	83.82	84.14	84.88	83.22
15	–	83.4	84.06	84.07	84.81	83.09
16	82.1	83.42	84.43	84.15	84.72	–
17	82.16	83.35	84.13	84.12	84.43	–
18	82.24	83.29	83.96	84.02	84.39	–
19	82.28	83.44	83.84	84.1	84.36	–
20	82.1	83.68	83.83	84.53	84.27	–
21	82.48	84.11	84.04	84.48	84.13	–
22	82.37	84.6	84.34	84.27	84.03	–
23	82.42	84.7	84.31	84.44	83.94	–
24	82.22	84.48	84.22	85.1	83.85	–
25	82.46	84.33	84.2	85.5	83.76	–
26	82.7	84.3	84.29	85.49	83.69	–
27	82.83	84.27	84.32	85.28	83.54	–
28	82.74	84.35	84.5	85.1	83.47	–
29	82.62	84.5	84.65	84.97	83.36	–
30	82.46	84.6	85.44	84.94	83.22	–
31	82.39	–	85.57	84.88	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Table 7.2 Gauge Station Data for the Brahmaputra River near Majuli for the year 2004

Station: Neamatighat	2004					
	Danger Level: 85.04 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	82.96	84.69	84.86	84.63	83.4
2	–	82.99	84.71	84.8	84.87	83.32
3	–	82.93	84.58	84.78	85.05	83.19
4	–	82.95	84.52	85.02	85.03	83.28
5	–	83.03	84.67	84.98	84.86	83.35
6	–	83.36	84.7	84.97	84.67	83.81
7	–	83.54	84.64	85.1	84.61	85.08
8	–	83.2	85.73	84.99	84.69	85.04
9	–	83.07	86.07	85.1	84.85	84.52
10	–	83.09	86.64	84.93	85.3	84.34
11	–	83.21	86.65	84.79	84.97	84.37
12	–	83.21	86.21	84.7	84.63	84.06
13	–	83.14	85.59	84.57	84.36	83.69
14	–	83.23	85.28	84.43	84.29	83.47
15	84.61	83.61	85.27	84.31	84.13	83.35
16	84.76	84.03	85.15	84.33	83.78	–
17	84.37	83.87	85.39	84.49	83.57	–
18	83.7	83.59	86.09	84.5	83.26	–
19	83.38	83.95	87.04	84.37	83.24	–
20	83.56	84.49	86.66	84.34	83.17	–
21	83.74	84.62	85.83	84.37	83.16	–
22	83.37	85.19	85.36	84.42	83.25	–
23	83.17	85.46	85.3	84.45	83.31	–
24	83.27	85.78	85.07	84.51	83.3	–
25	83.56	86.09	85.13	84.61	83.44	–
26	83.5	85.44	85.09	84.64	83.89	–
27	83.46	84.89	84.95	84.58	83.84	–
28	83.58	84.71	84.87	84.7	83.51	–
29	83.32	84.64	84.86	85.03	83.28	–
30	83.12	84.64	84.84	84.94	83.29	–
31	83	–	84.95	84.7	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Table 7.3 Gauge Station Data for the Brahmaputra River near Majuli for the year 2008

Station:	2008					
Neamatighat	Danger Level: 85.04 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	83.96	84.81	85.16	85.92	83.6
2	–	83.88	84.74	85.18	85.89	83.64
3	–	83.81	84.81	85.11	85.83	83.56
4	–	83.62	85.06	84.99	85.81	83.51
5	–	83.56	85.49	84.93	85.6	83.52
6	–	83.65	85.97	84.94	85.4	83.47
7	–	83.77	85.64	85.15	85.5	83.38
8	–	83.74	85.32	85.09	85.28	83.3
9	–	83.93	85.12	84.9	85.01	83.27
10	–	84.09	84.96	84.75	84.8	83.2
11	–	84.18	84.8	84.62	84.65	83.27
12	–	84.32	84.74	84.62	84.53	83.33
13	–	84.7	84.83	84.69	84.43	83.12
14	–	84.63	85.3	85.04	84.33	83
15	82.87	84.98	85.48	85.28	84.29	82.89
16	82.85	84.98	85.4	85.4	84.14	–
17	82.87	84.71	85.35	85.43	84.03	–
18	83.05	84.63	85.28	85.58	83.96	–
19	83.17	84.66	85.22	85.84	83.89	–
20	83.34	85.11	85.16	85.64	83.82	–
21	82.42	85.16	85.24	85.46	83.78	–
22	82.7	85.1	85.3	85.41	83.76	–
23	82.63	85.18	86.09	85.31	83.78	–
24	83.46	85.35	85.71	85.26	83.82	–
25	83.36	85.26	85.5	85.19	83.72	–
26	83.34	85.13	85.54	85.11	83.62	–
27	83.49	85.18	85.45	85.22	83.57	–
28	83.56	85.22	85.44	85.64	83.6	–
29	83.68	85.08	85.3	85.71	83.55	–
30	83.9	84.92	85.23	85.8	83.55	–
31	83.97	–	85.25	85.92	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Table 7.4 Gauge Station Data for the Brahmaputra River near Majuli for the year 2010

Station: Neamatighat	2010					
	Danger Level: 85.04 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	83.91	85.73	85.16	85.26	84.52
2	–	84.36	85.51	85.04	85.22	84.3
3	–	84.75	85.36	84.94	85.18	84.19
4	–	84.54	85.23	84.94	85.13	84.1
5	–	84.4	85.16	85	85.19	83.94
6	–	84.46	85.11	85.03	85.76	83.83
7	–	85.44	85.17	84.94	85.97	83.84
8	–	86.02	85.21	84.75	85.96	83.9
9	–	85.58	85.39	84.69	85.65	83.74
10	–	85.05	85.61	84.63	86.28	83.66
11	–	84.84	85.67	84.48	86.26	83.7
12	–	84.98	85.7	84.44	86.04	84.34
13	–	84.92	85.76	84.42	85.68	83.96
14	–	84.78	85.68	84.4	85.42	83.68
15	85.38	84.74	85.46	84.58	85.33	83.49
16	85.33	84.69	85.26	84.52	85.26	–
17	85.43	84.73	85.27	84.45	85.24	–
18	84.93	84.73	85.43	84.49	85.19	–
19	84.51	84.8	85.48	84.54	85.01	–
20	84.35	84.85	85.65	84.7	84.98	–
21	84.37	84.9	85.48	84.63	84.95	–
22	85.44	85.17	85.37	84.68	84.92	–
23	85.52	85.15	85.5	85.15	84.75	–
24	84.88	85.42	85.52	85.36	84.62	–
25	84.5	85.59	85.35	85.73	84.58	–
26	84.39	85.49	85.25	85.68	84.47	–
27	84.31	85.46	85.21	85.45	84.41	–
28	84.3	85.56	85.43	85.36	84.49	–
29	84.15	85.8	85.12	85.29	85.04	–
30	84.08	85.91	84.95	85.26	85.02	–
31	83.93	–	84.99	85.28	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Table 7.5 Gauge Station Data for the Subansiri River near Majuli for the year 2004

Station: Badatighat	2004					
	Danger Level: 82.53 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	79.61	81.78	81.42	81.3	80.33
2	–	79.5	81.71	81.44	81.62	80.08
3	–	79.41	81.55	81.38	81.98	80.15
4	–	79.66	81.42	81.23	81.76	79.99
5	–	80.07	81.45	81.32	81.52	80.16
6	–	80.16	81.44	81.46	81.39	80.78
7	–	79.88	81.48	81.47	81.33	81.23
8	–	79.91	81.9	81.85	81.28	81.33
9	–	79.96	82.33	81.57	81.16	81.51
10	–	80.1	82.74	81.29	81.24	81.43
11	–	79.98	83.2	81.05	81.01	81.2
12	–	79.94	83.21	80.92	80.75	81.09
13	–	79.93	82.94	80.9	80.68	80.95
14	–	79.91	82.67	80.69	80.47	80.79
15	80.73	80.18	82.5	80.59	80.17	80.73
16	80.99	80.38	82.34	80.69	79.97	–
17	80.84	80.12	82.24	80.68	79.79	–
18	80.16	80.26	82.43	80.54	79.65	–
19	80.46	80.61	83.08	80.43	79.59	–
20	80.57	80.85	83.23	80.59	79.65	–
21	80.29	81.08	83.03	80.86	79.75	–
22	80.23	81.49	82.84	80.74	79.89	–
23	80.13	82.3	82.62	80.66	80.23	–
24	80.34	82.58	82.34	80.61	80.29	–
25	80.33	82.72	82.17	80.9	80.24	–
26	80.32	82.63	82	81.28	80.16	–
27	80.29	82.25	81.69	81.39	80.24	–
28	80.01	82.06	81.59	81.24	80.16	–
29	79.8	81.84	81.46	81.12	80.24	–
30	79.7	81.77	81.45	81.81	80.45	–
31	79.68	–	81.44	81.19	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Table 7.6 Gauge Station Data for the Subansiri River near Majuli for the year 2008

Station: Badatighat	2008					
	Danger Level: 82.53 m above m.s.l.					
Date	May	June	Jul	Aug	Sep	Oct
1	–	80.4	80.63	81.91	82.57	79.23
2	–	80.33	80.62	81.78	82.64	79.18
3	–	80.28	80.76	81.63	82.69	79.11
4	–	79.98	80.88	81.49	82.69	79.08
5	–	79.63	81.56	81.33	82.5	79.05
6	–	79.59	82	81.39	82.35	79.02
7	–	79.66	81.79	81.56	82.19	79.05
8	–	79.9	81.35	81.51	82.07	79.11
9	–	79.93	81	81.36	81.87	79.04
10	–	79.87	80.52	81.17	81.59	79.02
11	–	79.86	80.42	81.06	81.35	79.08
12	–	80.46	80.55	81.03	81.18	79.04
13	–	80.59	81.1	81.22	80.98	79
14	–	80.66	81.37	81.5	80.74	78.96
15	78.95	81.47	81.55	81.8	80.5	78.92
16	78.89	81.11	81.58	81.97	80.32	–
17	78.84	80	81.45	82.21	80.09	–
18	78.83	80.66	81.23	82.31	80.2	–
19	78.94	80.91	81.02	82.49	80.05	–
20	79.11	80.98	81.09	82.62	79.94	–
21	79.35	81.02	81.3	82.5	79.93	–
22	79.47	81.03	81.5	82.26	79.86	–
23	79.56	80.99	81.76	82.06	79.91	–
24	79.5	81.12	81.91	81.89	79.79	–
25	79.35	81.18	82.08	81.78	79.59	–
26	79.15	81.02	82.32	81.74	79.5	–
27	79.18	81.11	82.47	81.89	79.52	–
28	79.39	80.97	82.35	82	79.41	–
29	79.75	80.76	82.18	82.21	79.29	–
30	80.05	80.59	81.98	82.36	79.29	–
31	80.18	–	81.92	82.5	–	–

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam

Annexure – II: Accuracy Assessment

Table 7.7 Comparison between the Estimated (E) and Predicted (P) Riverbank Erosion Probability

Distance Class	2001-2004		2004-2008		2008-2010		2001-2008		2001-2010		2004-2010	
	P _{ij} (E)	P _{ij} (P)	P _{ij} (E)	P _{ij} (P)	P _{ij} (E)	P _{ij} (P)	P _{ij} (E)	P _{ij} (P)	P _{ij} (E)	P _{ij} (P)	P _{ij} (E)	P _{ij} (P)
1	0.33	0.564	0.48	0.557	0.35	0.548	0.44	0.570	0.41	0.573	0.47	0.563
2	0.28	0.458	0.42	0.453	0.31	0.446	0.43	0.464	0.38	0.466	0.39	0.458
3	0.31	0.372	0.5	0.368	0.29	0.362	0.48	0.377	0.33	0.378	0.43	0.372
4	0.33	0.283	0.55	0.280	0.33	0.275	0.44	0.287	0.37	0.288	0.39	0.283
5	0.22	0.230	0.52	0.228	0.2	0.224	0.52	0.233	0.48	0.234	0.41	0.230
6	0.3	0.462	0.45	0.457	0.36	0.450	0.37	0.468	0.36	0.470	0.5	0.462
7	0.24	0.376	0.37	0.372	0.21	0.365	0.31	0.380	0.29	0.382	0.36	0.375
8	0.24	0.305	0.32	0.302	0.21	0.297	0.34	0.309	0.3	0.310	0.31	0.305
9	0.25	0.232	0.45	0.230	0.14	0.226	0.28	0.235	0.25	0.236	0.32	0.232
10	0.21	0.189	0.24	0.187	0.14	0.184	0.3	0.191	0.27	0.192	0.3	0.189
11	0.3	0.379	0.49	0.375	0.36	0.369	0.4	0.384	0.39	0.385	0.49	0.379
12	0.25	0.308	0.4	0.305	0.24	0.300	0.32	0.312	0.27	0.313	0.38	0.308
13	0.17	0.251	0.31	0.248	0.14	0.244	0.23	0.253	0.15	0.255	0.26	0.250
14	0.19	0.191	0.28	0.188	0.13	0.185	0.19	0.193	0.22	0.194	0.23	0.190
15	0.14	0.155	0.28	0.153	0.13	0.151	0.14	0.157	0.14	0.157	0.13	0.155
16	0.29	0.292	0.56	0.289	0.31	0.284	0.29	0.295	0.39	0.296	0.56	0.291
17	0.14	0.237	0.37	0.235	0.3	0.231	0.33	0.240	0.33	0.241	0.35	0.237
18	0.14	0.193	0.31	0.191	0.1	0.187	0.26	0.195	0.2	0.196	0.29	0.192
19	0.05	0.147	0.19	0.145	0.06	0.143	0.09	0.148	0.07	0.149	0.14	0.146
20	0.08	0.119	0.09	0.118	0.07	0.116	0.08	0.121	0.08	0.121	0.09	0.119
21	0.27	0.239	0.43	0.237	0.5	0.233	0.33	0.242	0.33	0.243	0.71	0.239
22	0.14	0.195	0.39	0.192	0.21	0.189	0.14	0.197	0.23	0.198	0.43	0.194
23	0.08	0.158	0.16	0.156	0.11	0.154	0.28	0.160	0.28	0.161	0.16	0.158
24	0.03	0.120	0.11	0.119	0.07	0.117	0.06	0.122	0.03	0.122	0.09	0.120
25	0.08	0.097	0.02	0.097	-	0.095	0.06	0.099	0.08	0.099	-	0.098
Pearson Product Moment Correlation Coefficient, $r = 0.651$												

Annexure – III: Questionnaire Format for Flood and Erosion Assessment

Name of surveyor:

Date:

Respondent Details:

1. Name:
2. Sex: (M/F)
3. Age:
4. Community:
5. Village Name:
6. Education:
7. Occupation:
8. No. of family members:
9. How long have you lived in the area? years

Flood characteristics:

1. How often is your house flooded?

Max Depth	How often.	Evacuated	Duration in days	Damage percentage estimate	Type of damage	Main Flood cause
Ankle deep						
Knee						
Hip						
Breast						
Head						
First floor						
Second floor						

2. In which year have you experienced the largest flood?

- a. Year:
- b. Duration of the event:
- b. Max. height of flood water:

3. What is the main cause of most of the floods in your area?

Flood causes:
1. Prolonged local rainfall
2. River overflow
3. River erosion
4. Embankment breach
5. Multiple causes
6. Other
7. I don't know

Damage assessment:

1. What is the total no. of family members affected due to flood?
 - a. Age:
 - b. Sex (M/F)
2. What is the distance from your house to your land?
3. How often were your fields flooded?

Max Depth	How often?	Duration in days	Damage percentage estimate for agricultural fields	Eroded land percentage	Type of damage	Main flood cause
Ankle deep						
Knee						
Hip						
Breast						
Head						
Above head						

4. What mechanism do you use for flood proofing?
 - a. Raised entrance of the house
 - b. House built on raised ground
 - c. House built on poles
 - d. Extra storage on higher places
5. Characteristics of recent flood 2012:
 - a. Duration:
 - b. Max. depth of flood water:
 - c. Main cause of the flood:
 - d. Type of damage:
6. Additional remarks:

Annexure – IV: Field Survey Data

Table 7.8 Respondent Details

Name	Sex (M/F)	Age (yr.s)	Village	Occupation	Duration of living in the area (yr.s)
Budhin Das	M	30	Aphalamukh	Business (changed his occupation due frequent flooding and erosion)	30 (since his birth)
Deepti Dutta	F	24	Boidiga	Housewife	5 (shifted due to flood)
Mila Dutta	F	30	Kharichakhowa	Housewife	4
Makoni Poga	F	26	Farm tiniali	Business	7
Sishuram Kalita	M	78	Salmora (Kalitagaon)	Pottery, Boat making	12 (shifted due to erosion)
Chiranjit Payeng	M	25	Bengenaati	Private service	5 (shifted due to erosion)
Ganesh Hazarika	M	32	Salmora	Farmer	10 (shifted due to erosion)
Parijit Das	M	27	Dakhinpat	Business	50
Kuheswar Payeng	M	55	Sukhunamukh (Pabokhowa)	Pottery, Craft	6 (shifted 3 times due to erosion)
Kamal Gayan	M	78	Uttar Kamalabari	Budha Bhakat, Uttar Kamalabari Sattra	70
Lohit Saikia	M	32	Ujoni Borbil	Farmer	32 (since his birth)
Banikanta Pegu	M	42	Borpamowa	Farmer	42 (since his birth)
Surya Deori	M	52	Petujaan	Teacher	40
Jeevadoi Deori	F	45	Petujaan Balideori	Farmer	42
Biren Bora	M	54	Namoni Borbil	Farmer	28
Prabhati Pegu	F	38	Kumarbari	Farmer	38 (since her birth)
Kanaklata Hazarika	F	60	Sonowal Kacahari (Phulbari)	Farmer	35

Khudeswar Sonowal	M	35	Sonowal Kacahari	Farmer	30
Dhanada Nazir	F	58	Haladhibari	Housewife	4 (shifted due to erosion and man-elephant conflict)
Niju Saikia	F	26	Pakajora	Business	7
Nandu Sahu	M	42	Pakajora	Farmer	42 (since his birth)
Arun Rai	M	35	Milanpur	Labour	35 (since his birth)
Bipin Dutta	M	48	Borfulani	Farmer Carpenter	25
Manik Saikia	M	38	Fulani	Farmer	38 (since his birth)
Hemanta Baruah	M	41	Santipur	Farmer	41 (since his birth)
Deepshikha Bora	F	20	Alimur Bamungaon	Housewife	24
Anjali Dutta Bhuyan	F	42	Goalgaon	Housewife	5 (shifted from korotipar due to erosion)
Amulya Sarma	M	31	Korotipar Maluwal Kalita gaon	Business (changed his livelihood due to regular flooding)	31 (since his birth)
Hima Saikia	F	45	Kordoiguri	Farmer	45 (since her birth)
Sarupai Das	M	80	Bormukali	Farmer	80 (since his birth)
Rudrakanta Medhi	M	77	Kakorikata	Labour (changed his livelihood due to regular flooding)	77 (since his birth)
Padma Saikia	M	40	Mohkina	Farmer	20
Biswajit Pegu	M	30	Balijaan	Farmer	30 (since his birth)

Table 7.9 Flood Characteristics

Name	Frequency of flooding	Max. Depth	Duration of flooding (days)	Main cause of Flood	Type of damage
Budhin Das	2-3 times every year	First floor	7-10	River overflow	Complete damage of the house
Deepti Dutta	Every year	Breast level	13-15	Embankment breach	Damage to house, livestocks
Mila Dutta	Every year	Head level	7	Embankment breach	Damage to house, livestocks
Makoni Poga	3-4 times every year	Breast level	7-10	Embankment breach	Damage to house
Sishuram Kalita	3-4 times every year	Breast level	7-10	River overflow, Breach in spur	Damage to house, loss of properties and stored grains
Chiranjit Payeng	Once in every year	Knee level	15-20	River overflow, Embankment breach	complete damage to house, loss of properties
Ganesh Hazarika	4-5 times every year	First floor	7	River overflow, Breach in spur	Damage to house, stored grains
Parijit Das	2-3 times every year	Hip level	7-10	River overflow	Damage to house and properties, loss of livestocks
Kuheswar Payeng	2-3 times every year	First floor	7-10	River overflow	Damage to house and properties
Kamal Gayan	once in every 5 years	Knee level	7-10	Embankment breach	Damage to house walls
Lohit Saikia	once in every 2 years	Head level	7-10	Breach in the Garmur-Haladhibari road	Damage to house and properties
Banikanta Pegu	once in every 2-3 years	Hip level	7-10	River overflow	Damage to house and properties
Surya Deori	2-3 times every year	Breast level	15-20	Breach in the road	Damage to house and loss of livestocks
Jeevadoi Deori	once in every 2 years	Breast level	7-10	Embankment breach	Dmage to house walls
Biren Bora	Once in every year	Hip level	15	River overflow Road Breach	Damage to house and loss of livestocks
Prabhati Pegu	2-3 times every year	Breast level	30	Embankment breach	Dmage to plant seedlings
Kanaklata	Every year	Breast level	7	River overflow	Damage to house

Hazarika				Embankment breach	walls and properties, loss of livestock
Khudeswar Sonowal	2 times every year	First floor	15	River overflow Embankment breach	Damage to house, properties and stored grains, loss of livestock
Dhanada Nazir	in 2012 only	Breast level	7-10	Breach in the ring dam	Damage to house, properties
Niju Saikia	once in every 2-3 years	Breast level	7	Embankment breach	Damage to house, loss of properties
Nandu Sahu	once in every 4-5 years	Hip level	7-10	Embankment breach	Damage to house, loss of livestock
Arun Rai	once in every 2-3 years	Knee level	7-10	River overflow Embankment breach	Damage to house, loss of livestock
Bipin Dutta	once in every year	Knee level	7-10	Embankment breach	Damage to house and raw materials for carpentry
Manik Saikia	once in every 3 years	Hip level	30	Embankment breach	Damage to house
Hemanta Baruah	once in every 4-5 years	Ankle deep	7	River overflow Embankment breach	No damage
Deepshikha Bora	2-3 times every year	Knee level	3-4	River overflow	Loss of properties and livestock
Anjali Dutta Bhuyan	once in every year	Ankle deep	7	Local rainfall Embankment breach	No damage
Amulya Sarma	2-3 times in every 2 years	Knee level	3-5	River overflow	Damage to house
Hima Saikia	4-5 times every year	Hip level	10-15	River overflow	Damage to house, properties
Sarupai Das	once in every 3-4 years	Ankle deep	7	River overflow	No damage
Rudrakanta Medhi	once in every 2 years	Ankle deep	15-20	River overflow	No damage
Padma Saikia	once in every 2 years	Hip level	8-10	River overflow Embankment breach	Damage to house
Biswajit Pegu	once in every 2-3 years	First floor	12-13	River overflow	Damage to house, properties and loss of livestock

Table 7.10 Characteristics of the Largest Flood experienced

Name	Year of largest flood experienced	Duration of the largest flood (days)	Max. height of largest flood water (ft.)	No. of family members affected by flood
Budhin Das	2012	15	7	No
Deepti Dutta	2012	13-15	4	No
Mila Dutta	2008 2012	7	5	No
Makoni Poga	2012	10	4	No
Sishuram Kalita	1984	10-12	5	No
Chiranjit Payeng	1998	90	7	No
Ganesh Hazarika	2004 2012	150-180	7	No
Parijit Das	1998	10-12	8	No
Kuheswar Payeng	2012 1962	10	7	No
Kamal Gayan	1998	7	2.5	No
Lohit Saikia	2012 1983	20 (2012) 7-10 (1983)	8	No
Banikanta Pegu	1998	7	2	No
Surya Deori	1998 2012	15-20	5	No
Jeevadoi Deori	1998	60	4	No
Biren Bora	1998 2012	45	2.5	No
Prabhati Pegu	1998	45	7	No
Kanaklata Hazarika	1998 2012	7	5	No
Khudeswar Sonowal	1998	20-25	6	No
Dhanada Nazir	1998 2012	7-10	4	No
Niju Saikia	1998 2012	7	5	No
Nandu Sahu	1998 2012	10-15	5 (1998) 6 (2012)	No
Arun Rai	1998	10-15	5	No
Bipin Dutta	1998	15	6	No
Manik Saikia	1998 2012	7	5	No
Hemanta Baruah	1998	7	10	No
Deepshikha Bora	2012	10	1	No
Anjali Dutta	1998	120	4	No

Bhuyan				
Amulya Sarma	1988 1998	7	3	No
Hima Saikia	1998 2008	15-20	3	No
Sarupai Das	1988 1998	7	4	No
Rudrakanta Medhi	1962	30	3	No
Padma Saikia	2008	15	4	No
Biswajit Pegu	1998	30	8	No

Table 7.11 Characteristics of flood in the Agricultural Fields

Name	Distance from house to agri. Field (km)	Frequency of flooding in agri. field	Height of flood water in the field	Duration of flood in the fields (days)	Main cause of flood in the fields	Type of damage
Budhin Das	Adjacent	Every year	Above head	15-20	River overflow	Loss of crops and loss of land
Deepti Dutta	1.6	once in every 2 years	Head level	30	Embankment breach	Partial damage of crops
Mila Dutta	1	once in every 4-5 years	Above head	7	Embankment breach	No damage
Makoni Poga	N/A	N/A	N/A	N/A	N/A	N/A
Sishuram Kalita	1	N/A	N/A	N/A	N/A	complete loss of land
Chiranjit Payeng	4	Every year	Above head	N/A	River overflow	complete loss of land
Ganesh Hazarika	Adjacent	Every year	Above head	10-15	River overflow, breach in spur	Loss of land, damage to crops
Parijit Das	1	Every year	Above head	N/A	N/A	complete loss of land
Kuheswar Payeng	2	N/A	N/A	N/A	N/A	complete loss of land
Kamal Gayan	0.2	once in every 2 years	Above head	60	Embankment breach	Damage to crops
Lohit Saikia	1	Every year	Above head	20-22	Road Breach	Damage to crops
Banikanta Pegu	3	Every year	Above head	30	River overflow	Damage to crops
Surya Deori	Adjacent	Every year	Above head	60	Road Breach	Damage to crops
Jeevadoi Deori	1	Every year	Above head	45	Embankment breach	Damage to crops
Biren Bora	Adjacent	Every year	Above head	30	River overflow	Damage to crops
Prabhati Pegu	1	Every year	Above head	60	Embankment breach	Loss in crop production
Kanaklata Hazarika	2	once in every 5-6 years	Above head	20-25	Embankment breach	Complete damage

						to crops
Khudeswar Sonowal	Adjacent	Every year	Breast level	120	River overflow Embankment breach	Damage to crops due to deposition of high amount of silt
Dhanada Nazir	N/A	N/A	N/A	N/A	N/A	N/A
Niju Saikia	N/A	N/A	N/A	N/A	N/A	N/A
Nandu Sahu	0.5	Every year	Above head	90-120	Embankment breach	Damage to crops
Arun Rai	1	Every year	Head level	45	River overflow Embankment breach	Damage to crops
Bipin Dutta	Adjacent	Every year	Above head	120	Embankment breach	Damage to crops
Manik Saikia	2	Every year	Above head	60	Embankment breach	Damage to crops
Hemanta Baruah	0.1	Every year	Head level	45	River overflow Embankment breach	Damage to crops, seeds
Deepshikha Bora	N/A	N/A	N/A	N/A	N/A	N/A
Anjali Dutta Bhuyan	6	N/A	N/A	N/A	River overflow	Complete loss of land
Amulya Sarma	Adjacent	Every year	Above head	90	River overflow	Loss of lands, damage to crops
Hima Saikia	Adjacent	Every year	Breast level	7	River overflow	Partial damage of crops
Sarupai Das	0.5	Every year	Above head	20	River overflow	Damage to crops
Rudrakanta Medhi	0.5	Every year	Above head	45	River overflow	Damage to crops
Padma Saikia	0.2	Every year	Above head	120-150	River overflow Embankment breach	Damage to crops
Biswajit Pegu	0.5	Every year	Above head	45	Embankment breach	Damage to crops

Table 7.12 Characteristics of Flood 2012

Name	Duration of flood (days)	Max. depth of flood water (ft.)	Main cause of the flood	Type of damage
Budhin Das	15	7	River overflow	Whole damage of the house, loss of crops, loss of land
Deepti Dutta	13-15	4	Embankment breach	Damage to house, loss of livestock
Mila Dutta	7	5	Embankment breach	Damage to house, loss of livestock
Makoni Poga	10	4	Embankment breach	Damage to house
Sishuram Kalita	7 (flooded 6 times in 2012)	6	Breach in the spur	Damage to house, loss of properties and stored grains
Chiranjit Payeng	60	6	River overflow	Damage to house, loss of livestock
Ganesh Hazarika	7-12 (flooded two times)	7	Breach in the spur	Damage to house, loss of land, loss of stored grains and damage to crops
Parijit Das	7-10	4	River overflow	Loss of livestock
Kuheswar Payeng	10	7	River overflow	Damage to house and properties
Kamal Gayan	7	1	Embankment breach	Loss in crop production
Lohit Saikia	20	8	Road Breach	Damage to house and properties, loss of crops
Banikanta Pegu	20	3	River overflow	Damage to crops, plant seedlings and properties
Surya Deori	15-20	5	Road Breach	Damage to house, crops and loss of livestock
Jeevadoi Deori	15	3	Road Breach	Damage to crops, loss of livestock
Biren Bora	45	2.5	Road Breach	Damage to crops, loss of livestock
Prabhati Pegu	30	5	Embankment breach	Damage to crops
Kanaklata Hazarika	7	5	Embankment breach Breach in the ring dam	Damage to crops, house and loss of livestock
Khudeswar	15-20	7	Breach in	Complete damage to

Sonowal			the ring dam	the house, loss of livestock, damage to the stored grains
Dhanada Nazir	7-10	4	Breach in the ring dam	Damage to house, properties
Niju Saikia	7	5	Embankment breach	Damage to house, loss of properties and livestock
Nandu Sahu	10-12	6	Embankment breach	Damage to house and properties, loss of livestock
Arun Rai	7	2	Embankment breach	Loss of livestock, damage to crops
Bipin Dutta	7	2	Embankment breach	Damage to house walls, raw materials and crops
Manik Saikia	7	5	Embankment breach	Damage to house and crops
Hemanta Baruah	7	1.5	Embankment breach	Damage to crops
Deepshikha Bora	10	1	River overflow	Loss of properties and livestock
Anjali Dutta Bhuyan	7	1	Local rainfall	Damage to house
Amulya Sarma	4	1	River overflow	Damage to house, crops
Hima Saikia	4	1	River overflow	No damage
Sarupai Das	5	2	River overflow	Loss of livestock, damage to crops
Rudrakanta Medhi	15	2	River overflow Embankment breach	Damage to properties, crops and loss of livestock
Padma Saikia	7	1.5	River overflow Embankment breach	Damage to house, crops and loss of livestock
Biswajit Pegu	15	6	River overflow Embankment breach	Damage to crops and loss of livestock

Annexure – V: Flood and Erosion Protection Measures

Table 7.13 List of Flood and Erosion Protection Measures in the Area

Protection Measure	Length (km)	Year of Construction
Dam across Kherkatia Suti	1.20	1965 – 66
Brahmaputra dyke from Tekeliphuta to Haladhibari	1.82	1954 – 55
Kherkatia dyke	10.17	1955 - 56
Brahmaputra dyke from Haladhibari to Bessamora	34.49	1952 - 53
Brahmaputra dyke from Bessamora to Dakhinpat	5.34	1953 - 54
Tuni right bank embankment from Kamalabari to Urakalita	7.49	1955 - 56
Brahmaputra dyke from Burakalita to Kakorikata	2.30	1962 – 63
Dyke along left bank of Subansiri from 10 th to 21 st mile of abandoned PWDPGJH road	19.38	1970 - 71
Embankment along left bank of Subansiri from Malapindha to Malowal	9.47	1964 - 65
Retirement from Kamalabari PWD road to Brahmaputra dyke from Dakhinpat to Kamalabari (Phase -III)	2.27	1996 - 97
Dowel bund along PWD road from Kamalabari to Brahmaputra dyke from Dakhinpat to Kamalabari (Phase-I)	5.54	2003 – 04
Brahmaputra dyke from Dakhinpat to Kamalabari	4.75	1996 - 97

Source: Office of the Chief Engineer, Water Resources Department, Govt. Of Assam