Flood Characterisation and Inundation Pattern Mapping using Radarsat Imagery for Rice Vulnerability Assessment

Sananda Kundu

January, 2010

Flood Characterisation and Inundation Pattern Mapping Using Radarsat Imagery for Rice Vulnerability Assessment

by

Sananda Kundu

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Geo-Hazards

Thesis Assessment Board

Chairman	: Prof. Dr. Victor Jetten (ITC)	**Thesis Supervisors:**
External Examiner	: Dr. S.K. Jain (IIT Roorkee)	Dr. S.P. Aggrawal (IIRS)
Supervisor	: Dr. S.P. Aggrawal (IIRS)	Drs. Nanette Kingma (ITC)
IIRS Member	: Dr. Suresh kumar (IIRS)	
ITC Member	: Drs. Michiel Damen (ITC)	

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS
&
INDIAN INSTITUTE OF REMOTE SENSING, NATIONAL REMOTE SENSING AGENCY (NRSA), DEPARTMENT OF SPACE, DEHRADUN, INDIA

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Sananda Kundu

Abstract

Nuna River basin is situated near the coastal area of Orissa which is frequently affected by disastrous floods and adversely affect the life of people and property. River overflows the banks or enters the region due to the breaching of the embankments and races through the agricultural land and settlements to cause havoc in the region. Flood disaster is difficult to predict but the route which it follows to inundate the region can be assessed to reduce the severity of the loss. The main objective of this research is inundation pattern mapping and rice vulnerability assessment. Radarsat images have been used for extracting flooded areas, depth and duration and also for identifying flooded paddy fields by backscatter values. To assess the pattern of flood inundation of the area and rice fields coming under the influence of flood, the path which flood water is following during its progress through the region and also while it is receding from the study area has been mapped and analysed with respect to the geomorphology, elevation and depth. This pattern of flow is directly related to the paddy vulnerability as it will be possible to understand the agricultural fields which will be directly affected by flood. Flood inundation pattern has been assessed from the temporal RADARSAT images of three years of 2003, 2006 and 2008 by relating it to the grid of 50*50m in order to find out the relation of the flood pattern with geomorphology, DEM and different flood characteristics like flood extent, depth and duration. Flood recession pattern is obtained from the year 2003 and flood progression pattern is obtained from 2006 and 2008. The results clearly show the flood pattern of the area from the analysis of three years inundation and that path can be used to consider the area which will come under the direct effect of flood. The flood pattern is also related to the damage of crops of the region which forms the basis of economy of the study area.

The identification of the flooded paddy fields has been done from the backscatter coefficients of the RADARSAT images as paddy fields are difficult to identify during floods. Detecting the flooded paddy fields directly from the images will also help in indicating the vulnerable area as field visit during flood may become dangerous sometimes. The study includes recognition of flooded paddy fields from the Radarsat imagery and distinguishing it from the non flooded paddy, settlements and water bodies by showing variation in the backscatter values. The growth stage of paddy has been given by doing field survey and co-relating it with the daily rainfall data. This has been done to consider the paddy crop which comes under damage.

Vulnerability assessment of paddy crops includes vulnerability assessment with respect to the depth and duration of flood. Paddy plants are water intensive plants, so low depth of water of less than 1m is not harmful for paddy and therefore they remain less vulnerable. But long duration of water in the field may affect it. While flood depth with more than 2m makes the plants highly vulnerable even if the duration is less. Vulnerability of paddy has been shown here for 2003, 2006 and 2008 which shows that in all the years' paddy fields are highly vulnerable to the flood inundation and because of more depth of water farmers face huge loss. Vulnerability assessment has been done on the basis of field observations. 2003 and 2008 have shown maximum loss as the flood was much disastrous during these two years while 2006 loss is little less with respect to the area under damage. A damage calculation is done on the basis of field information. It includes the variation in the damage of paddy when flood occurs at different stages of growth like when flood comes at the initial stage, damage is much less with respect to the monetary term than the flood occurrence at the middle or mature stage. This is again related to the flood depth and duration. This also reflects the damage the region may experience if flood occurs at different times.

Key words: *Flood Inundation Pattern, Geomorphology, DEM, RADARSAT, Backscatter, Paddy Growth Stage, Vulnerability, Damage.*

Acknowledgements

Completion of this thesis involved the cooperation of number of people to whom I am greatly indebted. I would like to utilize this opportunity to express my gratitude to these people. I would like to thank Indian Institute of Remote Sensing (IIRS), Dehradun and International Institute of Geo-Information Science and Earth Observation (ITC), The Netherlands for giving me the opportunity to pursue this joint course programme.

I would like to thank our Dean of IIRS, Dr. V.K. Dadhwal, who has given me the opportunity to undertake this thesis as a student in IIRS and his kind guidance has helped me a lot to improve my thesis.

My sincere gratitude goes to my IIRS supervisor Dr. S.P. Aggrawal, Scientist, ‘SF’ and Head of the Water Resource Division for not only taking me under his supervision and guiding and encouraging me constantly throughout my research phase but also for giving me the initial idea of the present research work.

I am also greatful to my ITC supervisor Drs. Nanette C. Kingma, Lecturer, Department of Earth System Analysis, without the constant encouragement, enthusiastic support and valuable suggestions of whom throughout my research work it would not have been possible for me to complete this thesis.

I would like to thank Dr. V. Hari Prasad (former Head of the Water Resource Division and former Programme Coordinator of Geo-Hazard course) for his guidance and valuable advices at the beginning of this research and also supporting me by providing data. My sincere thanks go to Mr. Praveen Thakur, Scientist ‘SD’ of Water Resource Division for helping and guiding me in collecting data from the field. I am greatful to Dr. S.K. Srivastava, Scientist ‘SF’ of Geo Science Division for providing me data and also guiding me in preparing the geomorphology map. I would also like to thank NRSA for providing me temporal RADARSAT data of the flood period of 2006 and 2008 of Nuna river basin.

My sincere thanks go to Dr. Suresh Kumar (Programme Coordinator) and Mr. I.C. Das (Course Coordinator) of IIRS and Drs. Michael Damen of ITC for providing all necessary supports and facilities during the research work.

I am greatful to Mr. Arun Mondal, senior M.Sc. student of Geo-Hazard course for helping me during my research phase. I profess my thanks to all my M.Sc. batch mates of Geo-Hazard and Geo-Informatics course for their help and support. I am also thankful to Ms. Swati Uniyal of M.tech in Remote Sensing and GIS for constant moral support and encouragement.

Finally I want to express my thanks and gratitude to my family members for their immense encouragement and support without which I would not have reached this position. I would thank my parents and my brother and sister-in-law and would like to dedicate this thesis to them.

Table of contents

List of figures

List of tables

1. Introduction

1.1. Natural Hazards

Unprecedented awareness developed among people regarding risks and hazards from the beginning of the 21st century. With the progress of time, man has developed his skill in enormous number of fields which also include some preparatory or prevention measures against natural hazards. Generally a paradox exists between the human beings progress and the increased risk due to natural hazards. Modernization has intensified and exposed many of the damaging events that resulted in big hazards. In case of developing countries this is often more serious as they are already facing problems regarding proper access to the resources. Natural hazard poses threats to human life and property and it usually gives very little warning time *(Khan and Rahman, 2007)*. These hazards include earthquake, volcanic eruptions, flood, cyclones etc. that are mainly caused by nature. According to *Blaikie et al (1994)* natural events which are extreme and occur singly or in combination with other events in different times and place over varying return period is called as hazard. Therefore natural hazards may be described as extreme geophysical events that release huge concentrations of energy or materials into the environment causing extreme damages.

Natural hazards can be broadly categorized as geological (earthquake, volcanism, landslides) and hydro-meteorological hazards (flood, cyclonic storms, tsunamis, drought). Generally geological hazards are considered as endogenous as they are the manifestation of some deep rooted cause inside the earth like volcanism, earthquake and other neo-tectonic causes. While most of the hydro-meteorological hazards are exogenous in nature as they occur above the earth's crust i.e. independent of any impact from the interior of the earth. Although earthquake sometimes may cause landslides which may block the river resulting in flood, but that is not considered in the direct cause of flood hazard. Drought and soil erosions are also related to the atmospheric conditions. Natural Hazards have increased both in terms of intensity and frequency in recent years *(Ermolieva and Sergienko, 2008)*.

India is a country with diverse climatic conditions. About 1/8th of India or about 40 million hectares of land is flood prone here. It is the most flood affected country just after Bangladesh *(Rao, 2000)*. Thousands of people suffer from different types of natural hazards every year in India. Major natural hazards include flood, drought, earthquake and tropical cyclones while the minor ones include landslide, forest fire, hailstorm, avalanches etc. The 2001 Earthquake of Gujarat and the 1999 Super Cyclone of Orissa have inflicted extreme misery. Natural hazards cause havoc by destroying infrastructure, resulting in mass migration, and decrease in food supplies and sometimes also it leads to drastic situations like starvation.

1.2. Natural Disasters

Natural disasters generally resulted from the hazards which adversely affect the environment and society leading to financial and environmental losses. It may be said that "disasters occur when hazards meet vulnerability" *(Wikipedia)*. Therefore disasters cannot occur unless there is any possibility of human or environmental losses or where human beings are involved.

Most of the developing countries are situated in the hazardous belts of the world and thus intensity of loss and damage is more in the Asia- Pacific regions where these countries are situated. Greatest are the climatic and seismic factors affecting this area with about 50% of the major natural disasters of the world *(ESCAP, 1995)*. The researches regarding the prevention and mitigation of the disasters have developed as a committee has been set i.e. the International Decade for Natural Disaster Reduction which began in 1990. Number of estimated deaths in this region is more than 200,000 due to natural disasters with a huge property loss of about US$ 100 billion *(ESCAP, 1995)*. Occurrence of different types of disasters are shown in the Fig. 1-1.

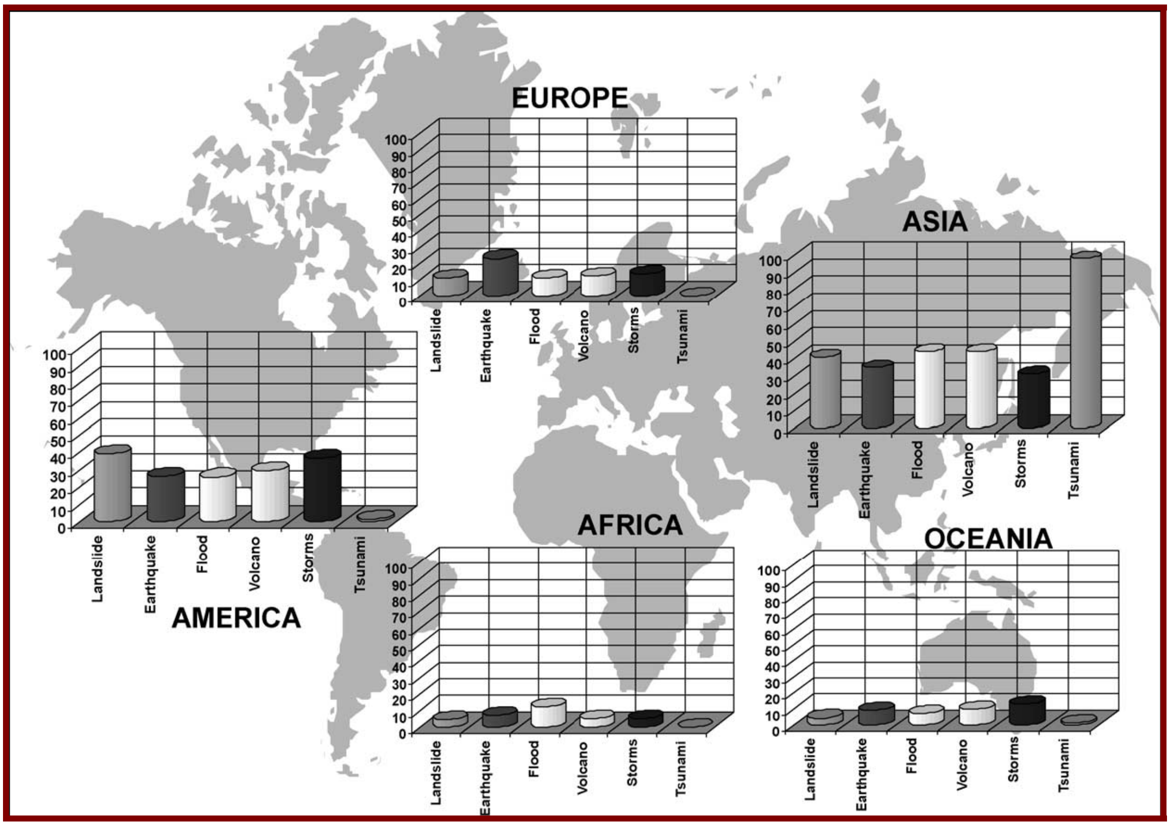


Figure 1-1 Occurrence of different types of disaster of the world
Source: in Ayala, 2002; EM-DAT database

Environmental degradation and natural disasters are generally closely related to each other as the environmental decay leads to poor quality of life and thus poor sustainability of the people of the area. Even a small hit of any natural hazards may lead to very adverse consequence in the less developed region. There are over 3000 deaths per natural hazards in any less developed countries while it is reduced to less than 400 in some high income countries (ESCAP, 1992). Excessive population growth and accelerating rate of land use for settlements have largely contributed to the extreme losses due to natural hazards. Although substantial progress have led to the prediction, early warning and infra-structure development, but increase in the hazards have led to more disasters i.e. damage to the people and property.

About one half billion people of the world have residences near the coastal area or the river sides. Therefore flood is one of the devastating hazards adversely influencing their life and causing huge property loss every year.

India is a country that faces almost all type of hazards with varying intensity. Among these disasters, flood is one of the common disasters that occur here. All river floods, flash floods, urban floods are common here causing huge loss of property and life.

1.3. Flood

Flood is a climate caused natural disaster described as the excess of river flow that exceeds the channel that has been specified for it. It may also be described as the very high flow of water overtopping the artificial or natural bank inundating the entire surrounding area. Flood is considered as the most disastrous and damaging and causes more economic loss than other natural or technological disasters *(Huang et al, 2008)*

In the last decade, over 90% of those died in natural disasters were affected by hydro-meteorological events. Of the annual average of about 211 million people who are affected by natural disasters every year, flood contributed more than two third of this total *(International Federation of Red Cross and Red Crescent Society).*

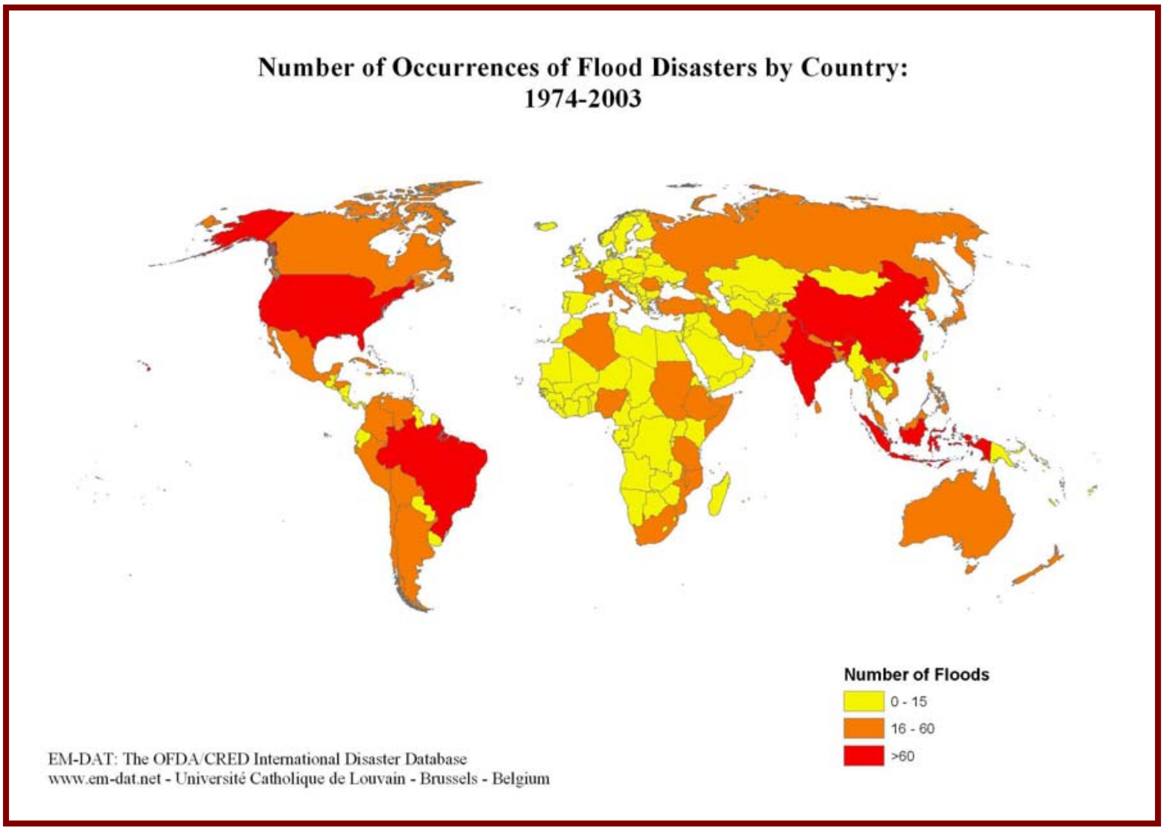


Figure 1-2 Occurrence of flood in different countries
Source: EM-DAT data

Floods, although are natural hazards, sometimes are induced by human beings. It is the natural instinct of human beings to settle near the river plains or flood plains thus resulting in maximum loss in comparison to other hazards. The damage and destruction caused by flood is immense every time it occurs in any flood plain. Therefore proper measures should be taken for minimizing the loss and thereby comes the need for prevention, prediction and mitigation. Intense participation of people is needed regarding this matter as human interference leads to flood in many cases. Proper understanding of both natural and anthropogenic causes should be examined. As it directly affects the people and their property almost every year, therefore the impact of this hazard causes recurring losses. Government and private sectors together can affect the mitigation purpose effectively so proper interaction is necessary between these two as well as between different organizations and people.

In India about 40 million hectares of land are subjected to flooding each year and thereby posing a loss of more than US$ 240 million *(ESCAP, 1995)*. India is one of the worst flood affected country as shown in the Fig. 1-2. As assessed by Rashtriya Barh Ayog (RBA) or National Flood Commission in 1980; average areas that will be affected every year are about 8 million hectares. It is one of the worst flood affected country after Bangladesh. About 22 states and one union territory of India are vulnerable to flood. Major parameters responsible for flooding are climate or rainfall intensity, basin size and character, soil type, presence of vegetative cover, snow melting etc. Here, in India monsoon seasons are mainly responsible for the occurrence of flood, i.e. high rainfall intensity with long duration lead to the overflowing of the rivers. Although Indian monsoon provides about 80% of the rainfall of India, precipitation with very high intensity, even in non-monsoon period over small catchments may cause sudden flash floods. This type of flood is more destructive as prediction is almost not possible and it swayed almost everything with it. Therefore management of flood water is of utmost importance as it saves life and property in one hand and intelligent use of this excess flood water may save life in some dry parts of the country. But the human interference in flood may also prove fatal sometimes as while reducing risk in some areas; it may be increasing risk to some other areas. Flood prone areas of India are shown in Fig. 1-3.

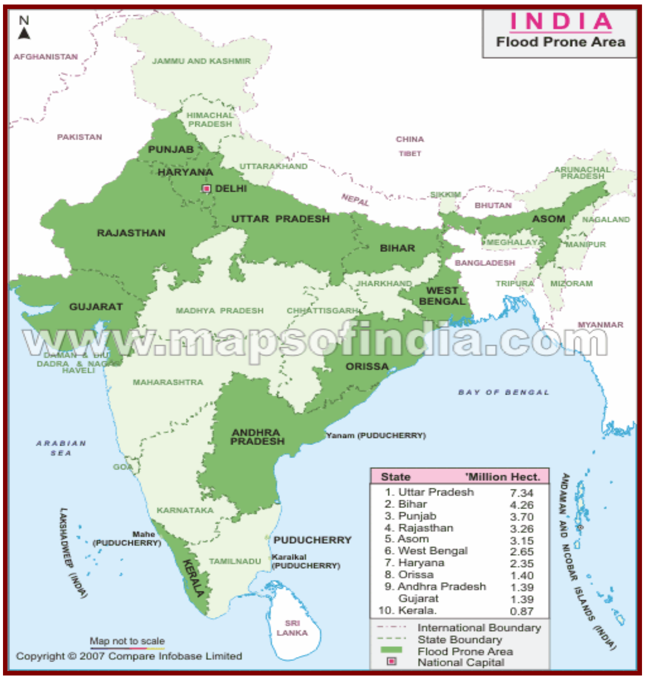


Figure 1-3 Flood Map of India

Source: www.mapsofindia.com

1.4. Motivation for the Research

Orissa is one of the major flood affected states of India. As it is in the coastal area, therefore faces strong tropical cyclones and rainfall resulting in overflowing of the rivers causing havoc every year.

Flood generally occurs in the monsoon season with highly intensified precipitation *(Mohapatra and Mohanty, 2008)*. Many rivers are found here, get swollen during rainfall and thereby face heavy discharge of water along with the excess water from the land surface or flood plain due to heavy rainfall. During storms and heavy rainfall, rivers are unable to carry the excess discharge of water and thus inundate the surrounding areas.

Study area is located in the Mahanadi flood plain region between Nuna and Chitrapala rivers and faces flood from these rivers almost every year. Super Cyclone of 1999 has caused huge destruction of life and property. Recurring flood have caused havoc in this region, of which 2003 flood during September affected most of the districts damaging many lives and properties. This area is considered as the Very High Damage Risk Zone *(UNDP and BMTPC, 2002)*.

Economically the region is backward with more than 65% of the population below poverty line and about 90% of the population lives in the flood prone area. Most of the people practice agriculture here with paddy as the major crop. Vulnerability assessment of rice is required as the farmers face huge losses every year during flood. Microwave images are mainly used for this purpose as optical images cannot penetrate through the cloud cover which hinders the process of imaging at the time of flood. Moreover the specular reflection of the water helps in identifying the flooded area from the Radar image more easily than the optical images. At the initial stage, paddy plants remains under water, any interference of flood water may not be possible to identify at this stage because digital classification techniques will identify these watered paddy fields as flooded zone from the Radar images, as there is not much tonal variation between the flooded area and watered paddy fields. Therefore, backscatter values of the paddy fields are taken from active microwave sensor for identifying the paddy fields which will show the difference in values between paddy and other elements like settlement or water. And this will help in estimating the loss that occurred to the paddy agriculture due to flood. Flood with more depth of water and long duration may prove fatal to the plants. So, how much loss the farmers will face regarding any deficiency of production which is obvious during disastrous floods, needs to be taken into consideration. Growth stage of paddy needs to be considered to find out the damage if flood comes in different stages with different intensity. This type of survey has not been done before in this area, so the vulnerability assessment of rice should be done which is the main agriculture of people living here.

The source of flood water in the area should be identified for recognizing the pattern of inundation and will help in flood mitigation, prevention and preparedness in order to reduce losses.

1.5. Objective

The main objectives of this work are: flood inundation pattern mapping and rice vulnerability assessment using RADARSAT images and field observations.

Sub Objectives

- Flood characterization of the study area of 2003, 2006 and 2008 for the assessment of inundation patterns of the area.
- Identification of paddy fields and determination of rice growth stage with microwave data.
- Vulnerability assessment of paddy: collection of synthetic data

1.6. Research Questions

- How to assess the inundation pattern of the area in three different years?
- How to identify the paddy fields at the time of flood in comparison to other elements at risk and how to determine its growth stage?
- How to distinguish paddy from the RADAR image during flood?
- What is the vulnerability of paddy in relation to the flood characteristics?

1.7. Structure of the Thesis

Here each chapter is explaining the purpose, different requirements and methodology for completion of this thesis along with its final results.

Chapter 1 is an introductory chapter explaining the natural hazards, disaster, flood hazard and flood in India together with the motivation for the research, objectives and research questions.

Chapter 2 consist of literature review giving an account of different works done in this field and their methodology and purpose of establishing some facts.

Chapter 3 describes the area of study with its location and geographical and climatic account along with the infra structure.

Chapter 4 explains the materials used in the course of this thesis and also the detail methodology for achieving the objectives and the research questions here.

Chapter 5 consist of the results that are obtained after accomplishing different methods and also the discussion about the results or the analysis of the results.

Chapter 6 concludes the major findings in the whole thesis and also some suggestions and recommendations.

2. Literature Review

A river flood is considered as the high flow of water which overtops the natural or artificial bank of the river but such event cannot be considered as hazard until and unless it affects human life and property. Flood magnitude is the best term for explaining the instantaneous peak flow of river (discharge) for the hydrologists but hazard is related to the maximum level that water reaches.
Floods may be distinguished as river flood and coastal flood. River floods can be again subdivided according to the causes which are floods due to atmospheric hazard, technological hazards and tectonic hazards.
Atmospheric Hazards causing River Flood: these are caused due to heavy rainfall, snowmelt at the upper reaches of the river. Torrential rainfall from the cyclones or hurricanes results in river flooding in most cases.
Technological Hazards causing River Flood: dam failure and different constructional problems lead to the flood hazards under this category
Tectonic Hazards causing River Flood: this mainly leads to the flood caused by earthquakes which in turn results in the landslides causing river blockage. Volcanic eruptions also cause river floods by blocking the river.
Coastal floods are subdivided under atmospheric and tectonic causes. Storm surges or cyclones or off shore low pressure wind may drive the ocean water inland causing coastal floods. Tectonic cause includes Tsunami which results due to earthquake under the sea and destroy everything near the coastal areas by creating huge waves *(Keith, 1996).*

2.1. Floods in India

Flood has killed over 2000 people in 2004 and 2005 flood and causes a damage to about 4lakhs of people in India. According to the National Flood Commission of India about 400 lakh hetares of land is under the flood threat and out of that 320 lakh hectares would be provided protection *(National Disaster Management Authority, Government of India)*. Monsoon months of July, August and September experience worst flood in a year in the country. While floods occuring in the pre and post monsoon months of May and October are very few. About 23 gauge site on 15 rivers of the north east India, 24 sites on 10 rivers of peninsular India and 69 sites on 26 rivers of north India experienced flood above their danger level of more 18m height from the year 1987 to 1997 *(Dhar and Nandargi, 1998)*. India accounted for about $1/5^{th}$ of the death in the world due to flood. Crop areas affected due to flood every year is about 3.5 million hectares which rises to about 10 million hectares in the worst affected years *(Rao et al, 1998)*.
According to the Indian Disaster Statistics (Fig. 2-1), flood accounts for maximum loss of property than other hazards like earthquake, drought, storm etc.

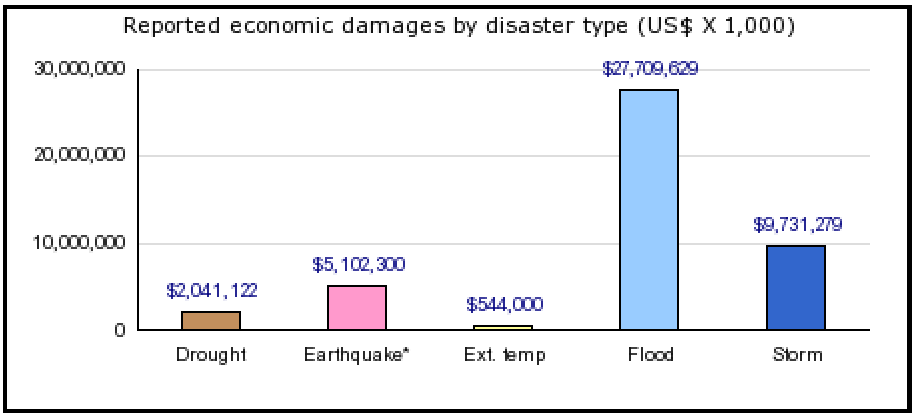


Figure 2-1 India disaster statistics

2.2. Remote Sensing and Flood Mapping

Major flood characteristics to be taken into consideration are flood extent, depth, duration and flood magnitude. For forecasting and monitoring of flood, flood extent and water level are very essential. Water extent is needed to find out the area of damage and water levels give the intensity of damage to the elements at risk. Higher the water level more will be the damage as some elements like crops or low settlements or houses get affected by the higher water level. Water extent can be derived from the Radarsat imagery by discriminating the land and water boundary and then subtracting the permanent water body from the flooded water i.e. by applying simple threshold values. This will show the actual flood water extent in the area. Water usually shows low backscatter values in microwave because of specular reflection, therefore dark tone of water body are easily distinguishable from the image *(Remi et al).* But this backscatter values vary with the wind effect of the area or if there is wave in the water. Identification of vegetations in the flooded area can be done by Landsat TM and SAR data and their combined use together with GIS modelling is useful for forested Wetland mapping. Flooded forests returns higher backscatter than the non flooded one because of the double bounce backscattering and calm water has low backscatter. This relation has been used in finding out the forested wetland *(Townsend and Walsh, 1998).*

Optical Remote Sensing data were used previously for distinguishing flooded and non flooded because of the unique feature of the water to get absorbed in the near infra-red spectrum and thus distinguishing it from the other land surface which remains brighter. Therefore this feature of water has been used for delineating flooded and non flooded region *(Sanyal and Lu, 2003)*. During early 1970s data was obtained from the Landsat Multi Spectral Scanner of 60m resolution. Band from 0.8 to 1.1μm is suitable for distinguishing water or moist soil from the dry land *(Smith, 1997).* In later phase, Landsat TM with 30 m resolution had been used for flood mapping and also SPOT which had been used for delineating flood boundaries together with the use of Digital Elevation Model in case of Bangladesh flood mapping by *Sado and Islam, 1997*. Different Indian satellites have been used for the flooded area delineation and for estimating flood damages like IRS-1B, IRS-P2, IRS-P3, IRS-1C, IRS-1D which collects the information in various resolutions from the optical region of the electro magnetic spectrum *(Rao et al, 1998)*. AVHRR (Advanced Very High Resolution Radiometer) is used for flood monitoring and because of its very coarse resolution; it is feasible to use it in case of large area, so that the entire area can be covered without creating number of scenes. For this reason NOAA

(National Oceanographic Atmospheric Administrative) AVHRR is used as it has high repeativity and thus high frequency of the global coverage, wide swath and low cost which make it useful in flood monitoring *(Jain et al, 2006). Bryant and Rainey (2002)* have used AVHRR data to find out the flood inundated playas in southern Tunisia for monitoring changes in the lake areas and also to see the hydrological response of the lakes to the rainfall. NDVI is used for distinguishing the flooded region, as water has different spectral signature in the infra red region than the other elements. Thus when the surface area is inundated, the NDVI value changes which becomes negative in the inundated area but remains positive in the non inundated area. Threshold values is little difficult to chose in this case as the inundated area varies from one part to another and so NDVI method may not be always accurate in flooded area delineation (*Wang et al, 2002*). Although optical images are used for delineating flood boundaries, but there is a limitation to the optical imaging as they cannot penetrate through the cloud cover. For this reason microwave images gained importance in flood mapping.

Microwave Remote Sensing includes Radar imagery which can penetrate through the cloud, haze, rain or smoke and can take the image of the ground and thus are extremely useful in flood mapping and provides an independent environment for acquiring flooded data *(Matgen et al, 2007).* Different types of systems used for describing imaging Radar are Side looking Radar (SLAR) or Real Aperture Radar (RAR), Synthetic Aperture Radar (SAR), Scatterometer, Altimeter and Rain Mapping Radar etc. these are all active microwave sensors. Radar imagery is used for flood inundation mapping. It is also used to monitor the ocean surface for determining wave, wind and ice conditions, geologic mapping, mineral exploration etc. Radarsat1 is the first Canadian Radarsat satellite using SAR as an active microwave sensor was launched in 1995 for monitoring change in the environment and also for supporting resource sustainability. Microwave energy is transmitted in very short pulse that is radiated by the antenna and propagates to the scene. The incident energy is reflected towards the radar in a small fraction, which is gathered by the receiving antenna and is registered on the antenna response graph *(Lillesand and Keifer)*.

Radarsat 1 is placed on sun-synchronous orbit at a height of about 800km above the earth with the inclination of 98.6º and the return period is 24 days. It has SAR antenna with C band having wavelength of 5.6 cm and HH polarization, right looking antenna and covers a wide area. Radar frequency is 5.3 GHz.

2.2.1. Beam of Radarsat 1

In the radarsat1 there are seven beam modes each of which has different resolution and area coverage along the 500km swath (Fig.2-2). Different incidence angles are present within each beam mode known as Beam Positions. The elevation remains constant in the single beam mode throughout the operation period. This includes wide beam, standard beam, fine beam, extended high and extended low beam. But in case of scan operation of SAR, two to four beams are used for the data collection (Centre for Remote Imaging, 2006). The SAR has C band with the horizontal or HH polarization. There is variation in the return signal which is dependent on the property of the elements on the ground, roughness and the surface topography.

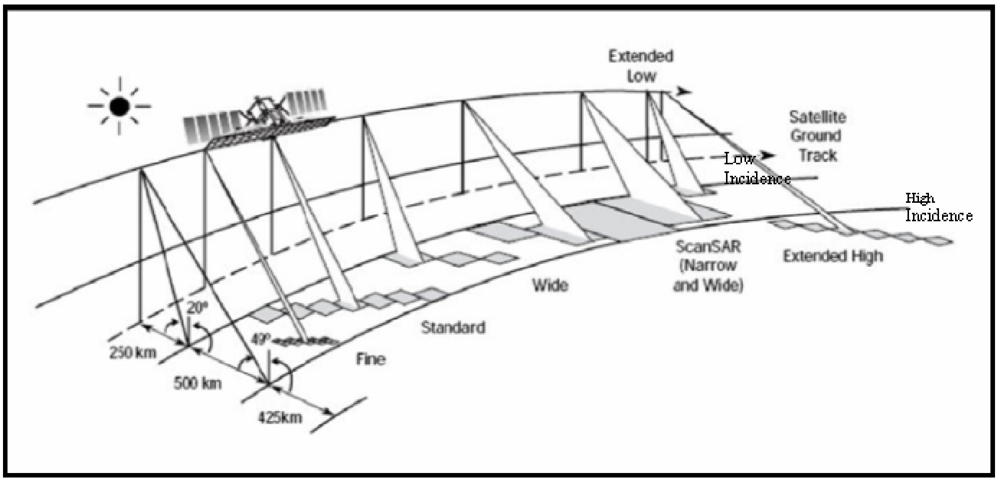


Figure 2-2 Radarsat Beam Modes
Source: Lillesand and Keifer

Radar image usually have grey scale and the intensity of the pixels depend on the property of the material on the ground each of which will have different backscatter value. Each pixel of a SAR image contains information on both intensity and phase of the received signal. Pixel intensity is related to the radar backscattering properties of the surface. It also depends on the shape, size and orientation of the object that will determine the scatter of the area. Moisture content and the incident angle of the radar beam are also important factors considered in this case *(Wan Quing, 1999)*. Increase in the reflectivity occurs with the presence of moisture in the soil or vegetation. Therefore moisture content is more important than the property of the material in determining the Radar signal strength. Together with this corner reflection also increases the strength of the reflected energy because settlements reflect more and looks brighter due to this reflection *(Lillesand and Keifer)*. Sometimes during flood ground based surveys are not always possible as it becomes dangerous. Radar Remote Sensing helps in flooded area identification in such cases and soil moisture plays an important role here particularly for the upper few centimetres *(Zribi and Dechambre, 2003)*. In the past soil moisture has been used for predicting discharge in flood forecast models *(Pauwels et al, 2001)*.The intensity values of the pixels are converted to the backscatter coefficient values which are the physical quantity and are expressed in decibel (dB). Roughness increases the intensity of the backscatter values. So the calm water will appear dark as most of the radar pulses will be reflected away, but rough surface water will appear little bright for this reason particularly when the incident angle is small *(Wan Quing, 1999)*.

Extent of flood is generally defined by using a threshold method which divides the area into flooded and non flooded zone and it is mainly dependent on the spectral signature of the image. In urban area it may be a problem because of the high backscatter of buildings overlaying the backscatter of water within the settlem*ents (Brivio et al, 2002; Sanyal et al, 2004)*. According to *Pappenberger et al (2007)* inundation models which are used for the prediction of flood extent and flood risk, can be best done with the extent data because the model should be conditioned on the criteria which is linked to the purpose of modelling. Therefore for the flood inundation purpose extent is the major criteria. But other factors like flood duration, water level and contaminations are also important parameters for damage assessment (*Thieken et al, 2005*). Different temporal images show different backscatter values revealing pattern of flooding, areas with low backscatter have deep water than the areas with high backscatter and thus having features inundated under water *(Kiage et al, 2005)*. Factors like embankments and high roads have great impact on the flood extent. Therefore their representation in the DEM is important to observe the accuracy of the flooded area that has been mapped. Extreme fine grid may take more time in calculating while the coarse grid applied for finding the flooded area may average the elevation of these higher lands which will have impact on the result of the inundated area. So proper grid size should be selected and balance should be maintained between the DEMs of different resolution for providing maximum accuracy *(Werner, 2001).*

Flooded area with vegetation or cropland will be little brighter than the water bodies because of higher backscattering from these elements than water. Flood extent map obtained from the reflection of water in the image together with landuse map will help in providing information about the actual inundated area because water gives very low backscatter values. Wind may sometimes make the water surface rough which can be confused with the land surface. Flood hazard map gives basic physical information for flooded areas so provides a base for planning. As water has high dielectric constant, therefore it reflects away from the radar producing very low backscatter values which in turn helps in identifying flooded regions. Sometimes the wind effect on the smooth surface may make the flooded area so rough that it may return very high backscatter value almost similar to the dry land. Radar return from the vegetation of the dry land, impact of vegetation and meteorological effect of water surface create problem in the inundation mapping. Emergent vegetations are important in identifying the flood inundation *(Horritt et al, 2003).*

Flood duration is an important factor as it indicates the number of days or time for which an area remains under water. Longer the duration of flood, longer an area will be inundated and thus causing maximum damage. Longer duration of flood water i.e. reason for water logging in an area is also determined by some factors like geomorphological factors or the elevation factors. *Matgen et al (2007)* have mentioned about the flood depth extraction from extent data and river cross section by incorporating them in Hec-Ras model. Geomorphology of the area shows the presence of any levees, back swamps or presence of any paleo channels etc. This will also decide the presence of water in the area. Standing water for longer period will cause damage to crops and settlements. Digital Elevation Model helps in assessing flood depth of a region as areas with low elevation have more depth of water than the areas with high elevation so it forms an important part in calculating flood depth. According to *Werner, 2001* flood depth can be obtained from the water level of an area by subtracting the elevation from the Digital Elevation Model (DEM) of the area.

2.3. Paddy field identification and Backscatter coefficient

Optical images are used for the identification and mapping of paddy fields like Landsat TM or ETM+ which were used for creating database for paddy *(Fang, 1998, Okamoto et al, 1998, Okamoto and Kawashima, 1999,Van Neil et al, 2003).* But optical imagery cannot always provide proper information because of cloud cover and Radarsat images can penetrate cloud and are more sensitive to the crop structures *(Phoompanich et al, 2005)*. The microwave energy that is scattered by a particular target or object is recorded by the Synthetic Aperture Radar (SAR) at 5.3GHz frequency, the wavelength which is long enough to penetrate through the clouds. It is said that increase in the moisture content of the target object usually increase the backscatter values of the radar. Radar backscatter from the crops with some amount of dew has 1.7 to 2.5dB greater value than crops without dew *(Wood et al, 2002)*. The intensity values are converted to the backscatter values which are represented in decibel. Backscatter coefficients are being widely used in the assessment of paddy plants and their growth stage. Paddy plants generally remains under water initially, thereby it is difficult to detect them during flood. Backscatter values help in identifying them with some specific incidence angle and polarization. Radarsat image at C band and with HH polarization and 36º to 46º incidence angle are used in recognizing paddy *(Shao et al, 2001).* The DN or the digital number is converted to the backscatter values by following way:

$$ß^0_j = 10*\log_{10} [(DN_j^2 + A3) / A2_j] \text{ db} \qquad \text{(eq.1)}$$

in the equation, $ß^0_j$ is the radar brightness, DN_j is the digital number and it represents the jth pixel's magnitude from the starting of the range line in the image, then the radar brightness of the pixel will be eq1 and A2j is the scaling gain value for the jth pixel and A3 is the fixed offset. This brightness data can be converted to the backscatter coefficient in the following way:

$$\sigma^0_j = ß^0_j + 10*\log_{10}(\sin I_j) \text{ db} \qquad \text{(eq.2)}$$

Where Ij is the incidence angle at the jth range of pixels *(Ogawa et al, 1999).*
Backscatter coefficients of different elements are shown in the figure 2-2.

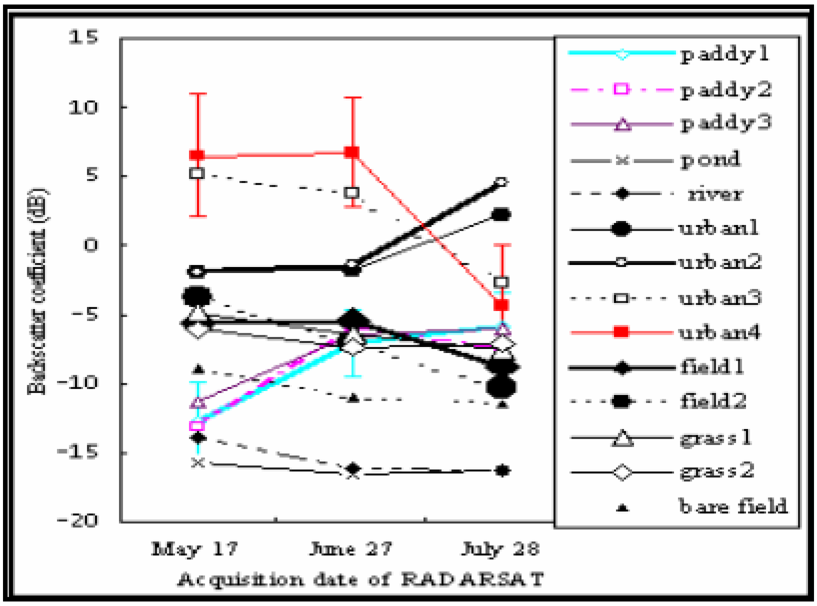


Figure 2-3 Backscatter coefficient of different landuse
Source: Ogawa et al (1999)

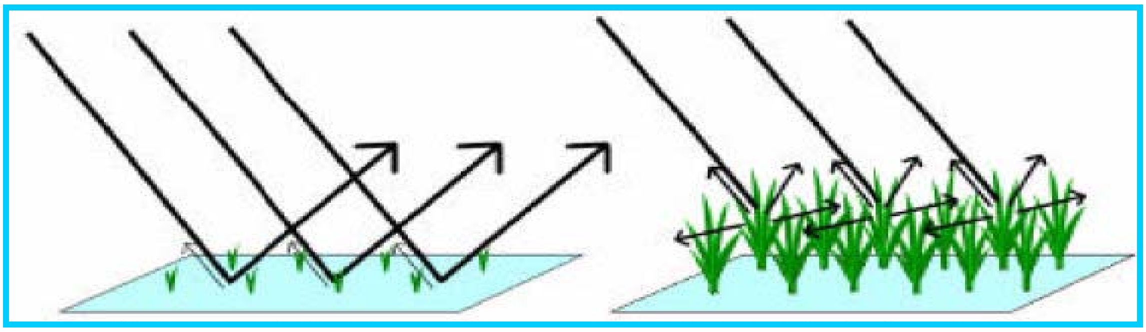
Paddy is planted during the month of May, therefore it remains at its early growing stage which reflects high backscatter from middle of May to June (Fig. 2-3). As the water has low backscatter coefficient usually, it is easy to distinguish paddy during flood and growth period. As the Radarsat is HH polarized, therefore the double bounce effect between the vertically aligned rice fields and horizontally aligned flooded field is very prominent. This is the reason for high backscatter value during the mature stage of rice than the initial stage.

In ENVI software also, the digital number of the image has been converted to the radar brightness or dB by "Radar calibration". Almost similar formula has been used to convert the DN value to dB:

$$\sigma^{\circ} = \beta^{\circ}\_dB + 10*\log10(\sin I)dB$$

Here σ° is the backscatter coefficient and I is the incidence angle of the pixel. It shows the relation between the backscatter coefficient (σ^{o}) and the radar brightness (β^{o}) *(Magsud et al).*

Multi temporal Radarsat imagery has the capability to monitor rice growth at different stages. The flooded field has low backscatter with -22 to -13 dB as the surface remains smooth due to standing water. After reaching a little higher value of -10 to -4 dB during the growing period from transplantation to maturity, radar backscatter get stabilized in the mature stage at -11 to -6dB. The backscatter values get higher with the rough surface and thereby in the mature stage; it gives high backscatter coefficient value. And these values are not very different from the mean backscatter values. So it proves that even during rain or flood, the trend of backscatter values are quite prominent and thus making it possible to monitor paddy field by this method from Radarsat image *(Magsud et al).*



Initial stage (water mainly) **after a month (cultivable land)**

Figure 2-4 Backscatter of paddy field
Source: Ishitsuka et al (2001)

During the transplanting period, the rice fields remains under water but they can be identified because of scattering by the paddy plants (Fig.2-4) *(Ishitsuka et al, 2001).*

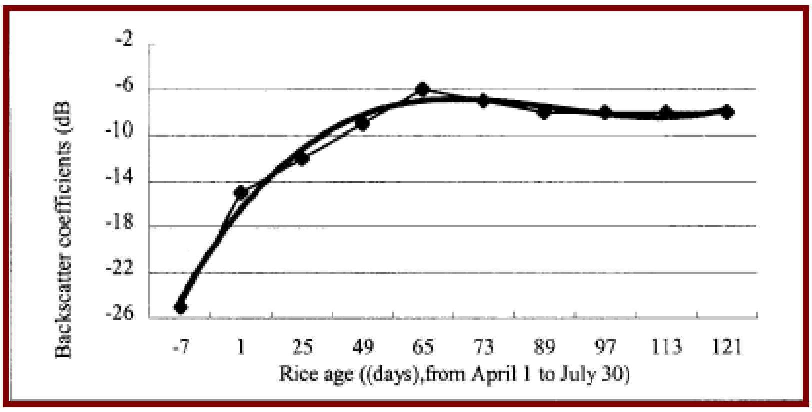


Figure 2-5 Backscatter model of paddy; Source: Shao et al, 2001

The backscatter model (Fig.2-5) of paddy by *Shao et al, 2002* is showing the low backscatter of paddy at the initial stage (-25dB), increasing to -12dB after few days and then reaching maximum at -6dB with quite stable at -8dB during the mature stage.

Radarsat I imagery with C band and HH polarization is able to identify crops and also determine the growth of crops with relation to height, leaf area index and biomass *(McNairn et al, 2000).*

Because of the unique specular feature of water, backscatter variation of rice is identifiable even during flood *(Kurosu et al, 1997)*. Crop backscatter is dependent on LAI (Leaf Area Index), leaf size, soil moisture, roughness and even relation with the polarization and incident angle it may change. Just after the transplantation of the rice seedlings, rice fields are inundated so that only few centimetres remain above the water. But this change is detected if the incidence angle is large as in C band. Microwave backscatter values are therefore able to identify even smaller rice seedlings with high frequency bands *(Inoue et al, 2002).* In L band and HH imagery there is a clear distinction between the dry land and the water body and the flooded vegetations having mixed values in between these two *(Horritt et al, 2003).*

NDVI and NDWI (Normalized Difference Water Index) are used for identifying surface water increase in the rice field due to flood and also the transplanting stage of rice *(Xiao et al, 2002). Xiao et al (2006)* has suggested that as there is a mixture of vegetation and a flooded area in a paddy field, therefore a spectral band is required which is capable of identifying both water and vegetation. Normalized Difference Vegetation Index (NDVI), Land Surface Water Index (LSWI) and Enhanced Vegetation Index were used by him with blue, red, NIR and SWIR band for identifying paddy.

2.4. Vulnerability

Vulnerability generally refers to that characteristic of society which specifies the potential for the damage to occur as a result of different types of hazards *(Capobianico et al, 1999).*
Vulnerability can be defined as the degree to which people, property, system, environment, social and economic activities are subjected to harm, degradation or being exposed to any destructive factors or cause.

Flood vulnerability describes the damage or the exposure to damage due to flood. It may cause both tangible and intangible damage which may be further divided into direct or indirect damage of flood *(Smith, 1991).* Flood damage is generally related to the direct loss, particularly vulnerability of paddy will be discussed here. Vulnerability is defined broadly as the "potential for loss", thereby largely describing the exposure of an element to damage. *Cutter, 2001* has defined vulnerability as an exposure to the hazard, response of the society and place.
A community is considered as vulnerable when it gets exposed to the crisis or problem and is likely to be affected by the damage *(Reganit, 2005)*

Flood damage analysis is required for quantifying the damage that has been caused due to flood so that it can be further used for prevention or management purposes or policy decisions. Regions which lack the perception for risk and have low level of preparedness are much more vulnerable, i.e. above average *(Messner & Meyer, 2006).* Thereby remote areas or villages, which have their lives based on agriculture or cultivation, suffer more loss.

Flood vulnerability scale has been given by Kelman (2002) and Nadal (2007). They described the scale in terms of damage from scale 1 to 5 with minimum damage at the scale 1 to maximum damage at the scale 5. But this has been given for the structural damage. For agricultural damage of rice a scale is given with 20% to 100% damage with the water depth varying from 1 to 6m and duration from 10 days to more than 27 days by *Dhillon, 2008*.

If water has much more depth in the paddy field for a long time, then it may prove hazardous for the plant. Variation in the water level will determine the level of damage by flood. Flood depth may vary from one part to another. Paddy plants with low level of water can survive, even with longer duration of water logging. When the water depth is high, survival of paddy is possible only if the duration is less i.e. for few days. But if the depth and duration both are long, then it will be hazardous. This flood level also varies in different years. Therefore, flood of a particular year with low level will cause less damage than the flood with high level of water in some other year. This will also have impact on the rice production and thereby will help in assessing the vulnerability in each year which will ultimately give the loss in the production.

Vulnerability assessment of paddy with different growth stage is related to the depth and duration of flood. As more depth results in damage, similarly long duration of flood water in paddy field, particularly in the mature stage may prove fatal. So vulnerability curve for different years with respect to growth stage and depth and duration is needed for getting the total loss. Flood risk can be estimated from the study of vulnerability which gives the estimation of the damage that may occur. It is related to the hazard, vulnerability and elements at risk which will determine the loss. It is related to the loss of the property of people due to flood. Therefore risk is not only related to the magnitude of flood but also on the coping mechanism which will determine the damage *(Treby et al, 2006).*

3. Study Area

The study area is located in the state of Orissa which lies in the eastern part of India having great diversity related to its ecological property. Wide extent of coastline in the eastern part, hilly regions and forests, mangrove ecosystem, brackish water and intricate riverine system with extensive floodplains has endowed the state a unique feature. Orissa extends from 17º49´ N to 22º34´ N latitude and 81º27´ E to 87º29´ E longitude with Jharkhand in its northern part, Andhra Pradesh in the south, West Bengal in the north-east, Chattishgarh in the west and Bay of Bengal coastline in the east. Among number of rivers crossing the coastal plain of Orissa, Mahanadi is one of the major rivers draining about 65,628 sqkm area in this state. Chilka Lake is one of the biggest lagoons in India situated here in the eastern part.

Orissa (not to scale)

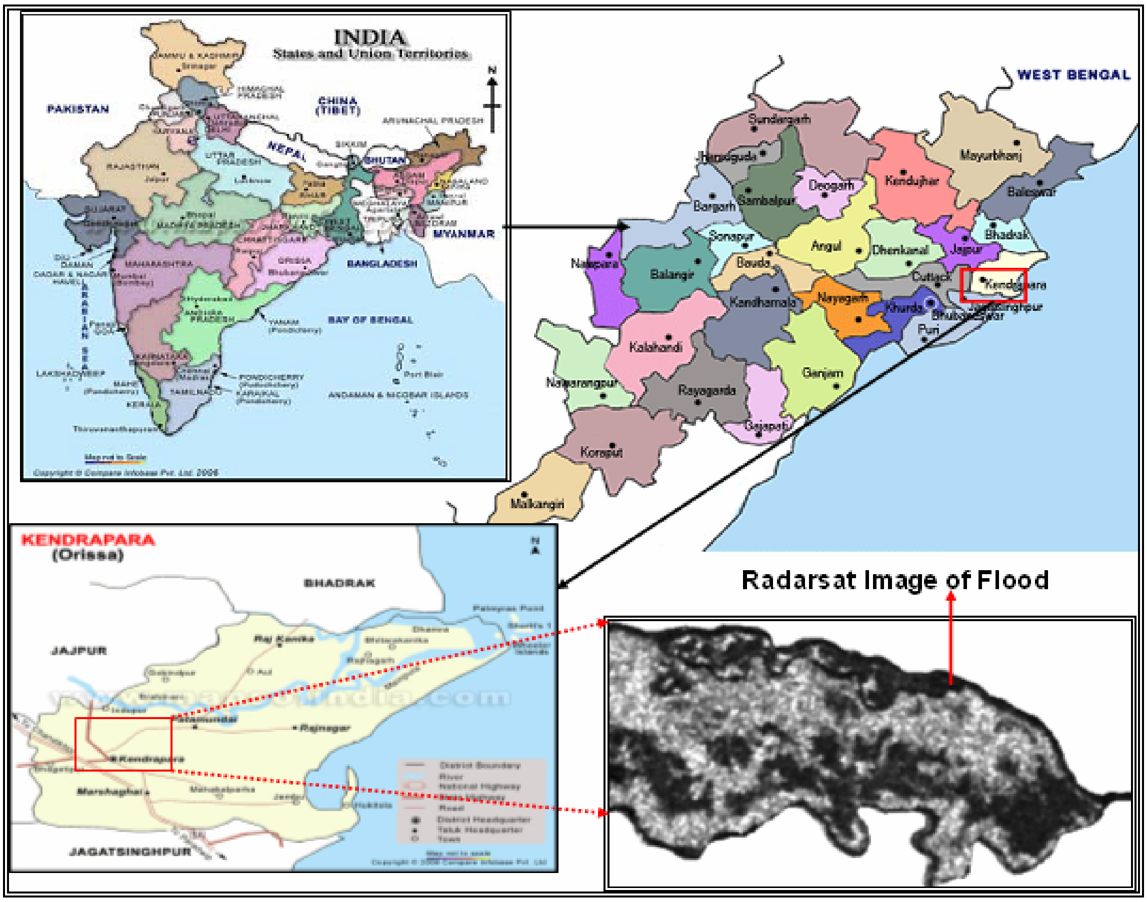


Figure 3-1 Location of the Study Area

3.1. Location of the study area

Kendrapara district is found in the eastern part of Orissa covering about 2644 sq km area. According to the Agro-Climatic categorization of Orissa, it is situated in the central coastal plain. It is bounded by the districts of Bhadrak in the north, Jagatsinghpur in the south, Cuttack in the west and Jujpur in the north-west. The district has extensive stretch of fertile land and therefore contributing much to the agriculture here. The location of the Kendrapara district is from 20º20´N to 20º37´N latitude and from 86º14´E to 87º01´E longitude. The district has Bay of Bengal lies in the east of Kendrapara where the coastline extends for 48 kms from Dhamra Muhan to Batighar. The location of the study area, Nuna river basin is from 20º22´N to 20º28´N latitude and from 86º17´E to 86º29´E longitude covering an area of about 130sq.km (Fig.3-2).

Figure 3-2 Overview of the study area

1. Paddy field near Indalo village in the north western part
2. Paddy field
3. Paddy field after transplantation
4. A man showing the flood height in the agricultural land in Raghabpur village
5. Nuna river
6. Measuring height in the Chitrapala river
7. Metal road on the embankment
8. Unmetal road in the village

3.2. Physiography of the Area

The region is fed by six rivers of Subarnarekha, Mahanadi, Baitarani, Budha Balanga, Rushikulya and Brahmani. The entire area is fertile flood plain and is extremely good for paddy cultivation. The study area is bounded Nuna and Chitrapala river. Chitrapala is a branch of Mahanadi River and it is further divided into Nuna and Barandia River. Mahanadi River has formed extensive flood tract here. Chilka is the major source of attraction here as it is one of the largest lagoons in India particularly in the eastern coast. The climatic condition is tropical monsoon type with maximum rainfall of around 1500mm during rainy seasons. Storms from Bay of Bengal affect the area adversely as depressions formed in the sea have first impact in the coastal areas. Super Cyclone of 1999 had caused havoc in whole Orissa with about 80 to 140 km wind speed per hour and heavy precipitation.

3.3. Geomorphology of the Study Area

Geomorphology reflects the surface configuration of a region which is mainly due to the interplay between fluvial action and time over the earth's surface. Therefore to understand the flood character of the region i.e. its movement, it is necessary to understand the surface configuration of the earth.

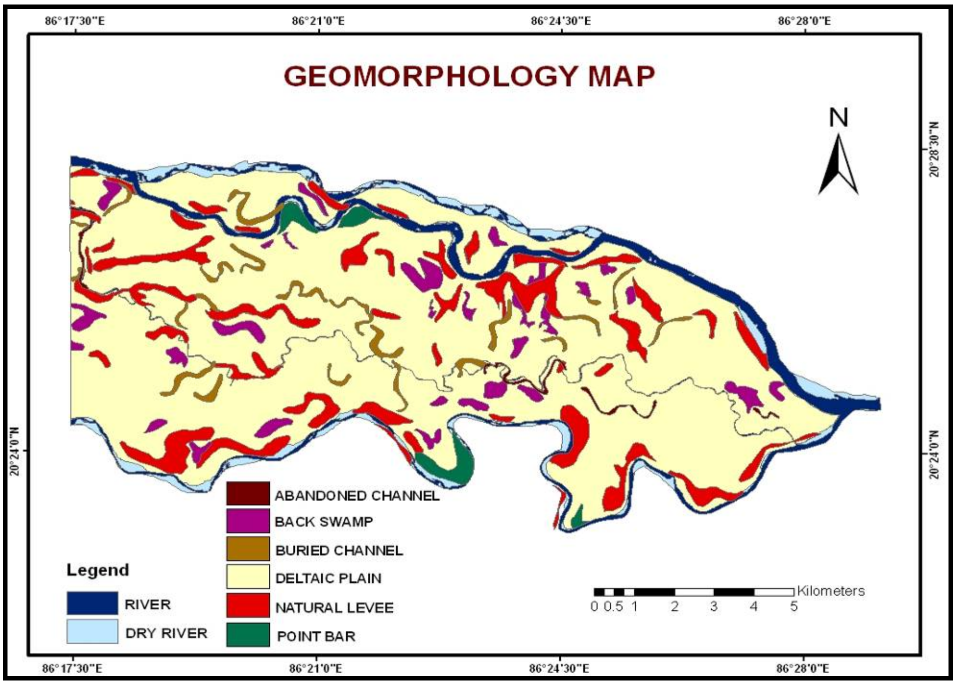


Figure 3-3 Geomorphology
Source: Orissa Remote Sensing Application Centre

Geomorphology of the area (Fig.3-3) is consists of abandoned channels in the western and the central part which are mainly agricultural land now. Buried channels are scattered in the entire area and some are little occupied by the settlements. Natural levees are found along the banks of Chitrapala and Barandia River and also in the western, central and north central part. Most of these levees have form the bases for the development of settlements as these regions area little higher. Back swamps are found in the western, central and southern parts near the rivers and are also scattered in the entire region particularly in the eastern region where it remains water logged in most of the year. Few point bars are found in the north-central and south-central region along the Barandia and Chitrapala River and the entire region is lower deltaic plain serving the agricultural lands.

3.4. Soil

The soil type of the study area varies from coarse sand to silt clay to clay and therefore the colour ranges from light grey and yellow to dark grey. The soil is very fertile especially for paddy but the nitrogen content is low with some phosphorus at some specific places. Soil character is slightly acidic and near the coastal area, the soil is saline with some sandy strips. The district has mainly two types of soils, alluvial soil in the northern and south-eastern part and saline soil near the coast in the north-east. Different soil categories found in the study area are given below (Table 3-1):

Table 3-1 Soil Classification in the Agricultural Area (in ha)

Name of the Block	Sandy Loam	Clay Loam	Loam	Saline	Total
Aul	1988	8210	6500	62	16760
Derabish	3300	8568	3100	0	14968
Garadpur	4150	1642	5420	0	11212
Kendrapara	4240	11200	2501	0	18241
Mahakalpada	4085	9200	3616	12539	29440
Marsaghai	4600	2017	5500	0	12117
Pattamundai	5404	10500	2680	4109	22693
Rajkanika	4230	1795	10809	3216	20050
Rajnagar	0	10446	1630	12424	24500
TOTAL	31997	63578	41756	32350	169981

Source: www.kendrapara.nic.in

3.5. Landuse of Study Area

Landuse describes the surface occupation of any land and also indicates the type of settlement there, mode of livelihood, agriculture types etc.

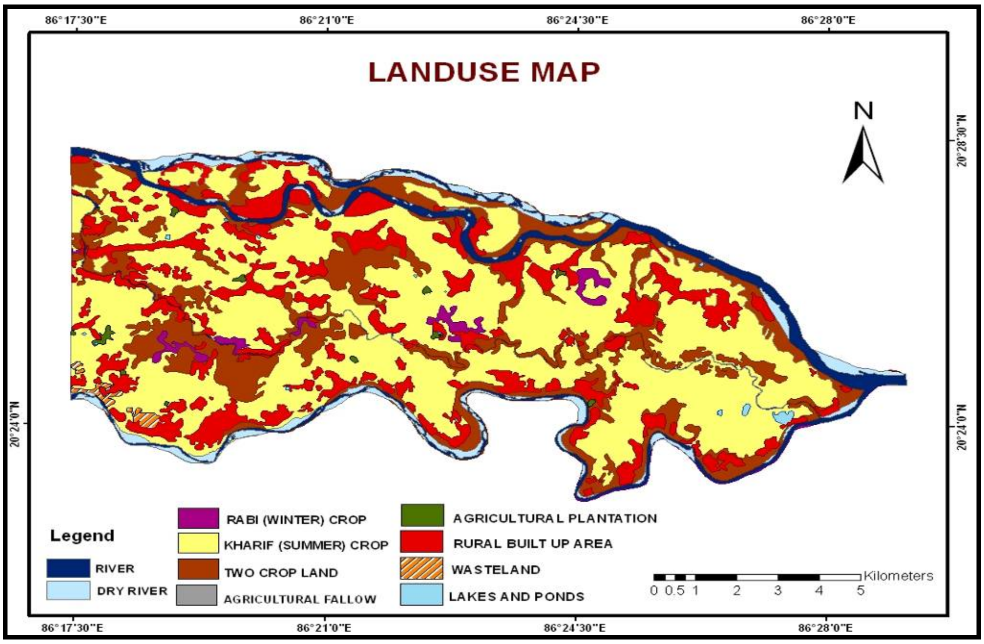


Figure 3-4 Landuse

Source: State Remote Sensing Centre

The landuse (Fig.3-4) consists of summer crop or 'kharif' crop which is mainly rice in the entire area, and the 'rabi' crop or the winter crop in very few areas of the central and south western part. Settlements are scattered in the entire study area particularly along the side of the river. Two rivers of Nuna and Chitrapala form the northern and the southern boundary of the region.

The landuse of the Kendrapara district (Table 3-2) and total land under the paddy cultivation showing maximum, medium and least yield out of the total cultivable land's maximum, medium and least yield (Table 3-3) are given below:

Table 3-2 Block wise land category

S.No	Name of the Block	Agricultural Land (ha)			Grazing land(ha)	Forest Land (ha)	Miscellaneous Trees & Groves (ha)
1	Aul	3800	4350	7025	840	-	62
2	Derabish	1408	8652	3445	170	-	61
3	Garadpur	3820	4182	3020	600	-	50
4	Kendrapara	1974	8200	6360	452	-	82
5	Mahakalpada	1288	14665	11842	1250	5126	2927
6	Marsaghai	2082	6084	2834	701	-	215
7	Pattamundai	3570	6750	11003	1000	-	717
8	Rajkanika	3904	8227	12130	1586	19	58
9	Rajnagar	3440	10008	5962	545	2811	378
10	TOTAL	25286	71118	63621	7144	7956	4550

Source: DDMP Report, 2006

Table 3-3 Land Classification (in hectres)

Block Name	Cultivated Area				Paddy Area			
	High	Medium	Low	Total	High	Medium	Low	Total
Aul	3880	4380	8500	16760	3800	4350	7025	15175
Derabish	2382	9141	3445	14968	1408	8652	3445	13505
Garadpur	3890	4252	3070	11212	3820	4182	3020	11022
Kendrapara	2850	8200	7191	18241	1974	8200	6360	16534
Mahakalpada	2587	15011	11842	29440	1288	14665	11842	27795
Marsaghai	3199	6048	2834	12117	2082	6084	2834	11000
Pattamundai	4670	6997	11026	22693	3570	6750	11003	21323
Rajkanika	4107	8259	12134	24500	3904	8227	12130	24261
Rajnagar	4072	10016	5962	20050	3440	10008	5962	19410
TOTAL	31637	72304	66004	169981	25286	71118	63621	160025

Source: DDMP Report, 2006

Although the study area has the agriculture as the major occupation, but there are no big farmers. Small and the marginal farmers form the major category with landless and agricultural labourers. Therefore the economic condition is extremely poor here and the major earn is from the kharif crop which also get wasted during floods in most of the time.

3.6. Climate

Orissa has a tropical monsoon type of climate which is characterised by high humidity (more than 80%) and temperature (above 35ºC) and heavy shower during the summer season when south west monsoon winds enters this land. Therefore this type of climate supports paddy cultivation dominantly in this place as paddy plants require high temperature, humidity and water.

Rainfall of the area varies from 1.50 to 147.90 cm monthly but the average annual rainfall of the study area is about 146.36cm and maximum of it occurs due to cyclonic storms and depressions. The monsoon period during summer (June to September) and sometimes post monsoon period (Oct to Jan) brings heavy shower (about 350cm in a month) through cyclonic storms originating in Bay of Bengal with some reaching the intensity of about 80 to 140 km/hr. The mean minimum and mean maximum temperature of the area varies from 11.5ºC to 39º respectively (Meteorological Department at Cuttack, Government of Orissa). Annual rainfall graph for Kendrapara is shown in Fig. 3-5.

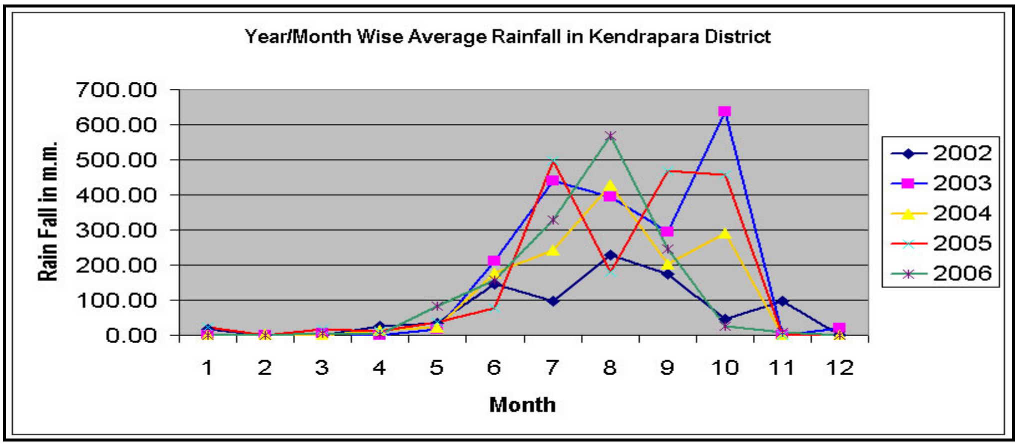


Figure 3-5 Rainfall Graph
Source: Official website

3.7. Demography

The study area has mainly agriculture as the dominant occupation, but still the literacy rate is little higher with 77.33% according to 2001 census report with respect to the literacy rate of India which is 65.38%. The total population is 1301856 with 646356 of male and 655500 of female. Density of population is 448 persons per sq.km. Male literacy is about 87.62% with respect to 75.85% of India and the female literacy rate is 67.29% with respect to 54.16% of India. Oriya is the main language spoken here.

3.8. Transport

The study area lies only 75 km from the main city of Bhubaneshwar. National Highway 5 and 5A are crossing near the region at Chandikhol to Paradip and also Cuttack-Jagatpur-Salipur state highway can be availed to reach here. National Highway 5A has the junction with 5 near the port of Paradip which lies about 94km away from the Cuttack Railway Station. The nearest railway station is in Cuttack which lies about 55 km from the main town of Kendrapara and the nearest airport is Bhubaneshwar which is only one and half hour drive from here. The study area has mainly some cart tracks and path with the main road on the embankment around the entire region. Most of these unmetal roads are inundated during floods and thus making the region inaccessible during flood times (Fig. 3-7). Village roads are generally unmetal which create problems during flood (Fig.3-6).

Figure 3-6 Village Roads

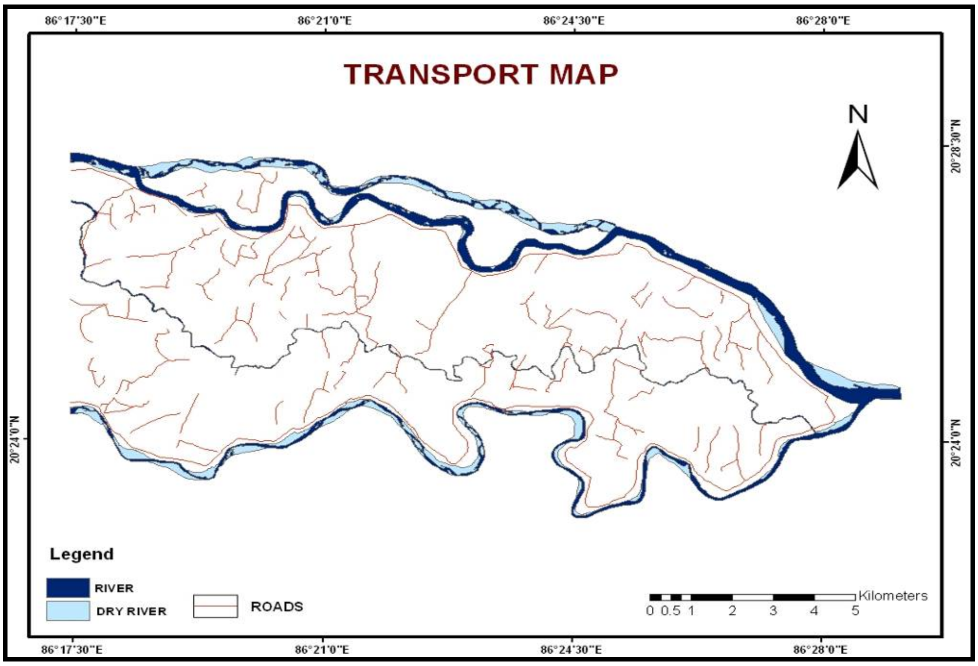


Figure 3-7 Transport Map
Source: Toposheet and Cartosat Image

4. Materials and Methods

Remote Sensing techniques have been implemented in this research for the extraction of flood extent, depth and duration; i.e. basic characteristics of the flood and delineating the flood extent for inundation pattern mapping. Apart from this, Radarsat images are used for the identification of the variation in backscatter values in flooded and non flooded paddy and other elements at risk.

4.1. Data Requirement and Availability

This research work is done with the Radarsat1 imagery provided by the NRSA (National Remote Sensing Agency) and with Cartosat1 imagery. Radarsat1 was developed under the Canadian Space Agency and Cartosat1 under Indian Space Research Organization and Cartosat1 DEM provided by Indian Institute of Remote Sensing. Flood depth, duration and extent were calculated from the Radarsat imagery dated 4sep, 11sep, 13sep and 20sep of 2003., 4aug, 19aug and 26aug of 2006 and 18sep, 20sep, 22sep and 24sep 0f 2008. The Cartosat image has been used for permanent water body marking during non flooded time and also to identify the agricultural land from the image. Inundation pattern will be mapped in the grid of 50*50m to recognize the movement of water which is generated in the ERDAS 9.1. Geomorphology and elevation of the area are the main parameters that will be considered for recognizing the flood water movement because flood pattern of the area is mainly controlled by these two factors. Flood depth and duration will be considered to verify the pattern. Landuse is used to relate it with the geomorphology and thus it will help to identify the presence of different elements in the way of water movement. Flood water movement for each image of the year 2003, 2006 and 2008 will be identified and extra area that is submerging on each date, whether during recession or progression, will be mapped. Then reason for the inundation of that area will be analyzed on the basis of the geomorphology and elevation of the region. Elevation or height of the region above the mean sea level will be obtained from the mosaic of Cartosat and Aster DEM because Cartosat DEM for the entire study area is not available. Geomorphology represents the surface configuration of the earth and thus explains the reason for existence of an elevated or depressed region. For example, levees represents higher region while back swamps represent depressed region. So flow of flood water is largely dependent on this parameter and is required to understand the reason for inundation. Mapping of the pattern of flood water flow through the study area during its recession and progression and the analysis of the reason of its inundation will be done which will give the result of flood inundation pattern of the area in three years along with the source of flood water.
Data requirement for different methods and their availability are given below (Table4-1):

Table 4-1 Data Availability and Requirement

Data Requirement	Data Availability	Analysis of Data
Radarsat1 Image Cartosat1 Image Aster data	2003: 4th, 11th, 13th and 20thSep 2006: 4th, 19th and 26thAug 2008:18th, 20th, 22nd and 24thSep Pre flood Image 2004: 12thDec	• Flood extent, depth and duration mapping • Permanent water body mapping, agricultural field mapping • to merge with the Cartosat DEM to get the height information of the whole study area
Geomorphology Map Landuse Map	Orissa State Remote Sensing Centre	• Flood inundation pattern analysis
Elements at risk (Paddy)	Surveyed from field	• Analysis of paddy field under flood threat • Backscatter analysis of flooded and non flooded paddy field, water and dry land • Growth stage of paddy • Flood vulnerability from production cost • Damage assessment of paddy in different growth stage

4.2. Data Collection and Database Preparation (General Methodology)

Before visiting field a database has been prepared and used in the field for validation. Information has been gathered from the field regarding the damage of paddy according to the growth stage and also the vulnerability. Information about vulnerability of paddy with respect to flood depth and duration has been collected along with the damage that will occur if flood comes at the initial stage, middle stage or mature growth stage of paddy. Extent, depth and duration related surveys are also done from the field for the verification of the image interpretation. 2006 database was created after the field work as data was not available, so field verification could not be done for this year. Only information for 2006 flood was collected from the field. But pre field methodology is described together with the database of 2006 for comparing depth, duration and extent of flood of 2003 and 2008 with the database of 2006. Pre field methodology is described in Fig. 4-1:

PRE FIELD WORK

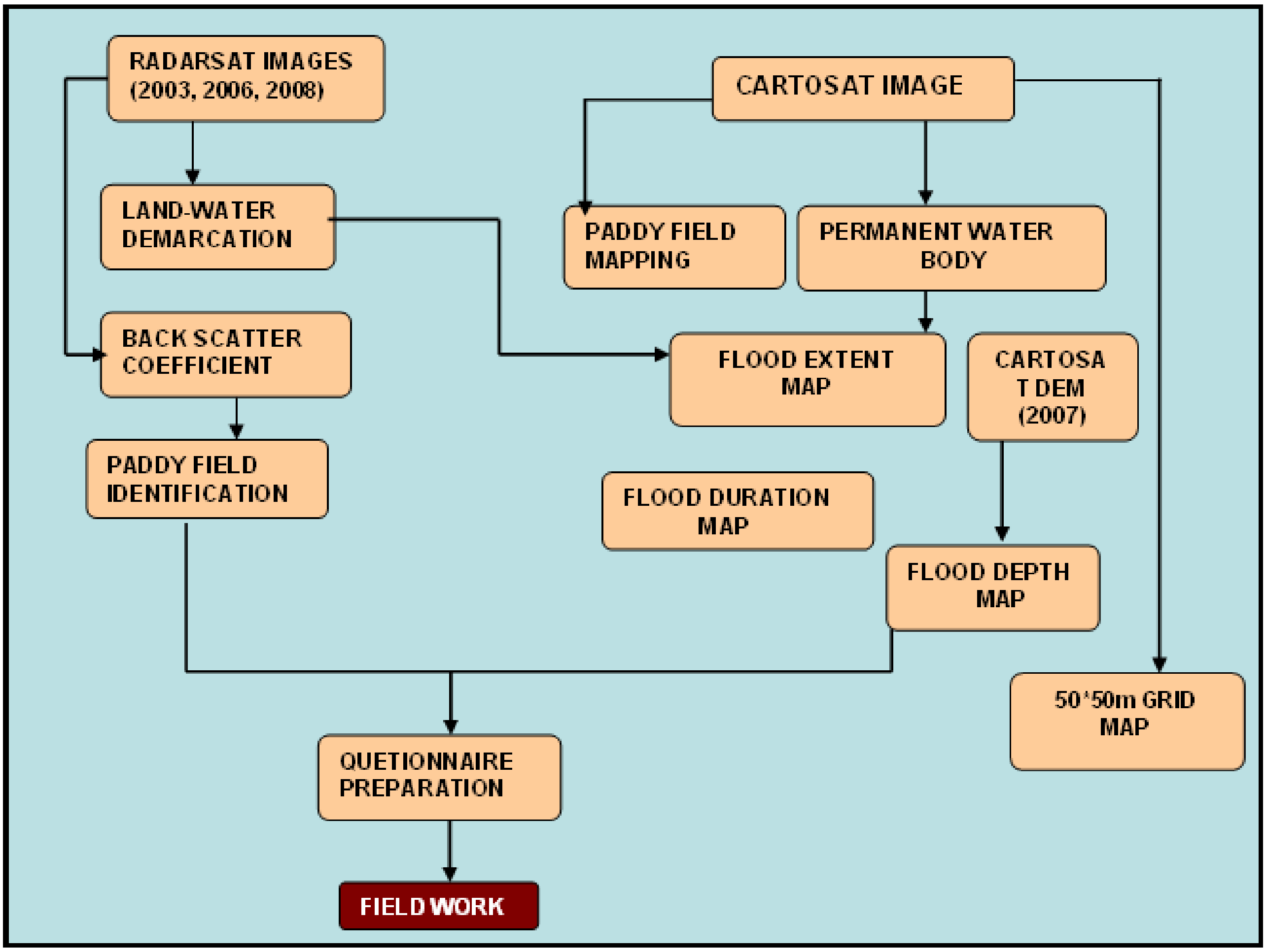


Fig.4-1 Flowchart for Pre Field Work

Radarsat and Cartosat images were used for the purpose of inundation pattern mapping. The extraction of the actual flooded area was needed which was done by taking a specific threshold value between the flooded and non flooded region. The flooded and non flooded zone has been categorized and flood duration map was done on the basis of common flood area, and non flooded area. A long, medium and short duration flood categorization has been done for the damage assessment of paddy and also to find out the inundation pattern of the area. Depth analysis is based on the DEM of the area as well as the geomorphic features so as to explain the water logging and also recession of the flood water from the area. Specific flood duration in a particular area is largely dependent on the geomorphology of the area. Recession of water is calculated from the Radarsat images of flood for four dates in each year of 2003, 2006 and 2008.

Backscatter variation for paddy is identified from other elements at risk like settlement and water body. Paddy plants have the growth period for four months, therefore during this period when flood comes, inundated paddy fields will show increasing backscatter values with time as the plant is growing. But the settlements and permanent water body will have constant backscatter values. This feature of paddy plants will distinguish it from other elements at risk like settlements and permanent water body. Backscatter coefficients from pixels were taken for flooded paddy, non flooded paddy, settlement and water body and a distinct variation is observed in the reflection of paddy plants. Backscatter values for paddy shows increasing trend with time in temporal images of Radarsat, while for settlements and water body backscatter values are almost constant. Growth stage of paddy is taken from the field data by correlating it with the daily rainfall and growing season on the basis of height of the plants.

4.2.1. Extraction of the flooded area

Flood extent reflects the area under flood water and thus indicating the area where damages could occur. For proper assessment of flood area, a specific flood boundary is required to be delineated. Threshold method is applied in this case for the delineation of flooded and non flooded area. Density slicing or threshold indicates the division of the histogram in to two or more parts with each range or slice having a specific class like flooded or non flooded. The water backscatter values ranges from -12dB as upper value to as low as -35dB. So to delineate the flooded from non flooded area -12dB was taken in this case by examining all images from different years. After studying different values from the images of different years it was observed that the threshold value between flooded and non flooded region is varying from -12 to -12.5dB. So a standard value of -12dB has been taken as the bounding line for flood extent as it is matching for most of the images. Threshold technique was applied on flood images and they were verified from the field regarding the accuracy of the flooded area.
The backscatter values may vary according to the texture of the features that remain within the water body like vegetation, sediment, road and settlement area. These will show different backscatter values than the clear water body, so the threshold values may vary for different areas as well as for different years but a specific value of -12dB has been taken to classify flooded and non flooded area as it is accurate for most cases in this study area.

DATES 2003	FLOOD EXTENT (SQKM)
4th September	72.15
11th September	69.35
13th September	54.72
20th September	26.66

Table 4-2 Flood Extent 2003

The table 4-2 describes the total flood extent during 2003 flood which is represented in a graph for indicating the total area under water during different dates or the total area affected by flood.

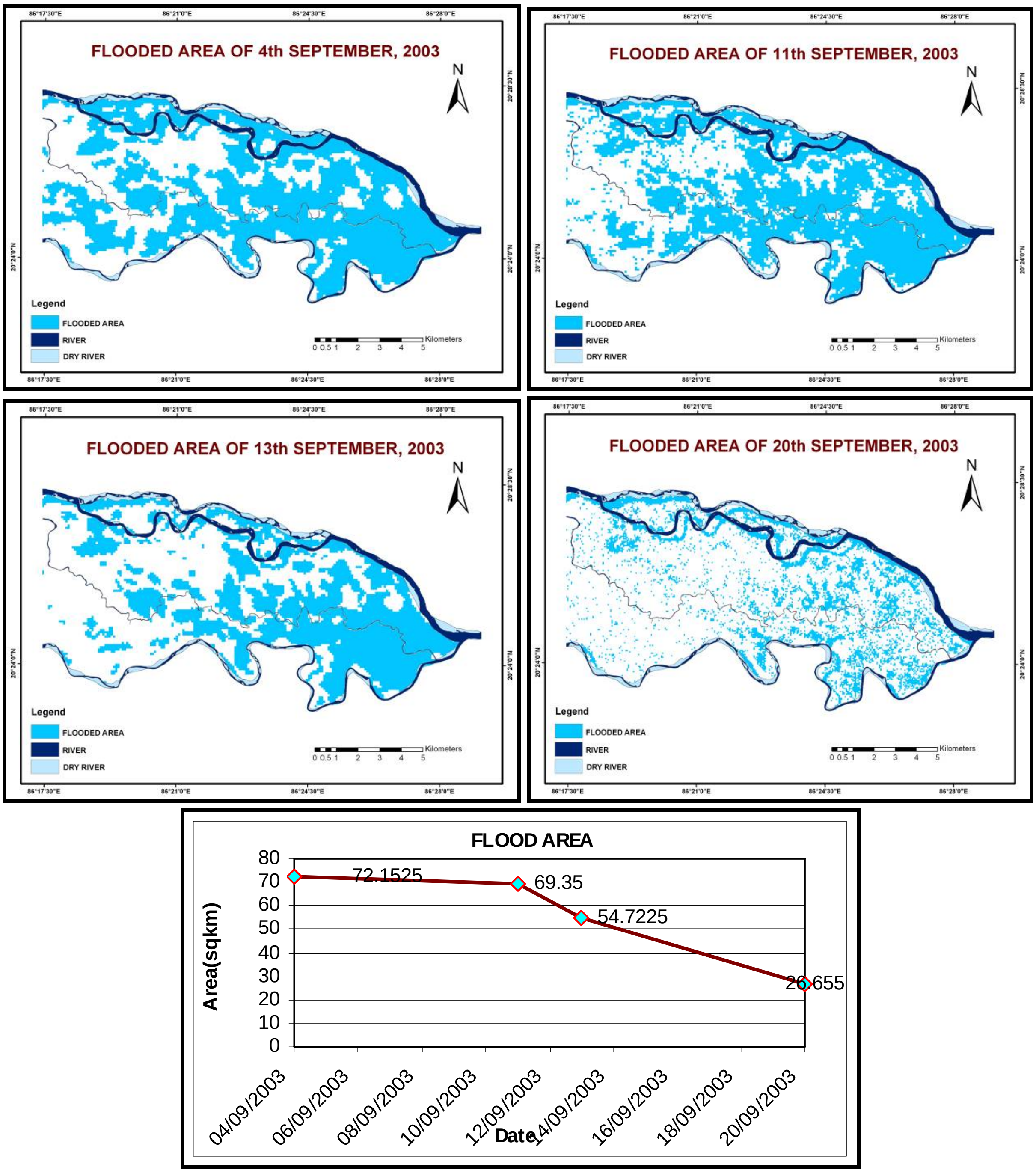


Fig.4-2Flood Extent, 2003

Threshold values have shown flooded and non flooded area with 4th September of 2003 having peak flood which gradually receded up to 20th September. Flooded area covers about 72.15sq.km decreasing to 26.66sq.km in 20th September (Fig.4-2).

DATES 2006	FLOOD EXTENT (SQKM)
4th August	35.98
19th August	37.63
26th August	42.24

Table 4-3 Flood Extent 2006

Table 4-3 gives the total area that was inundated during 2006 flood indicating the maximum inundation on 26th August.

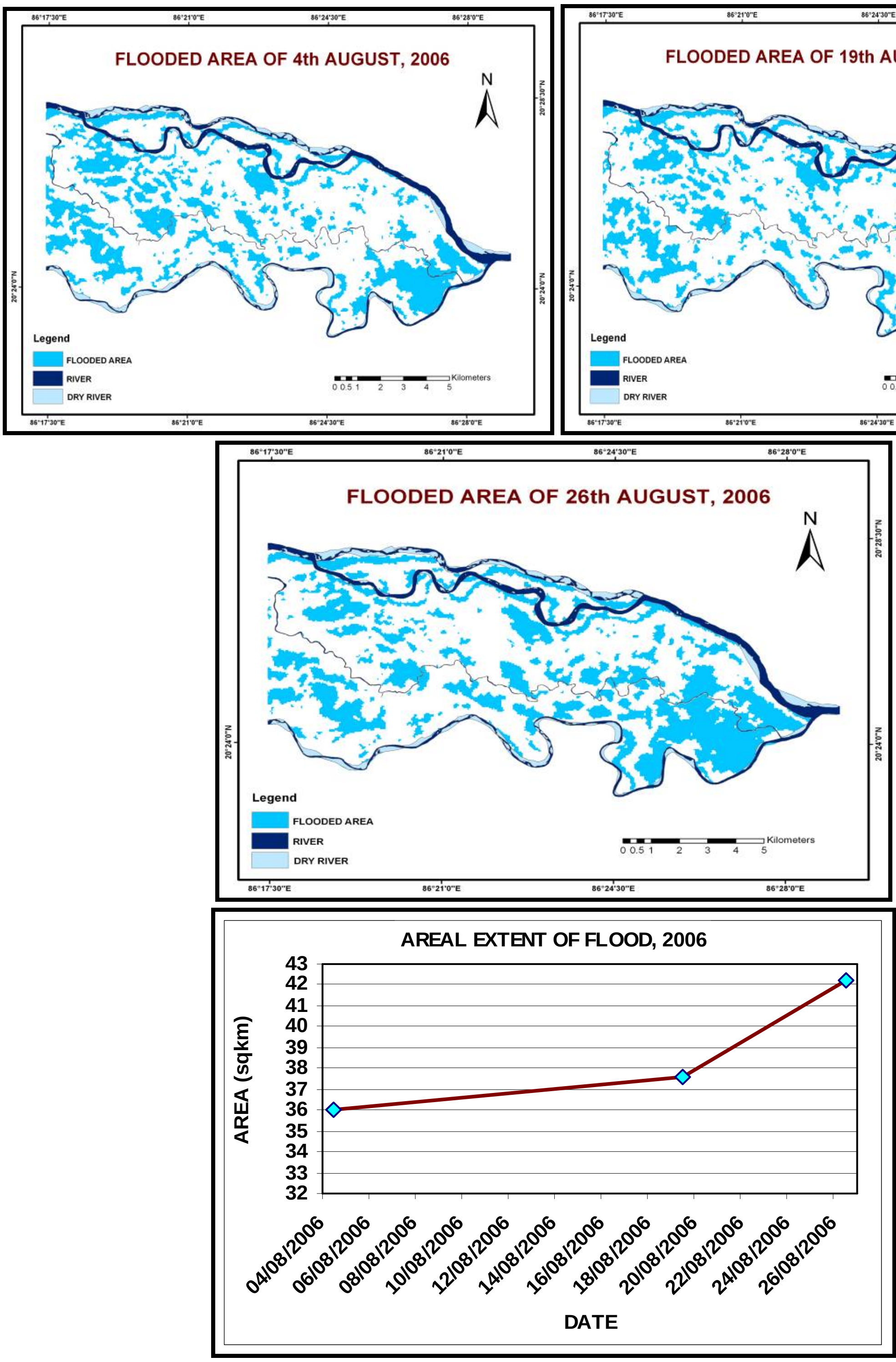


Fig.4-3 Flood Extent 2006

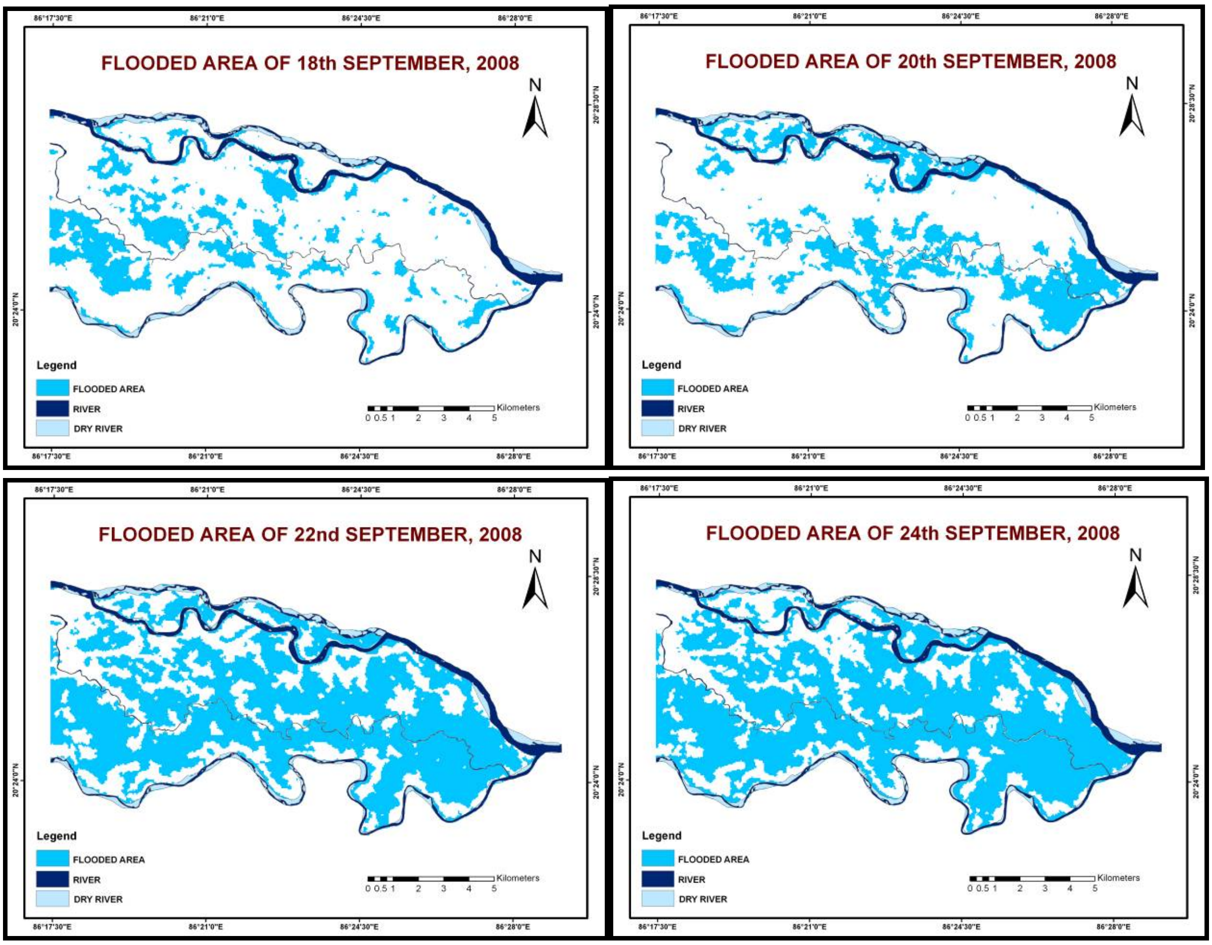
2006 flood is showing the increasing pattern from 4th August to 26th August with lean flood period on 4th August covering about 36sq.km area with little more flood area coverage on 19th Aug of about 38sq.km area and 26th August is showing maximum flood here with about 42.24sq.km area flooded

(Fig.4-3). From the images a shift in the river course could be seen which may be due to some problem in the geo-reference although it has been done by NRSA (National Remote Sensing Agency) and then again been geo rectified during the processing of this research work.

dATES 2008	FLOOD EXTENT (SQKM)
18th September	19.73
20th September	34.53
22nd September	76.93
24th September	73.07

Table 4-4 Flood Extent 2008

Four flooded dates were obtained from the temporal Radarsat images of 2008 covering area which is shown in the given table (Table 4-4).



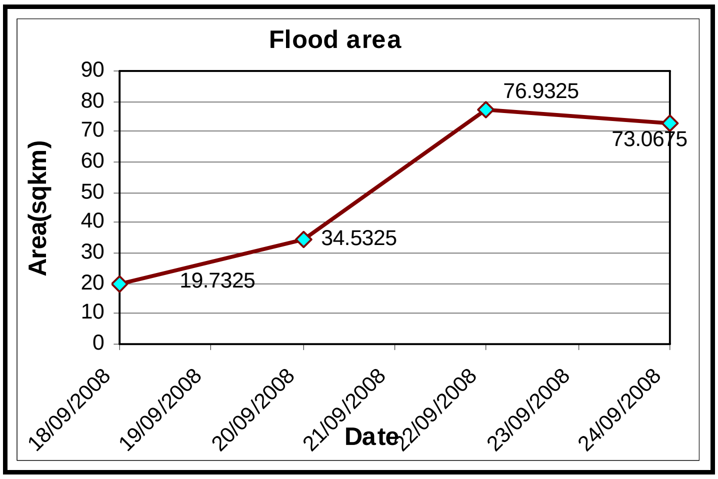


Fig.4-4 Flood Extent, 2008

2008 flood has the increasing pattern with 18th September having lean flood period occupying about 19.73sq.km areas increasing to 76.93sq.km areas on 22nd September and again decreasing to almost 73sq.km on 24th (Fig.4-4).

4.2.2. Flood Duration

Flood duration explains the period of water inundation in the field. Flood duration is one of the factors that define the flood losses particularly in case of crops where flood with long duration and depth may damage the entire crop. The total extent map for each year is considered for the duration calculation.
Temporal Radarsat images were taken for the calculation of duration. Images of 4th, 11th, 13th and 20th September of 2003, 4th, 19th and 26th August of 2006 and 18th, 20th, 22nd and 24th August of 2008 were taken for the extraction of the flood extent maps which has been done by the threshold method. 4th September of 2003, 26th August of 2006 and 22nd September of 2008 has the maximum flood. As the entire flood images of 2008 are not available, therefore it is not showing any long duration of flood. From the field survey it was known that 2008 flood was quite long staying with duration of about 30 days in the field like the 2003 flood. But according to the images, only four dates are available with 22nd September showing the peak flood and only one date of 24th September available after that. So the entire recessional phase is not available, the reason for which long duration of flood could not be identified from the images.
Calculation for the flood duration is done in the model maker of ERDAS 9.1 with the flood extent map of three years of 2003, 2006 and 2008. Flood duration was calculated from the flood extent maps of each year and it has been classified into short, medium and long duration flood with less than 5 days, 5 to 15 days and more than 15 days respectively. This has been done from the flooded Radarsat images of different dates in each year and categorization has been done on the basis of this duration. For example, each image like 4th, 11th, 13th and 20th September of 2003 has been classified into flooded and non flooded area. Then 4th and 11th September were combined and 13th and 20th September were combined separately which gave the common flooded area, dry land area which were not affected by flood, areas which were flooded at the beginning but became dry later, and areas which were not flooded at the beginning but get flooded in later dates. The results were then categorized into long

duration which are the common flooded area, medium and short duration were categorized according to the number of days that remains flooded in 2003.

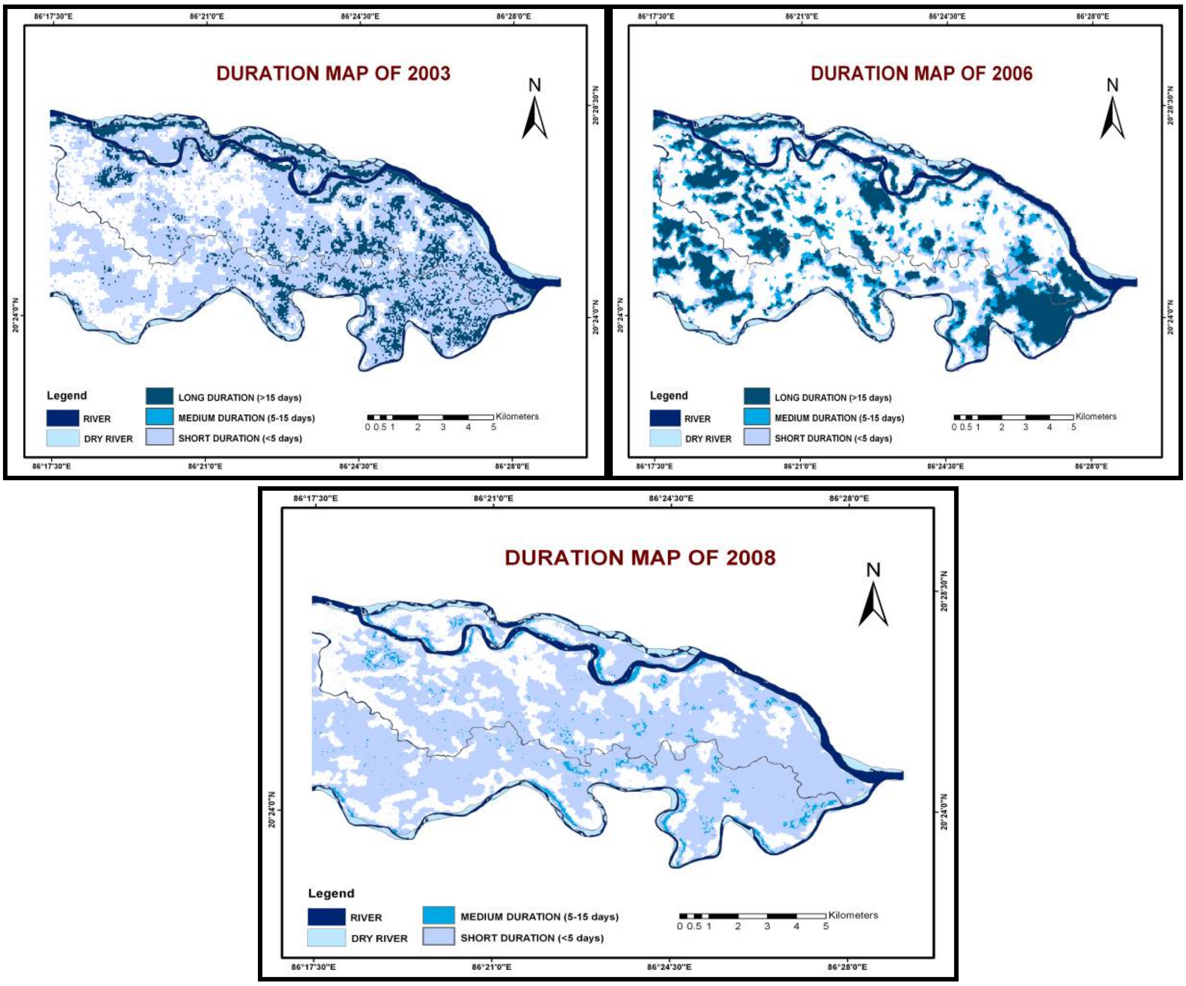


Fig.4-5 Flood Duration

The duration map of 2003 is showing that mainly short duration flood has occurred in the western part i.e. less than 5 days, but medium and long duration have occurred in the eastern part which have usually lower elevation and thus the water is staying there for longer time. 2006 is showing short duration flood of less than 5 days in the eastern, central and few areas in the western part. 2008 flood is not showing any long duration of flood from image with medium duration of 5 to 15 days in small areas of central and western part and few scattered area in the east while rest of the areas experienced short duration flood in this year (Fig.4-5).

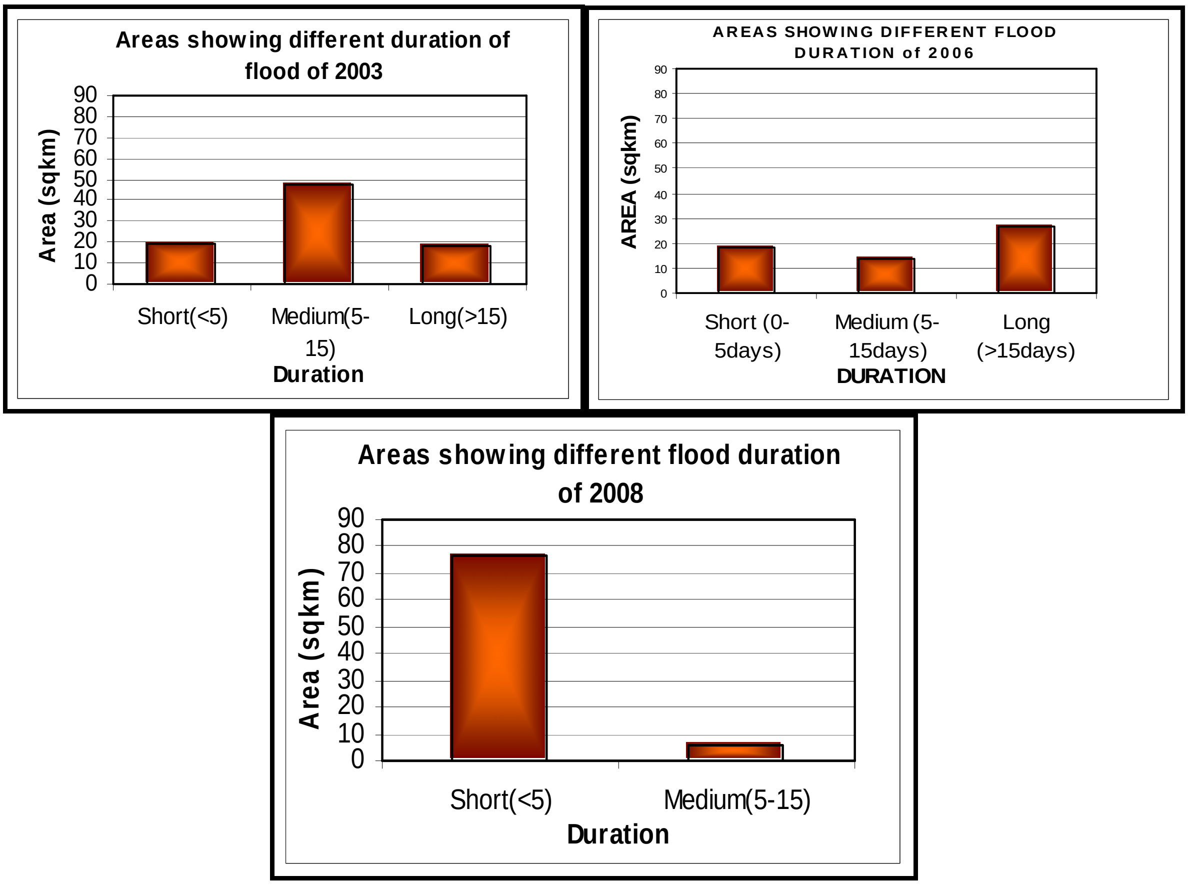


Fig.4-6 Graphs of Flood Duration

Bar graph of 2003 flood duration is showing about 20sq.km area of flood while medium duration i.e. within 5 to 15 days of duration is showing about 47sq.km covering the maximum area and long flood duration is found in only about 18sq.km area. 2006 is showing lesser flood area than 2003 and 2008 with short duration flood in less than 18.5sq.km, medium duration in about 14sq.km area and long duration flood of more than 15 days in about 27.3sq.km area. 2008 flood is not showing any long duration flood of more than 15 days but medium duration of water logging in some parts of about 5sq.km and short duration flood in about 77sq.km area (Fig.4-6).

4.2.3. Flood Depth

Flood depth (Fig.4-8) is the measure of flood water accumulation in a particular area. It is calculated by subtracting the DEM (Digital Elevation Model) value from the maximum water level. The height of water in the area has been surveyed during field work by asking farmers. The DEM was also checked using field measurements. The DEM of flooded area has been extracted and the maximum elevation of the flooded area is considered. The maximum elevation where flood has occurred is taken as the highest water level because it is the highest point in the region showing flood inundation. DEM or the height of the area above the mean sea level is then subtracted from this highest water level to get the flood depth. As there is no record of maximum flood height in different parts of the study area, it has been calculated from the flood image and DEM (Fig.4-7). This gives the flood height or the water level of the whole region. It may vary from one part to another according to the elevation in different parts.

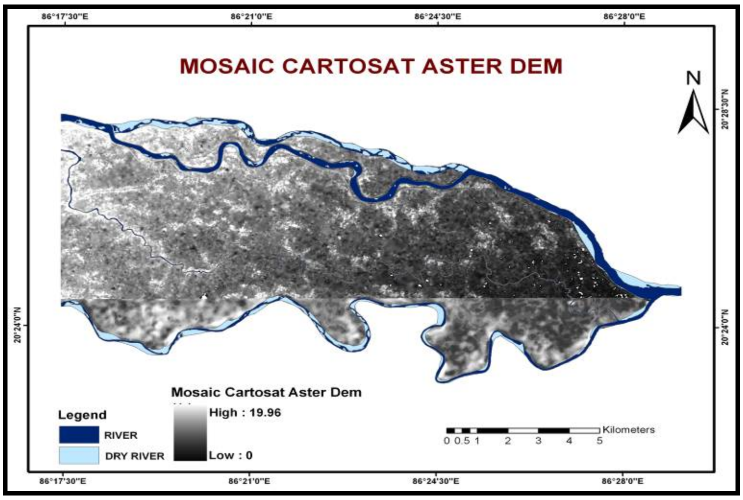
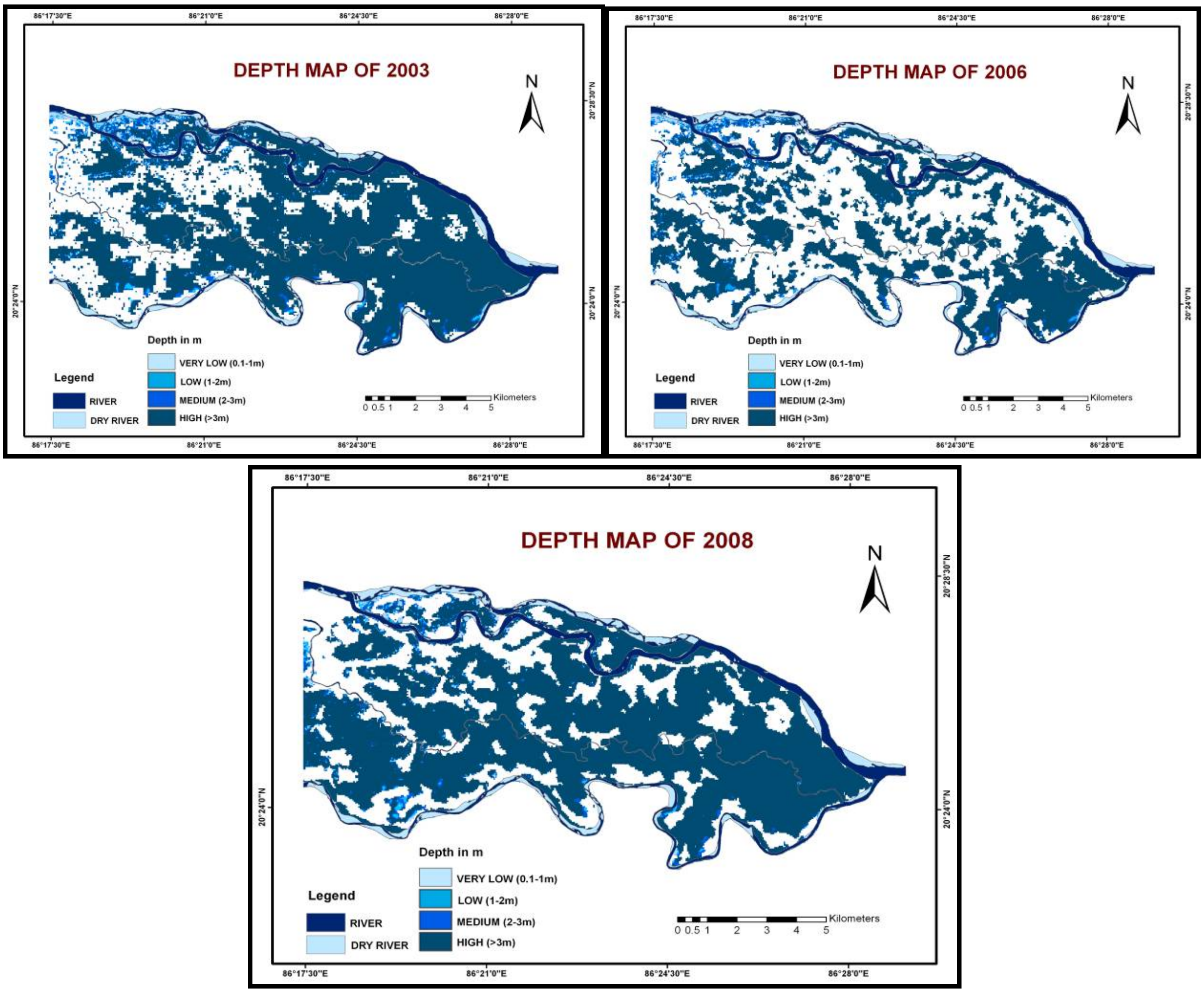


Figure 4-7 DEM



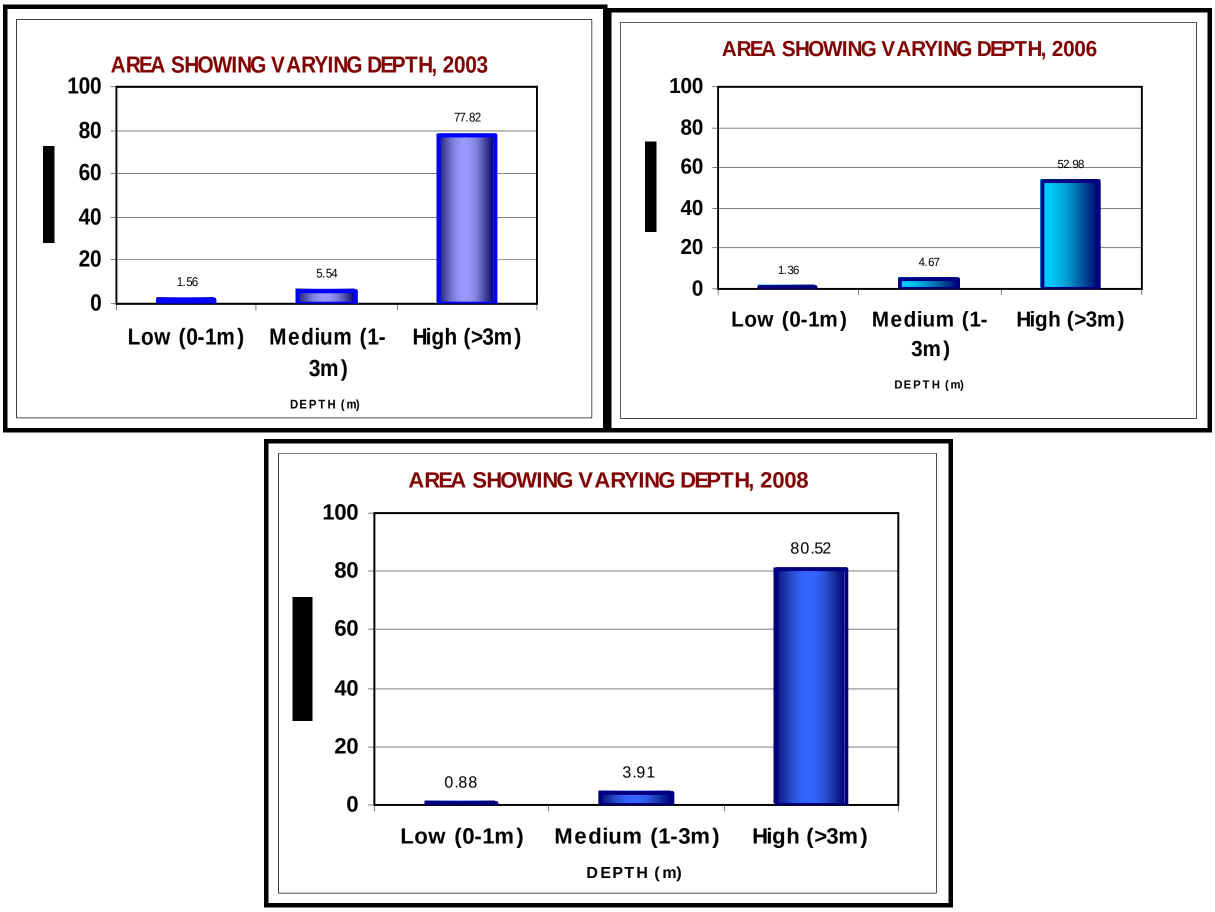


Fig.4-8 Depth Map and Graph

The depth map of 2003 is showing minimum depth of flood water in extreme north western part of the study area which is usually higher in elevation of above 12m and having a flood depth of <1m. The medium depth of water of about 1 to 3m is found in the northern and north western part and in very small patches in the southern part. Most of the area experienced high depth of water of above 3m particularly in the eastern and the central part where the elevation is low. Low flood depth is found in about 1.5sq.km area with medium depth of water in about 5.5sq.km area and more than 77sq.km area is facing maximum depth of above 3m.

2006 depth map is showing minimum depth of water in the extreme north western and western part of less than 1m with medium depth in the north western and western part with very little portion in the southern part. Maximum depth of water is found scattered in the entire region of over 3m particularly in the eastern, central and western part covering about 53sq.km area. Medium and low flood depth covers about 4.67 and 1.36sq.km area respectively.

The depth map of 2008 is showing low depth of water of less than 1m in the northern and western part. The north western, western and some southern parts are comprised of the medium depth of water from 1 to 3m and maximum depth of water is found in the entire region mainly in the eastern and central parts. Low depth of water is found in less than 1sq.km area with medium depth in about 3.91sq.km area and maximum flood depth in the major parts of about 80sq.km area (Fig.4-7).

4.2.4. Database for inundation pattern mapping

The inundation pattern mapping has been done by generating grid of 50*50m in ERDAS Imagine 9.1 from grid generation tool. Each of flood characteristics i.e. depth, duration and also landuse and geomorphology will be linked to this grid database to analyze the pattern of flooding in the study area.

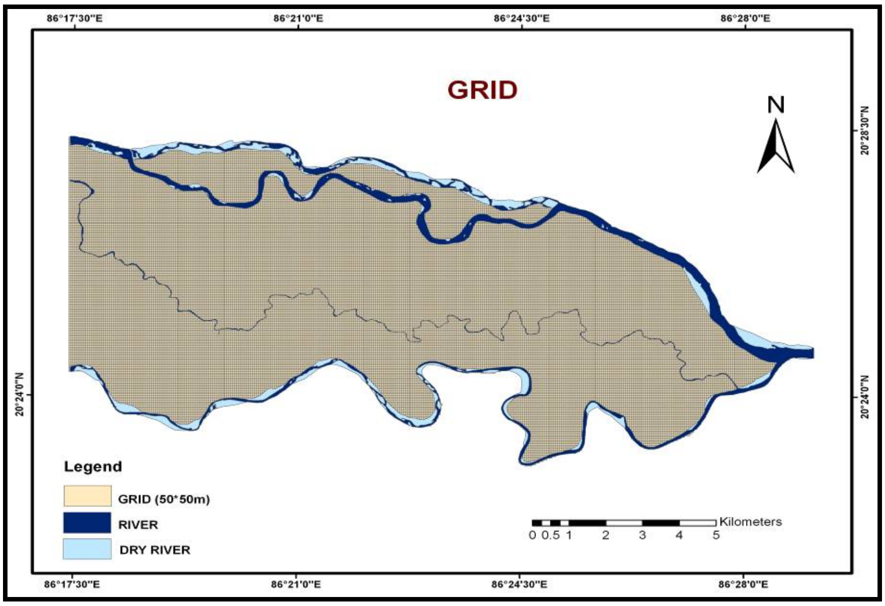


Fig.4-9 Grid Map

Attributes of flood depth, duration, extent, landuse and geomorphology are attached to the grid attributes in order to link the entire grid with these features (Fig4-9). Elevation or DEM is also attached to determine the height of the area above the mean sea level. From each grid cell then depth, duration, landuse, elevation and geomorphology are analyzed to explain the cause of accumulation of flood water and duration of staying. Excess area of flood during peak period has decreased in the recessional phase. So some grids which are flooded in peak flood date are not flooded in the later phase. This is mapped to show the recessional pattern or the inundation pattern of the study area in grids. For e.g. 2003 has flood on 4th September which gradually receded in 11th, 13 and 20th September. There are some areas which were flooded in 4th September but were not flooded during the11th, 13th or 20th September. This particular pattern of flood water recession or movement in different dates of each year and in different years is mapped to understand the entire flooding pattern of the area in these 5 years.

4.2.5. Paddy Identification from the Backscatter Coefficients

Optical images have cloud sometimes, especially during the monsoon seasons, so microwave data has been used for the identification of paddy fields through backscatter values during the flooded period. Paddy fields were mapped from the optical Cartosat I image. In the figure 4-10 sample point locations are indicated. In these points GPS locations were taken from the field and these sample points were taken on the basis of convenience as whole of the study area was not accessible. Location of flooded paddy, non flooded paddy, settlements and water bodies were verified from the field and settlements and water bodies are considered here to differentiate and identify the paddy fields from the rest of the elements at risk by backscatter values. Only paddy fields have shown increase in the backscatter values for both flooded and non flooded regions from the Radarsat images because of their growth. But water bodies and settlements did not show any variation in the value which clearly distinguishes them from paddy.

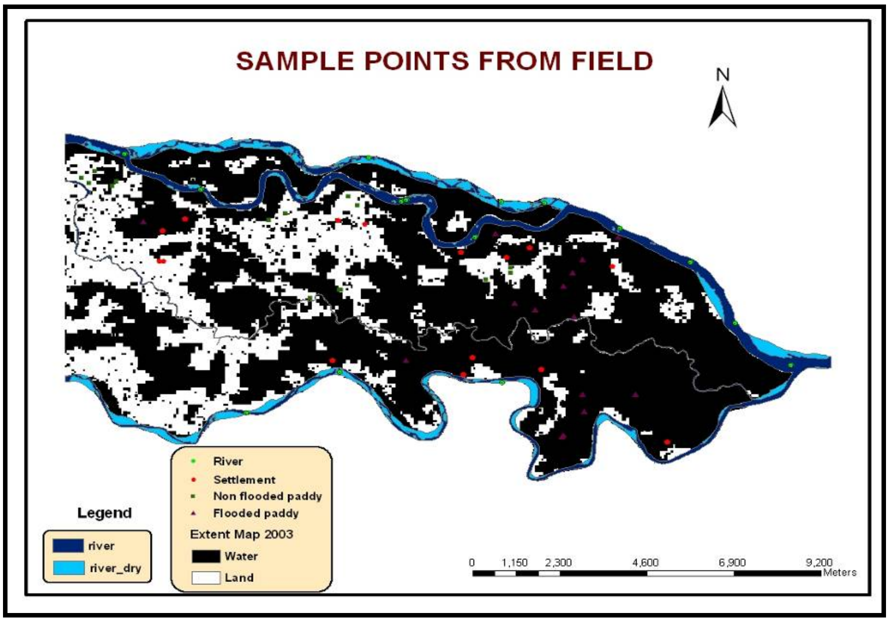


Fig.4-10 Sample Points from Field

The data for the growth stage of paddy has been collected from the field which is correlated with the daily rainfall data for the year.

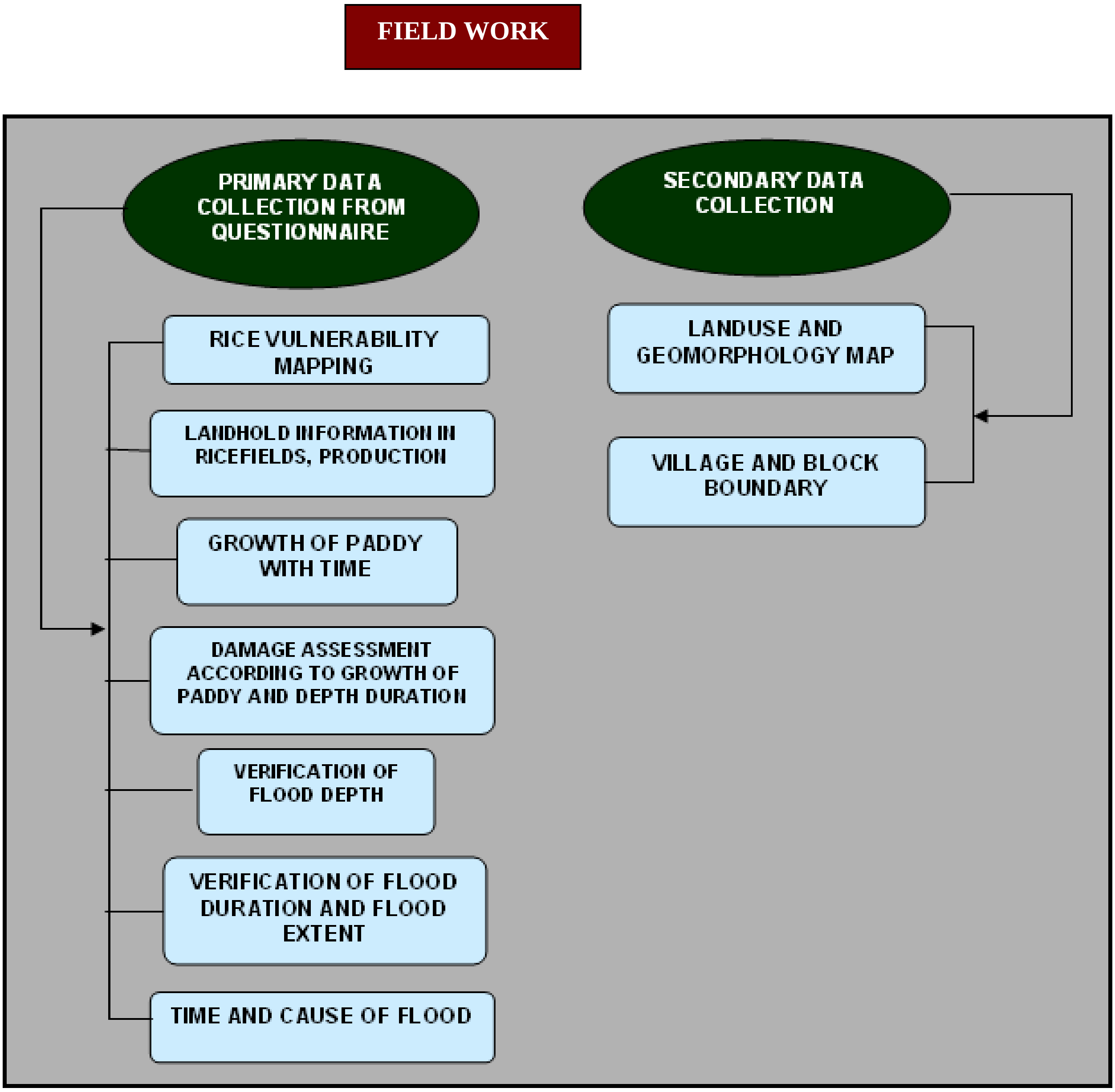


Fig.4-11 Flowchart for Fieldwork

4.2.6. Questionnaire

It was an important part of the survey as it includes all the required fields that are needed to carry out the research. The main purpose of the field survey is collecting information for rice vulnerability assessment and damages that may occur in different growth stages of paddy due to flood. Other objectives include collecting data regarding the growth of paddy plants in the entire paddy cropping season from the farmers, collecting information regarding flood depth and duration. The questionnaire includes questions regarding the landholding of the farmers, height of paddy during flood, height of paddy during the field work, cause of flood in the area, production in the paddy field, depth and

duration of water in three different years, damage of crop according to the growth stage with different depth and duration, time of flood in the paddy season, sowing and harvesting time etc. Flood depth and duration were given according to the estimation of people living there.
Field work included both primary and the secondary data collection and the proper validation requires the aggregation of both with the results (Fig.4-11).

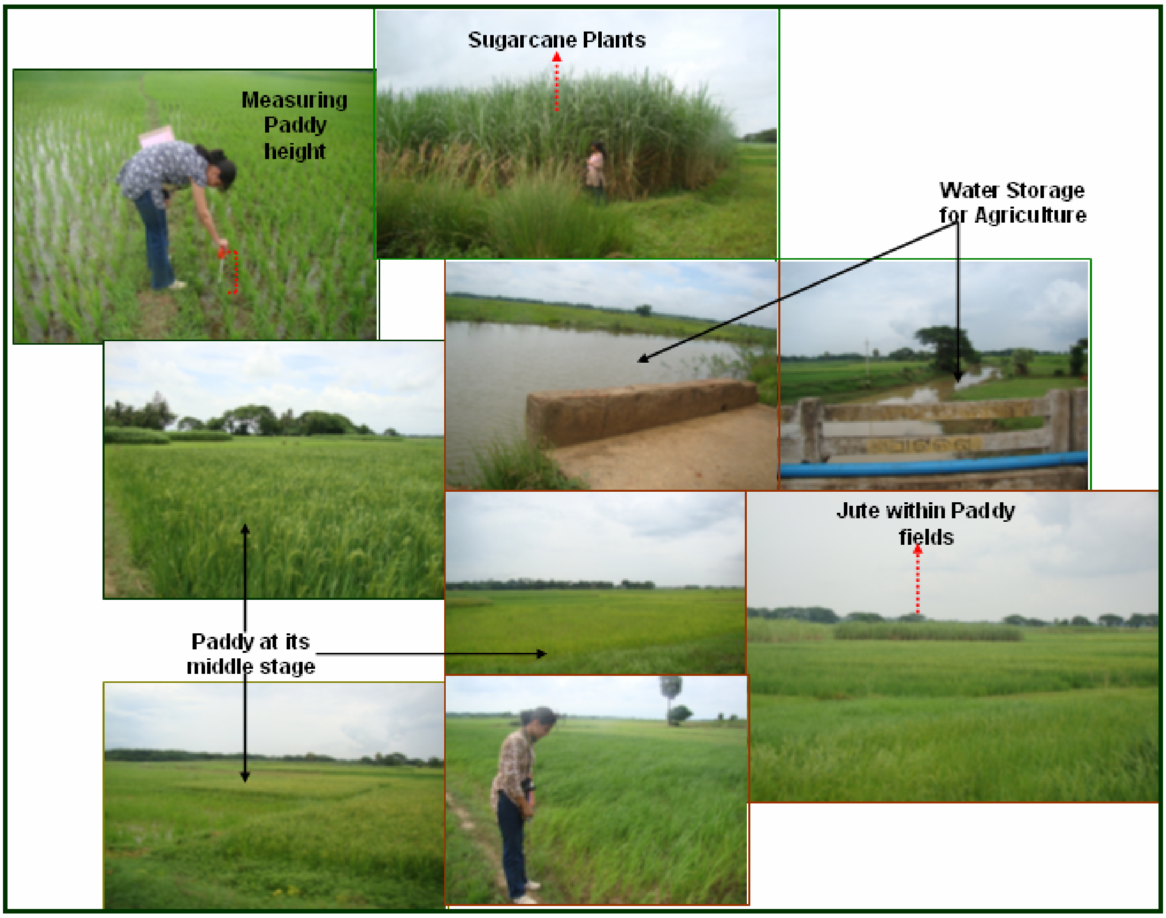


Fig.4-12 Measuring Height of Paddy in the Field regarding Growth Stage

4.2.7. Primary data

Primary data is of utmost importance as it gives the damage information together with the growth stage of paddy, cause of flood in different areas, depth of water in the field, production per acre in the filed and loss due to flood and also the verification of extent and duration together with the geomorphology map to identify any feature in the area. GPS survey was done in the field to locate any feature like settlement, road, paddy and non paddy field. Measuring height of paddy plants from the field during primary data collection is shown the Fig. 4-12.

4.2.8. Secondary data

Secondary data was mainly collected regarding the extent from OSDMA or Orissa State Disaster Management Authority in Bhubaneshwar, geomorphology and landuse map were collected from the Orissa State Remote Sensing Centre in Bhubaneshwar. These data were useful not only for the application in the research work but also to verify the existing results from the image as well from the field as these are the authentic sources from the government.

POST FIELD WORK

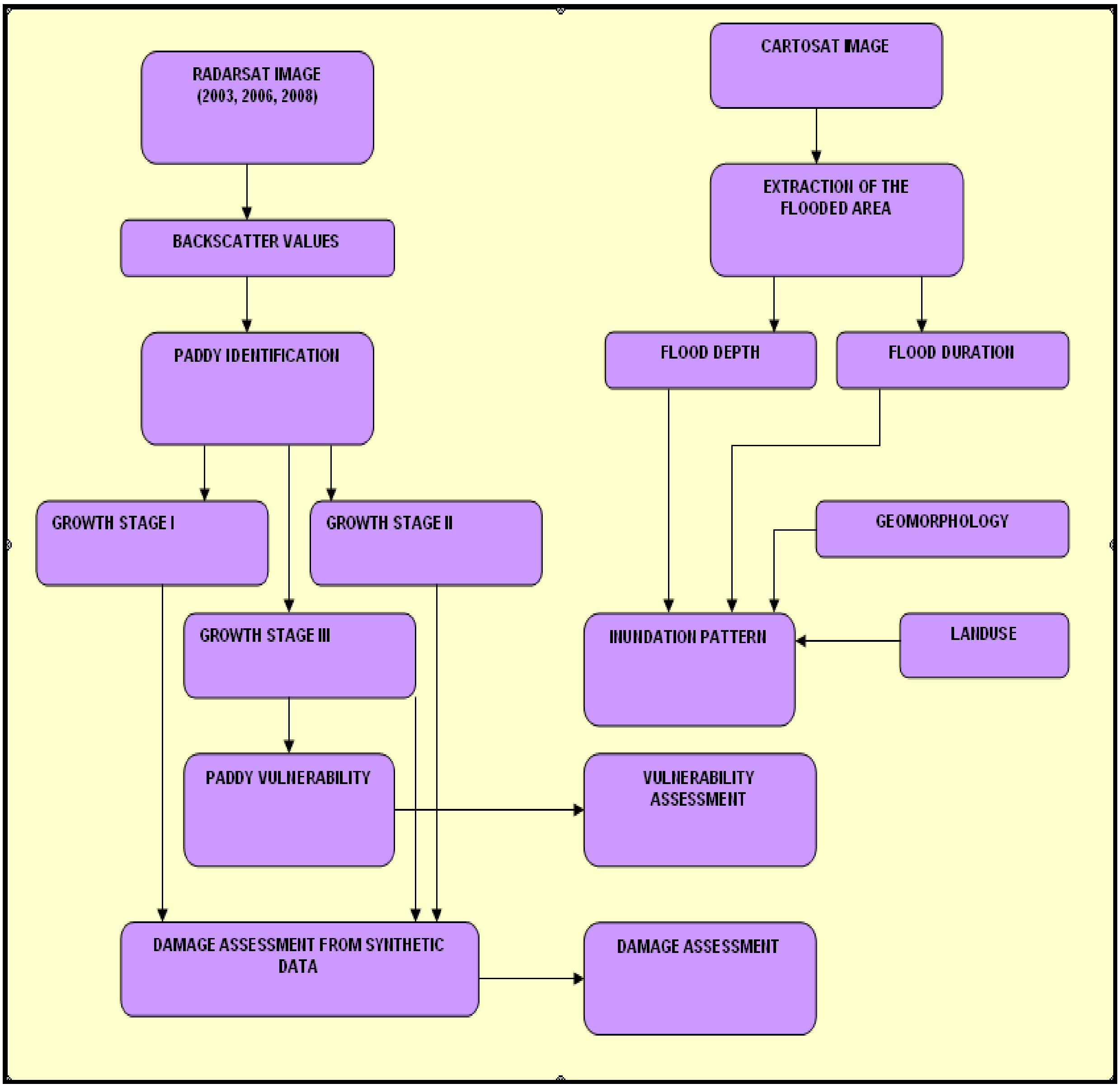


Fig.4-13 Flowchart for Post Field Work and Data Preparation

4.2.9. Preparation of Database during Post Field Work

The work during the pre field was done in ERDAS Imagine 9.1 like assessment of flood depth, duration and extent. Delineation of the permanent water body was done in Arc GIS 9.2 and the grid that was generated in ERDAS was edited in ArcGIS. Backscatter values were analysed from the permanent agricultural field map and flood extent map in ArcGIS. Flood depth was analysed from DEM and the maximum water height of the study area and flood duration was calculated in ERDAS from the temporal Radarsat images of 2003, 2006 and 2008. Vulnerability curves were drawn on the basis of information from the field according to their production cost and depth and duration of flood and it has been linked with the database in ILWIS. Damage analysis has been done on the basis of the growth stage of paddy, damage or loss in the production together with the depth and duration. This damage data is absolutely based on the field information (Fig.4-13).

5. Results and Discussion

The flood inundation pattern refers to the flood wave progression and recession and thus provides the opportunity for management or saving any property in the way of flood progression and recession. Inundation in one year may differ from the inundation of the next year, and thus it is necessary to consider the flow of flood water through the region in order to assess the flood pattern, because it has a profound impact on the suffering of people and loss of property. Major factors influencing the inundation of a region or recession from the area depends on the geomorphology or landscape, elevation, landuse type which, depth, duration etc. Artificial levees or embankments constructed around the river also have effect on flood as they stop the sudden inflow of flood water, but sometimes may cause breaching and water logging inside the embankment. All these factors have huge impact on the movement of water as well as the residential time of water in an area. Cause of flood in the area is also an important factor as it indicates the source of flood water or the route of entrance of the flood water, whether by breaching or by overtopping of the levees.

Different parameters considered in the case of this project are mainly geomorphology, elevation and depth of water in the area along with the landuse and duration. These parameters have helped to explain the inundation pattern of the region.

The pattern assessment includes the explanation of the inundation of each year of 2003, 2006 and 2008 and how they are behaving in different dates of flood from the temporal Radarsat images of these three years. Proper recession pattern has been obtained from the 2003 temporal images, but 2006 and 2008 images are showing the increasing trend of flood and the images for recessional phase were not available. Therefore field information has been incorporated to study the inundation pattern.

5.1. Factors affecting Inundation Pattern

Different factors or parameters that affect the recession pattern in a flooded area are discussed below:

5.1.1. Geomorphology and Landuse

Geomorphology (Fig5-1) of the area is showing levees in a large part of the area. Levees represent higher area and act as natural embankments where there is less or no accumulation of flood water. Therefore their presence in an area indicates low depth of water and also low duration because water tends to accumulate in the lower adjoining area. So levees are directly related to the depth and the duration of flood in that area. On the contrary, areas with swamps and marshes are more susceptible to flood and also experience longer duration of flooding in those areas as they are low lands. The geomorphology map that was obtained from the Orissa Remote Sensing Application Centre, Bhubaneshwar has been modified a little according to field survey and the image.

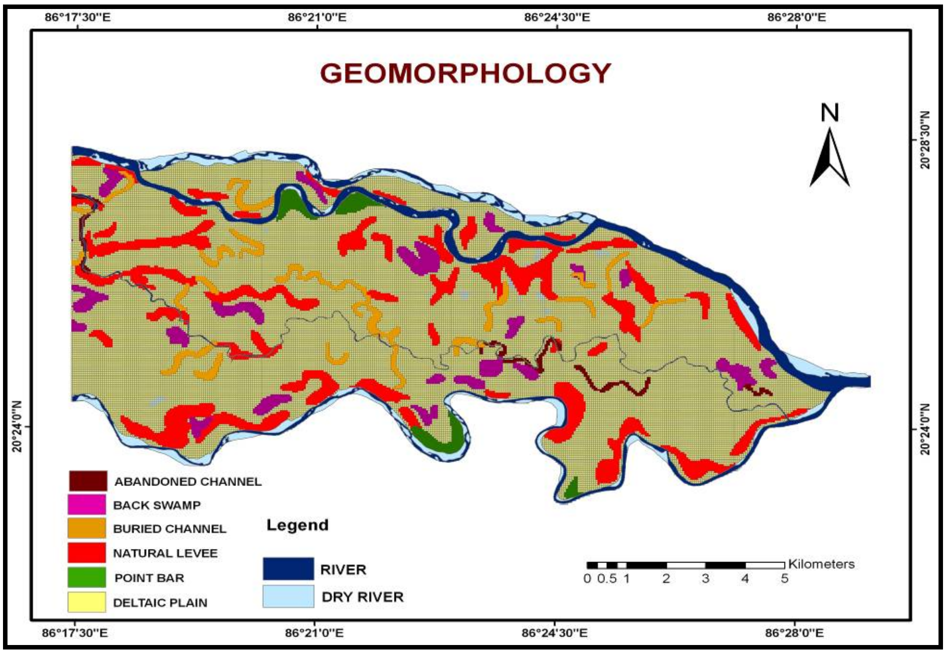


Figure 5-1 Geomorphology Map

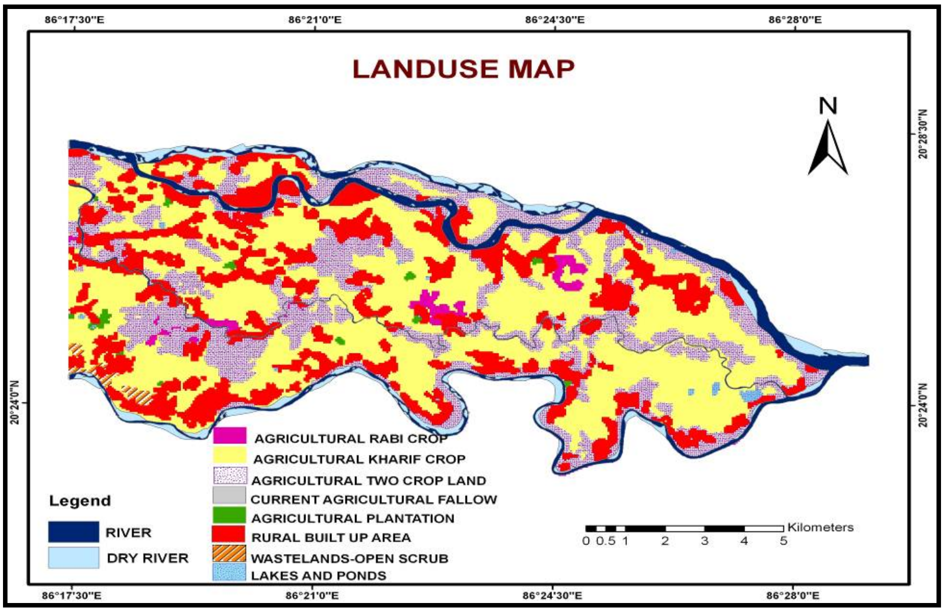


Figure 5-2 Landuse Map

Source: Orissa Remote Sensing Application Centre

Landuse (Fig5-2) is showing that most of the settlements are occupying the levee areas and some point bars, and agriculture is found in the deltaic plains. Deltaic plains are low fertile lands that are formed in this part by the river action dominantly. Thereby geomorphic features are influencing the landuse of an area, and thus indicating the low and high elevation of an area as settlements usually develop in higher areas and agriculture in lower areas. This tendency of settlements to develop in higher areas is because of having some protection from flood and agricultural lands occupy lower fertile areas of deltaic plain. So this also indicates low or maximum depth of water in the area as high lands usually have low depth of water and vice versa.

Table 5-1 Area of Different Geomorphic Features

Serial No.	Geomorphology	Area in sq. km.	Area in percentage (%)
1	Abandoned Channels	1.175	1.001
2	Back swamp	5.25	4.474
3	Buried Channels	4.785	4.078
4	Natural levee	18.315	15.608
5	Point bar	2.045	1.743
6	Deltaic plain	85.775	73.096

Table 5-2 Area of Different Landuse

Serial No.	Landuse	Area in sq. km.	Area in percentage (%)
1	Agricultural Land - Crop Land Kharif Crop	54.505	46.32
2	Agricultural Crop Land -Rabi Crop	1.705	1.449
3	Agricultural Crop Land -Two crop area	28.45	24.18
4	Agricultural Plantation	0.5575	0.474
5	Wastelands - Open scrub	0.6925	0.589
6	Water bodies-Lakes/ Ponds-Perennial	0.4	0.34
7	Built Up area (Rural)	31.355	26.65
8	Agricultural Land - Current Fallow	0.005	0.004

Geomorphology of the area has been considered because it influences the landuse pattern. The study area is situated in the delta part. Therefore the predominant geomorphic feature is deltaic plain here with the land coverage of 85.78 sq.km areas and the percentage is 73.1 of the entire land (Table5-1a). The other features are located within the deltaic plain of which abandoned channel covers about 1.18 sq.km area with 1%, back swamps 5.25 sq.km area with 4.47%, buried channels covering 4.79 sq.km area with 4.08%, point bars 2.05sq.km area with 1.74% and the natural levees occupying maximum area of 18.32 sq.km after the deltaic plain with 15.61% of the total land. Therefore the geomorphology of the area is explaining to some extent the landuse pattern as the major part of the region is cultivable land which mainly occupies the deltaic plain and the built up areas occupying the levees.

In the total area of 130sq.km, kharif or monsoon crop which is mainly paddy is the predominant land use covering about 54.5sq.km with a percentage of 46.32 of the total area (table 5-1b) with the two crop land with both kharif and rabi cropcovering 28.45 sq.km area and with the land cover of 24.18%. The area coverage of rabi or post monsoon crops i.e. mainly rice with jute or sugarcane is 1.71 sq.km area i.e. 1.45% of the total area. Therefore it is evident that the study area is mainly a mono crop area with dominance of paddy. Agricultural plantations include about 0.47% area with 0.56 sq.km coverage, open scrub with 0.69 sq.km area with 0.59% of the total landuse. Water bodies consists of small area with 0.4 sq.km area and thus with a very small percentage of 0.34, and the minimum occupancy of current fallow in the whole landuse of about 0.005 sq.km area with only 0.004% of the total area. Maximum land cover after paddy is rural settlement with about 31.36 sq.km area and 26.65% of the total cover. Thus from the above landuse pattern it is clear that major stay of the rural people is the paddy cultivation which covers the maximum area. And any damage due to flood during the cropping season may cause huge damage.

5.1.2. Elevation

Elevation or height of the area above the mean sea level is an important factor because it determines the slope of the land according to its height and thus helps in developing an idea regarding the movement of water during flood period. Therefore it is an important parameter and together with the land surface configuration provides a basis for the determination of the recession of flood water and thereby detecting areas to be more affected by flood.

The mosaic Cartosat and Aster DEM (Fig.5-2) has been used here because Cartosat DEM for the whole area was not available. Therefore mosaic of two DEM of different resolution has caused some error which is visible as a straight line in the south eastern part of the DEM. The study area is showing low elevation of 1 to 4m in the eastern part with 4 to 6m little towards the east central part. But south eastern part is showing elevation of 4m to 6m in few patches and upto12m till the south central part. The elevation gradually increases towards the west and north as the entire central, southern and few portions of the western parts area showing areas from 6 to 12m including the north central part while the region above 12m is indicated in the extreme north western part almost up to 14.5m. Thus it is clear from the elevation map that the region has slope towards its east and thereby explains the reason of those areas being more affected by flood than the other parts as most of the time it remains inundated during the flood period or monsoon time.

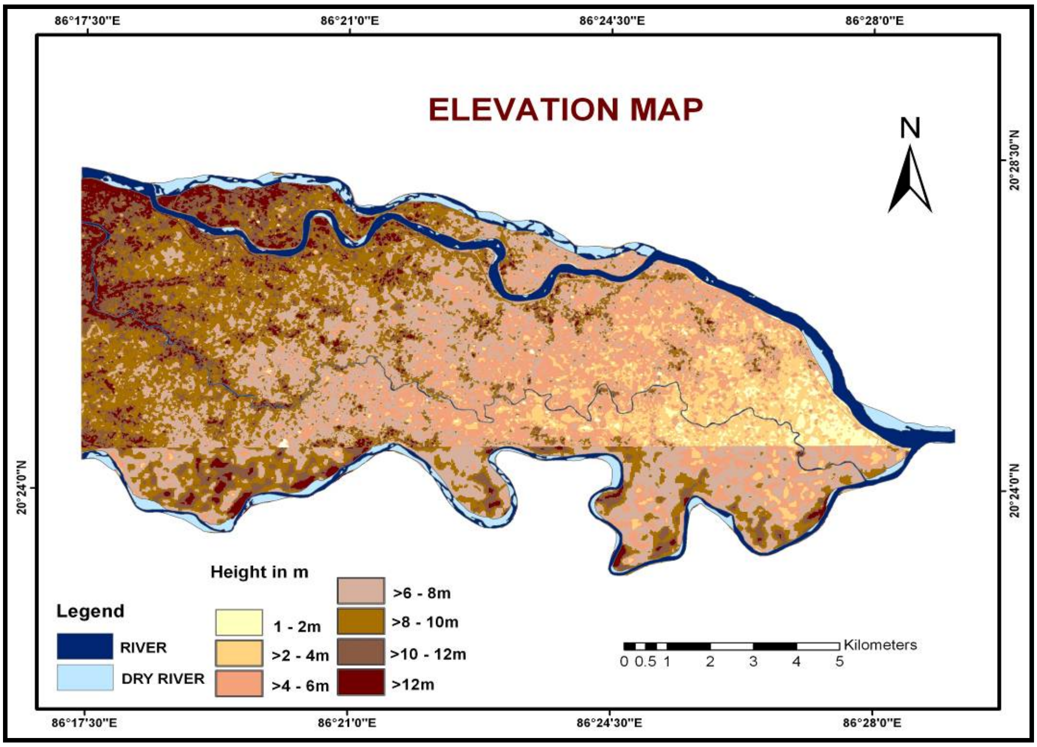


Figure 5-3 Digital Elevation Model

5.2. Inundation Pattern for 2003 Flood

2003 flood images include 4th September, 11th September, 13th September and 20th September of which 4th September has the peak flood period which gradually receded till 20th of September. This flood was one of the most destructive one and it covered almost entire area (76.12%) during its peak flood period (Fig.5-4).

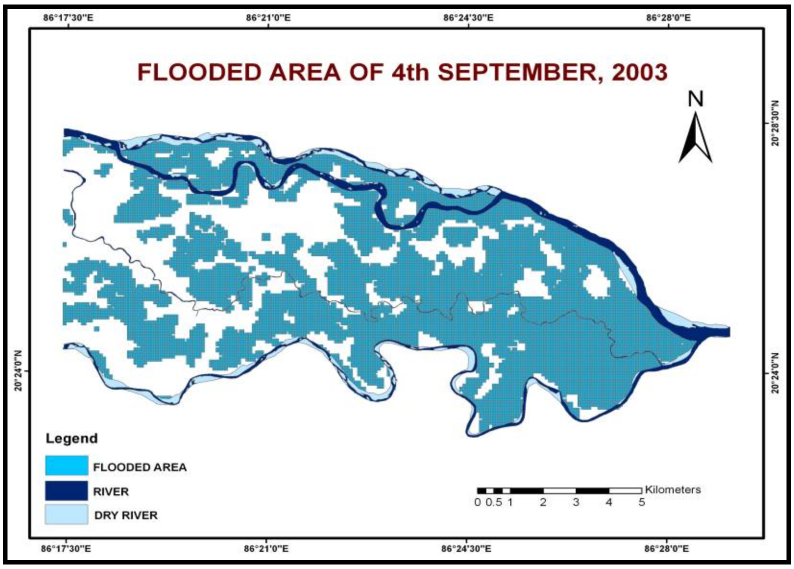


Figure 5-4 Inundated Area during Peak Flood Day of 2003

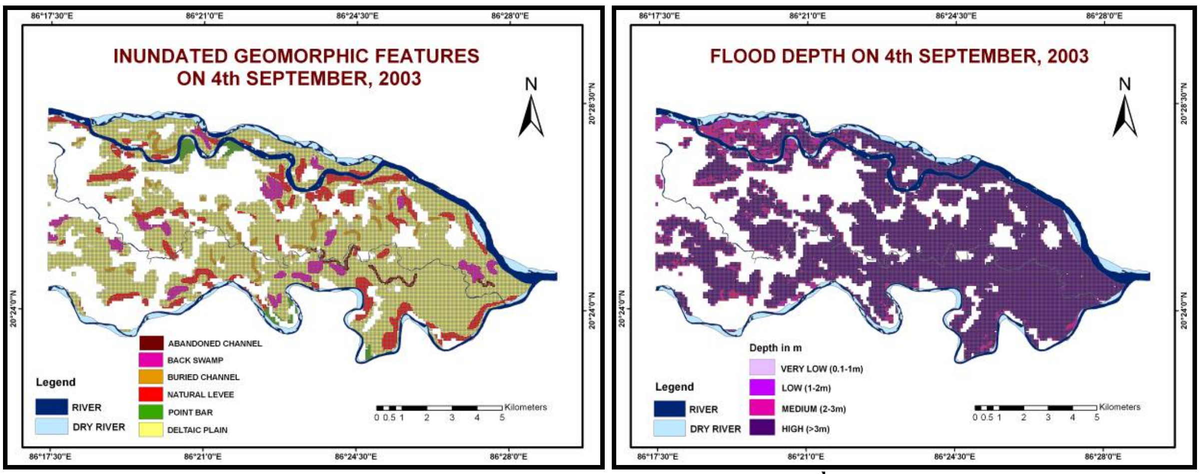


Figure 5-5 Inundated Geomorphic Features and Flood depth on 4th September, 2003

Major portion of the inundated area has deltaic plain (Fig.5-5 Geomorphic Features) with levees forming the next majority. Levees are found all over the region in the north east part and also in southern part. In the south western part levees are showing low to medium flood depth while in the north east flood depth is above 3m, therefore indicating higher areas in the south western part but low elevation in the north east which is supported by maximum flood depth. Back swamps are under deep water of above 3m in the entire flooded area and thus explaining that they lie in low area and are subjected to maximum flooding. Buried and abandoned channels also represent depth above 3m as they are paleo channels of the river with lower elevation and experience maximum water depth during flood.

Table 5-3 Inundated Geomorphic Features (sq. km) and Flood Depth (sq.km) on 4th September, 2003

Geomorphic Features	Inundated Geomorphic Features (sq. km) for 4th September Flood	% of Units Inundated
Abandoned Channel	0.81	68.94
Back swamp	4.16	79.24
Buried Channel	2.6	54.34
Levee	10.07	54.98
Point Bar	1.16	56.72
Deltaic Plain	57.33	66.84

Depth in m	Flood Depth (sq.km) for 4th September Flood
0 – 1	1.89
1 – 2	3.00
2 – 3	4.13
> 3	67.03

The Table 5-3 is showing geomorphic features which were inundated on 4th September flood and the flood depth of the inundated area on that day. Deltaic plains are found in maximum of about 58 sq.km followed by levees with about 10sq.km coverage and abandoned channels and back swamps cover about 5sq.km area. Flood depth of more than 3m is found in maximum area of more than 67sq.km area and 0 to 1m depth water is found in 2 sq.km area with little more of 3 sq.km area with 1 to 2m flood depth and 4.13 sq.km area with 2 to 3m flood depth. Among the geomorphic features, back swamps are found mostly in maximum flood depth area of more than 3m while levees are found within the flood depth of 0 to 1m or 2 to 3m. Abandoned channels comprised a small percentage area in the whole region covering about 0.02 sq.km area among all geomorphic features (Table 5- 1) and similar in the case of back swamps with 2.59 sq. km area and buried channels with 0.91 sq. km area coverage, therefore they are showing very small percentage of inundation with respect to other geomorphic features. Back swamps were mostly inundated features as almost 80% of them has inundated, followed by abandoned channel and deltaic plain with about 69% and 67% respectively. Least inundated were the levees and buried channels with about 55% of inundation for both. Levees remain at higher elevation, so they will face low inundation, but in case of buried channels low inundation may be due to accumulation of sediments over them which has caused little higher elevation causing less inundation.

In order to show the recession pattern with the extra area that was inundated during each day of flood, it is necessary to show the total area that was flooded on each day of 2003 (Fig.5-6).

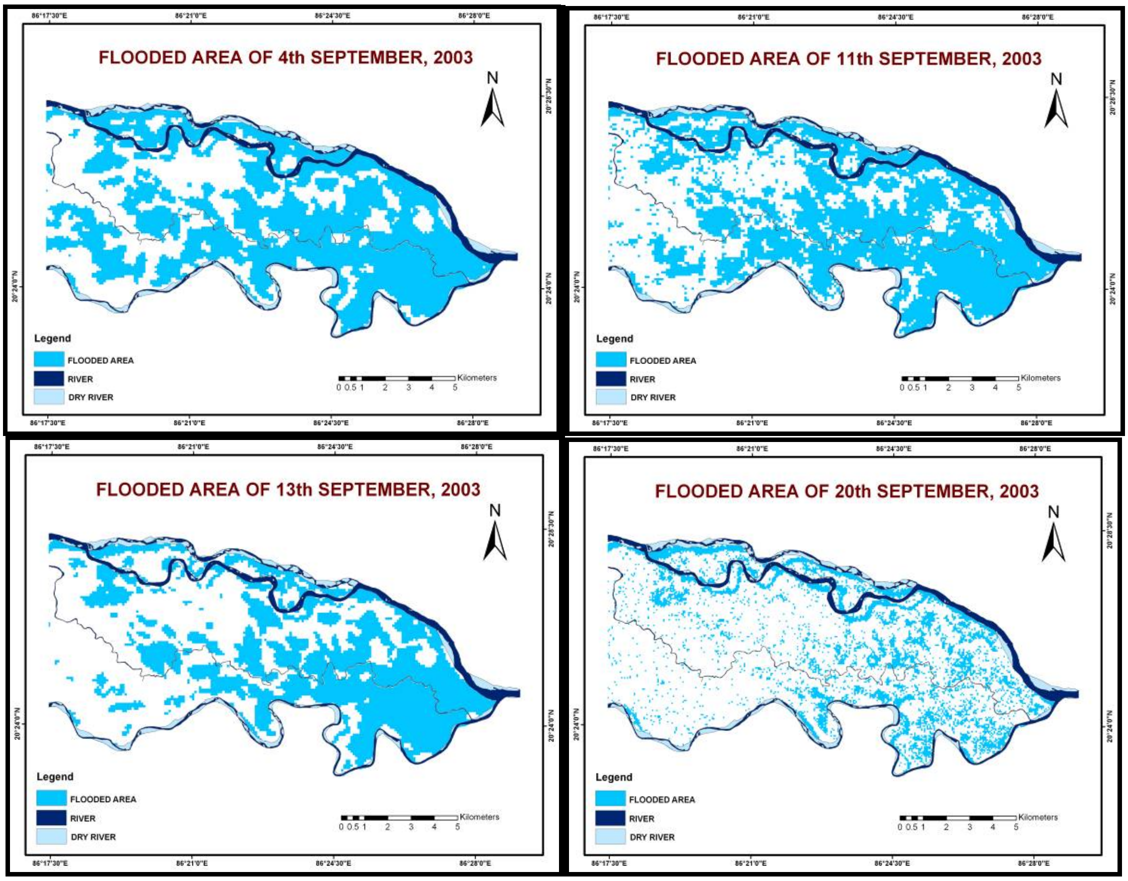


Figure 5-6 Original Flooded Area on Each Date of 2003

4^{th} September represents the maximum flood extent. But to represent the inundation pattern during the flood recession period and to show the flow of flood water through the region, only the extra area that was inundated on the peak flood day of 4^{th} September has been marked (Fig.5-7). This area shown in 4^{th} September was not inundated on any other dates. So, 4^{th} September is showing least flooded area in the Fig.5-7, while the actual flood area of 4^{th} September is area of 4^{th} September + area of 11^{th} September + area of 13^{th} September + area of 20^{th} September. Flooded area of 11^{th} September shown in the figure is the area which was flooded on 11^{th} and 4^{th} but not on 13^{th} and 20^{th} September. Similarly flooded area shown for 13^{th} September is the area that was flooded on 4^{th}, 11^{th} and 13^{th} but not on 20^{th} September. And the least flooded day of 20^{th} September is showing the common area that remained flooded for all the four days and thus represents the most adversely affected area by flood. Therefore to analyse the reason for the inundation of an area on a particular date, this trend has been followed to show the extra area that was inundated on each date.

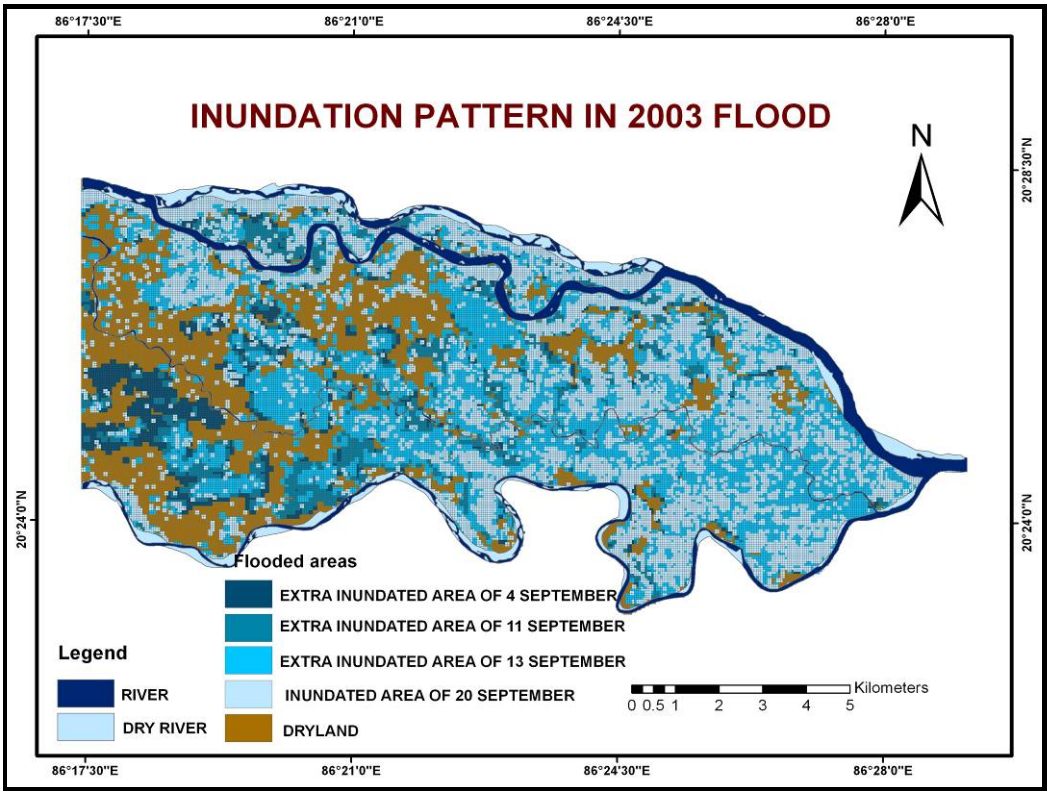


Figure 5-7 Inundation Pattern of 2003

2003 inundation pattern is showing that 4th September has the maximum flooded area particularly in the western and south western part of the study area with some scattered area in the central. On 11th it gradually shifted towards the central and east with some areas in the north. 13th September is showing the flooded pattern which has shifted more towards the east and the central part and thus it is showing recession from the west to the east. The lean flood day or the last day is showing some scattered pattern in the east and north thus indicating the recession of the flood water towards the east. This pattern of inundation is very significantly related to the geomorphology and elevation of the area, and to some extent on the landuse. Therefore it is necessary to consider these parameters in order to understand the reason for the recession and also inundation in these parts.

5.2.1. 4th September Inundation

The depth map of 4th September (Fig.5-8) is showing the flooded area with a minimum depth of less than 3m in the northern and few scattered parts in the western part. The extra area which was flooded during this day has more than 3m depth and therefore less affected than the rest of the region. The region with very low, low and medium depth of water has an elevation of above 10m and thus representing higher areas. Deltaic plain, natural levee and some back swamps are found here. Other areas also have almost same geomorphological features of few natural levees and back swamp with some variation in the elevation of 5m to 7m height above the mean sea level. But the flood depth is above 3m as these areas are comparatively lower.

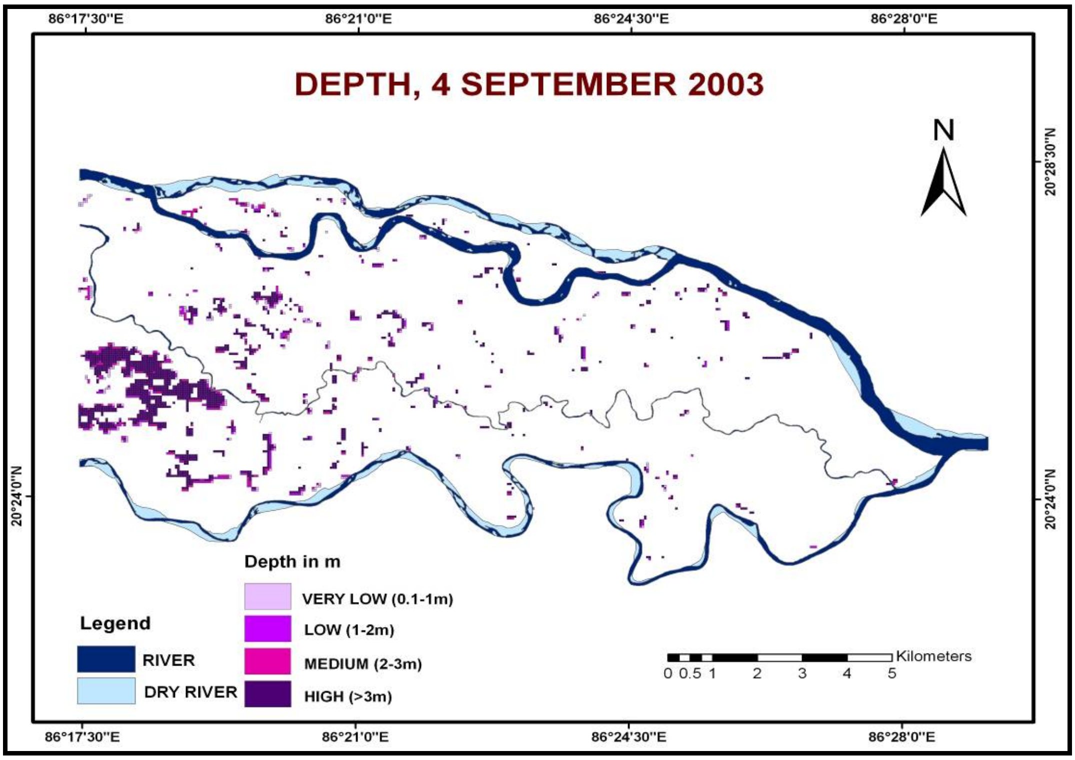


Figure 5-8 Depth of 4th September (Extra Area that was inundated on 4th which was not common in other days)

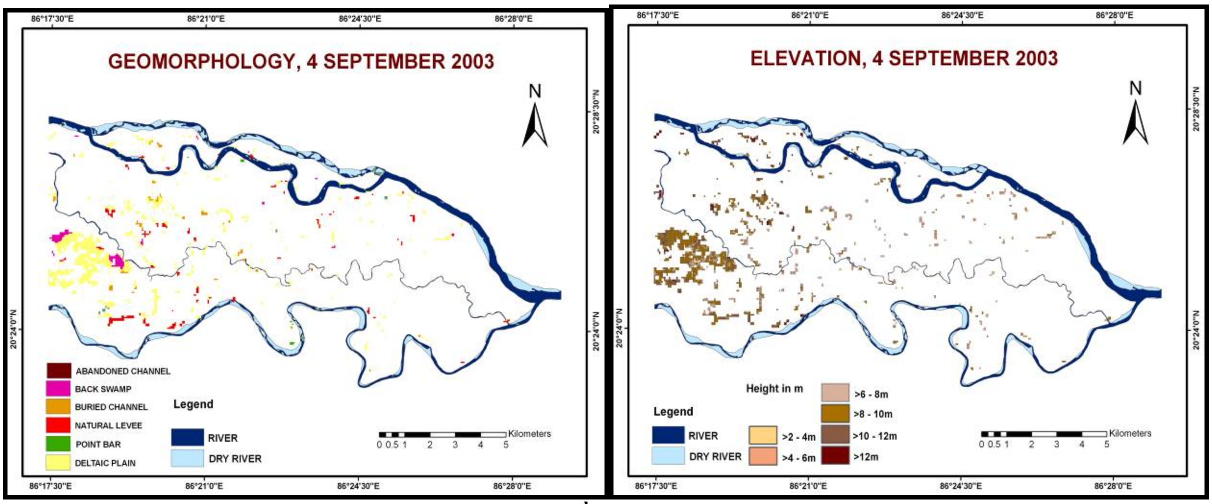


Figure 5-9 Geomorphology and Elevation of 4th September

Areas having elevation above 7 to10m but still having flood water are generally areas with back swamps and deltaic plains and thus indicating areas which are susceptible to flood as they have the geomorphic characters of flat terrain and also breaching from different sides have caused these regions to be flooded during peak flood period (Fig.5-9). But as they are highlands and have slope towards the east, therefore it subsided quickly with the residential time of water less than 5 days in those parts and the depth is also less from 1 to 5m as the region is higher.

Table 5-4 Area (sq.km) of different features on 4th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.0025
Back swamp	0.44
Buried Channel	0.31
Levee	0.76
Point Bar	0.06
Deltaic Plain	4.69

Landuse	Area in sq.km
Kharif Crop Land	2.57
Rabi Crop Land	0.1
Two Crop Area	1.83
Plantation	0.04
Open scrub Land	0.05
Lakes and Ponds	-
Rural Built Up Area	1.69
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.03
>2 – 4	0.13
>4 – 6	0.42
>6 - 8	1.44
>8 – 10	3.09
>10 – 12	1.01
>12	0.25

The dominant landuse of the area (Table 5-4) is kharif crop land with 2.57 sq.km area and it is also corresponding with the dominant geomorphic feature of deltaic plain with about 4.69 sq.km area. The maximum elevation of the area is more than 12m which covers about 0.2 sq.km area but the major portion of the area has the elevation from 11 to 12m covering about 4.69 sq.km area. But some areas with much lower elevation of 5 to 9m are also found in significant parts. Therefore from the elevation pattern it can be said that the area is situated in higher part but due to the existence of some lower portions flooding occurred during the peak flood period but with gradual recession of flood water, it moves towards the east.

5.2.2. 11th September Inundation

The depth map of 11th September (Fig.5-10) inundated area is showing maximum depth of more than 3m in the eastern and some in the central part. The inundated parts in the central and south central parts also have depth more than 3m and rest of the western, south western and north western parts have minimum water depth of 1 to 2m. Therefore areas in the western, south western and north western parts are comparatively less affected than the east on this date because of less water depth. This also indicates a specific pattern or trend in the region and as it receded from the inundated areas of 4th September, the depth has increased.

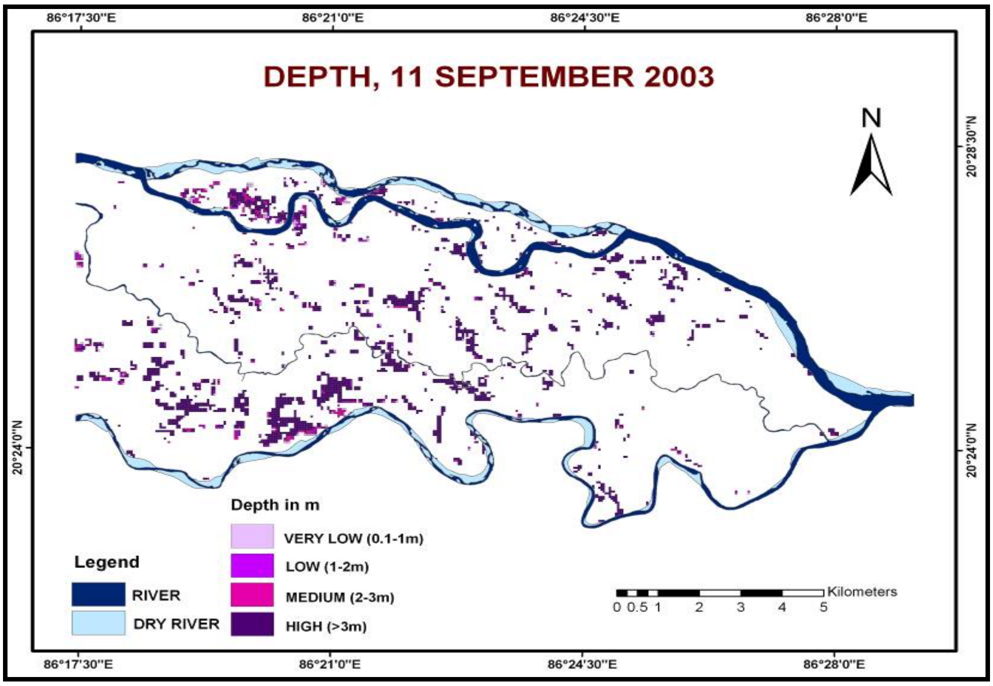


Figure 5-10 11th September depth (Area flooded on 11th and 4th September)

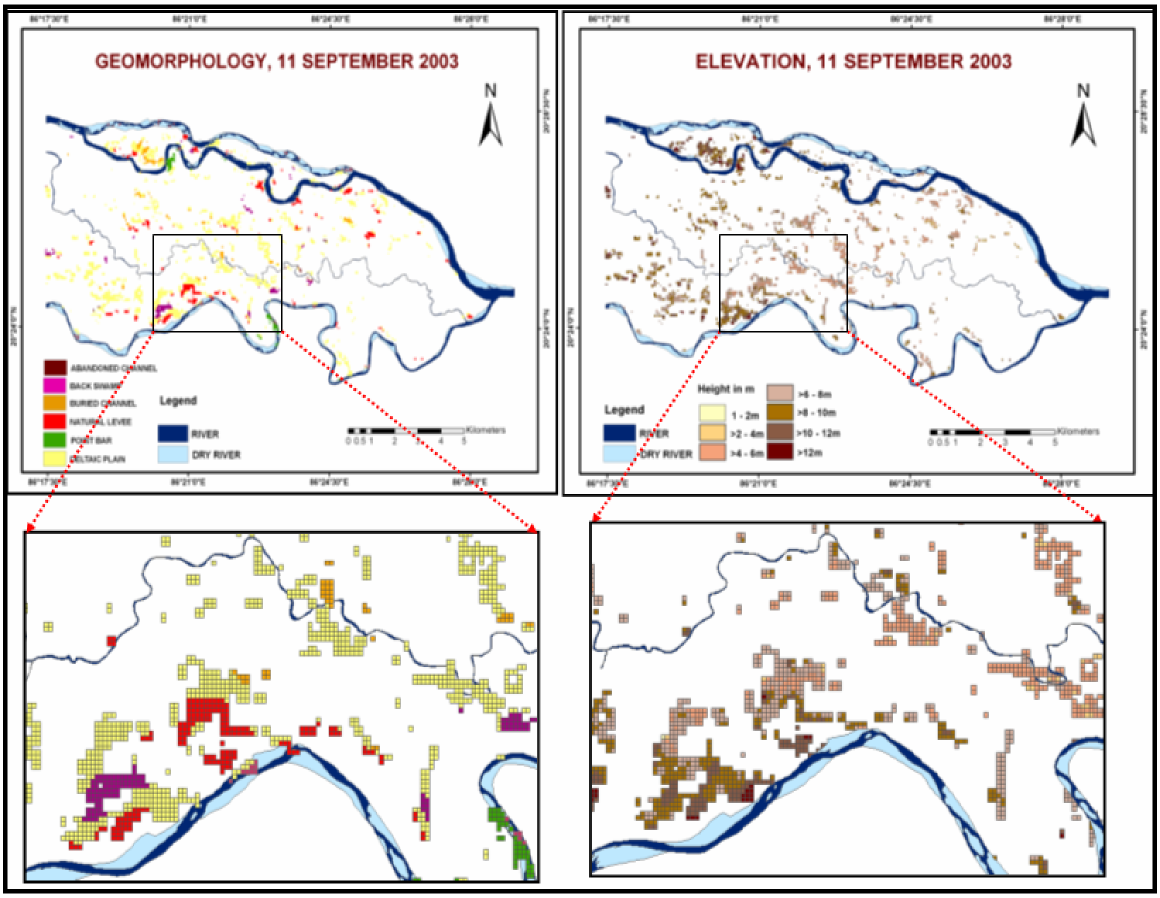


Figure 5-11 11th September Geomorphology and Elevation of the Extra Area

The marked area (Fig.5-11) has geomorphology of mainly deltaic plain with levee, back swamp, buried channel and point bar with levee areas having 7 to 10m or more than 10m of elevation and thus indicating higher areas. Back swamps and buried channel have elevation from 4 to 6m and some grids above 5m. Deltaic plains are usually lowlands and thus have low elevations from 3 to maximum of 7m. The depth map indicated that these elevated areas of levees and point bars have water depth of less than 3m in most of the places except for few areas which are due to the breaching or overflow of water as it lies near to the river. Deltaic plain have depth more than 3m as they are already lowlands. The inundated areas of 11th September are showing deltaic plain as its dominant feature together with few levee and point bars with the elevation varying from 3 to 10m predominantly. This also states that depth is increasing from the west to east because of the characteristics of its geomorphic feature which also indicate the elevation of the area. The general trend of inundation is showing movement of water gradually towards the east in the flat lands of plains and back swamps and buried channels.

Table 5-5 Area (sq.km) of different features on 11th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.02
Back swamp	0.49
Buried Channel	0.54
Levee	1.34
Point Bar	0.28
Deltaic Plain	6.68

Landuse	Area in sq.km
Kharif Crop Land	4.24
Rabi Crop Land	0.21
Two Crop Area	2.19
Plantation	0.04
Open scrub Land	0.02
Lakes and Ponds	0.01
Rural Built Up Area	2.63
Agricultural Fallow	0.005

Classes of Elevation (m)	Area in sq.km
1 – 2	0.1
>2 – 4	0.1
>4 – 6	1.87
>6 - 8	2.91
>8 – 10	2.8
>10 – 12	1.40
>12	0.36

The dominant landuse of the inundated area of 11th September (Table5-5) is kharif crop land with about 4.24 sq.km areas and the dominant geomorphic feature is deltaic plain with about 6.68 sq.km areas. Therefore major part is agricultural land with levees occupying the next maximum area of about 1.34 sq.km areas with the landuse of rural settlements being the next major landuse after kharif cropland with about 1.34 sq.km areas. Elevation of the area is mainly from 7 to 10m covering about 5.7 sq.km area but some portion are also showing lower elevation of less than 3 or 4m. Therefore, this region is comparatively lower than the inundated areas of 4th September which proves the flood movement from west to east. Some figures (Fig.5-7) are given below depicting the character of the region.

Figure 5-12 Breaching Point in the Chitrapala River

1. Breaching point in the embankment
2. Overflow of river water during flood have make muddy roads
3. Road on the embankment near the breaching point

5.2.3. 13th September Inundation

Maximum area during this date is showing quite deep water above 3m particularly in the eastern part (Fig.5-13), therefore it indicates that although the flood water is receding, some of the grids are facing extreme inundation problems like in the central and the eastern part with the central part having depth more than 3m while towards the east it is very high except for few area or grids in the south eastern part where the depth is less than 3m. Most of the western and north western parts are still showing inundated areas but with depth varying from less than 1m to 3m.

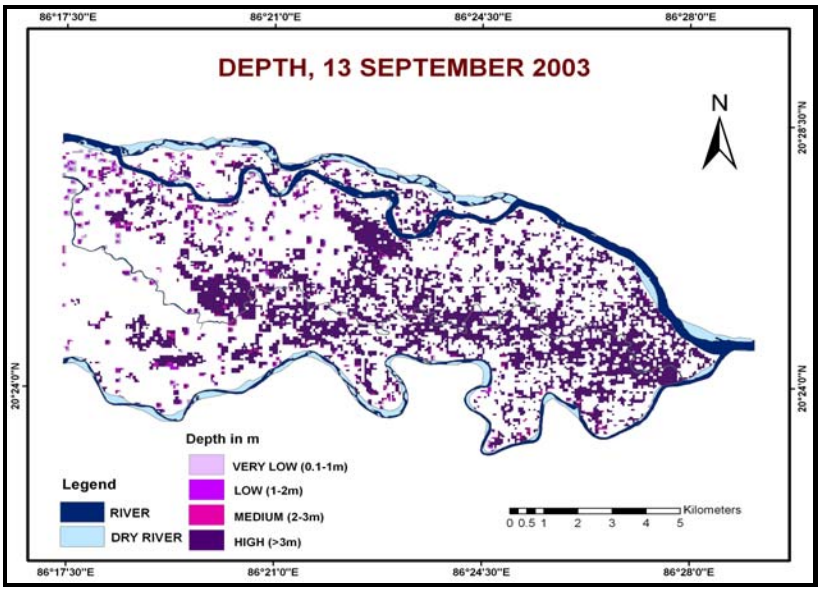


Figure 5-13 13th September depth (Area Flooded on 4th, 11th and 13th)

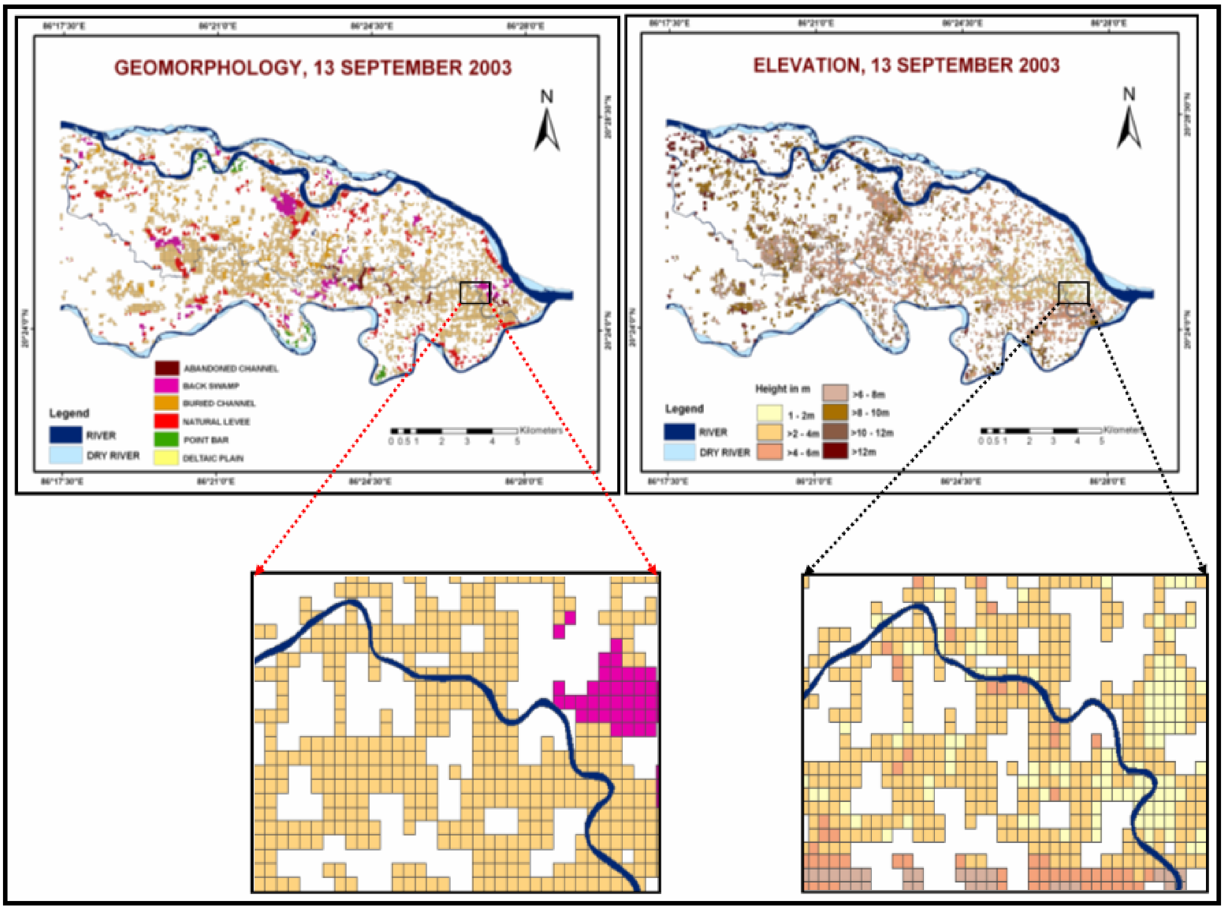


Figure 5-14 13th September Geomorphology and Elevation of the Extra Area

The marked area (Fig5-14) has geomorphic features of deltaic plain and the back swamp with maximum elevation of 5m. The back swamp area which is usually low has the elevation of less than 2m and the deltaic plain region has elevation from 1 to 6m and thus being a low region it has deep flood water accumulation in these areas. The general trend in the water depth is from west to east and this date usually shows different types of features like abandoned channels with 3 to 5m elevation and these areas are also showing more depth of water over 3m. Most of the area is deltaic plain with the elevation varying from 12 to 3m from west to east according to the slope of the land. In the north central part there are back swamps with the elevation ranging from 4 to 6m and the depth is above 3m as they already remain inundated. The levees are also located at higher elevation above 8m and thereby the depth of water is also little low here of about 3 m. Towards the east the elevation decreases to less than 2m and showing mainly deltaic plain region or the back swamps with deep flood water inundation of above 3m. Only in small portion in the south east, elevation above 10m or 7 to 10m is observed which are mainly levees and point bars and thus indicates naturally the higher region. These areas also show low flood depth of less than 3m i.e. low and medium flood depth respectively. Thus it is also proving the same trend of maximum depth towards the east with low elevation and plains and back swamps as major features which usually are the main causes of heavy flood here together with the slope towards the sea in this part.

Table 5-6 Area (sq.km) of different features on 13th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.55
Back swamp	2.12
Buried Channel	1.21
Levee	4.77
Point Bar	0.48
Deltaic Plain	25.15

Landuse	Area in sq.km
Kharif Crop Land	17.96
Rabi Crop Land	0.5
Two Crop Area	7.49
Plantation	0.14
Open scrub Land	0.07
Lakes and Ponds	0.23
Rural Built Up Area	7.18
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	1.21
>2 – 4	4.77
>4 – 6	8.2
>6 - 8	10.29
>8 – 10	6.09
>10 – 12	2.77
>12	1.05

The dominant landuse (Table 5-6) of the area is kharif crop land or paddy with about 17.96 sq.km areas and the minimum of scrublands of less than 0.07 sq.km areas. Two cropland area is also quite prominent here and thus signifying different types of agricultural pattern in this portion of inundation together with the settlements with more than 7 sq.km coverage by both of them. Dominant geomorphic feature of the area is deltaic plain with 25.15 sq.km area supporting most of the paddy cultivation and the least dominant feature is point bar with less than 0.5 sq.km area. Some back swamps and buried channel are also found here but levees are more dominant than these features with about 4.77 sq.km area. The elevation of this potion is mainly from 5 to 10m with about 24.5 sq.km area. There are major areas of 3 to 4m elevation in some parts.

5.2.4. 20th September Inundation

This is the day of 2003 when the flood has almost receded and the area which are under water during this stage are either very low area or areas just near to the river boundaries and some scattered areas in the west with very low flood depth of less than 2m particularly in the north west (Fig 5-15). But very distinctly from the central towards the eastern part, depth is still above 3m and most of the area here is inundated although the flood water is receding, except in very little area in the south east where the depth is low varying from 1 to 3m. So this inundated area indicates the region which remains inundated throughout the entire flood period starting from the 4th September i.e. the peak flood period up to 20th of September, the lean flood period. But depth map reveals that water accumulation is high in this part and it is the most affected area in the entire region. Slope of the land together with breaching are the main causes for the damage in this part.

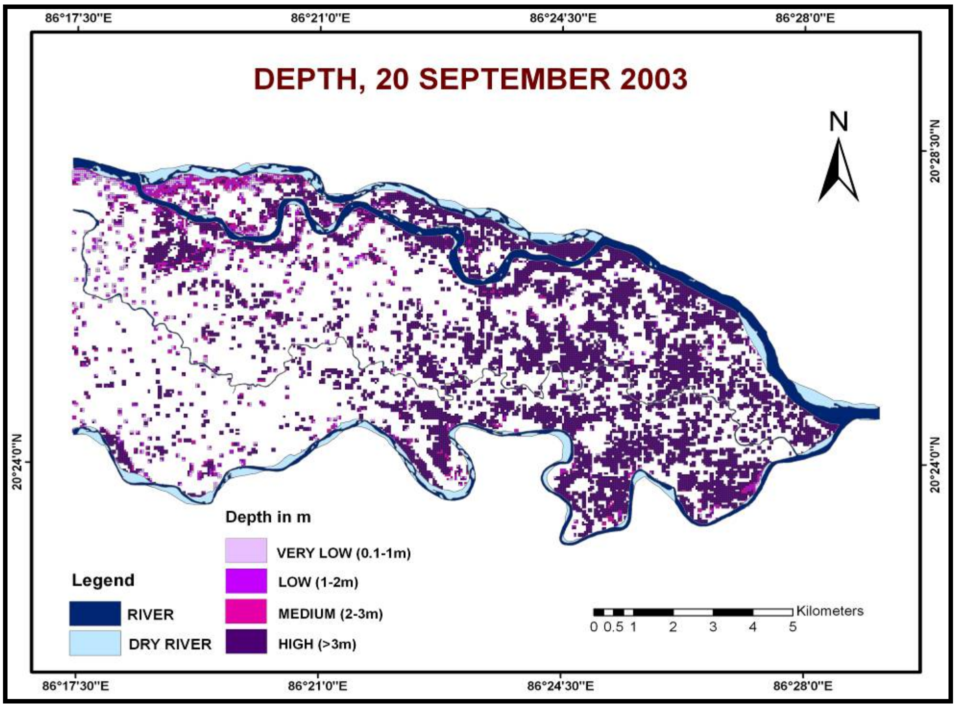


Figure 5-15 20th September depth (Common Area Flooded on All Dates)

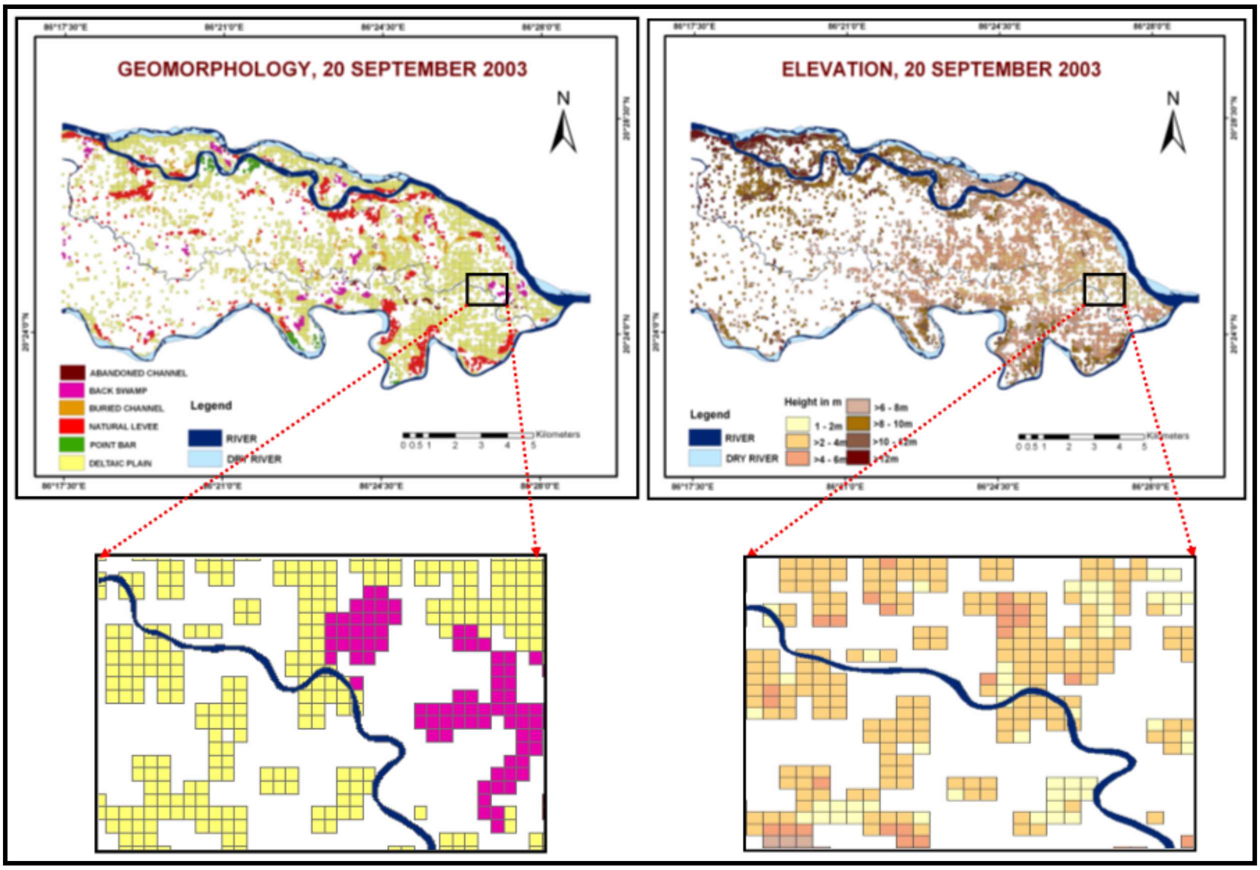


Figure 5-16 20th September Geomorphology and Elevation of the Extra Area

The selected area of the geomorphology map (Fig.5-16) is showing the general overview of the entire area mainly in the eastern side. The geomorphology reveals that the area has predominantly deltaic plain as its major feature together with the back swamp. The elevation is therefore very low as indicated in the elevation map which is mainly below 2m and somewhere 2 to 4m or above 4m. The depth map also supports the low elevation and inundated feature of the region as it is showing above 3m depth in this region. This also explains that these areas are so low, that they remain inundated for the entire flood period from 4th to 20th September. Geomorphic features found in this inundated parts of 20th September includes levees, back swamps, point bars, deltaic plain, abandoned channel, and buried channel with the elevation varying from 10m in the few portions of the north west to less than 2m in the east. The reason for the inundation of the levees and point bars are because of their location just beside the river banks which has overflowed the bank but the depth of water is low due to high elevation. Some deltaic plain in the northwest is also showing high elevation of 10m but still inundated are because of the same reason of being located at the side of the river which has overflowed the land, but the depth is medium to low of less than 3m.

Table 5-7 Area (sq.km) of different features on 20th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.34
Back swamp	1.63
Buried Channel	1.31
Levee	6.71
Point Bar	0.75
Deltaic Plain	31.1

Landuse	Area in sq.km
Kharif Crop Land	19.49
Rabi Crop Land	0.44
Two Crop Area	10.04
Plantation	0.18
Open scrub Land	0.18
Lakes and Ponds	0.15
Rural Built Up Area	11.51
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	1.35
>2 – 4	5.53
>4 – 6	10.94
>6 - 8	10.4
>8 – 10	8.52
>10 – 12	4.77
>12	2.10

As this date has the lowest flood inundation, therefore it indicates the area with minimum elevation or geomorphic features supporting inundation. Dominant landuse is definitely kharif crop lands with 19.49 sq.km area but this region also has many settlements which cover 11.5 sq.km area and two crop land area with a coverage of 10 sq.km (Table5-7). The dominant geomorphic feature is obviously deltaic plain with more than 31 sq.km area which proves why this area indicates major threat from flood. The elevation of the area is mainly from 5 to 8m with more than 21 sq.km area under this elevation and even about 7 sq.km area with 1 to 4m elevation which proves the reason of its flooding even at the least flooded day.

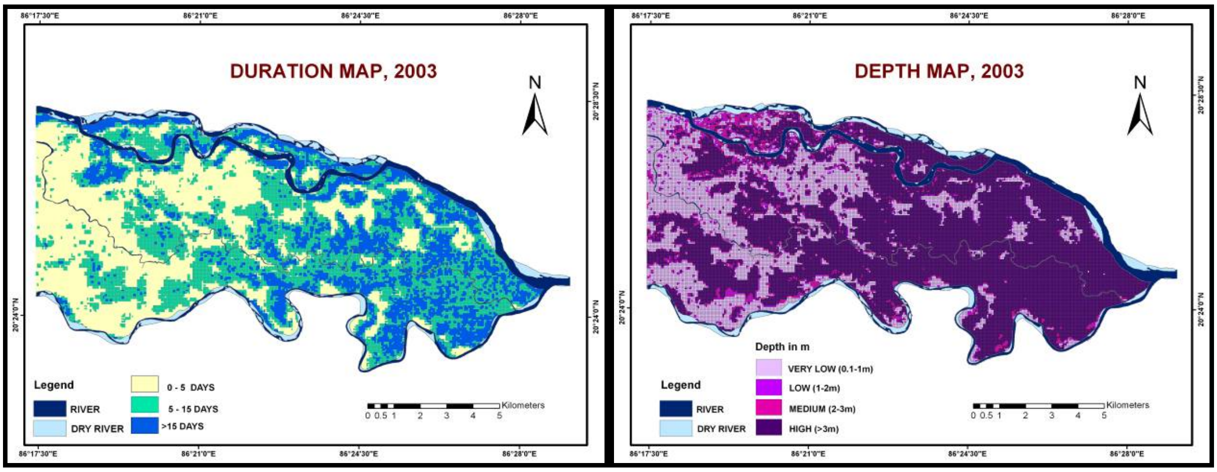


Figure 5-17 Duration and Depth Maps of 2003

The duration map (Fig.5-17) of overall 2003 is showing the trend of minimum duration of less than 5 days in the western part to the maximum of more than 15 days in the east following the trend of slope from west to east and thus proving the recession pattern of the area as supported by the geomorphology and the elevation of the entire land. And from the summarisation of the depth of four days flood image it has been found that low depth of flood in the west corresponds to the low duration of flood which gradually increases to maximum depth of flood in the east with maximum duration of flood water inundation. For the entire flood period of 2003, i.e. 4th, 11th, 13th and 20th September have shown clearly decreasing trend of flood duration and depth.

So after the analysis of the entire flood period of 2003, it can be concluded that the movement of the flood water is taking the general trend of moving from high to low land i.e. from west to east towards the sea following the slope which is also supported by the geomorphic features, as deltaic plains and back swamps are always low lands and remain inundated than the levees and point bars. Therefore, the recession from the peak flood period to the lean flood period which has been assessed by showing the extra inundated area in each date has proved the pattern of inundation with respect to the geomorphology and elevation and thus explaining the variation of depth in the entire region.

5.3. Inundation Pattern for 2006 Flood

2006 flood images include 4th August, 19th August and 26th August Radarsat images. Among these, 26th August (Fig.5-18) had the maximum flooded area and 4th August was the lean flood day. But there is not much significant difference between these dates regarding the flood extent and this flood has the longest duration as obtained from the images but not as destructive as the 2003 flood. As the images for the entire flooded period is not available, therefore recession pattern could not be shown here in this year. It is showing the increasing trend during this period up to 26th of August, i.e. progression of the flood water.

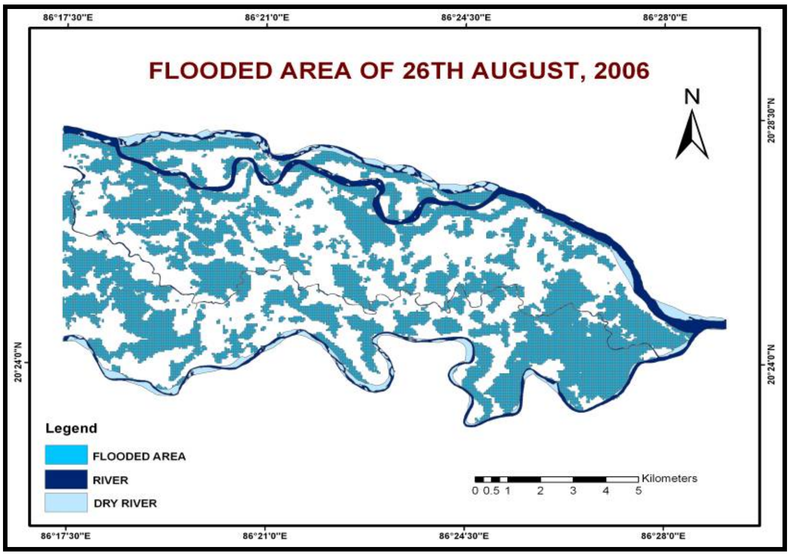


Figure 5-18 Inundated area of Maximum Flood Day of 2006

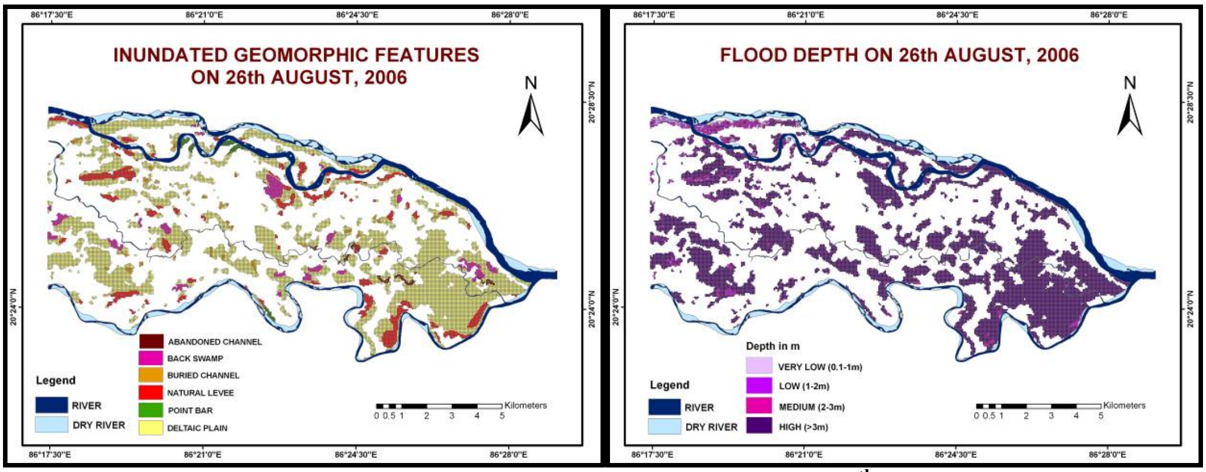


Figure 5-19 Inundated Geomorphic Features and Flood Depth on 26th August, 2006

The geomorphic features inundated (Fig. 5-19) were comparatively less than 2003 flood as the flood extent of 2006 was less. Deltaic plain area was under maximum depth of water of more than 3m in the eastern and the south western part. Levees were found in few areas of south east, south west and north west. Here the water depth varies from low to medium with 1to 3m depth. Therefore the levees are representing little higher areas which resulted in relatively low flood depth. Back swamps are showing inundation under maximum flood depth as they are low areas. Other features found under inundation are abandoned channels and buried channels which are also showing flood depth of more than 3m.

Table 5-8 of Inundated Geomorphic Features (sq.km) and Flood Depth (sq.km) on 4th August, 2006

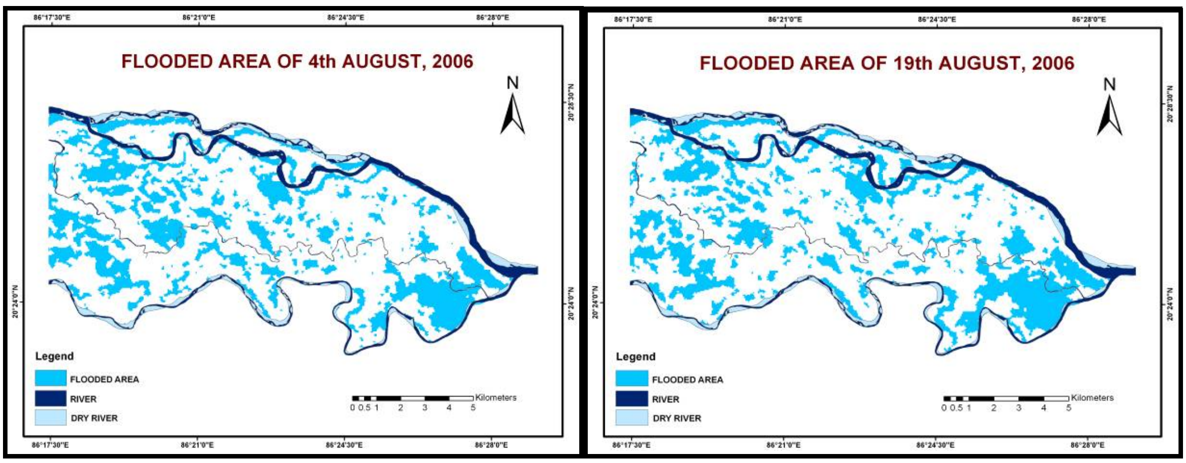
Geomorphic Features	Inundated Geomorphic Features (sq.km) for 4th August Flood	% of Units Inundated
Abandoned Channel	0.43	36.6
Back swamp	2.19	41.71

Buried Channel	0.88	18.39
Levee	5.64	30.79
Point Bar	0.49	23.96
Deltaic Plain	31.84	37.12

Depth in m	**Flood Depth (sq.km) for 4th August Flood**
0 – 1	0.76
1 – 2	1.19
2 – 3	1.9
> 3	37.59

The Table 5-8 is showing geomorphic features that were inundated on 4th August flood and also the flood depth of the inundated area on that day. Deltaic plains are found inundated in maximum area of about 32sq.km and covering 37% of the area. Levees covered about 5.5 sq.km area with 31% of inundation and abandoned channels inundated in 0.5 sq.km area with 36.6% of inundation and back swamps cover about 2.19sq.km area with about 42% of inundation. Flood depth of more than 3m is found in maximum area of more than 37.5sq.km area and 0 to 1m depth water is found in about 0.75 sq.km area. 1 to 2m flood depth covers 1.9 sq.km area and 2 to 3m flood depth covers about 2sq.km area. Back swamps are found mostly in maximum flood depth area of more than 3m while levees are found within the low or medium flood depth of 1 to 2m or 2 to 3m. Abandoned channels cover only 0.43sq.km of area but the percentage of inundation is high with 36.6%. Point bars also cover small areas as they represents higher region. Maximum inundation has been caused to the back swamps with about 42% of the area followed by deltaic plain and abandoned channel with 37.12% and 36.6% of inundation respectively. Abandoned channels, buried channels and back swamps which are the highly inundated regions comprise a small area with respect to other geomorphic features but the percentage of inundation is high.

In order to show the progression of flood with the extra area that was inundated on each day, it is necessary to show the total area that was flooded on each day of 2006 (Fig.5-20).



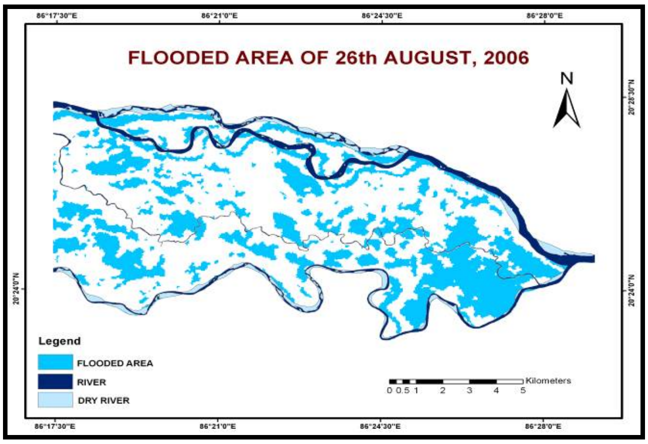


Figure 5-20 Original Flooded Areas on Each Date of 2006

The map shown below (Fig.5-21) indicates that the flooded areas of 4th August are the areas which were flooded first and are common for all the dates. On 19th of August, flood water increases and the area it is showing is the area of this day only and its total flooded area will be flooded area of 4th +flooded area of 19th August. Similarly the inundated area of 26th August as shown in the map is the extra area which was flooded on this date of maximum flood and the total flood area of this date includes the inundated area of all the three dates. Therefore as 2006 is showing progression of flood water, 4th August in the Fig. 5-21 is showing the area which remains flooded for 4th August, 19th August and 26th August. 19th August is showing the area which was flooded on 19th and 26th August, but not on 4th August. And 26th August is representing the area inundated only on that day and not on other dates. The total flooded area of 26th August is the flooded area of 4th August + flooded area of 19th August + flooded area of 26th August as shown in the map below.

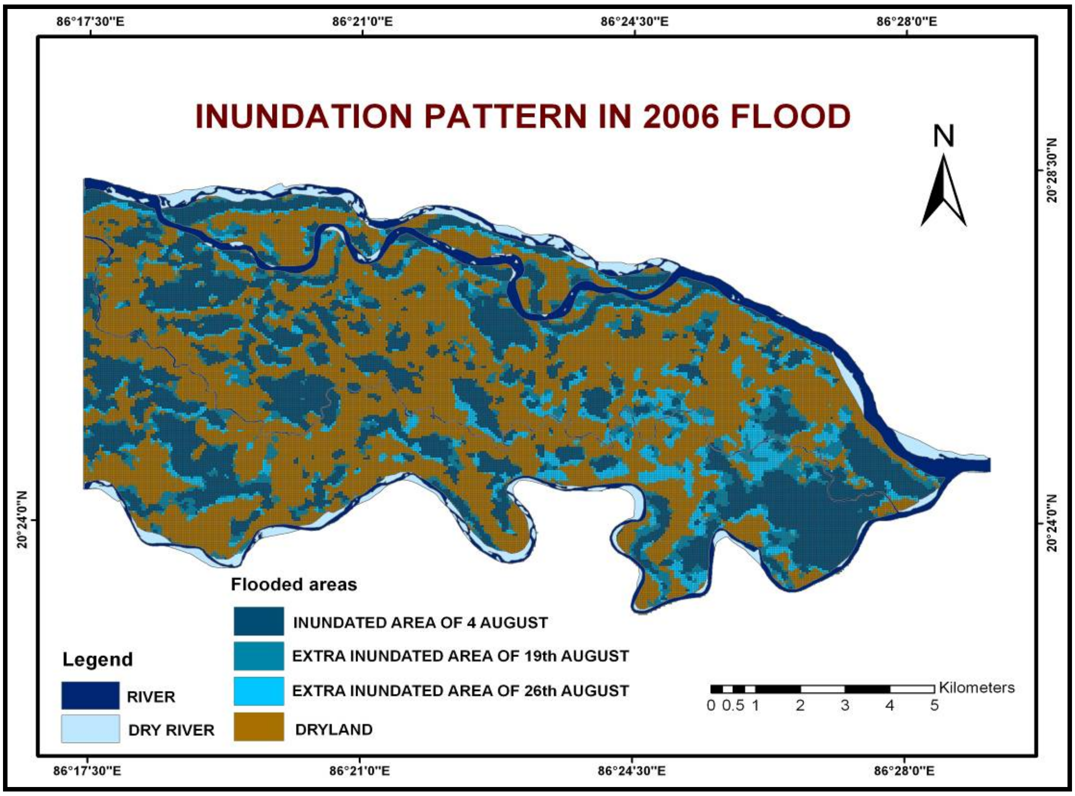


Figure 5-21 Inundation Pattern of 2006

The 2006 inundation pattern is showing (Fig.5-14) the flooded area of 4th August scattered in the entire area particularly in the east and it was the least flooded day. The western part is also showing flood on this date and also some northern and southern parts. Eastern part is showing complete inundation on this date. During 19th of August there are very few areas which are inundated on this date in addition to the 4th August. Inundation is found to have increased in the eastern part with some scattered areas in the central, northwest and south. On 26th of August there was sudden increase in the flooded area in comparison to the 19th as it is indicated in the image. This image is showing the increasing pattern and the general trend is from east to west. This is also very logical as the trend of increasing inundation is dependent on the geomorphology and the elevation of the area along with the landuse, depth and duration. Relation of all these parameters is discussed below with the explanation of the pattern or movement of flood water in the region.

5.3.1. 4th August Flood

This was the first date for 2006 and the inundation pattern is described below with relation to the depth, geomorphology and elevation.

4th August was the least flooded day for the year 2006 (Fig.5-22). Entire region was not flooded but few areas were affected at the first stage of flood. It can be clearly seen from the map that although many parts of the west were inundated, but the eastern part had maximum depth of water than the western part. The depth of water is low to medium in the west and northwest, as the elevation here is usually higher. But towards the east, only from the central part the region to the east, the region remains inundated with the flood depth of over 3m. Therefore it indicated deep water accumulation in these areas and it continued to the extreme east. The reason for flood in the west which has higher parts is due to presence of back swamps which get affected first because of their geomorphic characteristics. But west indicates low level of flood; therefore it is significant in relation to the elevation.

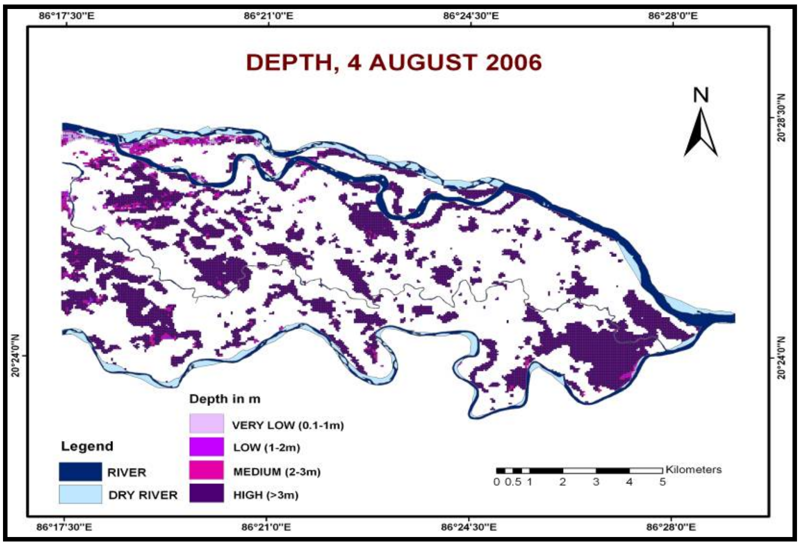


Figure 5-22 4th August Depth (Common Area Flooded on 4th, 19th and 26th)

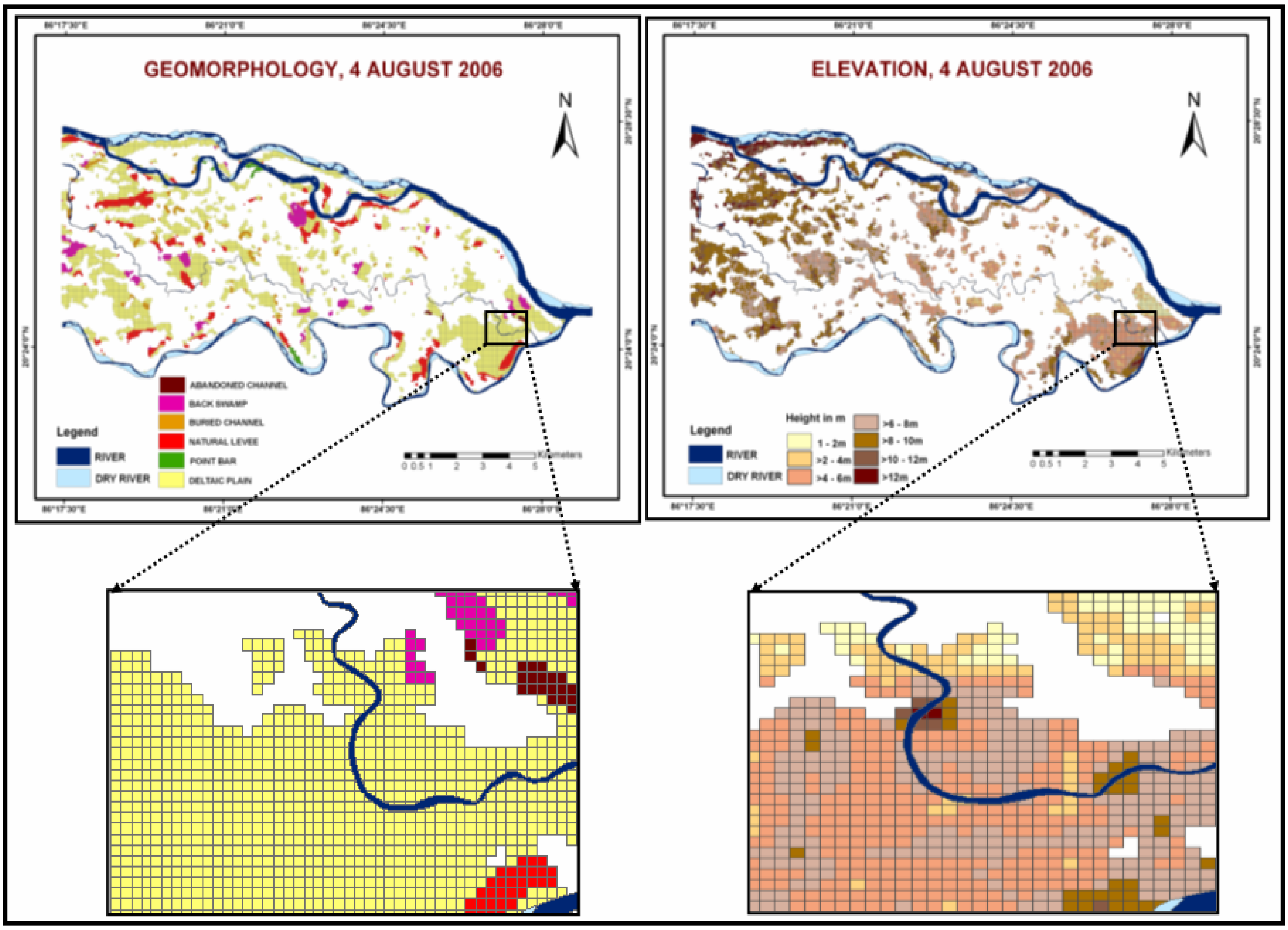


Figure 5-23 4th August Geomorphology and Elevation of the Extra Area

The marked area of the geomorphology map (Fig.5-23) is showing mainly deltaic plain in the extreme east of the region with some back swamps, levee and abandoned channel. Deltaic plains are usually at low elevation of about 2 to 4m or less than 2m and in some cases only up to 8m. There is also presence of a levee which was flooded with an elevation of 8 to 10m. This region was flooded mainly because of its location very near the river and thus overtopping of flood water has occurred. The back swamps and the abandoned channels have low elevation of less than 4m or 2 to 4m respectively and thereby gives the reason for its inundation as they already have low terrain features. The entire region has deltaic plain as its dominant feature which has flooded together with back swamps, buried channels and few levees. The back swamps moderate elevation in the west from 6 to 8m but the eastern part is dominated by the elevation of less than 2m or 2 to 4m in maximum. Most of the inundated region of 2006 has its elevation about 2 to 6m and this flood has occurred mainly because of breaching particularly in the west and central part. And the east central part has faced low flood mainly because of the absence of river and any breaching point there. From the depth map it is clear that water depth is much less in the western part which has higher elevation of less than 3m but the eastern part is heavily inundated with the flood depth of above 3m and thus it proves its relation with the elevation and also slope of the land which is from west to east.

Table 5-9 Area (sq.km) of different features on 4th August

Geomorphic Features	Area in sq.km
Abandoned Channel	0.19
Back swamp	2.11
Buried Channel	0.99
Levee	4.91
Point Bar	0.3
Deltaic Plain	26.47

Landuse	Area in sq.km
Kharif Crop Land	17.89
Rabi Crop Land	0.35
Two Crop Area	6.87
Plantation	0.14
Open scrub Land	0.19
Lakes and Ponds	0.31
Rural Built Up Area	9.28
Agricultural Fallow	0.005

Classes of Elevation (m)	Area in sq.km
1 – 2	0.93
>2 – 4	2.34
>4 – 6	6.83
>6 - 8	10.03
>8 – 10	9.76
>10 – 12	4.44
>12	1.85

The dominant landuse (Table 5-9) of the area is kharif crop land with more than 17.89 sq.km area and the next dominant feature is settlement with 9.28 sq.km area. This day mark the least flooded day but unlike 20033, 2006 images are showing increasing flood pattern from the beginning instead of flood recession. Therefore it indicated the area where flooding has started, not the areas through which flood water recedes. The dominant geomorphic feature is deltaic plain covering about 26.5 sq.km area levees with 4.91 sq.km area. Elevation of this region is mainly from 5 to 10m varying from west to east. Many low elevated areas are also found with less than 4m in some parts.

5.3.2. 19th August Flood

2006 represents the longest flood duration as it has continued for such a long time starting from 4th August to 19th August thereby it has affected the whole area for this entire period of 15 days continuously. Then according to the available dates, 26th September has the maximum flooded area and therefore it is taken as the peak flood date in this project.

19th August depth (Fig. 5-24) is showing minimum depth in the western and north western part of less than 3m from low to medium in some scattered areas but from the central part only it is showing more depth towards the east which is above 3m. On this date, there is little increase in the total flooded area than the 4th of August, which indicates that there is no sudden rise in the flood water which was continuing for these 15 days. So the increase is not much significant except for the eastern part where it is comparatively much more than the first date. The general trend of depth is supported by the geomorphology and the elevation of the region as low lands of deltaic plain and the back swamps will be mostly flooded and because of their soil condition also which area mainly clay or clay loam having less porosity, they cannot absorb water for long time so surface area of inundation also increases. Therefore the high elevated areas are also sometimes showing flooded as they have mostly plains, swamps and channels as their basic features.

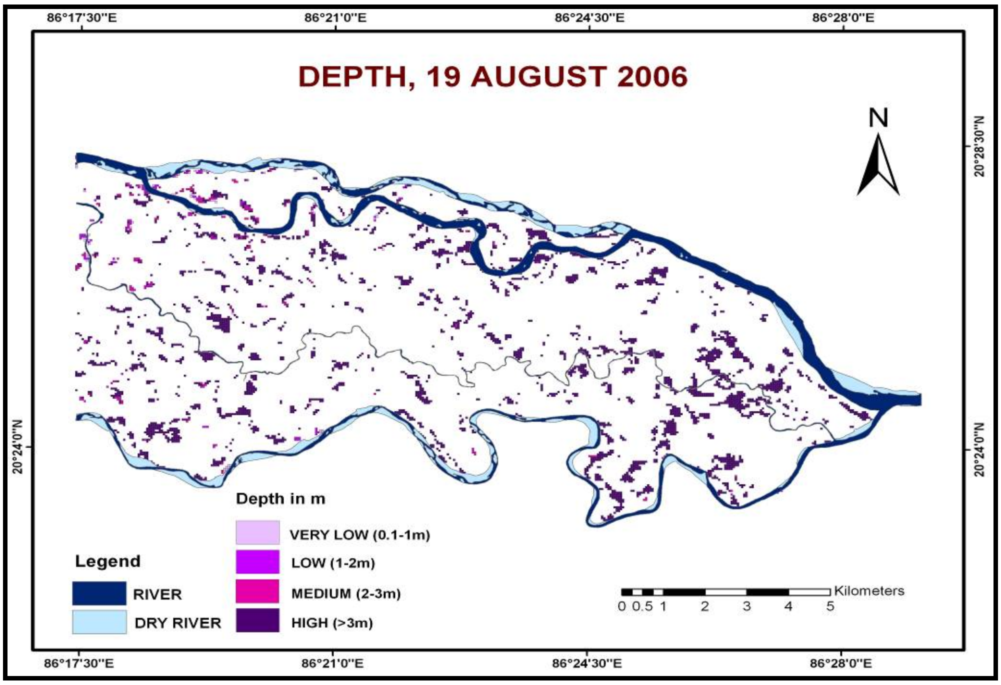


Figure 5-24 19th August flood depth (Area flooded on 19th and 26th August)

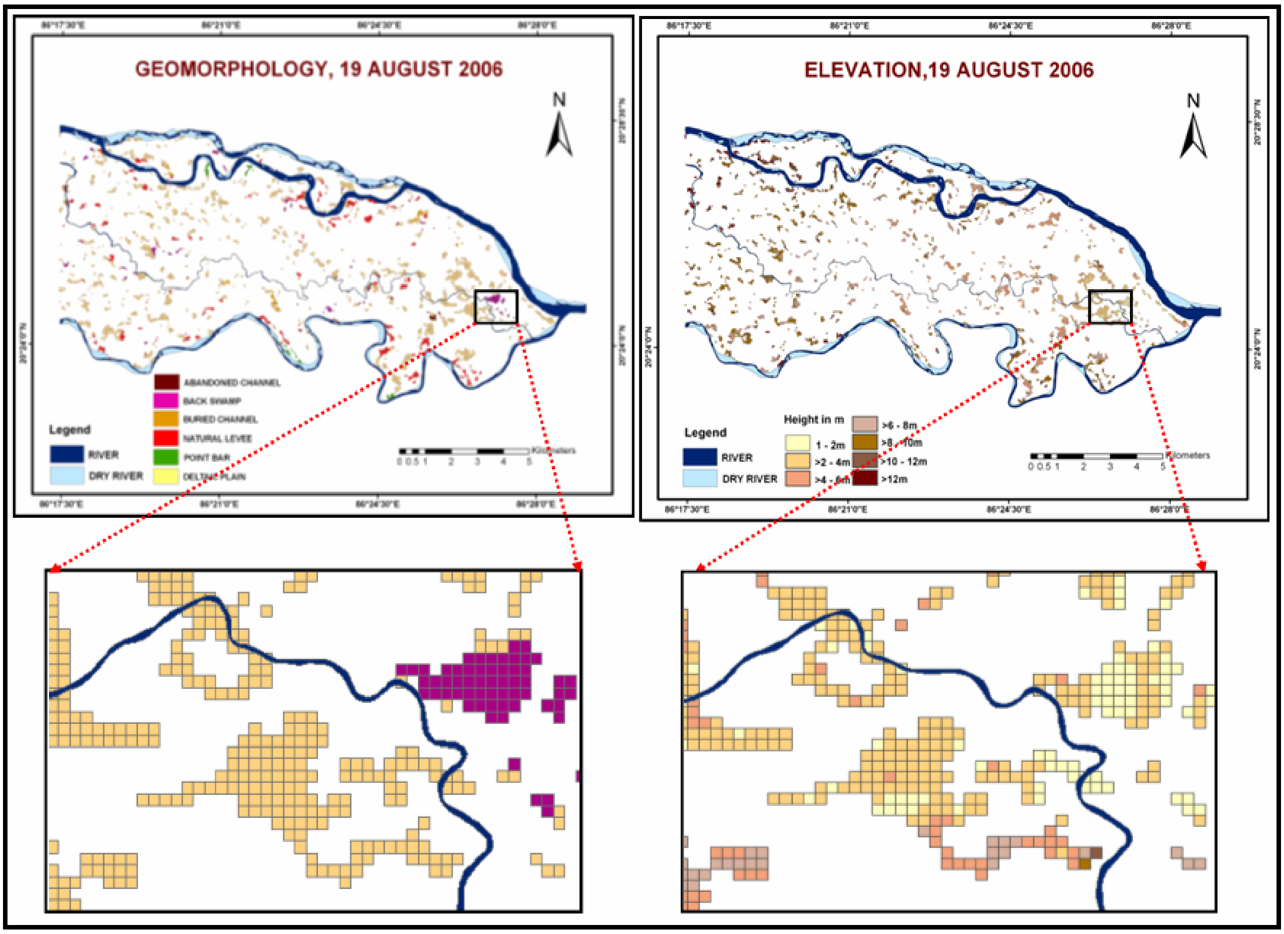


Figure 5-25 19th August Geomorphology and Elevation of the Extra Area

19th August represents the second day of flooding according to the image (Fig.5-25), but the extra areas which were flooded on this date was not much and although there is a general pattern of inundation but it is not much significant except for the little portion in the eastern part where it is showing comparatively more inundation than the first date. The marked area is showing deltaic plain and the back swamp which are the common features for the eastern part and their elevation varying from less than 2 to 4m and in some cases up to 6m. The entire area is showing different geomorphic feature of levees, buried and abandoned channels together but the predominant feature is always the deltaic plain and the elevation varies from more than 10m in the western part which gradually decreases in the central to about 4 to 6m and then further reducing to less than 2 or 4m. This elevation is supported by geomorphic feature of levees, abandoned channels in the west and buried channels and back swamps in the middle region to back swamps in the east. The whole region is deltaic plain; therefore its elevation varies accordingly from west to east. The depth map also reveals the same pattern of minimum depth in the west to maximum in the east.

Table 5-10 Area (sq.km) of different features on 19th August

Geomorphic Features	Area in sq.km
Abandoned Channel	0.14
Back swamp	0.45
Buried Channel	0.32
Levee	1.6
Point Bar	0.2
Deltaic Plain	7.54

Landuse	Area in sq.km
Kharif Crop Land	4.51
Rabi Crop Land	0.01
Two Crop Area	2.8
Plantation	0.05
Open scrub Land	0.08
Lakes and Ponds	0.02
Rural Built Up Area	2.71
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.35
>2 – 4	1.31
>4 – 6	1.99
>6 - 8	2.67
>8 – 10	2.56
>10 – 12	1.26
>12	0.5

This date is showing very little area of extra flooding than the 4th august. Therefore there is no such dominant feature here as the extra flooded area on this date is very less. Still the dominant feature on this day was kharif crop land with 4.51 sq.km area (Table 5-10). Dominant geomorphic feature is deltaic plain with 7.54 sq.km area. This feature also signifies that increase of water has led to its movement in the deltaic plains mainly. Elevation is 7 to 10m in most parts with 5.23 area coverage and also some areas with less than 6m.

5.3.3. 26th August Flood

26th of August represents the maximum flood among these three images. As all the flood images for the entire 2006 flood period was not available, therefore it is not possible to find out the peak flood period and thereby to identify the recession from it. The general inundation shows that this date experienced more inundation than the previous two days of 4th and 19th August.

The flood depth map is showing the minimum depth of less than 3m from low to medium depth in the west to more than 3m in the east (Fig.5-26). There are very little portion in the west and northwest where the flood depth is below 3m. From the west central part only the flood depth increases towards the east following the elevation of the land. But 26th August represents mainly increase in the area of flood water mainly in the east. In the western part depth is quite less and in the north central part it is even lesser. But towards the east it increases in area as well as depth. The geomorphology and the elevation also supported this trend. But this increase in the inundated area is more compared to the 19th of August and therefore it can be said that flood inundation is increasing in case of 2006 flood till this date since 4th August and thus representing the maximum duration of flood in comparison to 2003 and 2008.

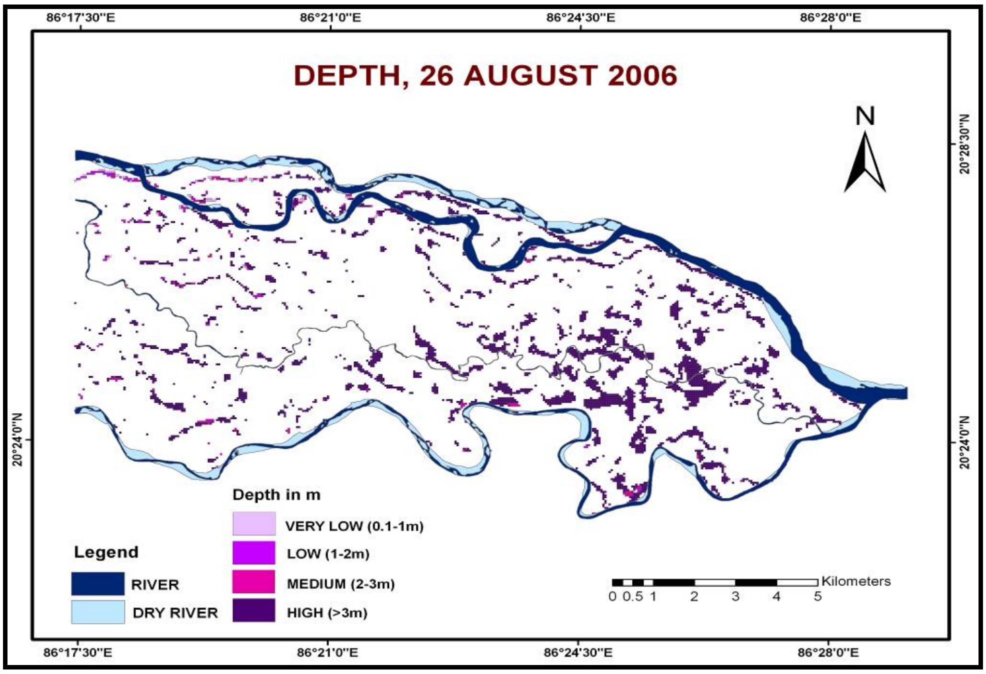


Figure 5-26 26th August flood depth (Extra Area Flooded only on this Date)

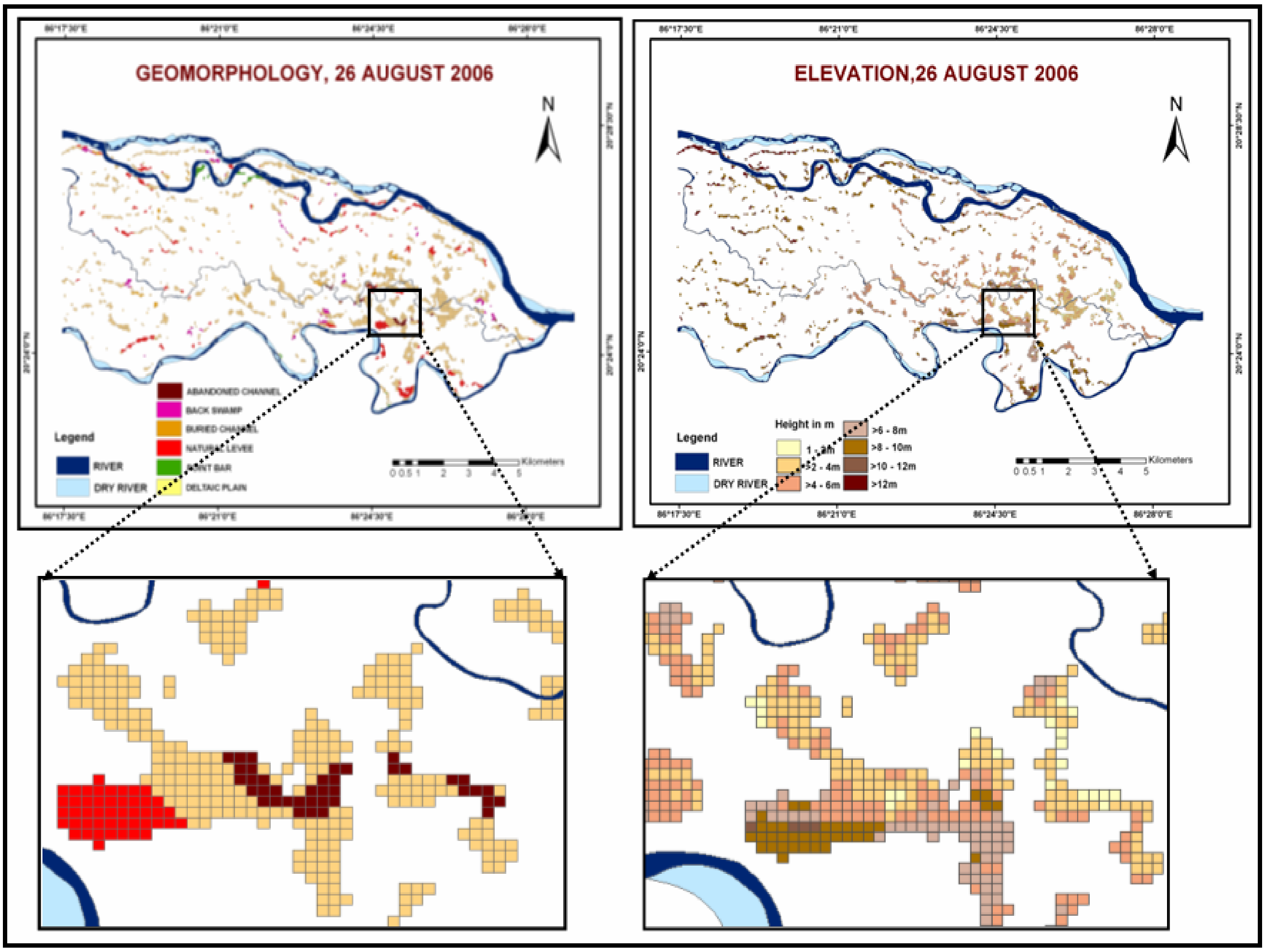


Figure 5-27 26th August Geomorphology and Elevation of the Extra Area

Geomorphology of the marked area (Fig.5-27) is showing deltaic plain, levee and abandoned channel and the elevation of the area is showing mainly 6 to 8m for the levees and some parts of the deltaic plain while the abandoned channels have elevation less than 4m and in some parts less than 2m. So it is clearly indicating the difference between the levees and the abandoned channels. For the entire region, the parts which were inundated during this date have deltaic plain as very dominant feature with very little area of levees in the west and north and point bar in the north. Towards the east, in the central part there are some levees, back swamps and the abandoned channels. The geomorphic features supported the elevation of more than 10m or 8 to 10m in the west with gradual decrease in the middle of 4 to 6m to less than 2m in the east. Therefore regarding the geomorphology and the elevation, the trend is logical with levees having more heights and channels and back swamps much low in elevation. The depth of water also increases towards the east.

Table 5-11 Area (sq.km) of different features on 26th August

Geomorphic Features	Area in sq.km
Abandoned Channel	0.23
Back swamp	0.41
Buried Channel	0.34
Levee	1.62
Point Bar	0.21
Deltaic Plain	8.98

Landuse	Area in sq.km
Kharif Crop Land	5.51
Rabi Crop Land	0.09
Two Crop Area	3.14
Plantation	0.06
Open scrub Land	0.003
Lakes and Ponds	0.02
Rural Built Up Area	2.99
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.42
>2 – 4	2.09
>4 – 6	2.83
>6 - 8	2.73
>8 – 10	2.38
>10 – 12	1.10
>12	0.47

Although this date shows maximum flooded area among the three dates, but the extra area it inundated is not much than 19th of august. Dominant landuse feature is kharif cropland with 5.51 sq.km area (Table 5-11) as usual but it is not much dominant as the area coverage is less. Deltaic plains form the dominating geomorphic feature with about 9 sq.km area along with some levees. Elevation of the inundated area is varying from 3 to 10m with each category having less than 3sq.km area coverage from west to east. So this can be said that as flood water increases, it spreads and covers the adjacent areas which show the inundation more towards the east.

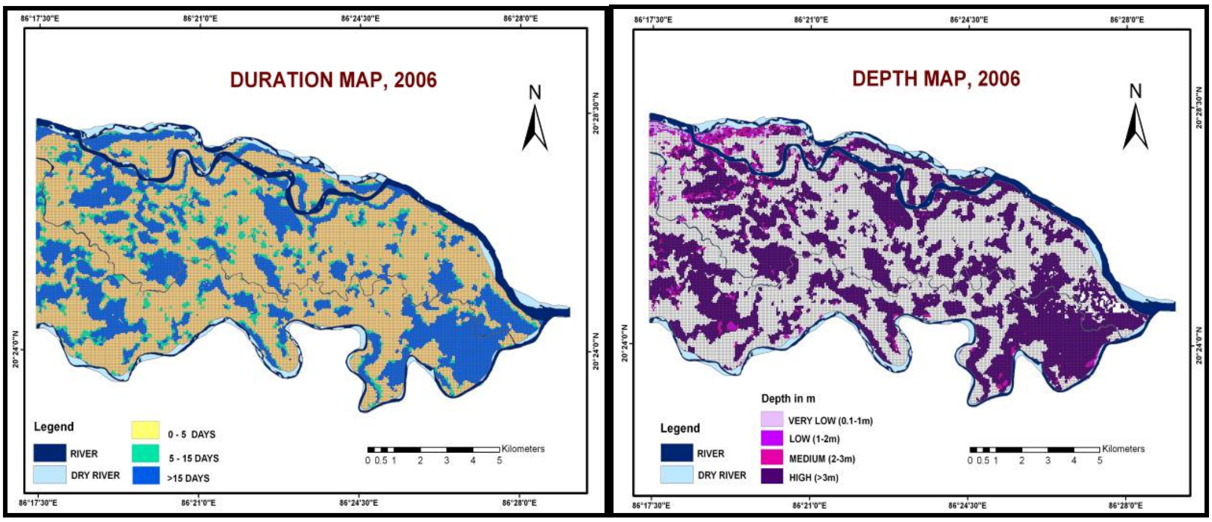


Figure 5-28 2006 Duration and Depth

The overall duration map of 2006 (Fig 5-28) has shown maximum areas of low duration flood of less than 5 days as the inundation pattern map of 2006 has shown that the total flooded area is much less than 2003 and area for medium flood duration i.e. 5 to 15 days is even less and comparatively greater areas of long duration flood particularly in the east and west. This also supported by the geomorphology of the region as major deltaic plain and back swamps are flooded. Although the duration is supported by the less flood depth in the west with short duration and more depth in the east also with long duration, it is not showing the trend of slope of the land. Many long duration areas have low depth in the west which is mainly due to the high elevation and more depth in the east with again long duration and low elevation. Therefore here the depth and duration are not relative but the elevation and geomorphology are the major controlling factor for the inundation. The general increase in the flood water for these three days is not clearly explaining the trend of increase which is because of the non availability of data particularly in the recession phase.

2006 flood experiences heavy rainfall as well as breaching from different sides which has caused flood even in the west from the initial date. So after analysing the water movement in the area it can be said that although the inundation pattern follows the slope and geomorphology of the land but have not clearly shown what will be the trend of inundation like the year 2003 while it was a long duration flood. It is mainly because of the non availability of the peak flood data together with the non availability of the recessional phase image which could have clearly explained the recession pattern or course of the movement of water.

5.4. Inundation Pattern for 2008 Flood

2008 flood includes the Radar images of 18^{th}, 20^{th} 22^{nd} and 24^{th} of September. The flood started from the 18^{th} of September which was the lean flood day and reached its peak on 22^{nd} of September. Within just five days this flood covered most of the study area and it was almost as destructive as the 2003 flood mainly because of its excessive extent. In this case, flood water increases till 22^{nd} of September with the maximum extent and then decreases little on the 24^{th}. Thus this 2008 flood also do not have the images for the recessional phase and the total flood duration for this year could not be assessed from the images as it covers only seven days of flood. But from the field survey it was known that the total duration of 2008 flood was more than 15 days, i.e. of long duration. Up to the peak flood date of 22nd September (Fig. 5-29), 2008 flood is showing progression.

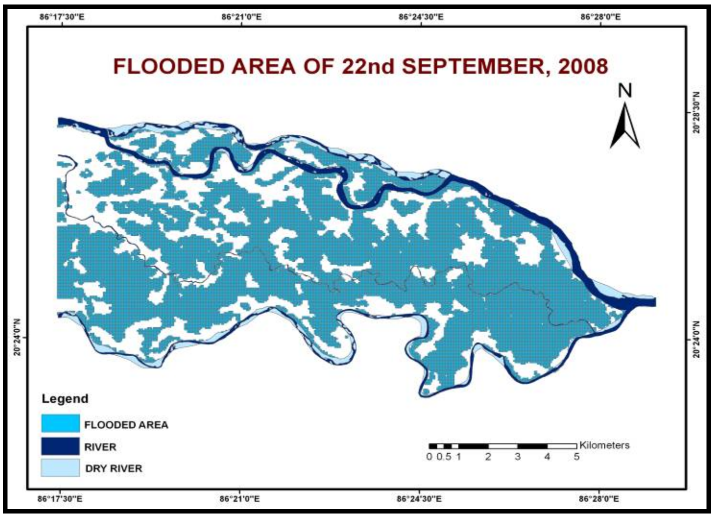


Figure 5-29 Inundated area of Peak Flood Day of 2008

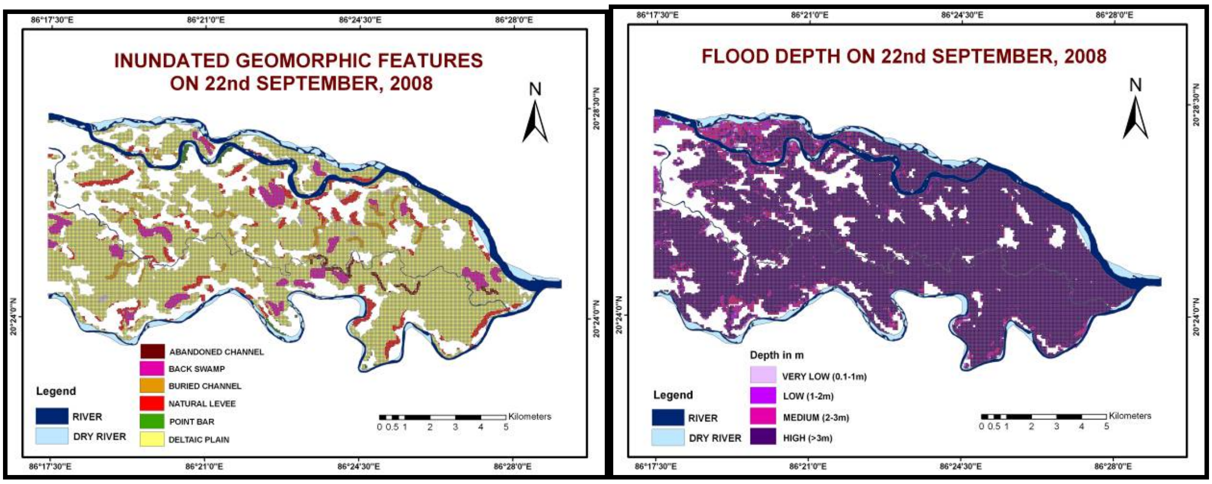


Figure 5-30 Inundated Geomorphic Features and Flood depth on 22nd September, 2008

Major portion of the study area was inundated on 22nd September. Almost the entire deltaic plain region (Fig. 5-30) and back swamp area was heavily inundated with flood depth above 3m. Levees found in some parts of the south east, south west and north west are showing low to medium depth of water as they little higher areas. Rest of the abandoned and buried channels are also showing maximum depth of water of more than 3m.

Table 5-12 Inundated Geomorphic Features (sq.km) and Flood Depth (sq.km) on 22nd September, 2008

Geomorphic Features	Inundated Geomorphic Features (sq.km) for 22nd September Flood	% of Units Inundated
Abandoned Channel	0.78	66.38
Back swamp	4.74	90.29
Buried Channel	2.2	45.98
Levee	5.5	30.03
Point Bar	0.51	24.94
Deltaic Plain	64.51	75.21

Depth in m	Flood Depth (sq.km) for 22nd September Flood
0 – 1	0.65
1 – 2	1.63
2 – 3	3.00
> 3	72.91

Geomorphic features which were inundated on 22nd September and the flood depths of that peak flood date are given in Table 5-12. Deltaic plains cover the maximum area of 64.51sq.km followed by levees with 5.5sq.km. Back swamps are showing inundation in 4.74 sq.km area but according to the percentage of inundation they are highest with more than 90% was drowned under deep flood water. Abandoned channel covers 1sq.km area and buried channels cover 2.2sq.km area. After back swamps deltaic plain was most affected by floods with 75% of inundation followed by abandoned channel and buried channel with 66.38% and 46% inundation respectively. Levees and point bars are showing least inundation of 30% and 25% respectively as they represent higher areas. Maximum flood depth is found in the major portion of the area with back swamps, abandoned and buried channels under high water depth. Flood depth with more than 3m is found in about 73sq.km area with medium, low and very low depth in 3sq.km area, 1.63sq.km area and 0.65sq.km area respectively.

To show the flood progression with the extra increased area inundated on each day, it is necessary to show the total flood extent of all the days of 2008 (Fig. 5-31).

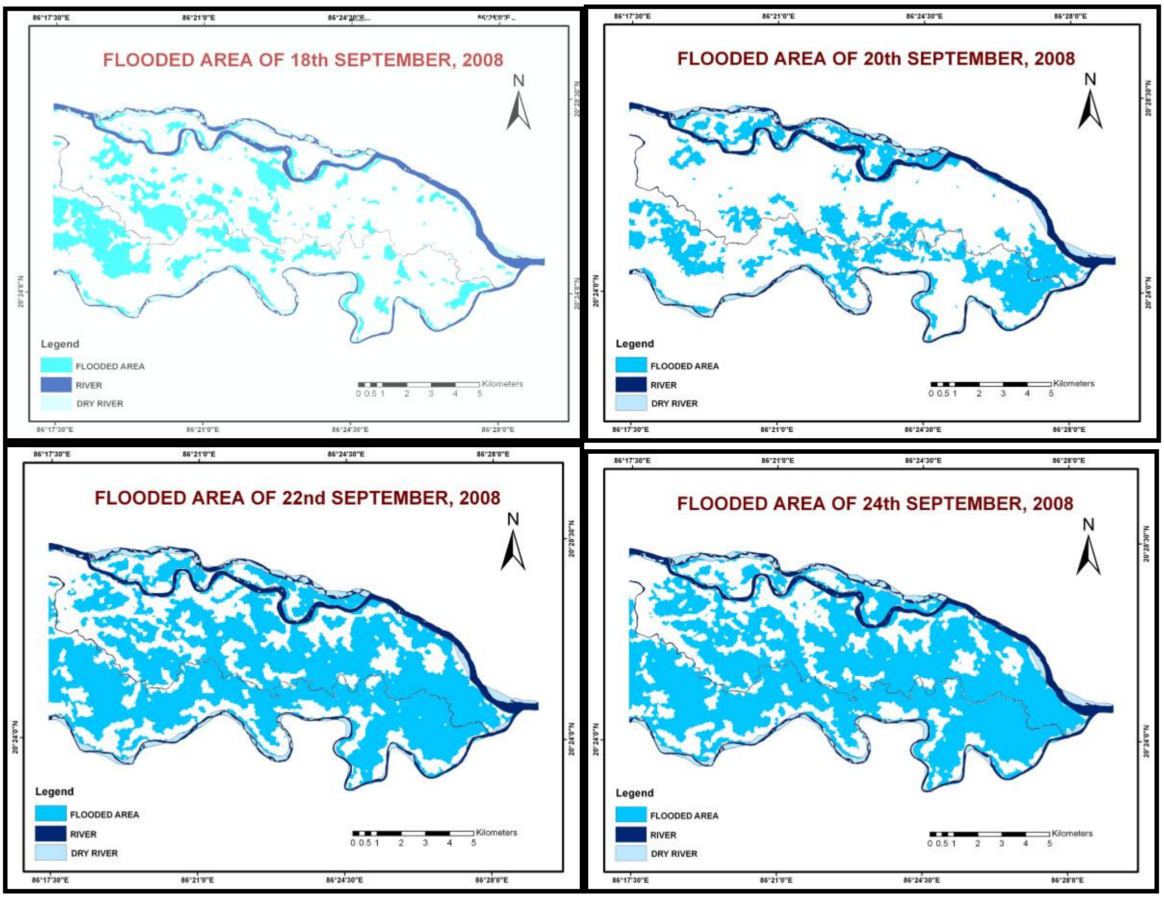


Figure 5-31 Flood Extent of 2008

18th September of 2008 had the least flood extent; therefore flooded area on this date is indicating common area which was flooded on all four dates of 18th, 20th, 22nd and some areas of 24th. 20th September represents the flooded area of 20th + flooded area 22nd + flooded areas of 24th (some portion of 24th, because flood started receding on this date). 22nd September was the peak flood day showing the area that was inundated only on 22nd and not on other dates. The total flood extent of 22nd September will be the flooded area of 18th + flooded area of 20th + flooded area of 22nd September shown in the Fig. 5-32. 24th September image is showing the recession for the first time in 2008. Therefore it represents the area which was inundated on this date only because water spreads out in the surrounding region on 24th, and was receded from some other areas. So it is showing is the extra area which was inundated after peak flood of 22nd September due to spreading of water in the adjacent areas (Fig. 5-32).

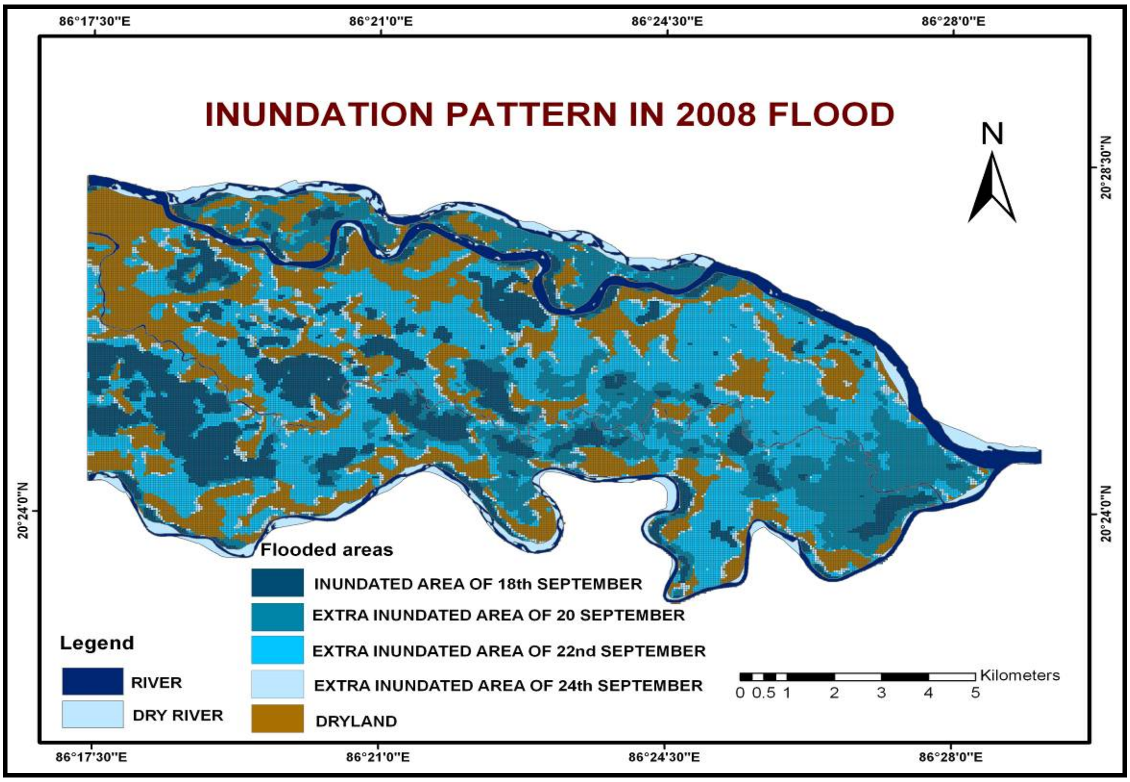


Figure 5-32 Inundation Pattern of 2008

According to the Fig.5-32, 18th of September is showing the flooded area mainly in the western part which means breaching has occurred in this region that has caused flood in the western and the central part. On 20th of September flood water increases towards the east and covered most of the areas in the east and north thereby here it follows the trend of moving in the low elevated parts. After two days the flood reached its highest point and covered most of the areas and extends from the west to the east. Some parts of northwest and west were out of the threat of flood and it represents much higher part of the region. But on 24th the flood started receding, and it spreads in some areas while it started receding from other areas. But recession in 24th was very insignificant and most of the areas remain inundated on this date. The trend of movement of water is from the west during this year and to the east, and then it spreads to the entire area. To understand its pattern, it is necessary to understand the geomorphology and the elevation of the area and its relation to the depth and duration.

5.4.1. 18th September Flood

2008 flood started from this date. So this date represents the least flooded day of the year 2008.
The depth map of 2008 (fig.5-33) is showing minimum flood depth of less than 2m in very small area in the northern part. But maximum depth is showing in the rest of the flooded area of this date. The flood water accumulation has occurred in the western part at the beginning and with some small patches in the central part. Although the elevation of the western part is higher than the east, but on this date western portion inundated first. This is because the accumulation of flood water has occurred in the relatively low area of the west, but the surrounding region of this inundated area is at the higher elevation. Therefore breaching has occurred in the levee here which has caused this relatively low area to be flooded. The inundation also occurred in the west central part in few areas which are relatively

lower. While the eastern part in this case is showing much less inundation as river from the eastern side has overtopped the bank in very small area. Geomorphology also supporting this inundation as the region has mainly deltaic plain, back swamps and buried channels which are characterised by lower terrain features.

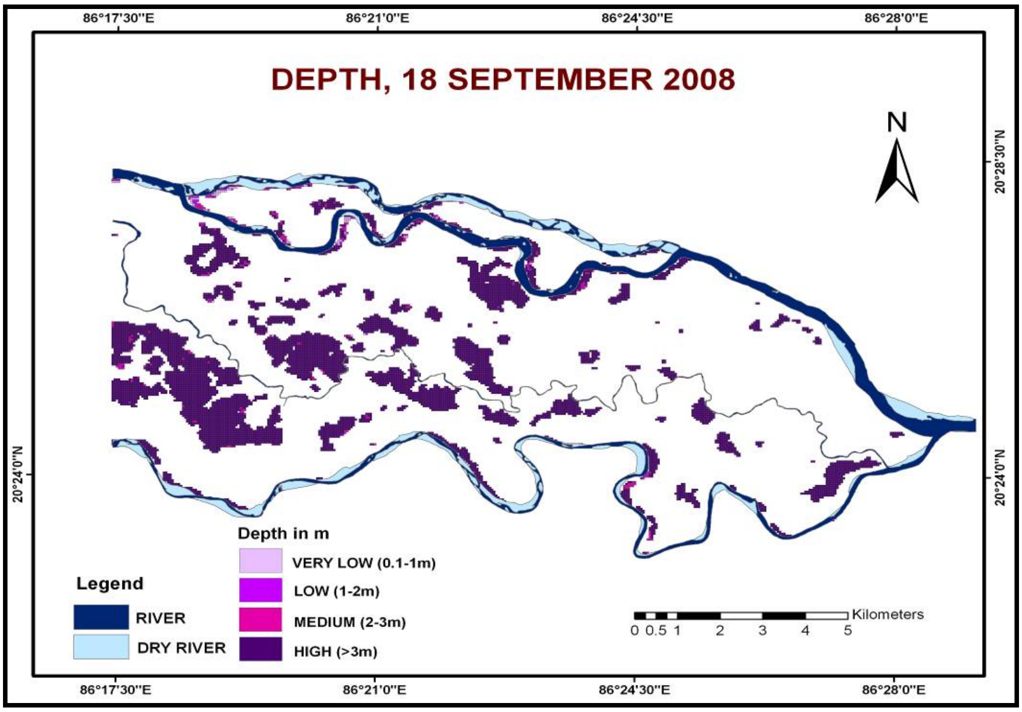


Figure 5-33 18th September Flood Depth

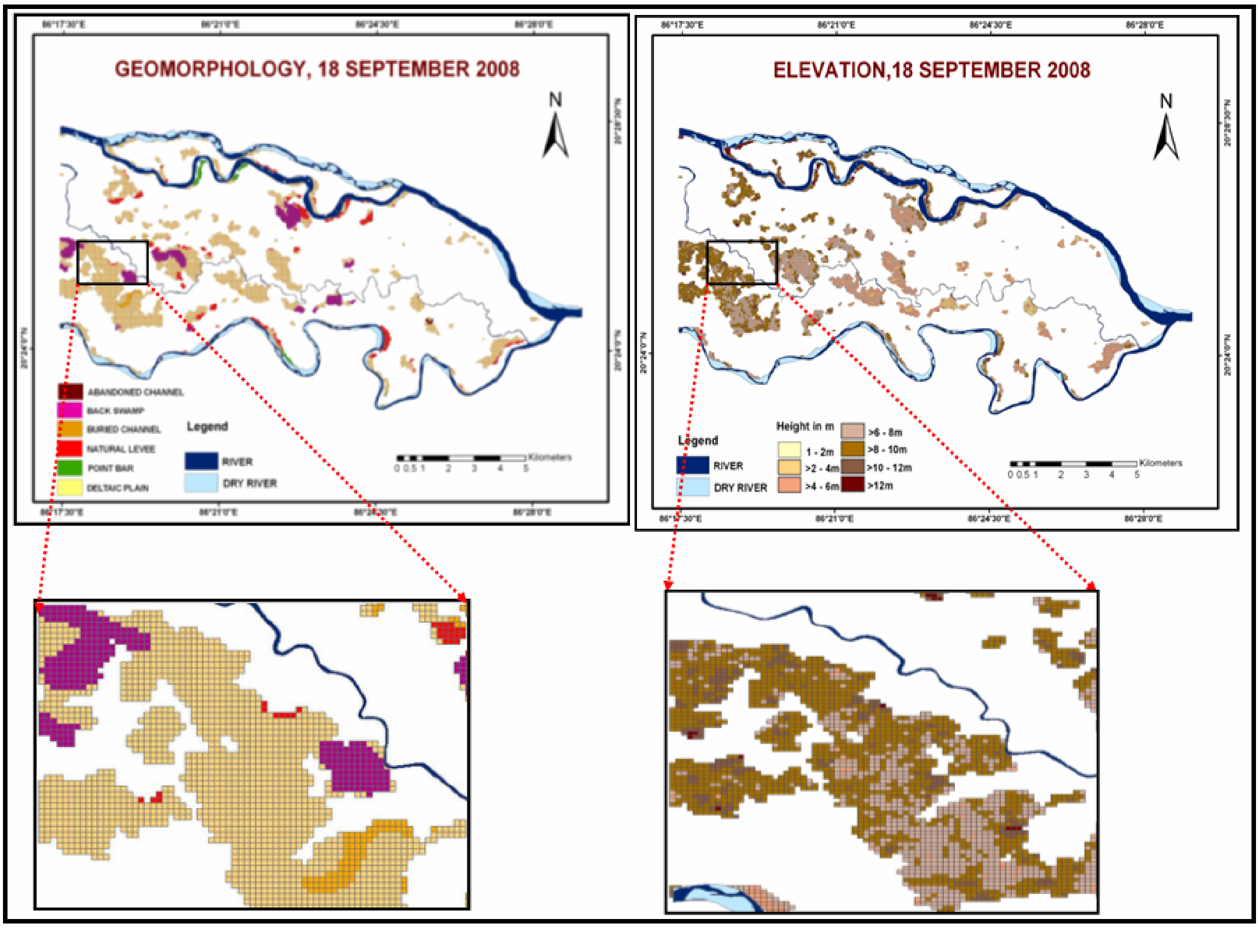


Figure 5-34 18th September Geomorphology and Elevation

Geomorphology of the marked area (Fig.5-34) is showing deltaic plain mainly with back swamps and the buried channel as its features which indicate lower regions. The elevation of the region is about 6 to 10m but some higher elevated grid cells can be found in the border areas of the inundated area and by examining the elevation of the entire region it has been found that the surrounding areas of this inundated region are much higher of about 11 or more than 12m in some parts. Therefore due to breaching at this part, water has accumulated in this respectively lower region from the adjacent higher regions resulting in the inundation. The depth map of the area is therefore supported by the elevation and geomorphology. Although the slope of the land is from west to east, but in this year of 2008 south western part flooded first because of the reason of breaching leading to flood here on the first date which is a minimum flooded day according to the Radar image.

Table 5-13 Area (sq.km) of different features on 18th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.04
Back swamp	2.17
Buried Channel	0.31
Levee	1.76
Point Bar	0.40
Deltaic Plain	15.45

Landuse	Area in sq.km
Kharif Crop Land	11.45
Rabi Crop Land	0.2
Two Crop Area	4.51
Plantation	0.24
Open scrub Land	0.09
Lakes and Ponds	0.21
Rural Built Up Area	3.44
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.21
>2 – 4	1.22
>4 – 6	4.01
>6 - 8	7.48
>8 – 10	6.72
>10 – 12	1.54
>12	0.43

This date marks the least flooded day which increases till 22nd of September. The dominant landuse of the area which get flooded is kharif crop land (Table 5-13) with the area of about 11.45 sq.km area and settlement being the next dominant one with 3.44 sq.km area. Deltaic plain is the dominant geomorphic feature with about 15.5 sq.km area coverage but levee and rabi crop land area also found in this area of inundation next to plains. The elevation of the area is mainly from 7 to 10m with about 14.2 sq.km area. Some lower elevated regions are also found here with 3 to 4m height covering about 1.22 sq.km area. In this case the flooding has started from the west which has higher elevation as it is supported by the presence of levees.

5.4.2. 20th September Flood

This was the second flooded day of the year 2008 and it shows increase in the area of inundation on this day. So the total area it will cover is the area of 18th September and 20th September, but here only the extra area of 20th September has been shown.

The flood depth (Fig.5-35) is less with very low, low and medium category flood in the northern part and some parts in the west which is logical as the elevation is much higher in these parts of the study area. Very small areas in the western parts are inundated further, so there is no spreading towards the west any more. The north has low depth in major part which is also supported by the elevation of the region. But as the geomorphic characteristics of the area are mainly deltaic plain and back swamps, therefore it was inundated. The movement of the inundated area is significantly towards the east with much more depth in this part together with the central part. Therefore the flood depth in the area is showing relation with the geomorphology and the elevation as it is clearly following the slope of the land. Depth of more than 3m is found in the eastern part.

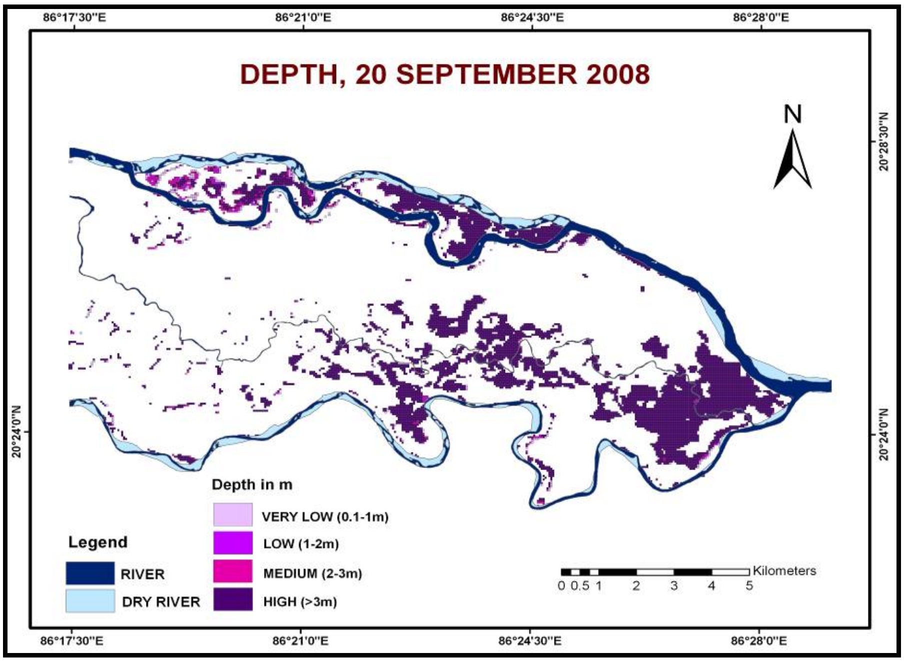


Figure 5-35 20th September Flood Depth (flooded Area of 20th, 22nd and 24th September)

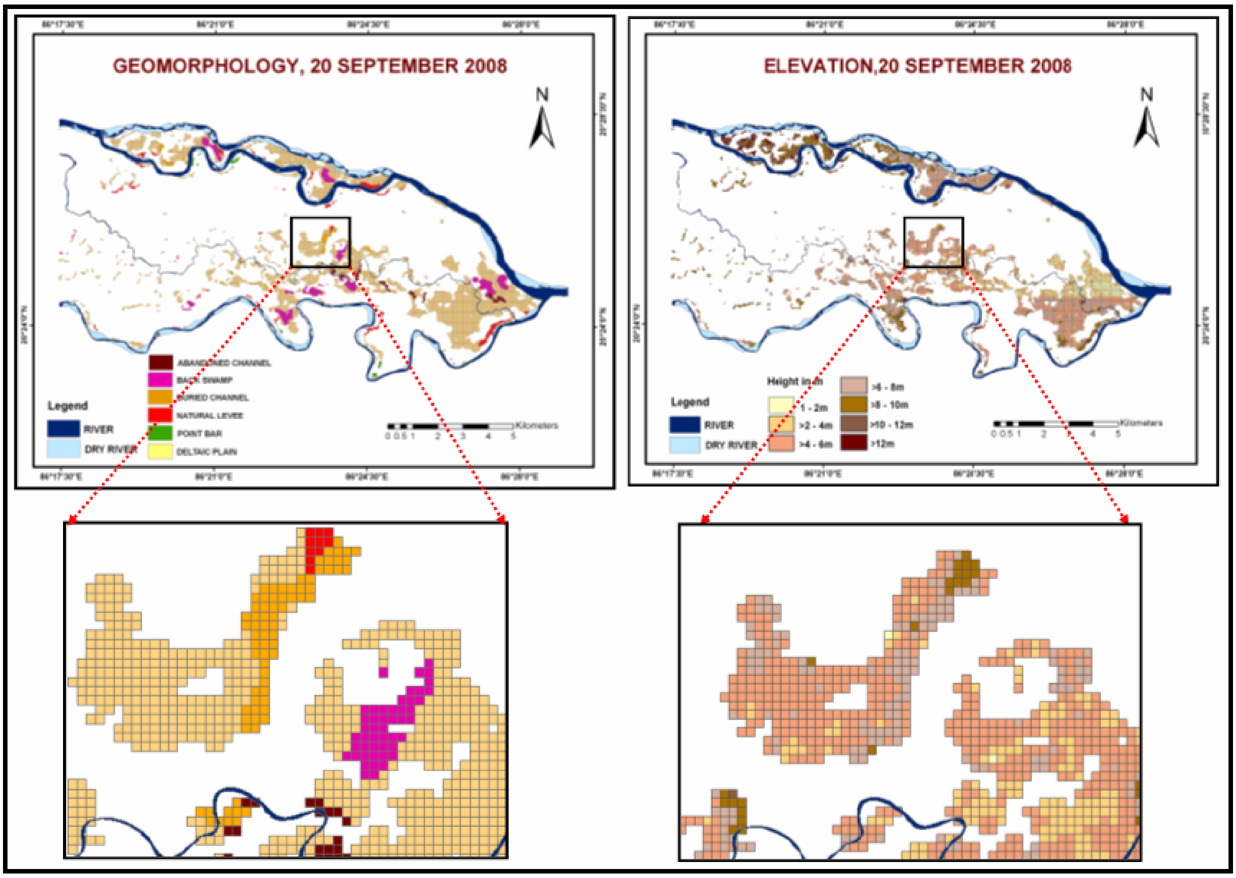


Figure 5-36 20th September Geomorphology and Elevation of the Extra Area

The marked area (Fig.5-36) belongs to the central part of the region and it has the geomorphic characteristics of deltaic plain, buried channel, back swamps, abandoned channel and small portion of levee. The levee area has the height of 8 to 10m while the back swamps, buried channels, abandoned channel and the deltaic plains have 2 to maximum of 8m elevation. Deltaic plains in some parts are showing elevation of less than 4m and this also explains the flood depth of the region which is quite deep of more than 3m. The predominant geomorphic feature is deltaic plain in the whole region with the other features. Towards the east it is mainly plain with some back swamps and abandoned channels thus the elevation of this area is also very low of less than 4m to 6m. Flood depth has followed the slope of the land as less than 3m areas will have maximum depth than areas with more than 8m elevation. Therefore the inundation pattern after 18th of September is following the slope and surface configuration of the area. After breaching flood water has submerged the area following the trend of the slope from west to east.

Table 5-14 Area (sq.km) of different features on 20th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.4
Back swamp	1.67
Buried Channel	0.46
Levee	1.01
Point Bar	0.19
Deltaic Plain	11.12

Landuse	Area in sq.km
Kharif Crop Land	12.1
Rabi Crop Land	0.19
Two Crop Area	5.52
Plantation	0.01
Open scrub Land	0.01
Lakes and Ponds	0.13
Rural Built Up Area	2.88
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	1.3
>2 – 4	3.17
>4 – 6	6.55
>6 - 8	5.37
>8 – 10	2.85
>10 – 12	1.47
>12	0.58

On this day flood water increases in some area to the eastern part and the dominant landuse inundated on this date is mainly kharif crop land with 12.1 sq.km (Table 5-14) area together with two crop lands in many parts covering about 5.54 sq.km area. Maximum inundation of deltaic plains occurs with 11.12 sq.km area together with some back swamps and levees in less than 2 sq.km area each. Thus inundation on his day indicates the submergence of low lying areas. Elevation is mainly from 5 to 6m with 6.55 sq.km area. Some areas with very low elevation is found with less than 4m covering about 3.17 sq.km area.

5.4.3. 22nd September Flood

This is the peak flood day of the year 2008 and it has immersed almost the entire part of the study area. This has proved to be one of the disastrous floods in term of damage like 2003.

The flood depth of 22nd September, which has the peak flood day is showing minimum of depth of less than 3m in the west and south west increasing to more than 3m in the eastern part. The image (Fig.5-37) is showing that major portion of the study area has been inundated with a stretch from west to east. The north eastern and the northern part which was not submerged on 20th September, they are showing total inundation with maximum flood depth. These areas also have low elevation and deltaic plain as the existing feature, thus it is showing flood although 20th September had no flood in this region. This may be because flood inundation occurred in even lower part in the east on that day. From the central part of the study area the depth of water increases and it also supports the geomorphology and the slope of the land to the east. Extension of inundated area in the western part is comparatively less than the 18th of September but the north western part gets heavily submerged under water although the depth is low compared to the east where it is above 3m. It represents the extra area only which were inundated in this day. Total submerged area of this date includes the area of 18th September flood, 0th September flood and 22nd September flood.

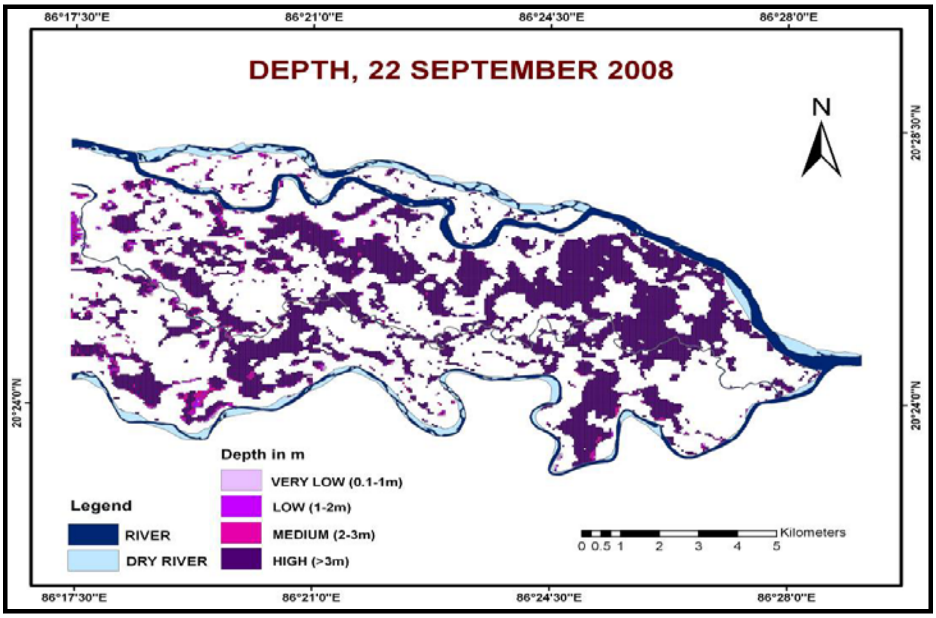


Figure 5-37 22nd September Flood Depth (Extra Flooded Area of this date)

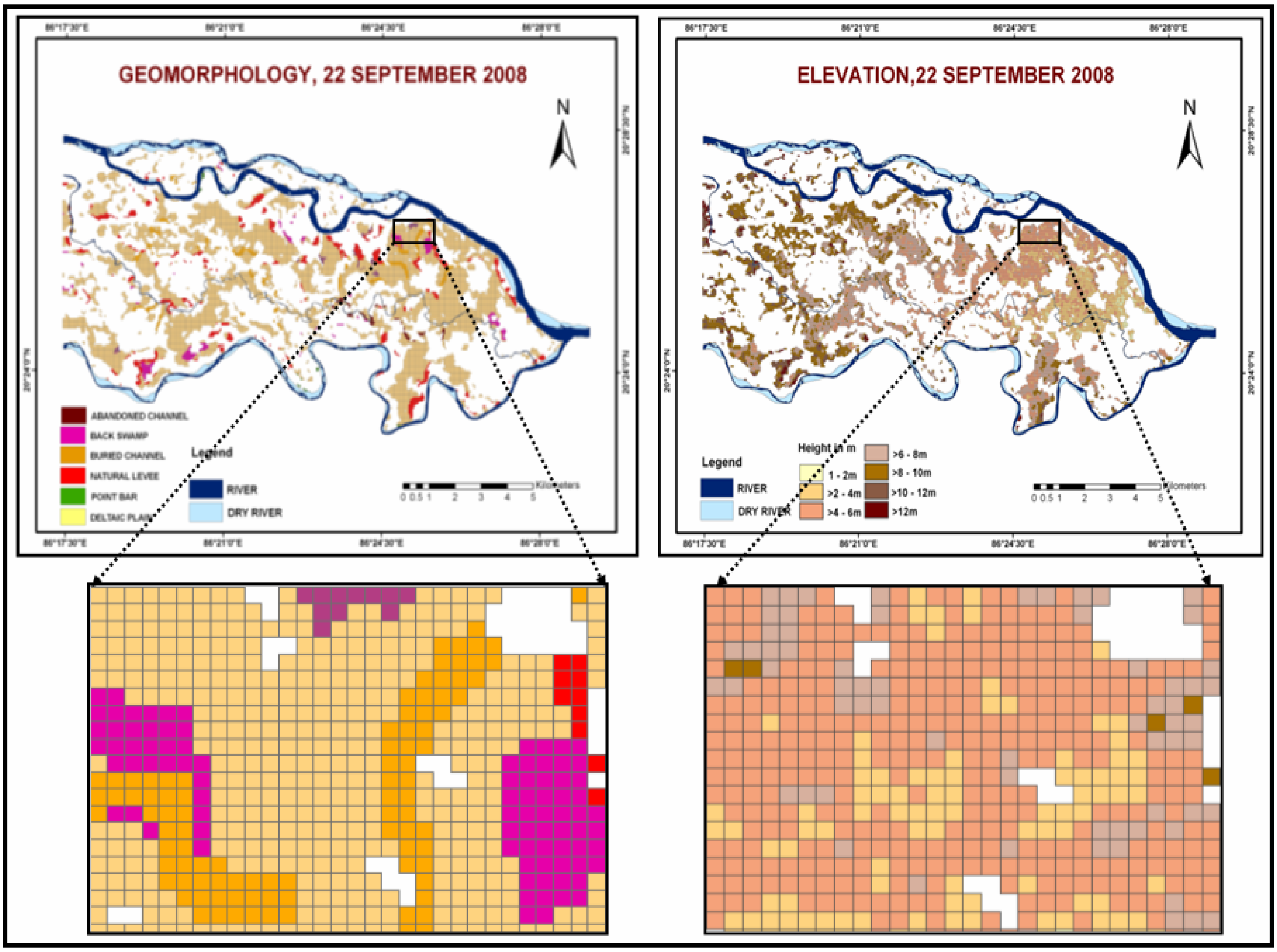


Figure 5-38 22nd September Geomorphology and Elevation of the Extra Flooded Area

The marked area (Fig.5-38) is showing mainly deltaic plain, buried channels and the back swamps in this region with the elevation of less than 4m to 6m. The rest of the region has mainly back swamps, few levees and buried channels together with the deltaic plain with the elevation of the entire region varying from less than 2 to 6m in elevation and so these regions faced submergence. Flood depth of the area also supported the geomorphology by showing less depth in the west with levees and more depth in the east with low features and thus following the slope. Towards the east and north east it is mainly delta region and showing very low elevation of less than 4m. Thus it is explaining the pattern of inundation here with the peak flood time inundating the entire area leaving only few higher parts in the extreme northwest. In some levee areas there are 6 to 8m of elevation.

Table 5-15 Area (sq.km) of different features on 22nd September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.34
Back swamp	0.96
Buried Channel	1.56
Levee	3.28
Point Bar	0.11
Deltaic Plain	33.44

Landuse	Area in sq.km
Kharif Crop Land	21.35
Rabi Crop Land	0.88
Two Crop Area	10.32
Plantation	0.17
Open scrub Land	0.33
Lakes and Ponds	0.05
Rural Built Up Area	6.82
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.98
>2 – 4	5.87
>4 – 6	9.41
>6 - 8	10.97
>8 – 10	9.03
>10 – 12	3.43
>12	0.78

As it is the peak flood day, major part was inundated. About 21.35 sq.km of the kharif crop land has submerged (Table5-15) which indicates a big loss in the paddy crop lands together with two crop land area of about 10.32 sq.km area. Dominant geomorphic feature inundated during this day was deltaic plain with 33.44 sq.km area with back swamps being the next with 1.56 sq.km area. The dominant elevation is from 5 to 10m varying from west to east with 5 to 6m and 9 to 10m having more than 9 sq.km area and 7 to 8m having about 11 sq.km area. Thus the peak flood day has inundated most of the areas from higher to lower elevation.

5.4.4. 24th September Flood

On this day, flood water shown recession for the first time although it is very less. It has receded from some parts but spreading in some other parts. Thereby the area it represents is not the areas which were inundated during 22nd September, but it is the extra inundated area which experienced some dispersal from the main inundated area of 22nd.

The depth map of the inundated area of 24th September (Fig.5-39) explains that extra area which was submerged on that day was much less and are scattered in the entire region. Here the flood water spreading has occurred adjacent to the inundated area of 22nd September and from other parts it has receded. So the flood depth is not showing any specific trend but it is following the same trend as of 22nd September. The western part has low depth like the other dates and the eastern parts have more depth but that is also showing in very small area. The elevation and geomorphology explains that the area which was not flooded on the day of 22nd, came under the impact of the general flow of water in its adjacent region. As images after this date is not found, therefore it is not possible to say the movement or recession of water in this region. But from the inundation pattern it can be said that except for the breaching and submergence in the west, the pattern of movement of water is from west to east.

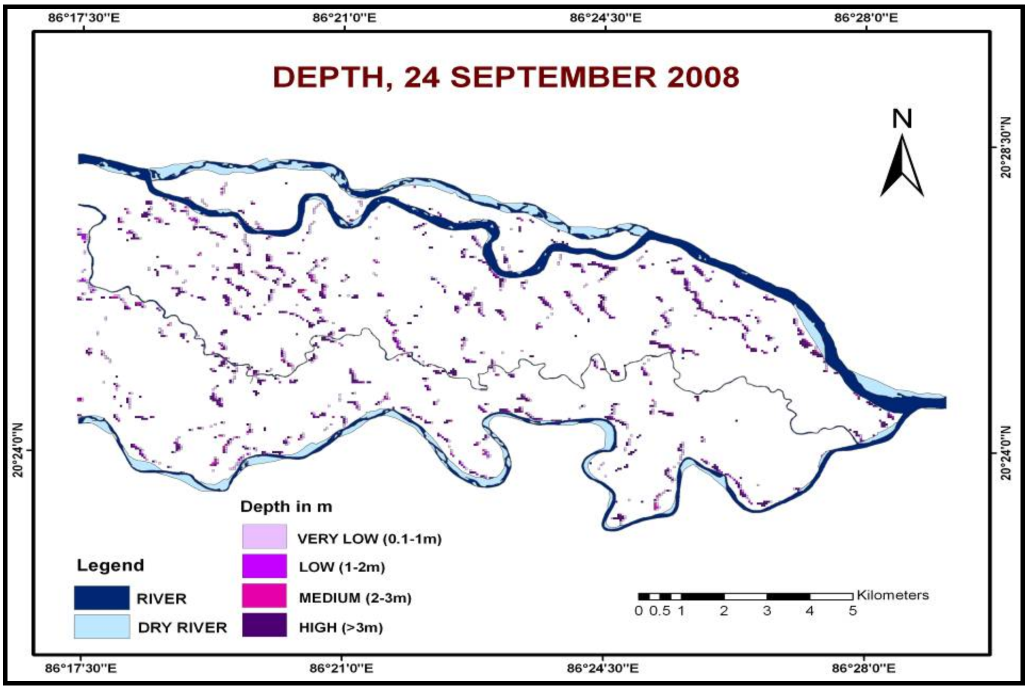


Figure 5-39 24th September Flood Depth (Extra Flooded Area of this Date only)

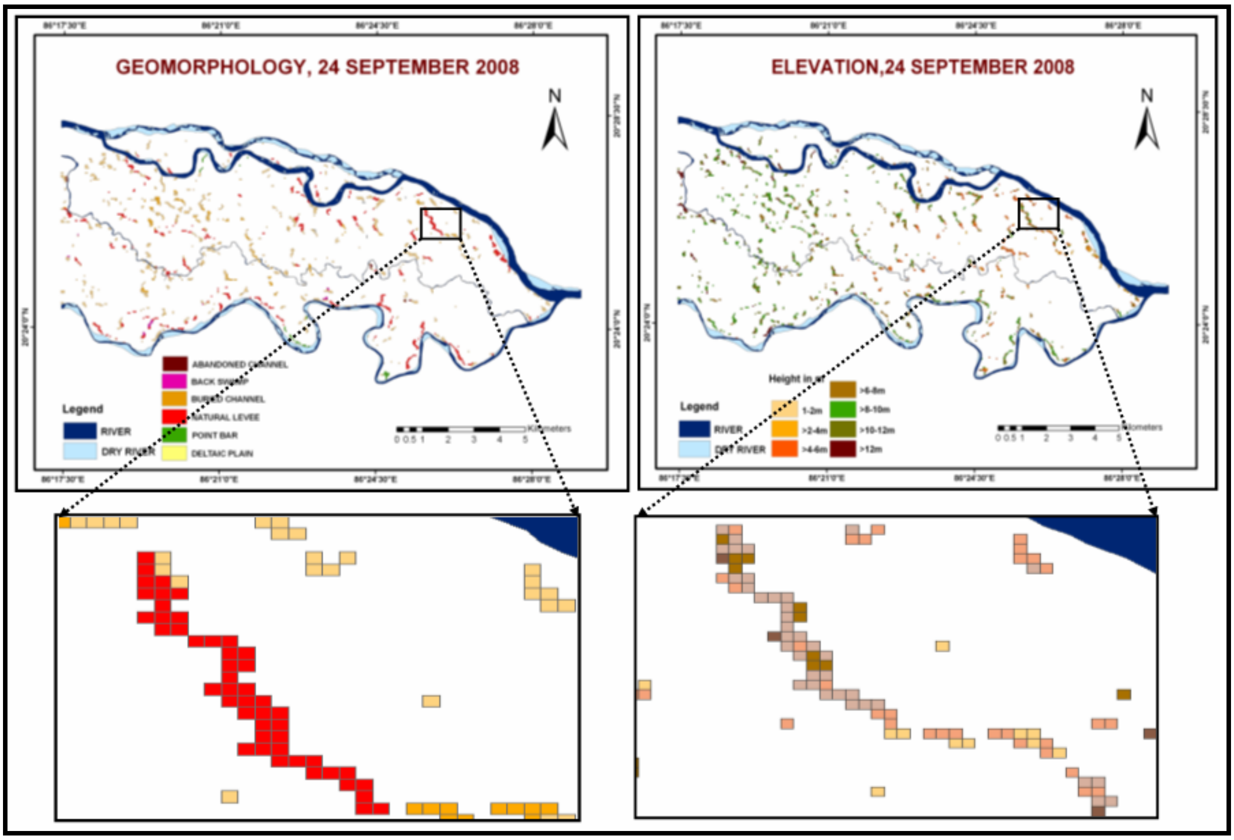


Figure 5-40 24th September Geomorphology and Elevation of the Extra Flooded Area

The marked area (Fig.5-40) is showing mainly levee and the elevation of the region is 2 to 10m from south to north. Therefore it is proving the fact that this area did not come under the influence of flood on 22nd September because of its natural resistance as it is a levee but after few days it also get affected as the huge volume of water starts receding and thus inundating the surrounding areas. Depth in this part is more than 3m. Entire region on this day experienced sudden movement of water in some of the adjacent regions.

Table 5-16 Area (sq.km) of different features on 24th September

Geomorphic Features	Area in sq.km
Abandoned Channel	0.05
Back swamp	0.07
Buried Channel	0.44
Levee	0.44
Point Bar	0.15
Deltaic Plain	3.33

Landuse	Area in sq.km
Kharif Crop Land	1.5
Rabi Crop Land	0.07
Two Crop Area	1.31
Plantation	0.02
Open scrub Land	0.02
Lakes and Ponds	0.01
Rural Built Up Area	2.94
Agricultural Fallow	-

Classes of Elevation (m)	Area in sq.km
1 – 2	0.05
>2 – 4	0.27
>4 – 6	0.8
>6 - 8	1.48
>8 – 10	1.83
>10 – 12	0.11
>12	0.38

As the flood starts receding on this day, therefore some areas which are adjacent to the flooded area were submerged. Dominant landuse (Table5-16) submerged on this date was settlement with 2.94 sq.km area as water spreads here with kharif crop land being the next with 1.5 sq.km area. Dominant geomorphology was deltaic plain with 3.33 sq.km area and some levees as some settlements were also inundated located on these levees. Elevation of the region is mainly from 7 to 10m which with 3.31 sq.km area coverage and the entire land has varied elevation from west to east.

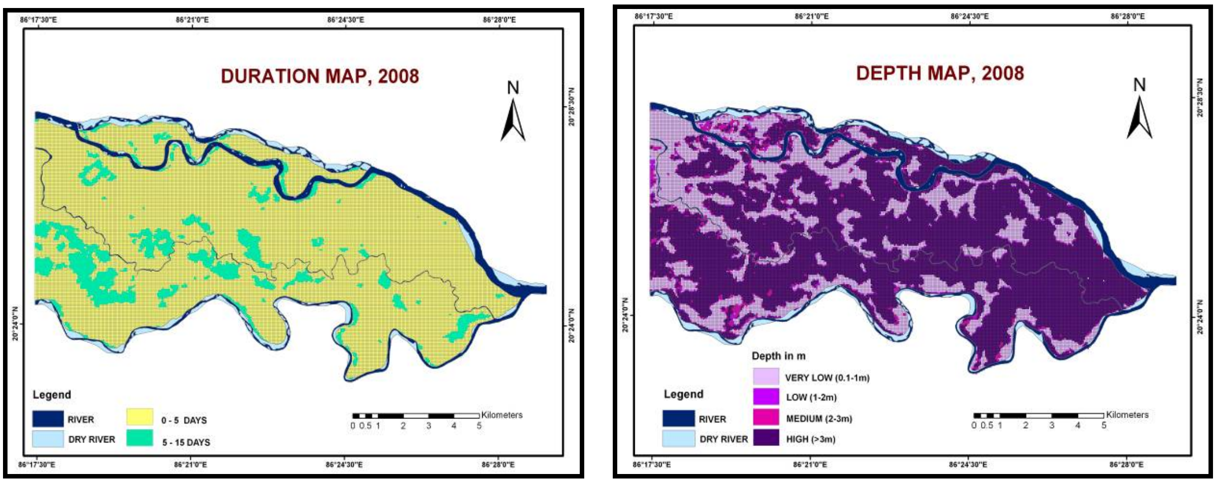


Figure 5-41 2008 Duration and Depth

The duration map (Fig.5-41) of the region is showing that there is no long duration of flood water in this region as the Radarsat images are not available for this year and medium duration flood from 5 to 15 days is found mainly in the western part which continues till the central part of the region and small portion in the east. Rest of the area is showing low flood duration of less than 5 days as the Radar image for the flood period of 2008 is showing only 7 days of flood although the original flood duration was more than 20 days according to the field survey. After summing up the depth of flood for these four days it is found that it is showing relevance with the flood duration in most parts but with some exceptions in the west. The areas with medium flood duration in the west are indicating medium flood depth of 3m. While eastern part with low flood duration is showing more depth of greater than 3m. The main reason behind it is the geomorphology and the elevation of the region. The depth is corresponding with the elevation of the region very well, because this area in the west is higher than the eastern parts. But the occurrence of medium duration in this part is corresponding to the geomorphology and also elevation of the region. This region has particularly lower elevation than the surrounding area and breaching in the levee of the adjacent areas has resulted in the submergence. Therefore instead of the flood movement or pattern from west to east, it has become opposite, i.e. western part has inundated on the first day of flood followed by the east during peak phase. As the data of the recessional phase of 2008 flood is not available, therefore whether flood water is receding from the west at the beginning could not be known. But definitely from the inundation pattern of 2008 it can be concluded that although a separate reason worked behind the submergence of the western higher region first, the pattern has followed a specific trend from higher to lower elevation with respect to both depth and geomorphology.

5.4.5. Comparative Analysis of Three years of Inundation Pattern

After the analysis of the entire work an effort has been made to summarise the inundation pattern of three years flooding to find out the pattern or trend of movement of the flood water through the region during its recessional phase. But before analysing the pattern it is necessary to consider some of the constraints that have affected the analysis of the pattern of three years. 2003 flood has Radarsat images of 4th September, 11the September, 13th September and 20 September of which 4th September had the highest flood which gradually receded till 20th September. Therefore it has shown the recessional phase of flood with duration of 7days between first two dates, 2 days between next two dates and again 7 days between last two dates of Radar imagery. 2006 flood has images of 4th August, 19th August and 26th August with 26th showing maximum flood and the duration between first two dates is 15 days and last two dates is 7 days. Therefore in this year it is showing increase in flood water and not the recession. 2008 flood has 4 images of 18th, 20th, 22nd and 24th September with 2days gap between two dates. This year has peak flood on 22nd September and thus it also shows the increasing phase and not the recession. So there is a limitation in assessing the flooding pattern as in 2003 it is possible to show how the flood water is behaving or how it is moving during its decreasing phase. But 2006 and 2008 are showing how the flood water is increasing in the study area which is different from the recession. Moreover the Radarsat images with dates showing equal duration are not available, so it is difficult to combine the inundation pattern maps of three years. Despite of all these constraints an effort has been made to relate three years inundation as it is following a trend in each case and inundating some specific region during recession or increase in flood water.

2003 flood water is showing recession from west to east as 4th September peak flood image is showing water in the entire region. Maximum flooded zone or high flood zones showing accumulation of water for all dates are the eastern portion which shows flooding for all 16 days of duration from the Radarsat images. And as the western part is showing recession after the peak flood date, therefore it can considered as less affected due to movement of water away from that region to the east. Therefore lower elevated region in the east and central part has more inundation than the west. And during flood recession, the pattern is from west to east and thus indicating that it is following the slope of the land.

All images for 2006 flood are not available, therefore recessional phase of flood is not obtained. It is showing the increasing pattern with a trend in inundation of the entire region from the starting date of flood on 4th August to 26th August of maximum flood. Part of the study area that was most adversely affected from the flood inundation is the eastern part and some parts of the west also. As the data for recessional phase is not obtained, therefore it is difficult to relate with 2003 flood pattern but the increasing pattern has some trend which starts from both west and east and gradually increases more towards the east through the central part. Although the flood water inundation starts both from the west and east, it has a tendency to move to the east following the slope of the land. So the eastern part with some parts in the central and south west have common flooding region.
For 2008 flood also, recessional phase is not available, therefore analysis has been done on the basis of the increasing trend. The 18th September is showing minimum flood with inundation in the south western part mainly. This has increased till 22nd of September and the eastern part has inundated next to west on 20th. On the peak flood day, water extended to the most part of the region and thus images of this year shows the increasing patter, which starts from west, then to east and finally stretch to the entire region. Thus areas suffering from maximum flood effect is south west with increase in east and central part. Thus areas of inundation that can be considered as most adversely affected is a small portion of south east and the east which is common in all the three years of flooding.

Table 5-17 Flood inundation pattern with respect to extra area flooded on each date except 20th September of 2003, 4th August of 2006 and 18th September of 2008 showing common flood area for all the days and 24th September of 2008 is showing the extra area that was flooded on that day only

Extra Area Flooded in 2003		Extra Area Flooded in 2006		Extra Area Flooded in 2008	
Date	**Area in sq. km**	**Date**	**Area in sq. km**	**Date**	**Area in sq. km**
4th September	6.41	4th August	37.58	18th September	18.3025
11th September	9.8425	19th August	11.4475	20th September	26.65
13th September	35.33	26th August	12.3025	22nd September	40.9225
20th September	45.5675	-		24th September	6.065

The table 5-17 explains the extra area that was flooded on each day with 4th September of 2003 which was the peak flooded day showing only the extra area that was flooded on that day and the total flood extent of that day will be the summation of all the four days inundated area. Similarly total flood extent of 26th of August 2006 has the area equal to the flooded area of all three days and the total flood area of 22nd September, 2008 is equal to flooded area of 18th, 20th and 22nd and as 24th starts recession, it is showing the extra flooded area of 24th only and not included within 22nd September.

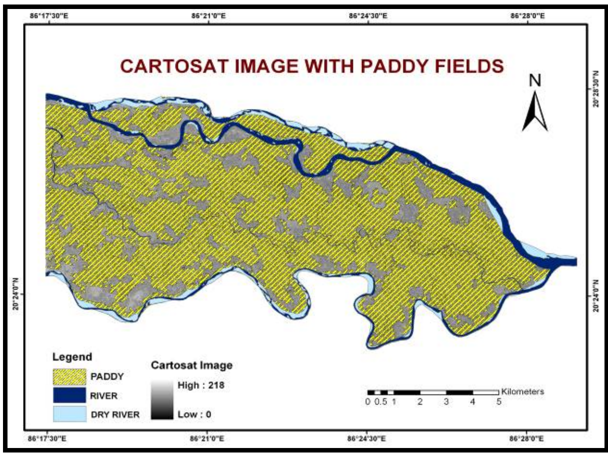
So, it can be said that when the flood water is receding away from the west in 2003, increase in flood water is occurring from the west in 2006 and 2008. As all the flooded images for three years from the beginning till the recession period are not found, therefore one year (2003) is showing recession from west to east i.e. higher to lower elevation, and other two years (2006, 2008) are showing increase in water from west to east i.e. again higher to lower elevation indicating the south western part and eastern part as the major areas of flood in three years. Among these, west is facing flood at the beginning and east is facing flood at the beginning and at the end as it is identified as the very low region. Thus it can be concluded by saying that pattern of flooding is following the trend of inundating west at the beginning, gradually increasing towards the east covering the entire region and then starts moving from the west and finally accumulating in the eastern lowlands.

5.1. Paddy Field Identification from the Radarsat

Radarsat 1 images are used to identify the flooded region as microwave data can penetrate through the clouds. Flood mainly occurs during the monsoon seasons when cloud covers hinder the imaging of ground object by the optical images. Therefore microwave images are most important in identifying the flood boundaries. As paddy plants remain under water during the initial stage, therefore it is necessary to distinguish it from the flooded land. In optical images, the non flooded paddy fields with water may be taken within the flood boundary or by giving only threshold value to differentiate between flooded and non flooded zone, the watered paddy plants are also considered as flooded. Therefore microwave data with backscatter values are required to identify the paddy fields.

Water backscatter values are more, but due to the specular reflection of water, it reflects away from the sensor leading to the decreased backscatter value. Taking this concept in mind paddy field is chosen. Only in case of paddy, the plant will grow with time and therefore the backscatter values will increase and thus the backscatter coefficient of paddy during its growth stage will be the varying which in turn will help in differentiating the paddy fields from the flood. There is also a difference between the reflectivity of flooded and non flooded paddy fields. Therefore to differentiate the flooded paddy field, non flooded paddy fields were also taken into account in order to understand the growth stage and backscatter variation with that. Some objects like settlements and river were taken to understand and support the backscatter values of paddy, as only the value for paddy will change while land and water will remain almost constant.

Field points were randomly chosen on the basis of convenience before going to the field from the base map of paddy fields (Fig.5-42) that was prepared from the Cartosat image and flood extent maps were used to consider whether the area was flooded or not. Landuse map helped in identifying the paddy fields during the field survey (Fig. 5-43) and field verification was done regarding the flood extent and whether the chosen fields were flooded.



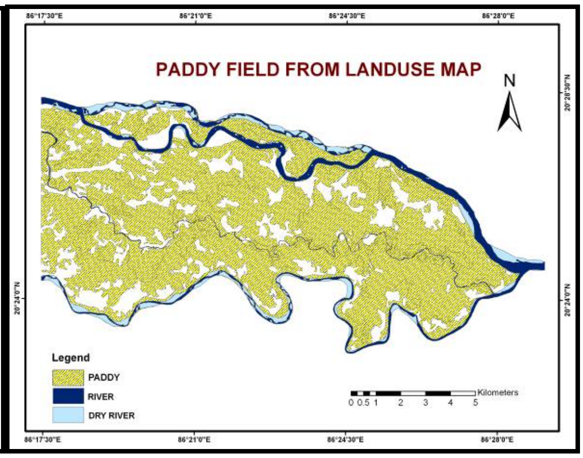


Figure 5-42 Base Map of Paddy Field from Cartosat Image
Figure 5-43 Paddy Fields from Landuse Map and Field Survey

There was only 2003 data during the field survey with the gap of minimum of 9 days between each image. Complete dataset of 2006 arrived later and 2008 dataset could not be used for assessing the variation in backscatter values of paddy because it had only two days gap between each image and identifying paddy growth within just two days was not possible. Three Radarsat images of 4th September, 11th September and 20th September were taken to find out the backscatter variation of paddy, flooded or non flooded (Fig. 5-44) together with the settlement and water.

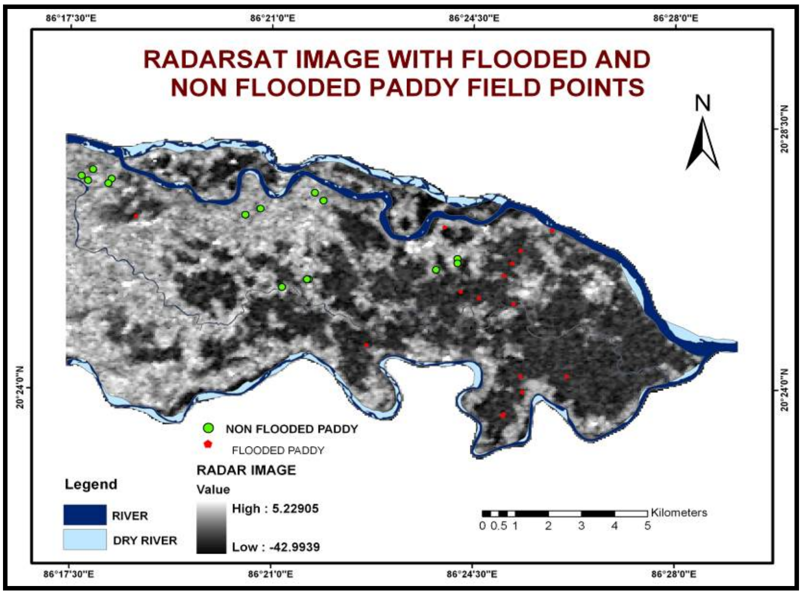


Figure 5-44 Flooded and Non-Flooded Paddy Field Points on Radar Image

5.5.1. Flooded Paddy Field Identification

Backscatter values were taken for the flooded paddy fields from the radar image which was verified from the field during the survey. The backscatter values for flooded paddy are given below in the table (Table5-18):

Table 5-18 Backscatter Values for Flooded Paddy

FLOODED PADDY				
S. No.	Lat Long	04-Sep	11-Sep	20-Sep
1	86º25'2"-20º23'34.1"	-16.218327	-14.854795	-13.878142
2	86º25'0.4"-20º23'32.4"	-16.218327	-14.211102	-12.334824
3	86º25'19.3"-20º24'13.1"	-16.857225	-14.211102	-12.748515
4	86º25'20.9"-20º23'56.8"	-17.525762	-15.19462	-13.397489
5	86º25'1.8"-20º25'57.3"	-17.898003	-14.854795	-13.431447
6	86º25'11.9"-20º25'28.1"	-17.543427	-15.218286	-12.974017
7	86º24'35.8"-20º25'34.3"	-16.857225	-15.550037	-13.675669
8	86º24'16.8"-20º25'40.8"	-16.523125	-14.188255	-13.230985
9	86º25'19"-20º26'23.3"	-19.927156	-13.929126	-12.146163
10	86º25'10.2"-20º26'10.1"	-15.131948	-14.233926	-12.974017
11	86º18'38.3"-20º26'57.5"	-16.650949	-14.96602	-12.998527
12	86º22'38.6"-20º24'45.1"	-17.801086	-13.814795	-13.280892
13	86º26'7.6"-20º24'13.3"	-17.915707	-15.965325	-12.715396
14	86º23'59.6"-20º26'47.4"	-17.166819	-13.028417	-11.440018
15	86º25'51.4"-20º26'44.5"	-17.561132	-14.572607	-12.334824
	Total	**-257.796218**	**-218.793208**	**-193.560925**
	Average	**-17.1864145**	**-14.5862139**	**-12.904062**

The backscatter values of flooded paddy are showing a trend for these three dates as 4th September is showing much less backscatter values from -19dB to -15dB in different points as it was the peak flood day. On 11th of September it increased slightly from -15dB to -13dB in different points and on the lean flood day of 20th September, backscatter value was highest with the range varying from -13 to -12. Therefore although land was flooded, the increasing range of values with time proves that this is possible only in case of a crop growth, otherwise it would have been almost equal in all three days.

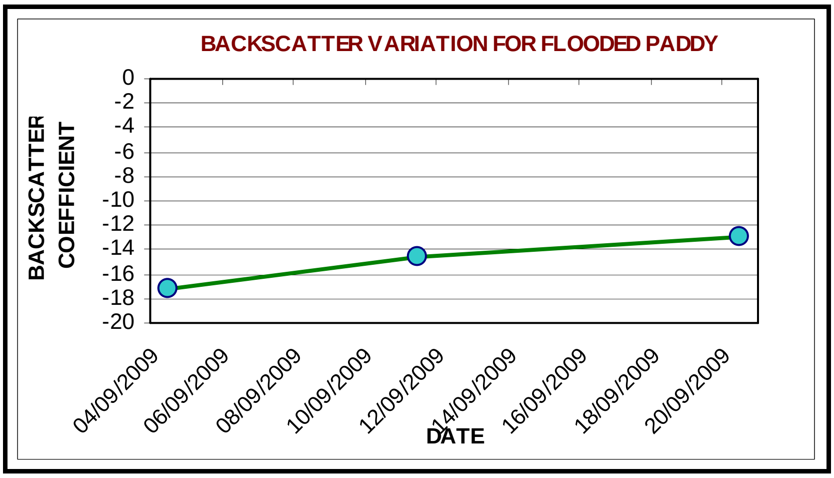


Figure 5-45 Backscatter Variation of Flooded Paddy

Fig.5-45 explains the graph is higher in case of 20th September. Although it is very small but paddy growth has occurred within the flooded area and therefore it is showing comparatively higher backscatter values.

5.5.2. Non-Flooded Paddy Field Identification

Backscatter values were also taken for the non flooded paddy in order to support the growth stage of paddy during the non flooded time and also to differentiate the paddy fields from the settlements in terms of backscatter coefficients. This growth stage varies from the flooded one as water is not included and thereby increasing the values significantly. The values taken are given in the table5-19 below:

Table 5-19 Backscatter Values for Non-Flooded Paddy

NON FLOODED PADDY				
S. No.	Lat Long	04-Sep	11-Sep	20-Sep
1	86º24'13.2"-20º26'14.8"	-9.759689	-6.106249	-3.114076
2	86º24'13.2"-20º26'10"	-9.618452	-4.341031	-3.990708
3	86º23'50.8"-20º26'3.3"	-8.179523	-6.206594	-2.785975
4	86º21'10.3"-20º25'44.9"	-8.717551	-4.42849	-2.679915
5	86º21'38.2"-20º25'53.2"	-9.661133	-4.763548	-3.418811
6	86º21'36.6"-20º25'53.1"	-8.590747	-6.239887	-3.347905
7	86º21'53.3"-20º27'14.5"	-9.968531	-4.349856	-2.734529
8	86º21'44.5"-20º27'22.7"	-8.735393	-4.451447	-2.285712
9	86º18'12.5"-20º27'36.4"	-8.376265	-5.400531	-3.337743
10	86º18'9.1"-20º27'31.7"	-8.376265	-6.914945	-3.337743
11	86º17'53.1"-20º27'46.1"	-9.273455	-4.625479	-3.631097
12	86º17'48"-20º27'34.8"	-8.610087	-4.602557	-3.488702
13	86º17'41.2"-20º27'39.5"	-9.412432	-7.761337	-2.875326
14	86º20'47.7"-20º27'6.1"	-8.828373	-4.932089	-2.509283
15	86º20'32.2"-20º26'59.6"	-9.226269	-5.492663	-3.324102
	Total	**-135.334165**	**-80.616703**	**-46.861627**
	Average	**-9.022277667**	**-5.37444687**	**-3.12410847**

The backscatter for non flooded paddy is also showing a specific trend like the flooded one with increasing value with time. 4th September is showing least values from -9 to -8dB as this is the first date. On 11th September the values increases from -6 to -4dB in different points and on the last day of 20th September it was much higher from -3 to -2dB and thus showing clearly increasing pattern with time which supported the crop growth.

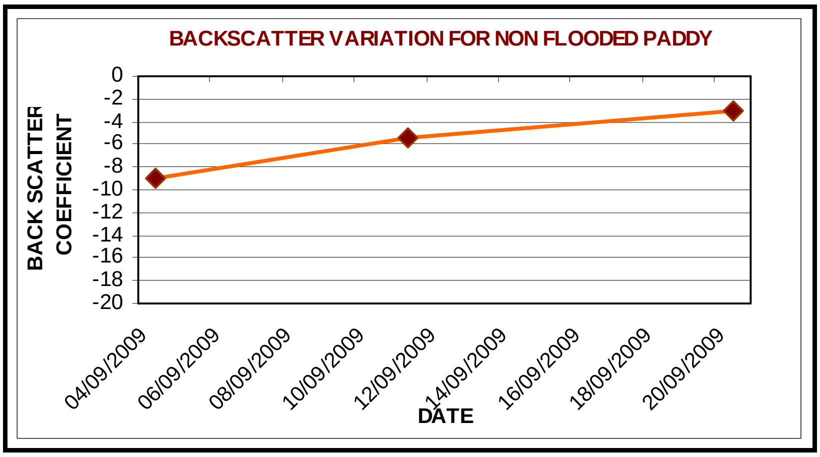


Figure 5-46 Backscatter Variation of Non-Flooded Paddy

The reflection of non flooded paddy (Fig.5-46) is showing an increasing trend from -9dB in first day to -3dB in the last day within a gap of 16 days. Therefore it is indicating a regular growth of the plant in its mature stage. But is definitely showing variation in the values from the flooded paddy and non flooded has much higher values than the flooded ones.

5.5.3. Backscatter Values for Settlements

Settlement points were taken in order to support the growth stage of paddy. To differentiate the flooded and non flooded paddy fields from the rest of the elements at risk and to prove paddy fields existence even in the flood water, these points of land or settlements were taken. The backscatter values for these points are given below in table 5-20:

Table 5-20 Backscatter Values for Settlements

SETTLEMENT				
S. No.	Lat Long	04-Sep	11-Sep	20-Sep
1	86º24'41.3"-20º24'37.3"	-2.543725	-1.620477	-1.053977
2	86º23'28.1"-20º26'29.4"	-2.839304	-2.360025	-1.91015
3	86º24'9.7"-20º26'24.6"	-2.989253	-2.959413	-2.976202
4	86º24'30.3"-20º26'34.6"	-2.813723	-2.648145	-1.872454
5	86º23'38.9"-20º24'48.7"	-2.27873	-2.280701	-1.0369
6	86º23'30.3"-20º24'32.5"	-1.619021	-1.35847	-1.958121
7	86º21'36"-20º26'59.8"	-2.27885	-2.61604	-2.411596
8	86º22'0.2"-20º26'56.6"	-2.098513	-1.901729	-2.337481
9	86º19'16.1"-20º27'0.8"	-1.908853	-1.733912	-2.495504
10	86º18'55.4"-20º26'49.5"	-2.498584	-1.341195	-1.778637
11	86º21'31.4"-20º24'44.8"	-2.140369	-1.802912	-2.789637
12	86º26'36.8"-20º23'27.8"	-2.597371	-2.859216	-2.670092
13	86º25'46.3"-20º26'16.8"	-2.413211	-2.451353	-2.592714
14	86º18'52.4"-20º26'20.2"	-2.561754	-2.096966	-2.635687
15	86º18'56"-20º26'20.2"	-1.378173	-1.863251	-2.257981
	Total	**-34.959434**	**-31.893805**	**-32.777133**
	Average	**-2.330628933**	**-2.126253667**	**-2.1851422**

The settlement points (Fig. 5-47) are showing almost equal values for all the images from 4th to 20 September. All the three dates have values ranging from -1dB to -2dB and thus giving the average of about -2.3dB. Thus it is easy to differentiate from the paddy fields in the Radar image as it is not showing any increasing trend like paddy and identified as a fixed object.

Figure 5-47 Survey in Villages / Taking Settlement Points

1. Survey of agricultural lands just beside the village road
2. Survey for the damage of paddy fields in the house of a small farmer
3. Survey for flood damage of paddy in the house of a medium farmer

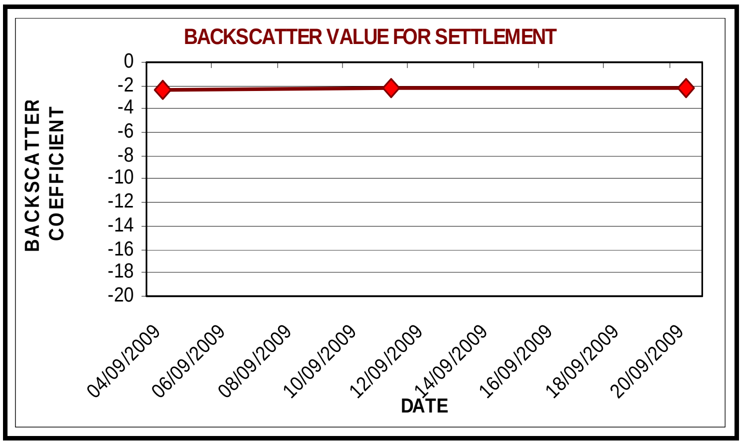


Figure 5-48 Backscatter Value for Settlements

Fig.5-48 is showing almost equal value for all the three days or images of 4th, 11th and 20th September. Therefore the trend line is almost straight with higher values and thus showing almost fixed backscatter values which were not observed in the other two previous graphs.

5.5.4. Backscatter Values for Waterbody

Like the settlements, points from water bodies also were taken to find out the trend of backscatter coefficients in different days, whether they are varying or stagnant. Table for backscatter values of water is given below (table5-21):

Table 5-21 Backscatter Values for Permanent Water Body

RIVER				
S. No.	Lat Long	04-Sep	11-Sep	20-Sep
1	86º22'32.8"-20º27'18"	-18.191099	-20.140194	-18.679726
2	86º22'38"-20º27'19.5"	-20.81667	-20.163105	-20.018661
3	86º24'4.4"-20º27'18.3"	-19.445686	-20.208855	-20.982443
4	86º24'43.9"-20º27'17"	-18.267672	-20.231701	-20.430725
5	86º23'40.3"-20º26'44"	-19.425381	-20.829687	-19.971951
6	86º18'20.7"-20º28'2.5"	-19.257626	-18.819357	-19.255344
7	86º25'53"-20º26'52.7"	-19.075546	-20.921015	-18.983593
8	86º26'57.1"-20º26'20.3"	-19.980219	-19.723585	-18.111565
9	86º27'38.6"-20º25'21.9"	-18.724491	-19.746313	-19.351751
10	86º19'29.7"-20º27'28.7"	-20.208637	-19.426043	-20.620937
11	86º24'5.9"-20º24'24.3"	-11.642058	-11.287263	-18.595318
12	86º21'37"-20º24'33.3"	-21.28533	-21.433245	-14.505485
13	86º20'12.6"-20º23'54.1"	-19.293488	-22.120014	-17.221262
14	86º28'29.2"-20º24'41.3"	-21.508177	-22.461636	-21.382822
15	86º22'3.2"-20º28'0.2"	-19.83024	-18.980356	-20.040558
	Total	**-286.95232**	**-296.492369**	**-288.152141**
	Average	**-19.13015467**	**-19.76615793**	**-19.2101427**

Water bodies or river has shown almost constant values for all the three days of flood from -17dB to -22dB and the average of all the points have given almost a constant value within -19.7dB. Thus there is no increase in the value with date. 4th September is showing value from -18dB to -21dB, 11th September from -18 to -22dB and 20th September is showing the value range from -17dB to -21dB. Thus all the three radar images are showing the same value.

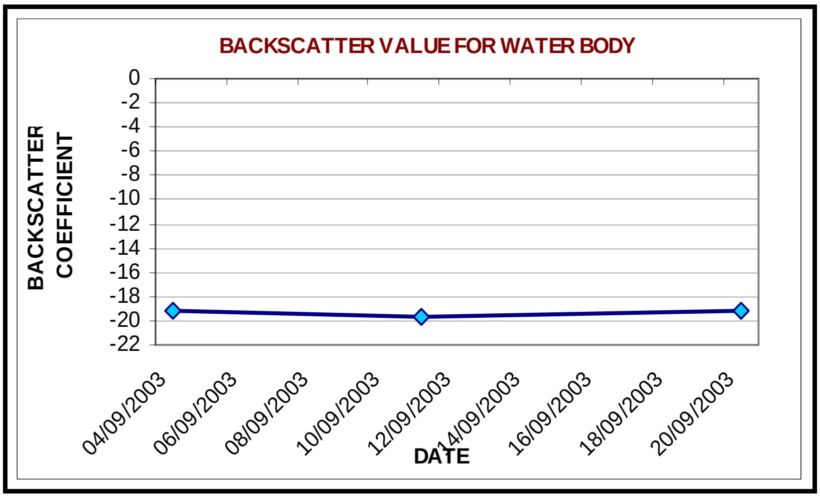


Figure 5-49 Backscatter Value for Water Bodies

Fig.5-49 explains that water has the lowest backscatter values than all other objects and it is almost constant for these three days. Although the backscatter may change for clear or the turbid water but the overall backscatter in average remained same. Windy conditions may also change the backscatter value of water, but here it is not considered and the value which water is giving is almost constant for three days.

5.5.5. Comparison of Backscatter Values of Paddy in relation to other Elements at Risk

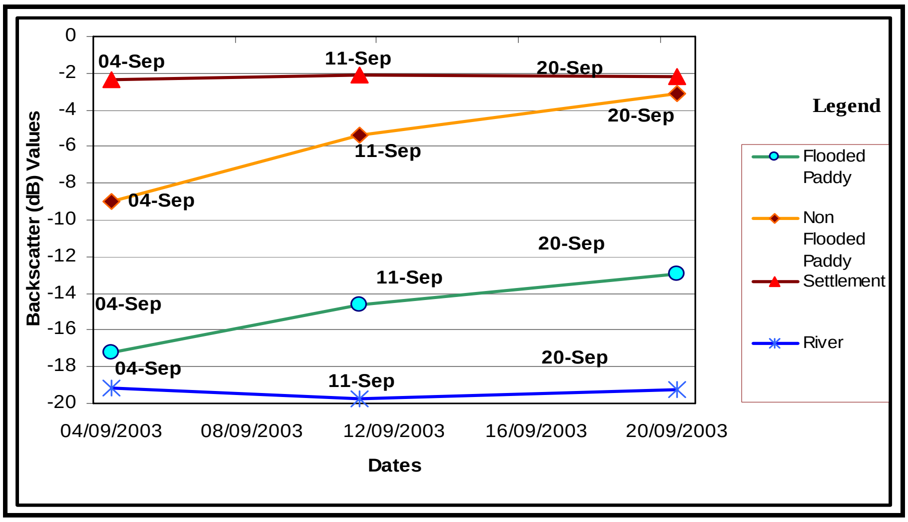


Figure 5-50 Backscatter Value for Water Bodies

Fig 5-50 is explaining the backscatter variation of flooded and non flooded paddy in relation to the other elements like settlement and river. This graph is proving that flooded paddy can be identified from the radar image as it is distinctly showing an increasing trend which proves the growth of paddy plants with time. Similarly the non flooded paddy is also showing increasing trend of growth but the backscatter values are much more than the flooded paddy and that is obvious as the presence of water has decreased the values of the flooded paddy. This is again supported by the constant values of pure water and settlements. Settlement as an element is not showing any increase or decrease in trend and maintaining a constant high value as it has higher reflectivity. Water is showing the constant low value because of the specular reflection.

All images are not available therefore it was not possible to identify the entire growth stage from the Radar. More temporal images are required and long duration images of flood are also required to assess the rate of growth.

Thus the main aim of distinguishing paddy from the Radar Image during flood and identification of paddy field in relation to other elements at risk has been achieved together with the evidence of the growth of paddy with time. Paddy fields from different locations are given in Fig. 5-51.

Figure 5-51 Paddy fields in different Locations

1, 2. Paddy field at its Middle stage
3. Water logged Paddy field, problem during flood
4. Paddy fields near the settlement
5, 6, 7, 8, 9. Field survey of Paddy

5.5. Growth Stage of Paddy

Growth of paddy has already been identified in the radar images. But data for the entire growth stage of paddy in Radarsat images are not available, therefore growth stage has been shown by taking into consideration the field data, the rate of growth of paddy as stated by the farmers and correlating it with the daily rainfall data of the study area so as to find out the approximate date of initiation of paddy cultivation or the starting season for the paddy cultivation.

After a minimum rainfall of 15 to 20cm paddy bed can be prepared for sowing. Germinating seeds were sprinkled with water and after 6 to 7 days seedbed is irrigated. The seedlings are transplanted after 20 or 25 days. In the study area, mainly the 'Beali' crop grows which continue for about 4 months from May-June to October *(Handbook of Agriculture: Indian Council of Agricultural Research, 1980).*

According to the field survey, after 30 days paddy achieved a height of about 15 to 18cm. Then it is transplanted and therefore for the next 10 days it has very little growth, this marks the first stage of paddy. Just after the transplantation it remains under water for sometimes. Maximum growth occurs for the next 2 months continuously up to 1.07m height i.e. about 3.5feet (Table5-22). This is the middle stage of paddy and in the last one month there is no further growth, paddy gets ripened and this marks the mature stage of paddy. Therefore paddy growth has been shown in 3 stages, initial, middle and mature stage for this entire period.

Table 5-22 Height of Paddy

Days	Ht of paddy(cm)
Jun-15	0
Jun-25	4.8
Jul-05	10.8
Jul-15	18
Jul-25	22
Aug-05	36.2
Aug-15	50.4
Aug-25	64.6
Sep-05	78.8
Sep-15	93
Sep-25	107
Oct-05	107
Oct15	107

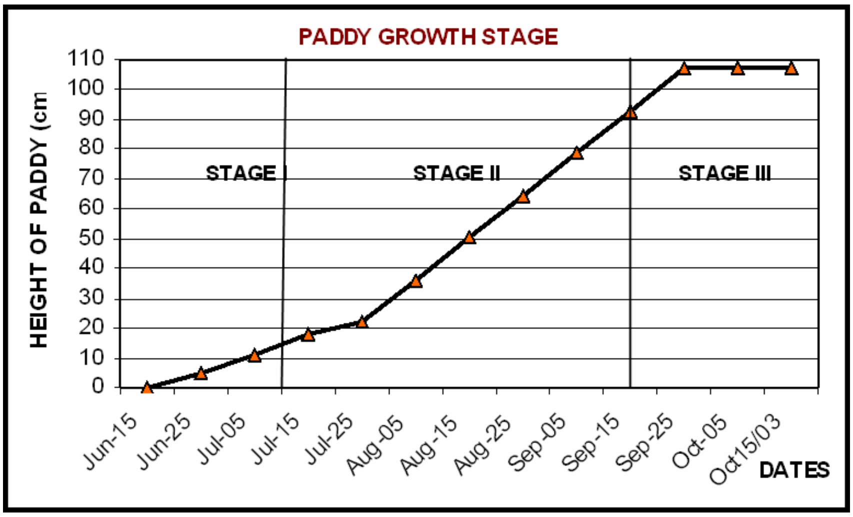


Figure 5-52 Paddy Growth Stage

The graph (Fig.5-52) explains the growth of paddy with time as it is observed that in the first stage, up to 1 month there is very little growth. After that from July 15th it gradually increases up to 80 or 90cms after two months which marks the middle stage of paddy. After this, in the last one month the growth becomes almost constant and stagnant as the paddy plants ripen then which marks the mature stage. Thus, if flood comes at this mature stage, it will be total loss to the plant.

5.6. Vulnerability Assessment of Paddy

Vulnerability assessment of paddy has been done here in order to find out the areas or degree of losses that is occurring every year in the paddy fields which is the main crop of this region. Vulnerability refers to the degree of loss to an element at risk or set of elements at risk which results from the occurrence of a natural phenomena of a definite magnitude and expressed on a scale from 0 (no damage) to 1 (total loss)*(UNDRO, 1991)*. Therefore scale for the vulnerability is taken from 0 to1 in order to signify the degree of loss. Vulnerability is also considered as the set of existing conditions which badly affect the ability of a community to mitigate, prevent or to respond to any hazardous situation *(ADPC, 2005)*. While assessing flood vulnerability many indicators should be taken into account like exposure indicator which involves the elements which are near to the source of flooding, elevation of the elements, area of inundation near to it, return period of flood, flood depth, duration, velocity, extent etc. Elements at risk indicators provide the information for different physical, economic and social elements like the person, economic activity, buildings, firms, public infrastructure, landscape, bio-diversity etc. These are also very important in assessing the flood damage. Susceptibility indicators define how much sensitive an element is to a particular hazard or how it will react if it confronts a hazardous situation. Like what will be the effect of flood depth or duration on the building material. It also includes the coping strategies of people to the flood or how they will recover from the damages or shock of flood hazard. Therefore it also relates to the ability of the ecological system to survive and function properly during such disturbances *(Messner and Meyer, 2005)*.

In the present case of study, an element at risk like paddy has been taken into account for the vulnerability assessment. Among different indicators like inundation depth, velocity, return period, only depth and duration are taken into consideration for all three years of 2003, 2006 and 2008. Depth and duration are major factors for the assessment of vulnerability of paddy as long duration may destroy the crop completely while deep water for one or two days may not be a problem. For this field data and Remote Sensing data has been used for collecting information of paddy vulnerability.

To assess the vulnerability of paddy, damage information due to flood was collected from the field and what was the paddy height during the time flood was also collected as it is highly relevant to the flood depth. The curves are drawn on the basis of damage of crop with respect to two exposure indicators like flood depth and duration. The vulnerability curves that are given are linear curves which consist of some straight lines between two points. Depth and duration are changed at each point of the curve according to the vulnerability values. This has been done by following the straight line equation.

$$y = a+bx$$

Where x and y are the two coordinates of the curve; b is the straight line gradient and a is the intercept of y of the straight line. This straight line equation is considered as the more accurate than the exponential or the logarithmic one because it calculates the value between two points in a straight line. But other type of curves will calculate the values for all the points together and so although they will fit to the vulnerability values, but there will be generalisation in the total calculation. So this straight line curve has been applied for the assessment of paddy vulnerability in this case.

In this case vulnerability curves are drawn by taking depth as constant from 0 to 1m, 1 to 2m and above 2m and varying the duration according to the vulnerability as paddy plants usually have height little above 1m. So depth above 2m is sufficient to destroy it in long duration of flood.

Table 5-23 Vulnerability Scale for Paddy

Serial No.	Flood Duration (in days)	Flood Depth 0-1m	Flood Depth 1-2m	Flood Depth >2m
1	5	Less than 5% loss	Less than 10% loss	Less than 35% loss
2	10	5 to 7% loss	10 to 25% loss	35 to 55% loss
3	15	7 to 10% loss	25 to 45% loss	55 to 80% loss
4	20	10 to 13% loss	45 to 75% loss	80 to 90% loss
5	30	13 to 15% loss	75 to 90% loss	Total loss

Water depth is considered here because flood depth with more than 2m will be destructive for paddy plants but with 0 to 1m depth, it will not cause much harm as paddy plants remain under water for sometimes (Table 5-23).

5.7.1. Vulnerability Assessment of Paddy with Flood Depth of 0 to 1m

Mainly 'Beali' paddy with 3.5feet height is observed in the study area with four months of duration from May-June to October. Floods generally occur in the middle stage of paddy for all these three years i.e. during the month of September when the paddy height is about 2feet or 2.5 feet. Paddy plants having 0 to 1m flood depth are considered here because up to 1m of depth, paddy does not face much loss if the duration of water staying in the field is less. The curve is given below with the vulnerability values (Table 5-24).

Table 5-24 Vulnerability for 0-1m

Duration in days	Vulnerability
0	0
3	0.02
6	0.04
9	0.06
12	0.08
15	0.095
18	0.11
21	0.12
24	0.13
27	0.14
30	0.15

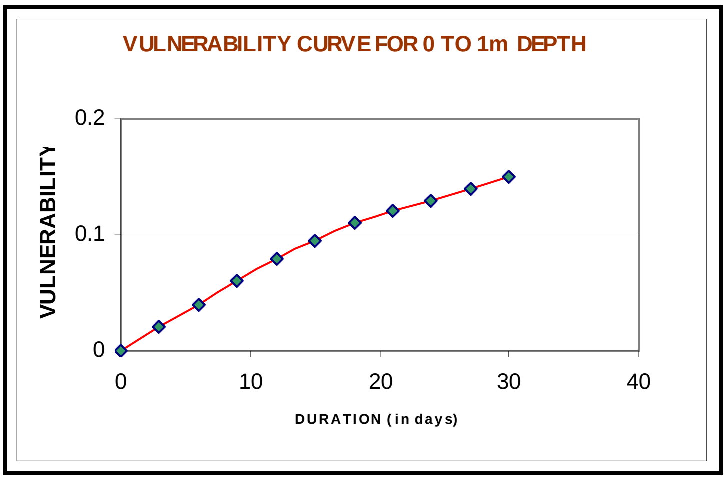


Figure 5-53 Vulnerability curve for 0 to 1m Flood Depth

At this depth of water, paddy does not face much loss as the paddy height is sufficient to cope up with this flood depth. Therefore at this stage vulnerability is very low of less than 0.2 even after long duration of flood as damage is much less and it can be again replanted or fertilized at this stage after the flood. The curve (Fig.5-53) is showing the positive trend of more duration with more vulnerability and it is showing only 0.15 vulnerability which is the maximum vulnerability after 30 days.

5.7.2. Vulnerability Assessment of Paddy with Flood Depth of 1 to 2m

Paddy under flood depth of 1 to 2m is considered as the height of paddy is about 3.5 feet and therefore it will cause much more vulnerability than the flood depth of 0 to 1m. Therefore much damage is caused to paddy in this case (Table 5-25). The curve is given below:

Table 5-25 Vulnerability for 1-2m

Duration	Vulnerability
0	0
3	0.05
6	0.07
9	0.14
12	0.28
15	0.45
18	0.65
21	0.77
24	0.82
27	0.85
30	0.9

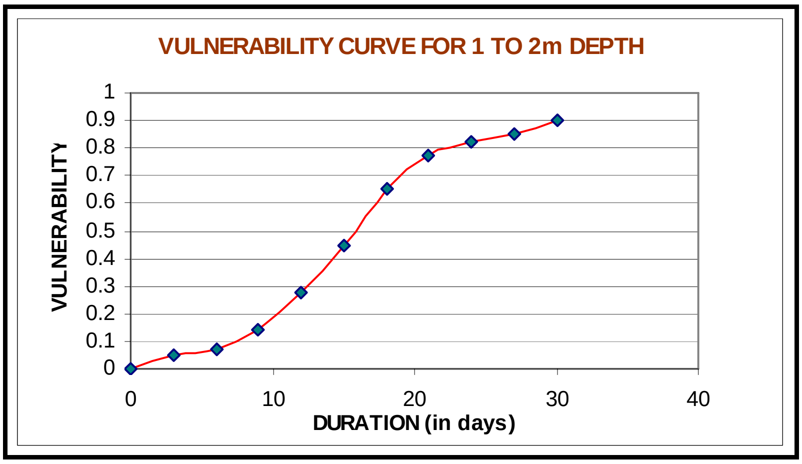


Figure 5-54 Vulnerability curve for 1 to 2m Flood Depth

At this stage of water depth, paddy is much more vulnerable with the increasing flood duration. Therefore the curve (Fig. 5-54) is showing maximum vulnerability of 0.9 after 30 days of inundation which means that paddy plants are almost destroyed. With the depth above 1m, paddy plants gradually become vulnerable up to almost 50% only after 15 days and then finally up to 0.9 after 30 days. With more flood depth, the growth of plants will be hindered and as paddy requires dry condition at its middle stage, therefore it will face heavy destruction.

5.7.3. Vulnerability Assessment of Paddy with Flood Depth above 2m

Paddy under the flood water of more than 2m will prove extreme damages as it has crossed the height of paddy to a great extent. And the vulnerability will increase drastically only after very few days of flood (Table 5-26). The curve is given below:

Table 5-26 Vulnerability for above 2m

Duration	Vulnerability
0	0
3	0.2
6	0.36
9	0.52
12	0.7
15	0.83
18	0.9
21	0.92
24	0.94
27	0.96
30	0.98

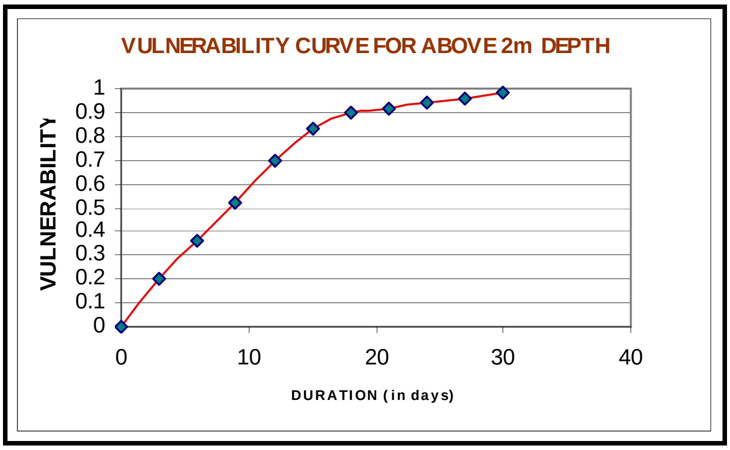


Figure 5-55 Vulnerability curve above 2m Flood Depth

Fig.5-55 describes the scenario very clearly as the there is sudden increase in the vulnerability values with the more duration from 0 to 0.2 within just 2 days. Just after 15 to 18 days, the vulnerability reached its maximum of 0.9 and thus it is showing almost total damage after 18 days. After that it becomes almost stable as it increases to 0.98 vulnerability after 30 days. So after reaching 0.9 vulnerability drastically just after 15 days, which is because the paddy plants are facing high damage at this water depth, the damage becomes constant.

5.7.4. Comprative Study of the Vulnerability

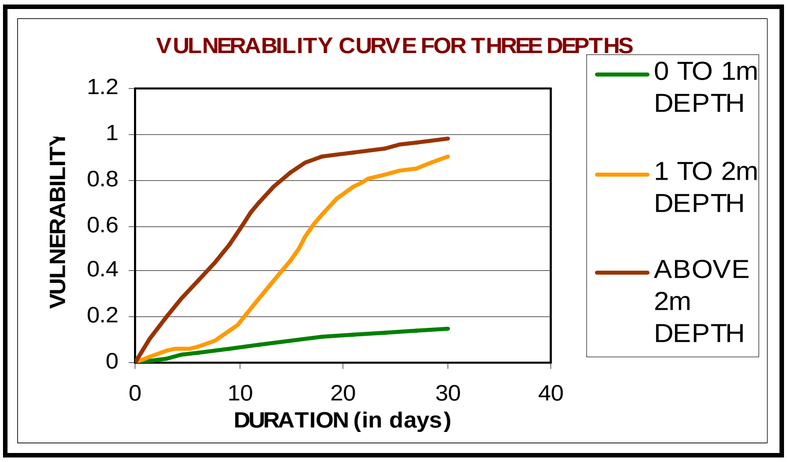


Figure 5-56 Vulnerability Curves

The comparative study of the vulnerability curves (Fig.5-56) shows that at the depth of 0 to 1m the damage is very low as paddy can withstand this much water depth and thus showing vulnerability below 0.2. But in cases of the depth of 1 to 2m and above 2m the damage is almost same i.e. equal to vulnerability 1 but the duration after which it reached that point is different. In case of depth of 1 to 2m the damage was gradual at the beginning and then reached to maximum damage after few days. But in case of the water depth of more than 2m, the damage was drastic at the beginning and then the curve becomes constant as it has already reached the highest point of damage. This is because, paddy after 10 to 15 days only will reach the maximum damage point with more than 2m water depth while it will take some time for lesser flood depth to reach that point as the entire paddy plant needs to be inundated completely to get destroyed. Some field photos of flood level are given below (Fig. 5-57)

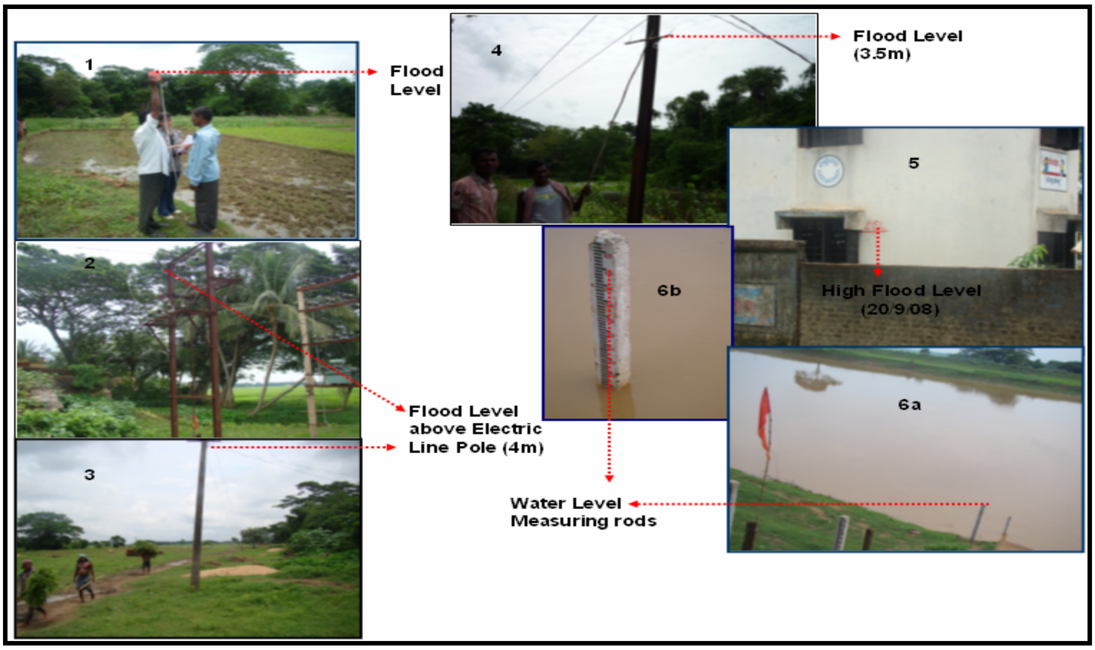


Figure 5-57 People showing Flood Height in the Field

1. Estimated flood level inside the field on 2008
2., 3. Flood level reaching near the pole to about 4m
4. A man showing flood height inside the village
5. Mark of flood height in a school building
6. Measuring rod to measure the increase in water level

5.7.5. Vulnerability of Paddy for the Year 2003

2003 flood was the most destructive one and it causes huge losses to the paddy plants as it stayed in the field for more than 25 days and therefore the vulnerability will also be much great in this case. According to the field survey, farmers faced huge loss this year as most of the paddy fields were destroyed due to flood and that also at its middle stage. So they could not recover much after this flood.

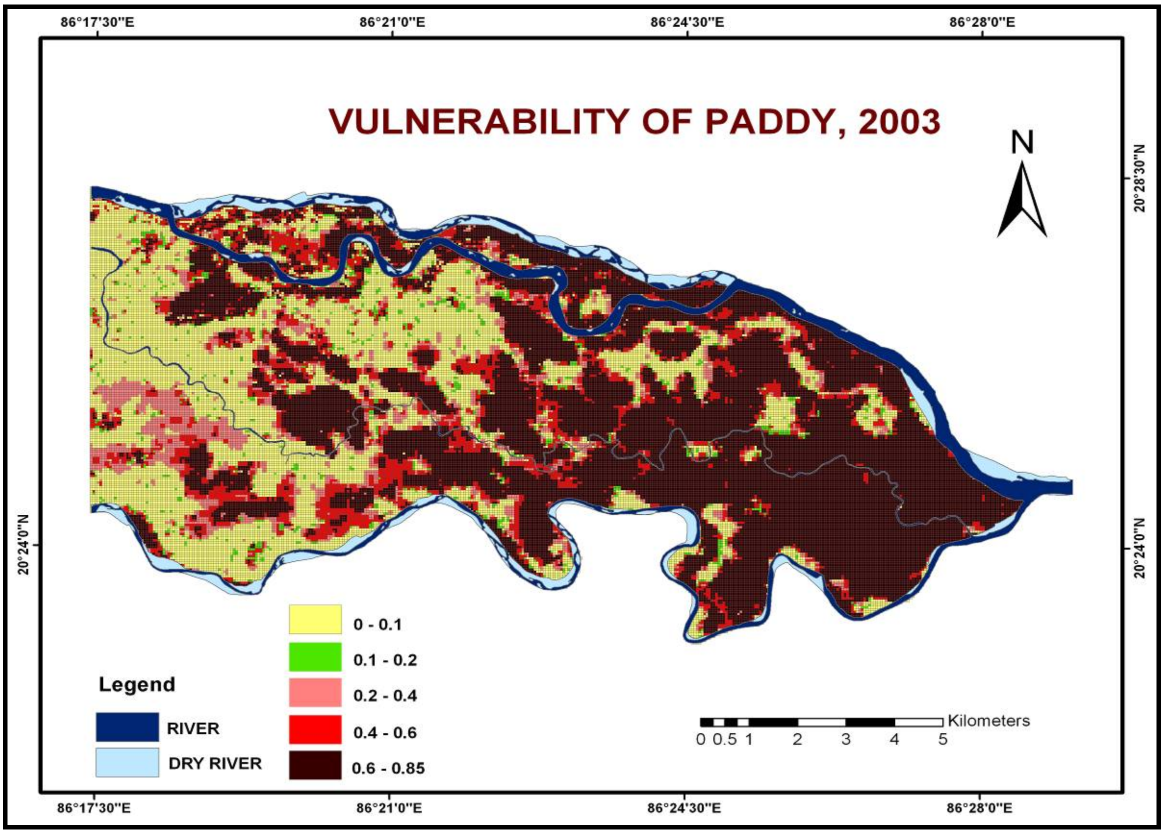


Figure 5-58 Paddy Vulnerability of 2003

Vulnerability in the western and west central part of the area is low showing up to 0.1 vulnerability (Fig.5-58), because this part of the region is much elevated one and the inundation map of 2003 also shows that the flood depth and duration was low in this part. Therefore farmers of this area did not face much damage. Medium vulnerability from 0.1to 0.4 m is observed in the in few parts of the west and central region. Western part where the vulnerability is medium, there flood depth and duration was more than 5 days and depth was also high. That portion therefore remains flooded for longer days than the other parts of the west. This is because the elevation of that particular area is lower than the surrounding areas. It has elevation of approximately 8 to 9m while the surrounding region has 10 to 12m. Therefore most of the flood water accumulation has occurred in that particular area which is a deltaic plain, from the adjacent high lands causing medium vulnerability there. Rest of the study area faced high vulnerability of more than 0.4 in the central and the eastern part. Paddy fields in this area get damaged totally as this portion of the area get inundated at the beginning of the flooded season on 4th of September and continued after 20th September. Elevation of this area is very low and therefore most of the paddy fields experienced huge losses with more than 3m flood depth and long duration of water in the field.

5.7.6. Vulnerability of Paddy for the Year 2006

This year experienced less intensive flood like 2003, but the duration was quite long for this flood. So the damage is less compared to 2003 but it has caused much loss due to its long duration.

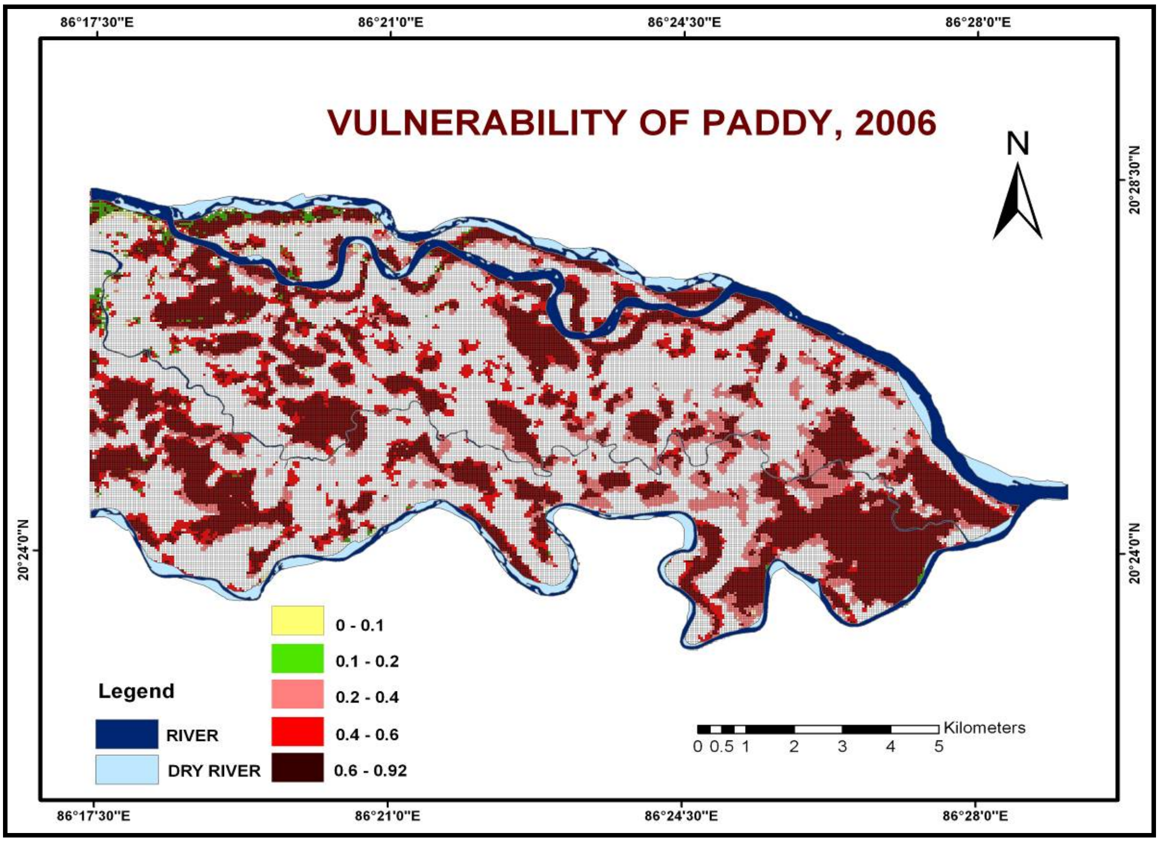


Figure 5-59 Paddy Vulnerability of 2006

Vulnerability of paddy is low of less than 0.1 in the extreme northern part (Fig.5-59). This is because 2006 flood has inundated scattered areas particularly with some prominent patch in the east, few areas in the west and small part in the central region. Northern part is an elevated region, so paddy fields located there faced less damage than the rest of the part. Paddy fields with medium vulnerability up to 0.4 are found around the areas adjacent to the highly vulnerable areas in the east, south west, northwest and some central parts. This indicates that these areas are lying adjacent to the areas with very heavy inundation. These highly inundated areas are showing maximum vulnerability of the paddy fields which is very obvious as these areas experienced long duration and maximum flood depth. Highly vulnerable paddy fields are found in the east, northwest, south west and few scattered parts in the central region.

5.7.7. Vulnerability of Paddy for the Year 2008

This is the recent flood during the field survey, and the areal extent for this flood was more so many paddy fields were damaged in this flood.

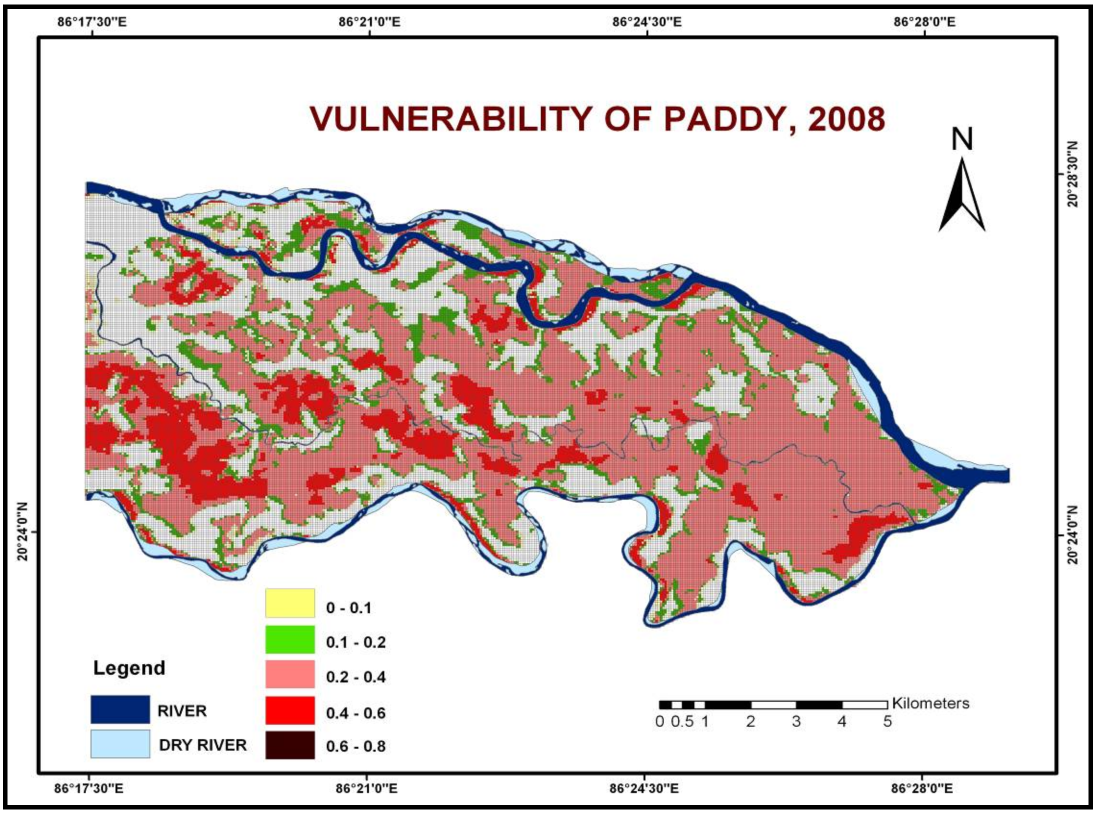


Figure 5-60 Paddy Vulnerability of 2008

Paddy fields in extreme northern part and very small part in the west experienced low vulnerability while major part has experienced medium vulnerability up to 0.4 because this year experienced medium flood duration compared to other years (Fig.5-60). But damage was high due to its greater depth and extent. Paddy fields in the south west faced maximum damage as flood water entered that region first on 18th of September. This is because of breaching of levees in that part and accumulation of water in the lower paddy fields. Some parts in the central area are also showing high vulnerability.

After comparing the vulnerability of three years, it can be said that paddy fields in the east and south west are highly vulnerable and experienced maximum damage while fields in the rest of the western part and central part have medium vulnerability and the paddy fields in the extreme northern part have low vulnerability facing least damages during these three years of flood.

5.7. Damage Assessment of Paddy in different Growth Stages

Damage is considered as the estimated loss of money due to the occurrence of any undesirable phenomena or natural disasters. Damage calculations are done to estimate the total loss that is occurring every year in order to find out the risk. Damage calculation is done by multiplying the damage values with vulnerability.

Damage = Vulnerability * Cost

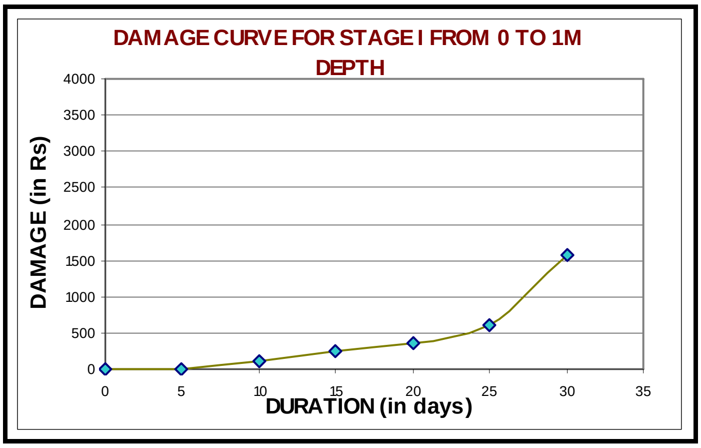
But here damage assessment has been done on the basis of field survey only. Here the general rule is not followed because damage assessment has been done according to the growth stages. And in the initial stage there for these three years there was no flood. Flood usually comes in the middle stage most of the time. Like 2003 flood occurred in the first week of September, 2006 flood occurred in August and 2008 flood again occurred in mid of September. During these times, paddy remains at its middle stage. The initial stage starts from June and continues till July, middle stage up to September and the mature stage till October (see context 5.6.). Therefore damage assessment will be done for all the stages although flood does not occur at the initial or the final stages.

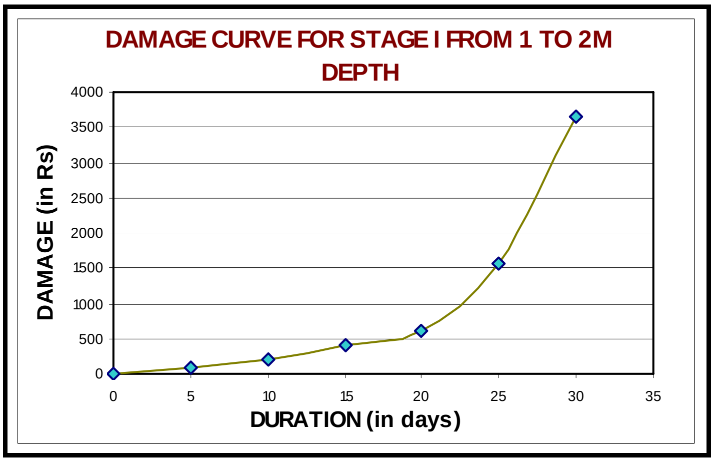
5.8.1. Damage Assessment of Paddy for the Growth Stage I

According to the growth stage explained in the section 5.6, damage curves are generated with different depth and duration for each stage and the probable damage it is causing for that particular depth and duration.

Table 5-27 Damage for Growth Stage I

Stage I					
0 to 1m depth		1 to 2m depth		above 2m depth	
duration	damage	duration	damage	duration	damage
0	0	0	0	0	0
5	0	5	100	5	200
10	100	10	200	10	450
15	250	15	400	15	800
20	350	20	600	20	1600
25	600	25	1560	25	2550
30	1560	30	3660	30	3660





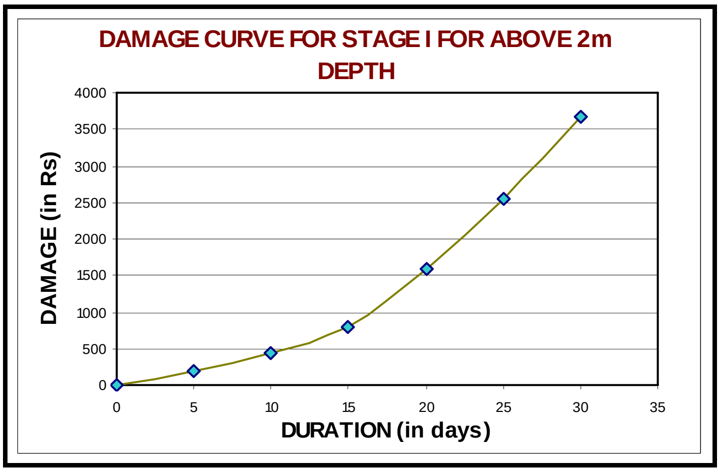


Figure 5-61 Damage within Growth StageI

The damage was calculated on the basis of the loss of money invested by the farmers at the initial stage which includes investment for seeds, tillage cost and the labour cost. Total of this will cost about Rs4140 per acre. So curves are calculated on the basis of loss of this investment if flood occurs at this time. Table 5-27 and Fig. 5-61 are explaining damage curves with varying depth at this stage. Curve with the depth 0 to 1m is showing less damage with the depth of 0 to 1m as at that stage paddy remains under water, and so the loss is not great even after 30 days of flood. It is showing the loss of seeds and labour cost of about Rs 1500 only after 30 days so the curve is low. In case of the water depth from 1 to 2m the damage is more as the flood water level becomes much higher. At the beginning the damage was less till 15 days, but then it increases to the cost of above Rs 3500 which includes the total cost of tillage also at the initial stage. For the depth above 2m from the beginning, there is total damage of the crop within few days as the curve rises very steeply and after 20 or 25 days only there was almost total loss. So at this stage paddy can support few depth of water as they remain under water for many days, but when the depth is more from the beginning, then it cannot survive after such long duration of flood.

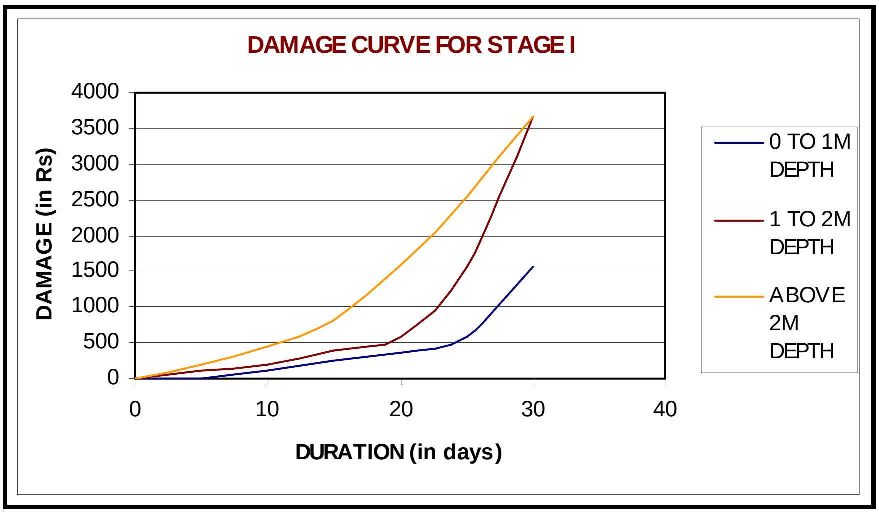


Figure 5-62 Comparative Damage curve

The comparative study of the damage curves (Fig.5-62) shows that curve above 2m depth is causing much damage with the duration which is obvious as paddy plants cannot survive at this depth. The curve with the flood depth of 1 to 2m is showing almost same loss like the curve with more than 2m depth, but the duration of days after which the loss is occurring is much more in case of the this curve. Less than 1m depth curve is showing much low damage as they can survive the flood water at this stage.

5.8.2. Damage Assessment of Paddy for the Growth Stage II

Table 5-28 Damage for Growth Stage II

Stage II					
0 to 1m depth		1 to 2m depth		above 2m depth	
duration	damage	duration	damage	duration	damage
0	0	0	0	0	0
5	100	5	400	5	600
10	400	10	900	10	1560
15	800	15	2000	15	3600
20	1560	20	3500	20	4500
25	2500	25	3900	25	4740
30	4140	30	4140	30	4740

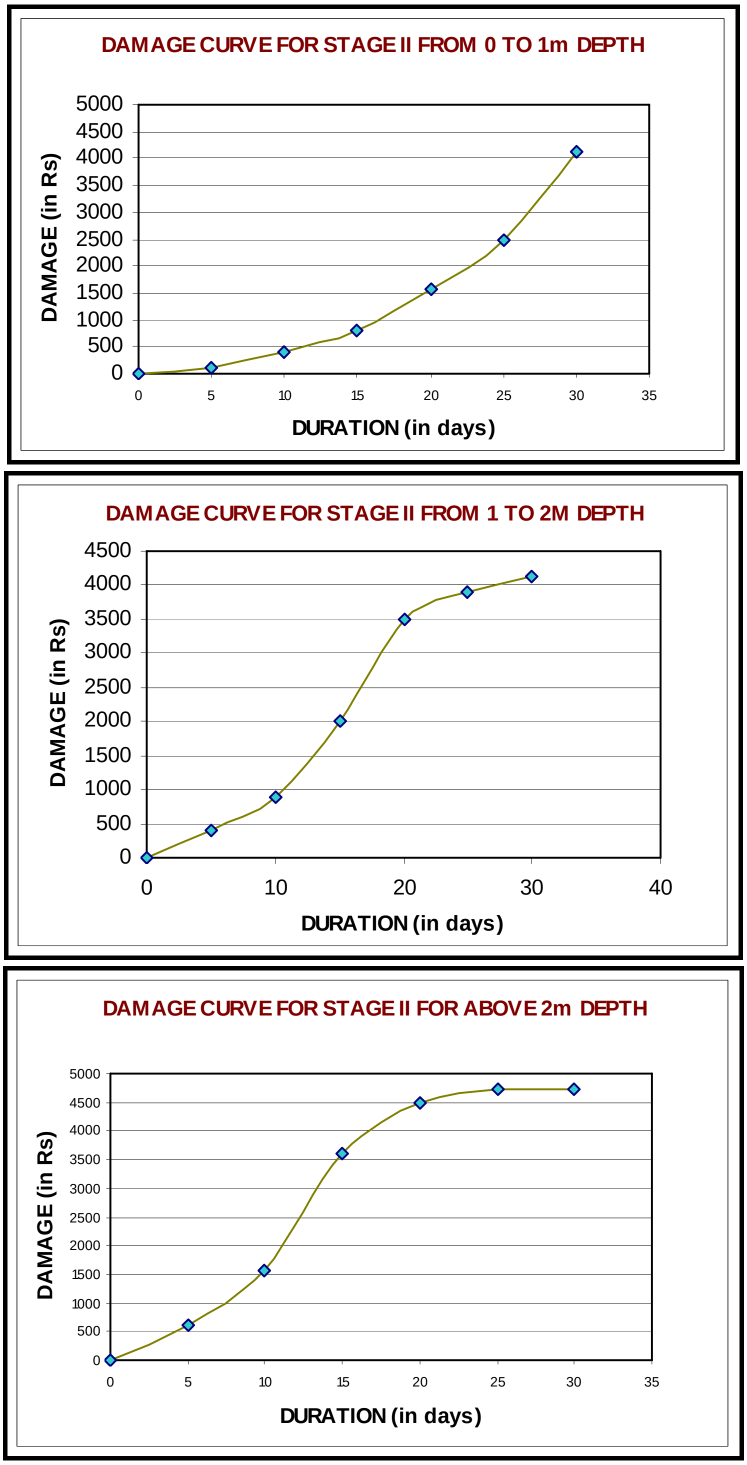


Figure 5-63 Damage within Growth StageII

Damage calculation at this stage of paddy growth has been done on the basis of the investment cost at the second stage of paddy growth. At this stage there is an extra cost of cleaning of grasses inside the paddy fields and fertilizer which costs about extra Rs 1000. So the curves are calculated by taking into account the investment cost at the stage I and stage II together. Table 5-28 values and the curve in fig.5-63 with 0 to 1m depth is showing gradual increase in the loss and after 30 days it will face the loss of about Rs 4000 which includes the approximate loss of the investment at the initial stage and the cost of labourers for cleaning the grass. Therefore at this depth of water, with 20 to 25 days duration the damage is more than the stageI as plants has grown to some height. With the flood depth of 1 to

2m, the damage is steep at the beginning but becomes gradual after 20 days as paddy will almost cease to survive at this stage, and then damage becomes almost constant up to 30 days. With the depth of above 2m, damage is very high at the beginning as the curve is very steep but becomes constant after 15 days only as the plant has faced total damage so the curve is flat after 20 days.

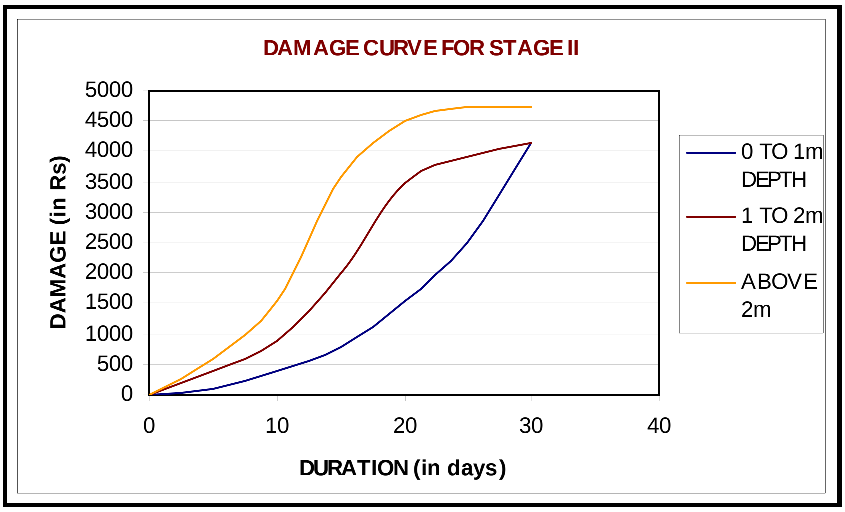


Figure 5-64 Comparative Damage curve

The comparative study is of three curves (fig.5-64) are showing that the curve of o to 1m depth has a constant pattern of increment in damage as the flood depth was less, but the other two curves are showing almost equal trend of damage with the only difference of the curve with more than 2m depth is reaching the point of maximum damage little before than the other curve. Both of these two curves are otherwise following the same trend.

5.8.3. Damage Assessment of Paddy for the Growth Stage III

Table 5-29 Damage for Growth Stage III

0 to 1m depth		1 to 2m depth		above 2m depth	
duration	damage	duration	damage	duration	damage
0	0	0	0	0	0
5	500	5	1000	5	2000
10	1500	10	3000	10	6000
15	4000	15	6500	15	10000
20	8000	20	10000	20	12000
25	10000	25	12000	25	12000
30	12000	30	12000	30	12000

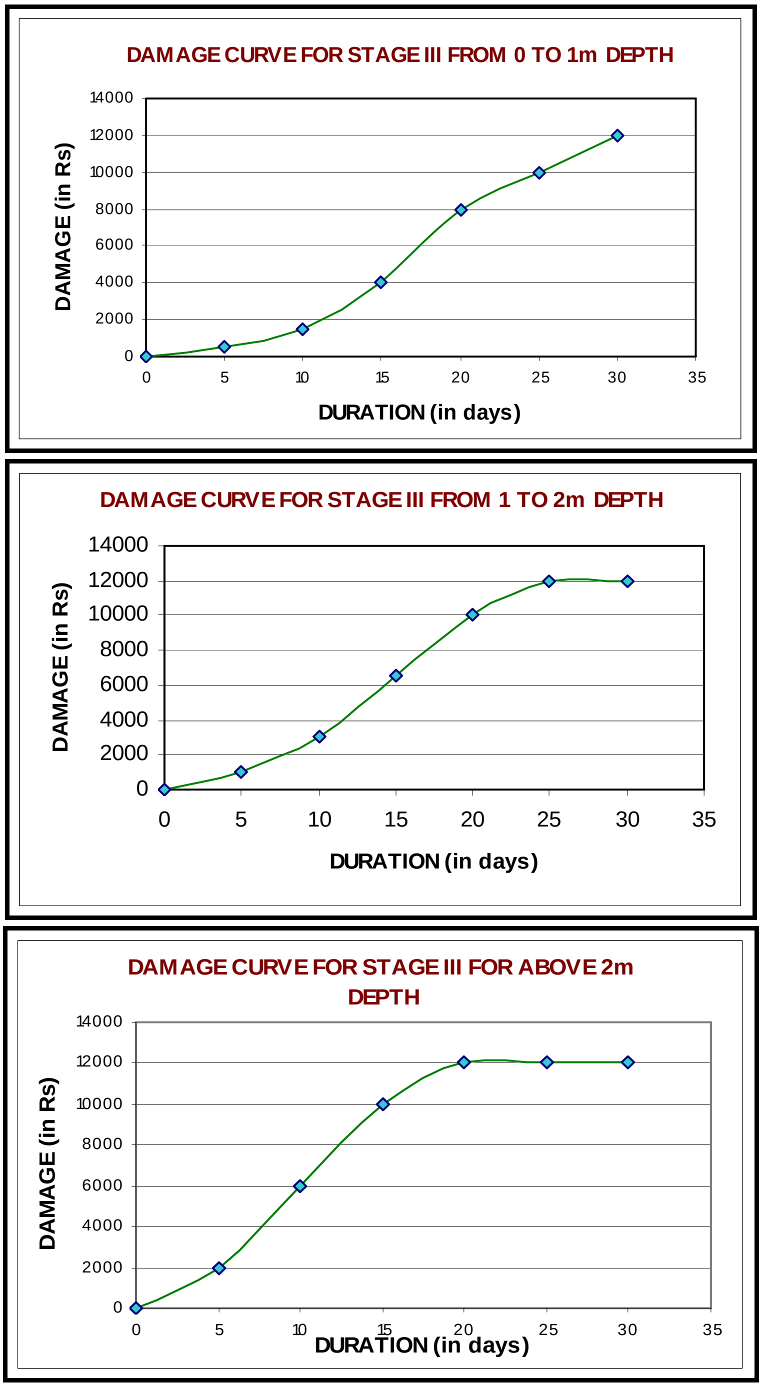


Figure 5-65Damage within Growth StageIII

The damage calculation at the third stage has been done by taking into consideration the entire investment and also the profit of the farmer after selling if there was normal production without any damage due to flood. Total sell price of paddy is Rs 12000 per acre approximately, therefore if flood water comes at this stage then there will be total loss. The curve with water depth with 0 to 1m (Table 5-29 and Fig.5-65) is showing that the damage is above 50% just after the 15 days and has reached the maximum damage of Rs 12000 within 30 days of duration because at that time paddy plants cannot withstand water. With the flood depth of 1 to 2m of flood water, the damage increases very steeply from the beginning indicating high damage and then it reached a constant point up to maximum damage after 20 days only. While the curve with the flood depth of more than 2m experienced total damage after 10 to 15 days. So these curves prove that if flood comes in this stage, there will be total damage of the crop with 0 returns for the farmer.

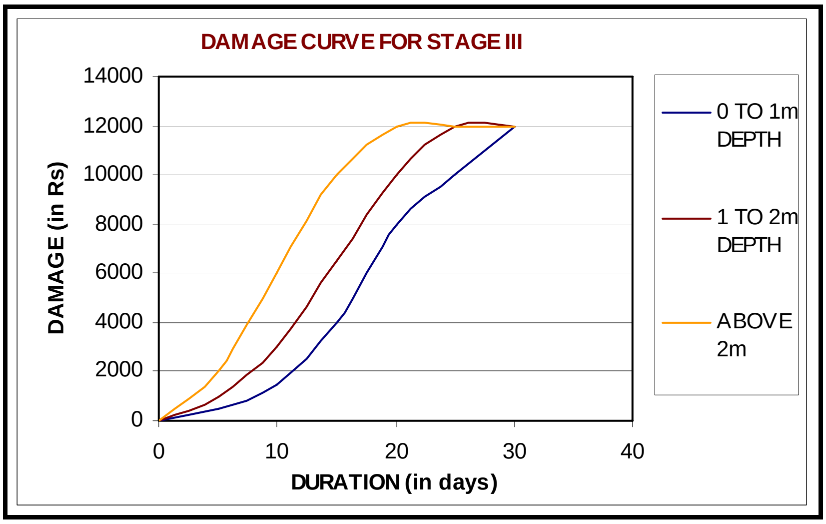


Figure 5-66 Comparative Damage curve

The comparative study for these three curves (fig.5-66) have showing that the damage is equal for all type of depth at this stage, only the duration after which it is occurring is varied. 0 to 1m flood depth has reached the total damage much later than the curve of 1 to 2 m depth and the curve with the flood depth of above 2m has reached the total damage much earlier as more the depth of water, more will be the damage of paddy at the mature stage.

Therefore it can be concluded by saying that at the mature stage or stage III, if flood comes then it will cause extreme damage for the farmer with no more recovery. In the middle stage with low depth of flood water cause less damage as some fertilizer cost was saved by the farmers while with more flood depth it is near to the maximum damage. At the initial stage loss is much less as paddy plants remain under water that time so low flood depth does not cause any damage at all while with more depth there is some damage regarding the fertilizer and labour cost invested by the farmers.

6. Conclusion

Conclusion

The main objective of the project is mapping of flood inundation pattern using the Radarsat images and field observations on three years of 2003, 2006 and 2008 and rice vulnerability assessment. The study of flood water progression pattern through the area is necessary to assess the rice vulnerability and damage because it is a mono crop being cultivated there.
The first objective is to analyse the flood inundation pattern of the area for three years and assessing different flood characteristics to understand the inundation pattern. Specific research question associated with the sub objective is ***How to assess the inundation pattern of the area in three different years of 2003, 2006 and 2008?*** To answer this research question or to obtain the specific result for this objective, different flood characteristic like flood extent, depth and duration were obtained for 2003, 2006 and 2008 from the temporal Radarsat data. Geomorphology and elevation of the area were taken as the main basis for recognizing the flood water flow because flood pattern of the area was mainly controlled by these two factors. Landuse has been used to correlate it with the geomorphology and thereby to identify the presence of different elements in the way of water flow. Pattern of 2003 flood has shown the recession of flood water from the higher elevation in the western part of the study area to the low elevated eastern part with low depth and duration to maximum depth and duration from west to east respectively. Flood pattern of 2006 has shown the progression of flood water in the west and some parts in the east at the beginning which finally spreads to the entire region describing the expansion of water from the breaching point and lower regions to the entire area. Inundation pattern of 2008 also shown the flood water progression till the peak flood period which starts from the west and south western part and gradually extended to the lower areas in the east. After taking the flood inundation pattern of three years it was seen that flood progression is occurring from the west and receding gradually to the east towards the sea.

The second objective is the identification of paddy field and determination of growth stage with microwave data and the research questions associated with it are ***how to distinguish paddy from the Radar image during flood?*** And ***how to identify the paddy fields at the time of flood in comparison to other elements at risk and how to determine its growth stage?***
To respond to the question of distinguishing paddy from the Radar image, backscatter values of paddy from the flood images were observed with respect to the base map of paddy from the Cartosat image. Existence of the paddy fields was verified from the field survey whose backscatter values were taken from the images and it was observed that it was following a specific trend to increase with time. To answer the question of identifying paddy fields at the time of flood from the Radarsat image, points were taken for the flooded paddy fields to obtain their backscatter coefficient values along with the non flooded paddy fields, settlement and river. It was observed that paddy fields were showing an increasing trend of backscatter values with time indicating growth, while settlements and water bodies

have constant values. Non flooded paddy plants also showed increasing backscatter values but their values were higher than the flooded paddy as water has low reflectivity (see section 5.5.5). The existence of these points was validated from the field survey. Therefore apart from the identification of the flooded area, flooded paddy can also be identified from the Radar images. Entire growth of paddy was determined from the field information and rainfall data since Radarsat data for the whole growth stages of paddy was not available. Paddy growth was shown in three stages for the entire growth period (see section 5.6).

The third objective is the vulnerability assessment of paddy and the research question associated with it is ***what is the vulnerability of paddy in relation to the flood characteristics?***
For achieving this objective, field information was collected through questionnaire which includes questions regarding the vulnerability of paddy with definite flood depth and duration, height of paddy plants during flood. Paddy plants are little above 1m in height in the study area. Therefore vulnerability assessment showed that paddy with low depth like 0 to 1m and long duration of more than 15 days may survive but with flood depth of 2m or greater than 2m is highly hazardous for the plant. In some other cases, maximum flood depth of 2m but duration of 1 to 2 days may not prove very damaging depending on the other conditions like growth stage of paddy at which flood occurs. Paddy in the eastern part was most vulnerable in 2003 and moderately vulnerable in the west while it was highly vulnerable both in the east and west in 2006 with moderate vulnerability in some parts of the east. But 2008 is showing paddy fields in the west are highly vulnerable and east has moderate vulnerability which explains that paddy vulnerability is related to the inundation pattern of flood for three years. Damage assessment of paddy was done in addition to this on the basis of synthetic data collection. The amount of damage faced by the paddy plants in the initial stage was much less as paddy remained under water in that period but in the middle and the mature stage the damage was significant because even less depth or less duration of flood can cause heavy damage. The level of damage increases with the depth and duration in the middle and the mature stage (see section 5.8).

6.2 Research Contribution

.

- This research has contributed to the proper understanding of the area under the maximum risk of inundation at the beginning of flood and also the areas through which water will flow and thus the elements or property lying on the way of water movement in future floods.
- The source of flood water in the area as shown during the progression of flood can be used to mitigate flood by constructing proper embankments at the point of water entrance to the region.
- An important contribution is distinguishing paddy fields from the flooded area from microwave image along with the flood area delineation which is necessary as the area has a monoculture of paddy. Therefore it is of utmost necessity to know the total paddy area coming under the flood threat.
- Vulnerability assessment of paddy gives the estimation of the cultivated area (paddy) that will be most, moderately and least vulnerable from the inundation pattern for three years and will help in mitigating the flood loss.

- Damage assessment done on the basis of synthetic data will help in estimating or predicting the damage that will occur if flood comes in the initial or mature stage of paddy cultivation in future and thus will help in reducing the loss by either cultivating more resistant paddy there or by cultivating different crops like jute.

6.3 Research Limitations

- Radarsat data with definite duration for three years were not available like 4th, 11th, 13th and 20th September of 2003; 4th, 19th and 26th August of 2006 and 18th, 20th, 22nd and 24th September of 2008 were available and thus it was not possible to properly assess the inundation pattern. Moreover entire flooded data from the starting date to recession is required to find out the trend or pattern of flooding properly.
- Peak flood data was not available for all the years, so it was not possible to show the actual flooded area.
- To identify the flooded paddy from the microwave data by backscattering needs the information on different bands of Radarsat with the variation in the backscatter value of different polarization and thus comparing them to take the best polarization and band for identifying paddy, which was not available.
- Due to the absence of Radar images with definite duration for the entire growth period of paddy, growth stages of the crop from the microwave image could not be shown.
- Information on the damage assessment is based on the answers given by the farmers.

6.4 Suggestions for the Orissa State Disaster Management Authority

During the field survey it was observed that the condition of roads were very poor with the damaged canals which is contributing to the water congestion in the area when excess water during flood is entering the region. Moreover embankments are not properly constructed (made up of stone, mud etc) and thus leading to breaching from many points which is a major cause of flood. More resistible variety of crop should be grown in the region to avoid the maximum loss. Inundation pattern has shown areas with maximum threat from the flood water submergence. Those areas should be given prior importance for the flood mitigation.

6.5 Recommendations for Future Research

- More temporal dataset can be used for accurately assessing the flood inundation pattern.
- The inundation approach and flood depth and duration can be used in the model of flood routing.
- Multipolarized Radarsat dataset should be used for differentiating the backscatter returned by both flooded and non flooded paddy with different incidence angle to achieve the maximum efficiency in getting the proper information of paddy backscatter values. Moreover wind condition should be taken into account in case of flooded paddy.

- Validation of the backscatter values of paddy in different growth stages should be done from the field with scatterometer which was not considered here.
- Vulnerability assessment should take into account the flood velocity.
- Damage assessment done on different stages of paddy can be used for further research in predicting the flood loss.

References

- ADPC,2005, Primer, Disaster Risk Management in Asia, Bangkok

- Ayala, I. A. 2002. Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. Geomorphology. 47: 107-124

- Blaikie, P., Cannon, T., Davis, I. and Wisner, B. 1994. At Risk: Natural Hazards, People's Vulnerability and Disasters, Routledge, USA, Canada.

- Brivio, P. A., Colombo, R., Maggi, M. and Tomasoni, R. 2002. Integration of remote sensing data and GIS for accurate mapping of flooded areas. International Journal of Remote Sensing. 23(3): 429–441.

- Bryant, R. and Raine, M.P. 2002. Investigation of flood inundation on playas within the Zone of Chotts, using a time-series of AVHRR. Remote Sensing of Environment. 82: 360-375

- Capobianico, M., and De Vriend, H.J. 1999. Coastal area impact and Vulnerability Assessment: The point of a Morphodynamic Modeller. Journal of Coastal Research. 15:701-716.

- Cutter, S.L., (ed.) 2001. The Changing Nature of Risks and Hazards. In American Hazard-scapes. DC: Joseph Henry Press, The Regionalization of Hazards and Disasters, Washington.

- Dhar, O.N. and Nandargi.S. 1998. Floods in Indian Rivers and their Meteorological Aspects, Memoir Geological Society of India, 41: 1-25

- Dhillon, R.K. 2008. Flood Damage assessment and identification of safe routes for evacuation using a Micro-level approch in part of Birupa river basin, Orissa, India. Indian Institute of Remote Sensing (IIRS), India and International Institute for Geo-information Science and Earth Observation (ITC), Enschede, The Netherlands.

- Ermolievaa, T.Y. and Sergienko, V.I., 2008. Catastrophe risk management for sustainable development of regions under risks of natural disasters. Cybernetics and Systems Analysis. 44(3): 405-417.

- Fang, H.(1998).Rice crop area estimation of an administrative division in China using remote sensing data. International Journal of Remote Sensing. 17: 3411–3419.

- Handbook of Agriculture: Indian Council of Agricultural Research, 1980

- Horritt, M.S., Mason, D.C., Cobby, D.M., Davenport, I.J. and Bates, P.D. 2003. Waterline Mapping in Flooded Vegetation from Airborne SAR Imagery. Remote Sensing of Environment. 85: 271-281

- Huang, X. et al. 2008. Flood hazard in Hunan province of China: an economic loss analysis. Natural Hazards, 47: 65–73.

- Inoue, Y., Kurosu, T., Maeno, H., Uratsuka, S., Kozu, T., Dabrowska- Zielinska, K. and Qi, J. 2002. Season-Long Daily Measurement of Multi frequency (Ka, Ku, X, C and L) and Full Polarization Backscatter Signatures over Paddy Rice Field and their Relationship With Biological Variables. Remote Sensing of Environment. 81: 194-204.

- Ishitsuka, N., Saito, Genya., Ogawa, S. and Fukuo, A. 2001. National Institute for Agro Environmental Sciences.
  www. Crisp.nus.edu.sg/acrs2001/pdf/1161SHIT.pdf

- Islam, M.M. and Sado, K., 2000. Flood hazard assessment in Bangladesh using NOAA AVHRR data with geographical information system. Hydrological Processes, 14: 605-620.

- Jain, S.K., Saraf, A.K., Goswami, A. and Ahmad, T. 2006. Flood inundation mapping using NOAA AVHRR data. Water Resource Management, 20: 949–959.

- Keith. 1996. Environmental Hazard: Assessing Risk and Reducing Disaster. Routledge, London

- Kelman, I., (ed.) 2002. Physical flood vulnerability of residential properties in Costal, Eastern England. University of Cambridge, UK.

- Khan, M.R. and Rahman, M.A. 2007. Partnership approach to disaster management in Bangladesh: a critical policy assessment. Natural Hazards, 41: 359–378.

- Kiage, L. M., Walker, N.D., Balasubramanian, S., Babin, A. and Barras, J. 2005. Applications of Radarsat-1 synthetic aperture radar imagery to assess hurricane-related flooding of coastal Louisiana. International Journal of Remote Sensing. 26(24): 5359–5380.

- Kurosu, T., Fujita, M. and Chiba, K. 1997. The Identification of Rice Fields Using Multi-temporal ERS-1C Band SAR Data. International Journal of Remote Sensing. 18: 2953–2965.

- Lillesand, T.M. and Keifer, R.W. Remote Sensing and Image Interpretation. John Wiley and Sons, Inc., U.S.A.

- Magsud, M, Parida, B.R., Samarakoon, L., Asilo, S.A., Casiwan, C.B. and Collado, W.B. Rainfed Rice Area Mapping and Backscatter Analysis Using Multi-Temporal Radarsat1 Images in Pangasinan and Nueva Ecija Provinces of Philippines.

- Matgen, P., Schumann, G., Henry, J.B., Hoffmann, L. and Pfister, L. 2007. Integration of SAR-derived river inundation areas, high-precision topographic data and a river flow model toward near real-time flood management. International Journal of Applied Earth Observation and Geoinformation, 9(3): 247-263.

- Messner, F. and Meyer, V. 2006. Flood damage, vulnerability and risk perception-challenges for flood damage research. Department of Economics, Leipzig.

- Mohapatra, M. and Mohanty, U.C. 2005. Some characteristics of heavy rainfall over Orissa during summer monsoon season. Journal of Earth System Sciences, 114(1): 17-36.

- McNairn, H., Van Der Sanden, J.J., Brown, R.J. and Eliis, J. The Potential of Radarsat 2 for Crop Mapping and Assessing Crop Condition.
  www.radarsat2.info/application/agri/rs2_crop_id_p.pdf

- Nadal, N.C. 2007. Expected Flood Damage to Bulidings in Ravine and Costal zone University of Puerto Rico, Mayaguez campus.

- Ogawa, S. and Genya, S. 1999. Determination of Rice Planting Area in Japan using Remote Sensing Data. National Institute of Agro Environmental Sciences.
  www.gisdevelopment.net/aars/acrs/1999/agri004.asp

- Okamoto, K., & Kawashima, H. 1999. Estimating of rice-planted area in the tropical zone using a combination of optical and microwave satellite sensor data. International Journal of Remote Sensing. 5: 1045–1048.

- Palmino-Reganit, M. 2005. Analysis of Community Coping Mechanism in Relation to Floods: A case study in Naga city, Philippines. International Institute for Geoinformation Science and Earth Observation, Enschede, Netherlands.

- Pandey, A. 2009. Mapping of 2006 Flood Extent in Birupa Basin, Orissa, India, Using Visual and Digital Classification Techniques on RADARSAT Image: A Comparative Analysis. Indian Institute of Remote Sensing (IIRS) and International Institute for Geo-Information Science and Earth Observation (ITC), Enschede, The Netherlands.

- Pappenberger, F., Frodsham, K., Beven, K., Romanowicz, R., and Matgen, P. 2007. Fuzzy Set Approach to Calibrating Distributed Flood Inundation Models using Remote Sensing Observations. Hydrol. Earth Syst. Sci. 11: 739-752

- Pauwels, V.R.N., Hoeben, R.,Verhoest, N.E.C., DeTroch, F.P. 2001. The importance of the spatial patterns of remotely sensed soil moisture in the improvement of discharge predictions for small-scale basins through data assimilation. J.Hydrol. 251(1/2),88–02.

- Phoompanich, S. 2005. Multi-Temporal Radarsat for Crop Monitoring. Geo-Informatics and Space Technology Development Agency.

www.aars-acrs.org/acrs/proceeding/ACRS2005/Papers/AGC2-3.pdf

- Rao, D.P., Bhanumurthy, V., Rao, G.S. and Manjusri, P. 1998. Remote Sensing and GIS in Flood Management in India, Memoir Geological Society of India, 41: 195-218

- Rao, D.P. 2000. Disaster Management, Hyderabad, National Remote Sensing Agency (Dept of Space, Govt.of India)

- Remi, A., Jiren, L., Yesou, H. Flood Extent Prediction From Lake Heights and Water Level Estimation from Flood Extents Using River Gauges, Elevation Models and Envisat Data .

- Sado, K. and Islam, M.M. 1997. Satellite remote sensing data analysis for flooded area and weather study: Case study of Dhaka city, Bangladesh. Journal of Hydraulic Engineering. 41: 945–950.

- Sanyal, J. and Lu, X.X., 2003. Application of Remote Sensing in Flood Management with special Reference to Monsoon Asia, A Review. Natural Hazards. 33: 283-301.

- Sanyal, J. and X. X. Lu. 2004. Application of Remote Sensing in Flood Management with Special Reference to Monsoon Aisa: A review. Natural Hazards. 33: 283-301.

- Shao, Y., Fan, X., Liu, H., Xiao, J., Ross, S., Brisco, B., Brown. R. and Staples, G. 2001. Rice Monitoring and Production Estimation Using Multi Temporal Radarsat. Remote Sensing and Environment. 76: 310-325

- Smith,K. 1991. Environmental Hazards: Assessing Risk and reducing disasters, Routledge, USA, Canada

- Smith, L.C. 1997. Satellite remote sensing of river inundation area, stage, and discharge: A review. Hydrological Processes. 11: 1427–1439.

- Thieken, A. H., Muller, M., Kreibich, H. and Merz, B. 2005. Flood Damage and Influencing Factors: New Insights from the August 2002 flood in Germany. Water Resour. Res., 41

- Townsend, P.A. and Walsh, J. 1998. Modelling floodplain inundation using an integrated GIS with radar and optical remote sensing. Geomorphology. 21: 295-312.

- Treby, E., Clark, M.J. and Priest, S. J. 2006. Confronting Flood Risk: Implications for Insurance and Risk Transfer. Journal of Environmental Management. 81: 351-359

- UNDRO, 1991, Mitigating Natural Disasters: Phenomena, Effects and Options. United Nations, New York

- Van Niel, T.G., McVicar, T.R., Fang,H., & Liang, S. 2003. Calculating environmental moisture for per-field discrimination of rice crops. International Journal of Remote Sensing, 24, 885–890.

- Wan Quing. 1999. Deciding the Flood Extent with Radarsat SAR data and Image Fusion. LREIS, Chinese Academy of Science, Beijing.
  www.gisdevelopment.net/aars/acrs/1999/ps3/ps3999pf.htm

- Wang, Y., Colby, J.D. and Mulchay, K.A. 2002. An efficient method for mapping flood extent in a coastal floodplain using Landsat TM and DEM data. International Journal of Remote Sensing, 23(18): 3681-3696.

- Werner, M., 2001. Impact of Grid Size in GIS Based Flood Extent Mapping Using a 1-D Flow Model. Phys. Chem. Earth. 26: 517-522

- Wood, D., McNairn, H., Brown, R.J. and Dixon, R. 2002. The Effect of Dew on the use of Radarsat 1 for Crop Monitoring Choosing between Ascending and Descending Orbits. Remote Sensing of Environment. 80: 241-247

- www.kendrapara.nic

- Xiao, X., Boles, S., Frolking, S., Salas, W., Moore III, B. and Li, C. 2002. Observation of Flooding and Rice Transplanting of Paddy Rice Fields at the Site to Landscape Scales in China Using Vegetation Sensor Data. International Journal of Remote Sensing. 23 (15): 3009-3022

- Xiao, X., Boles, S., Frolking, S., Li, C., Babu, J.Y., Salas, W. and Moore III, B. 2006. Mapping Paddy Rice Agriculture in South and Southeast Asia Using Multi-Temporal MODIS Images. Remote Sensing of Environment. 100: 95-113

- Zribi, M. and Dechambre, M. 2003. A new empirical model to retrieve soil moisture and roughness from C-band radar data. Remote Sens. Environ. 84(1), 42–52.

Appendix

Appendix 1: Questionnaire for production of paddy during flood

Id no	Location (lat/ long)	Normal Production	Production of Paddy during Flood	Year
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Questionnaire for location points of different elements

Id	GPS Locations					
	Agricultural land		Non Agricultural land			
	Paddy	Jute	Settlement	Road	Fallow land	Water body
1						
2						
3						
4						
5						
6						

Questionnaire for Cause of flood

Id no	Location (lat/ long)	Causes of flood				
1		Rain	River	breach	other	Remark
2						
3						
4						
5						
6						
7						
8						
9						

Questionnaire for Vulnerability

Initial condition					Middle condition					Mature condition				
Duration			Depth (m)	Damage (in Rs)	Duration			Depth (m)	Damage (in Rs)	Duration			Depth (m)	Damage (in Rs)
1-5 days	5-10 days	>10 days			1-5 days	5-10 days	above 10			1-5 days	5-10 days	>10 days		

Questionnaire for the verification of paddy growth stage using RADARSAT Data

Id no	Location (lat/ long)	Causes of flood					Flood duration category with depth in meter							
		Rain	River	breach	other	Remark	Short	Depth	Medium	Depth	Long	Depth	Remark
1														
2														
3														
4														
5														
6														
7														
8														

Questionnaire for damage

Id. No.	Total Investment	Total Income	Investment in Stage I (in Rs)	Investment in Stage II (in Rs)	Investment in Stage III (in Rs)
1					
2					
3					
4					
5					

Appendix 2: Vulnerability Calculation Table

DEPTH (m)	DURATION (days)	PRODUCTION (quintal)	LOSS (quintal)	VULNERABILITY	YEAR
0-1m	0 to3	19.5	0.5	0.025	2003
0-1m	0 to 3	19.5	0.5	0.025	2006
0-1m	3 to 6	19	1	0.05	2003
0-1m	3 to 6	19.5	0.5	0.025	2008
0-1m	6 to 9	19	1	0.05	2003
0-1m	9 to 12	18	2	0.1	2003
0-1m	9 to 12	19	1	0.05	2003
0-1m	12 to 15	18	2	0.1	2003
0-1m	12 to 15	18	2	0.1	2003
0-1m	12 to 15	18	2	0.1	2003
0-1m	15 to 18	17	3	0.15	2003
0-1m	15 to 18	18	2	0.1	2008
0-1m	15 to 18	18	2	0.1	2008
0-1m	15 to 18	18	2	0.1	2003
0-1m	18 to 21	18	2	0.1	2006
0-1m	18 to 21	18	2	0.1	2006
0-1m	18 to 21	17	3	0.15	2003
0-1m	21 to 24	18	2	0.1	2006
0-1m	21 to 24	17	3	0.15	2006
0-1m	21 to 24	17	3	0.15	2006
0-1m	24 to 27	17	3	0.15	2003
0-1m	24 to 27	17	3	0.15	2003
0-1m	24 to 27	18	2	0.1	2003
0-1m	27 to 30	18	2	0.1	2006
0-1m	27 to 30	16	4	0.2	2003
0-1m	27 to 30	17	3	0.15	2006
1-2m	0 to 3	19	1	0.05	2003
1-2m	0 to 3	19	1	0.05	2008
1-2m	0 to 3	19	1	0.05	2008
1-2m	3 to 6	18	2	0.1	2003
1-2m	3 to 6	19	1	0.05	2003
1-2m	3 to 6	19	1	0.05	2006
1-2m	6 to 9	17	3	0.15	2003
1-2m	6 to 9	18	2	0.1	2006
1-2m	6 to 9	17	3	0.15	2003
1-2m	9 to 12	15	5	0.25	2003
1-2m	9 to 12	17	3	0.15	2003
1-2m	9 to 12	17	3	0.15	2006
1-2m	12 to 15	10	10	0.5	2003
1-2m	12 to 15	12	8	0.4	2003
1-2m	12 to 15	11	9	0.45	2003
1-2m	15 to 18	8	12	0.6	2003
1-2m	15 to 18	7	13	0.65	2006
1-2m	15 to 18	6	14	0.7	2003
1-2m	18 to 21	5	15	0.75	2006
1-2m	18 to 21	4	16	0.8	2006
1-2m	21 to 24	4	16	0.8	2006

1-2m	21 to 24	3	17	0.85	2003
1-2m	24 to 27	3	17	0.85	2003
1-2m	24 to 27	2	18	0.9	2008
1-2m	24 to 27	4	16	0.8	2008
1-2m	27 to 30	2	18	0.9	2003
1-2m	27 to 30	3	17	0.85	2003
1-2m	27 to 30	1	19	0.95	2003
>2m	0 to 3	16	4	0.2	2008
>2m	0 to 3	16	4	0.2	2008
>2m	0 to 3	15	5	0.25	2008
>2m	0 to 3	16	4	0.2	2008
>2m	0 to 3	17	3	0.15	2008
>2m	0 to 3	17	3	0.15	2008
>2m	0 to 3	16	4	0.2	2008
>2m	0 to 3	15	5	0.25	2008
>2m	3 to 6	12	8	0.4	2003
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	15	5	0.25	2006
>2m	3 to 6	12	8	0.4	2006
>2m	3 to 6	15	5	0.25	2006
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	12	8	0.4	2006
>2m	3 to 6	10	10	0.5	2006
>2m	3 to 6	10	10	0.5	2006
>2m	3 to 6	14	6	0.3	2006
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	13	7	0.35	2006
>2m	3 to 6	15	5	0.25	2006
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	15	5	0.25	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	15	5	0.25	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	14	6	0.3	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	11	9	0.45	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	14	6	0.3	2008
>2m	3 to 6	12	8	0.4	2008

>2m	3 to 6	14	6	0.3	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	15	5	0.25	2008
>2m	3 to 6	13	7	0.35	2008
>2m	3 to 6	11	9	0.45	2008
>2m	3 to 6	12	8	0.4	2008
>2m	3 to 6	13	7	0.35	2008
>2m	6 to 9	9	11	0.55	2003
>2m	6 to 9	8	12	0.6	2003
>2m	6 to 9	10	10	0.5	2006
>2m	6 to 9	9	11	0.55	2006
>2m	6 to 9	11	9	0.45	2006
>2m	6 to 9	10	10	0.5	2008
>2m	6 to 9	11	9	0.45	2008
>2m	6 to 9	9	11	0.55	2008
>2m	9 to 12	6	14	0.7	2003
>2m	9 to 12	6	14	0.7	2003
>2m	12 to 15	2	18	0.9	2003
>2m	12 to 15	3	17	0.85	2003
>2m	12 to 15	5	15	0.75	2003
>2m	12 to 15	3	17	0.85	2003
>2m	12 to 15	5	15	0.75	2003
>2m	12 to 15	3	17	0.85	2003
>2m	12 to 15	2	18	0.9	2003
>2m	12 to 15	5	15	0.75	2003
>2m	12 to 15	3	17	0.85	2003
>2m	12 to 15	3	17	0.85	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	2	18	0.9	2003

>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	1	19	0.95	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	2	18	0.9	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	3	17	0.85	2003
>2m	15 to 18	1	19	0.95	2006
>2m	15 to 18	3	17	0.85	2006
>2m	15 to 18	0	20	1	2006
>2m	15 to 18	3	17	0.85	2006
>2m	15 to 18	1	19	0.95	2006
>2m	15 to 18	1	19	0.95	2006
>2m	15 to 18	2	18	0.9	2006
>2m	15 to 18	3	17	0.85	2006
>2m	15 to 18	2	18	0.9	2006
>2m	18 to 21	2	18	0.9	2006
>2m	18 to 21	1	19	0.95	2006
>2m	18 to 21	2	18	0.9	2006
>2m	21 to 24	1	19	0.95	2006
>2m	21 to 24	2	18	0.9	2006
>2m	21 to 24	1	19	0.95	2006
>2m	21 to 24	1	19	0.95	2006
>2m	21 to 24	2	18	0.9	2006
>2m	21 to 24	0	20	1	2006
>2m	21 to 24	1	19	0.95	2006
>2m	21 to 24	1	19	0.95	2006
>2m	24 to 27	0	20	1	2003
>2m	24 to 27	1	19	0.95	2003
>2m	24 to 27	1	19	0.95	2003
>2m	24 to 27	1	19	0.95	2003
>2m	27 to 30	0	20	1	2003
>2m	27 to 30	0	20	1	2003
>2m	27 to 30	1	19	0.95	2003
>2m	27 to 30	1	19	0.95	2003

Normal production is 20 quintals, during flood it has reduced and the vulnerability calculations have been done on the basis of the production during flood period.

Damage Calculation Table

SERIAL NO.	TOTAL INVESTMENT	TOTAL INCOME	INVESTMENT IN STAGE I (in Rs/acre)		
	(in Rs/acre)	(in Rs/acre)	Seed	Labourers	Tillage
1	7000	12500	650	960	2100
2	6500	11500	500	960	1800
3	7500	11500	550	840	2100
4	8000	13000	700	1000	2100
5	8000	12000	650	1000	2100
6	7500	12000	550	960	2100
7	7500	11000	550	960	2000

8	7500	12000	600	1000	2100
9	8000	13000	700	1020	2100
10	7500	13000	700	1000	2100
11	7000	11000	500	840	2000
12	8000	12500	500	960	2100
13	7500	12000	500	1000	2100
14	7000	12000	600	960	2100
15	7500	11000	500	960	2000
16	8000	13000	650	1000	2100
17	7500	13000	600	1000	2100
18	7500	12000	600	1000	2100
19	8500	12500	600	960	2100
20	7500	12000	600	1000	2000
21	8000	12500	700	960	2100
22	6500	12000	650	960	2000
23	8000	13000	600	960	2100
24	7500	12000	500	1000	2100
25	7500	12000	500	1000	2100
26	7500	12000	550	1000	2000
27	7500	11500	500	960	2100
28	7500	12000	600	1000	2000
29	8000	13500	700	1000	2100
30	7500	13000	750	1000	2100
31	7500	12000	500	1000	2000
32	7000	11500	600	960	2000
33	7000	11500	650	840	1800
34	7500	12000	500	1000	2100
35	8000	12500	600	900	2100
36	7500	12000	550	1000	2100
37	7500	11000	500	960	2000
38	7500	11500	600	960	2100
39	7000	12000	650	1000	2100
40	8000	12500	600	960	2100
41	7500	13000	700	960	2100
42	7000	10500	600	840	2100
43	7000	12000	600	960	2100
44	7000	12000	650	1000	2100
45	8000	13000	700	1000	2100
46	6500	12000	600	960	2000
47	7500	13000	600	1000	2100
48	7000	11000	700	840	1800
49	7000	12500	700	960	2100
50	8500	13000	600	1000	2100
51	7000	12000	600	1000	2100
52	7500	11000	600	960	2000
53	7500	12000	550	960	2100
54	7500	12000	600	1000	2100
55	7500	12000	600	1000	2000
56	7500	12000	600	1000	2100
57	7000	11000	600	960	2000
58	8000	12500	600	1000	2100

59	7500	12000	500	960	2100
60	7000	11500	500	840	2000
61	7500	12000	600	960	2000
62	7500	11000	600	840	1800
63	7500	12000	650	960	2000
64	8000	12500	600	960	2100
65	8000	12500	650	960	2100
66	7500	12000	600	960	2100
67	7500	11000	600	840	2100
68	7000	11000	500	840	2000
69	6500	10000	500	840	2000
70	7000	11500	750	960	2000
71	8000	13000	650	1000	2100
72	7500	13000	650	1000	2100
73	6500	11000	500	960	2000
74	7500	12000	600	960	2100

SERIAL NO.	**TOTAL INVESTMENT**	**TOTAL INCOME**	**INVESTMENT IN STAGE II (in Rs/acre)**	
	(in Rs/acre)	**(in Rs/acre)**	**Cleaning of grass**	**Fertilizer**
1	7000	12500	500	600
2	6500	11500	450	550
3	7500	11500	450	550
4	8000	13000	500	650
5	8000	12000	480	600
6	7500	12000	480	600
7	7500	11000	450	550
8	7500	12000	500	600
9	8000	13000	500	600
10	7500	13000	500	550
11	7000	11000	450	600
12	8000	12500	500	650
13	7500	12000	480	600
14	7000	12000	480	600
15	7500	11000	450	550
16	8000	13000	500	650
17	7500	13000	500	600
18	7500	12000	480	600
19	8500	12500	500	600
20	7500	12000	480	600
21	8000	12500	480	650
22	6500	12000	480	600
23	8000	13000	500	650
24	7500	12000	450	600
25	7500	12000	480	600
26	7500	12000	500	600
27	7500	11500	450	550
28	7500	12000	500	600
29	8000	13500	500	650
30	7500	13000	500	650
31	7500	12000	480	600

32	7000	11500	450	550
33	7000	11500	450	550
34	7500	12000	480	600
35	8000	12500	500	650
36	7500	12000	480	600
37	7500	11000	450	550
38	7500	11500	450	600
39	7000	12000	480	600
40	8000	12500	500	650
41	7500	13000	500	650
42	7000	10500	450	600
43	7000	12000	480	600
44	7000	12000	480	600
45	8000	13000	480	650
46	6500	12000	480	600
47	7500	13000	500	650
48	7000	11000	450	550
49	7000	12500	480	600
50	8500	13000	500	650
51	7000	12000	480	600
52	7500	11000	450	550
53	7500	12000	480	600
54	7500	12000	480	600
55	7500	12000	480	600
56	7500	12000	480	600
57	7000	11000	450	550
58	8000	12500	500	650
59	7500	12000	500	600
60	7000	11500	480	550
61	7500	12000	480	600
62	7500	11000	450	550
63	7500	12000	480	600
64	8000	12500	500	650
65	8000	12500	500	650
66	7500	12000	480	650
67	7500	11000	480	600
68	7000	11000	450	550
69	6500	10000	450	550
70	7000	11500	480	600
71	8000	13000	500	650
72	7500	13000	500	600
73	6500	11000	500	550
74	7500	12000	480	600

SERIAL NO.	**TOTAL INVESTMENT**	**TOTAL INCOME**	**INVESTMENT IN STAGE III (in Rs/acre)**			
	(in Rs/acre)	**(in Rs/acre)**	**Harvesting**	**Carrying Cost**	**Spreading**	**Cleaning**
1	7000	12500	480	960	960	150
2	6500	11500	500	900	900	150

3	7500	11500	450	900	900	140
4	8000	13000	500	1000	1000	200
5	8000	12000	480	1000	1000	150
6	7500	12000	480	960	960	150
7	7500	11000	450	900	840	140
8	7500	12000	480	960	960	150
9	8000	13000	500	1000	1000	200
10	7500	13000	500	1000	1000	150
11	7000	11000	450	840	840	140
12	8000	12500	500	1000	1000	160
13	7500	12000	480	960	960	150
14	7000	12000	480	960	1000	150
15	7500	11000	450	900	900	150
16	8000	13000	500	1000	1000	150
17	7500	13000	500	1000	1000	200
18	7500	12000	480	960	960	140
19	8500	12500	500	1000	1000	200
20	7500	12000	480	960	960	150
21	8000	12500	480	1000	1000	150
22	6500	12000	480	1000	1000	150
23	8000	13000	500	1000	1000	150
24	7500	12000	480	960	960	150
25	7500	12000	480	960	960	150
26	7500	12000	480	1000	1000	150
27	7500	11500	450	900	900	140
28	7500	12000	480	960	960	150
29	8000	13500	500	1000	1000	200
30	7500	13000	500	1000	1000	150
31	7500	12000	480	960	960	150
32	7000	11500	450	960	900	150
33	7000	11500	450	900	900	140
34	7500	12000	480	960	960	150
35	8000	12500	500	1000	1000	150
36	7500	12000	480	960	960	150
37	7500	11000	450	900	900	140
38	7500	11500	450	900	840	200
39	7000	12000	500	1000	1000	150
40	8000	12500	480	1000	1000	200
41	7500	13000	500	1000	1000	150
42	7000	10500	450	900	900	140
43	7000	12000	480	960	960	150
44	7000	12000	480	960	960	100
45	8000	13000	500	1000	1000	150
46	6500	12000	450	960	960	150
47	7500	13000	500	1000	1000	150
48	7000	11000	450	900	900	150
49	7000	12500	500	960	960	150
50	8500	13000	500	1000	1000	150
51	7000	12000	480	960	960	150
52	7500	11000	450	900	900	140
53	7500	12000	480	960	1000	150

54	7500	12000	480	960	1000	150
55	7500	12000	480	960	960	140
56	7500	12000	480	960	960	150
57	7000	11000	450	840	840	140
58	8000	12500	500	1000	1000	150
59	7500	12000	480	960	960	150
60	7000	11500	450	900	900	140
61	7500	12000	500	1000	1000	200
62	7500	11000	480	960	960	150
63	7500	12000	480	960	960	150
64	8000	12500	500	1000	1000	150
65	8000	12500	500	960	960	150
66	7500	12000	480	900	960	150
67	7500	11000	450	960	960	140
68	7000	11000	480	960	960	150
69	6500	10000	450	900	900	140
70	7000	11500	480	960	960	150
71	8000	13000	480	1000	1000	150
72	7500	13000	500	1000	1000	150
73	6500	11000	450	960	960	140
74	7500	12000	480	960	1000	150