Flood Risk Assessment on Meso scale, in a part of Birupa river basin using temporal RADARSAT data (2003, 2006 & 2008)

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by

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I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.
Signed …………………….

Disclaimer

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Dedicated

To my parents....

ABSTRACT

Birupa basin in Orissa is a typical example of how nature can play a major role in deciding the destiny of those inhabiting the area. The region has one of the richest fertile plain in the contrary but is still one of the poorest regions of Orissa as it is ravaged by recurrent floods. The region is surrounded by rivers on all sides. Floods have caused immense damage to life and property and based on the observations of a micro scale study carried for risk and damage assessment for the area, the present work aims at meso scale study to estimate damage to different elements at risk. Vulnerability was assessed for elements at risk by generating a vulnerability curves on the basis of flood damage information collected from field and official sources. How these elements at risk behaved at the time of flood is understood by field observation and background literature for the area. Elements at risk which were selected for the study area were roads, house and agricultural field and among different flood related parameter like duration, sediment load, velocity and inundation, flood depth and flood duration were taken for assessing damage due to flood for three flood events (2003, 2006 and 2008). Flood depth and flood duration have been used for the agricultural damage and flood depth has been used the house and road damage due to flood. Damage assessment of elements at risk has been assessed from their vulnerability of three different flood events and their construction cost. Damage value is expressed in rupees (Indian currency) from product of vulnerability and construction cost of each elements at risk. By calculating damage value for all elements at risk and finally adding them it gives total damage of a flood event. Flood extent map have been generated from RADARSAT images by threshold method for three different flood events. River and other semi-permanent water bodies were extracted from Cartosat-1 and Google image by visual interpretation. Flood depth was calculated from Cartosat-1 DEM and maximum flood level information. It is applied on the maximum areal extent among the different areal extent of different dates for a single flood event. Determination of value of assets of the elements at risk was decided on the basis of primary and secondary data which was collected from field and government offices and other authorized organization. Determination of the risk curve was one of the major objectives of the study. Risk curve has been derived from probability of flood occurrence and damage in 2003, 2006 and 2008 flood events. Damage of elements at risk has been classified on basis of vulnerability of elements at risk and cost which are necessary for coping. Construction cost of elements at risk has been collected from Govt. and other authorized organizations. Information of related damage and vulnerability has been collected from extensive field survey. Finally, the information generated was combined with remote sensing data and it was found that results were comparable with those of field observation. The comparison thus shows that assessment of damage due to flood was accurate on meso scale and that it can be used for flood damage assessment.

Key words: *Floods, RADARSAT, DEM, Vulnerability, Curves, Elements, Risk, Damage.*

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1. Introduction

Flood is the most common and disastrous event in human life. It occurs due to overflow of river banks and thus, is largely responsible for the destruction of human property and life. It may be defined as 'a relatively high flow which overflows the natural channel provided for the runoff. Flood is also defined as the body of water which rises to overflow land which is not permanently submerged. In many parts of the Indian subcontinent, flooding reaches catastrophic proportions during the summer monsoon season. River is said to be in flood when its water level crosses the Danger Level at that particular site. Flooding is not just confined to south Asia but is a globally pervasive hazard. Therefore lots of initiatives have been taken to develop the proper ground for the understanding and the mitigation of flood. In 1967, UNESCO and WMO supported international symposium on 'floods and their computation', organized at Leningrad to draw the attention of scientists and engineers to this continually destructive hazard. It has been found that flood is increasing with time. In earlier days, population was less; therefore impact of flood was also less causing less property damage and destruction. With the continuous increasing trend in population resulting in development of settlements along the river side which is in turn due to excessive sedimentation or natural meandering is resulting in overflowing of the banks. So human beings are somehow responsible for their own destruction due to flood.

Floods have been classified on the basis of duration into Single event, multiple event and seasonal floods. Single event floods in which widespread heavy rains of a longer duration of 5 to 7 days or more than that over a drainage basin results in severe floods; Multiple event floods which occurs when successive weather disturbances follow each other closely; and Seasonal floods occurring during different seasons, like summer monsoon season experiences many floods as major storm activity occurs during this season.

Typical characteristics of flood are largely dependent on the extent, duration, depth and frequency. Extent of flood includes the area it covers, larger the extent, larger will be the area under destruction. Duration is the total time of flood occurrence, the duration with which it is occurring, largely controls the demolition of an area. Its continuity is sometimes largely controlled by the intensity of rainfall. Therefore flood with long duration may results in larger extent and thus causing havoc in the affected area. Depth of flood is very important as it signifies the danger level. Up to what level the water has reached, is an important factor during the time of the hazard? Excessive depth may not only destroy the property but also life of people, which mostly occurs during the flood of long durations. Frequency is another important characteristic of flood as it maintains a definite time interval. The repetition of the flood of a specific magnitude after a definite time interval is called a flood frequency. For e.g. flood of 2006 with a definite magnitude will return again after few years. Therefore all these factors are correlated and dependent on each other where one factor leads to the other one.

Vulnerability and risk of flood are the most important factors which should be assessed in flood management. Risk is considered as a measure of the expected losses due to a hazard event of a particular magnitude occurring in a given area over a specific time period. It is a function of the probability of particular occurrences and the losses each would cause. The level of risk depends upon:

- The nature of the hazard
- Vulnerability of elements which are affected
- Economic value of the elements at risk

Vulnerability is the level of exposure of persons and property to the hazards. Timmenmen (1981) in Prasad, (2007) reviewed vulnerability at the society or community scale and defined it as the degree to which a system, or part of system, may react adversely to the occurrence of a hazardous event. There are physical vulnerability which is related to the physical location of people and elements at risk and their physical proximity to the hazard. So the properties of people which are exposed to the destruction due to flood are considered as physical vulnerability. So people are only vulnerable to flood because they live in flood prone areas. Socio-Economic vulnerability indicates that the degree to which a population is affected by a calamity will not purely lie on the physical components but also has a contextual realization to the prevailing social and economic conditions. Settlement which are dependent on river, their more prone to flood hazards and therefore are more prone to flood when source of flood comes from river due to overflow on river embankment.

In meso scale study is more accurate than micro level approach, but less accurate than micro level approach for assessing the damage due to flood. Here the variables of different category are averaged in pixel level. For Example, different characteristics like age, design, building materials, construction type, cost etc of house will be put on the basis of average of all houses within that pixel. All the variables will be collected from the field and the value will be determined by standard chart made by officials or other previous study for properly values and guidelines. In this case only the damaged part is mapped out and calculated for a particular hazard. Then their relative study is done on the basis of potential relative characteristics of the elements at risk and hazard parameters like depth, duration in case of flood hazard where as in micro level study the damage potentials are also taken into consideration on an object level.

1.1 Problem defination

Floods are the most common and well spread natural disasters and statistically more than half of world population lives near to sea coast or river delta or along the rivers. India is one of the worst flood affected countries in the world and is placed second after Bangladesh. In India particularly in Orissa most of the flood events happen during the monsoon period (June to September).As a result of heavy rain during the monsoon period almost all the rivers carry high discharge of water. Sediment deposition, drainage congestion and synchronization of river floods with sea tides in the coastal plain add to the impacts of the floods. Flood is frequently and almost yearly occurring phenomena in the study area taken up for this study. Houses are mainly made of mud, straw, bamboo etc and the economic situation is not very good; the people are poor. Life, property and other material resources are damaged due to the floods.

Prior to this study no flood risk assessment in Orissa has been carried out. For this particular area, Damage assessment has done only for one year (2006 flood event). For flood risk assessment at least 3 different flood events with different recurrence intervals are necessary. Flood risk assessment can be a valuable input for flood management. In this study it decided to work on a meso (regional) scale in order to have a wider applicability in Orissa.

1.2 Objective

Flood risk assessment on meso scale, based on the floods of 2003, 2006 and 2008.

1.2.1 Sub-objective

- Derive the nature of the 2003, 2006 & 2008 floods (extent, duration, depth and frequency).
- Define Land use map/ Elements at risk map (aggregated data).
- Derive vulnerability maps on basis of flood depth and flood duration of the three flood events (2003, 2006 and 2008).
- Determination of value of assets of the elements at risk (aggregated data).
- Damage calculation of the 2003, 2006 and 2008 floods.
- Determine the risk curve.
-

1.3 Research questions

- How to assess the flood properties of the 2003, 2006 and 2008 floods at meso scale?
- What information is to be extracted from the Quickbird image of 14/05/2004 (source: Google) in order to prepare the land use map?
- How to adapt and incorporate the vulnerability curves of the research of Dhillon. R.K. 2008 in to the meso scale flood risk assessment?
- On what basis and with what accuracy can the flood depth be recorded for the three flood events (2003, 2006 and 2008) on meso scale?
- What are the methods to be used in order to assess the value of element at risk on meso scale?
- How accurately can the damage be assessed from three flood events (2003, 2006 and 2008)?
- Why will the meso level approach be more suitable than the micro level approach for regional flood management?

1.4 Structure of thesis

The present thesis is elaborated in six chapters.
Chapter 1 deals with the introduction, problem definition and motivation, research objective and research questions.
Chapter 2 contains the theoretical background of the research and literature review.
Chapter 3 contains the selection and description of study area as well as data and material used in this research.
Chapter 4 elaborate with the approach to the experimental investigation which has been used in this research, deals on nature of flood events, generate the vulnerability curve for elements f risk, damage and risk calculation.
Chapter 5 contains the analysis part of the research and discussion.
Chapter 6 contains the conclusion of the study and recommendation for further studies.

2. Study area

2.1 Location

The study area is part of the Barchana block of Jajpur and Mahanga block of Cuttack districts of Orissa (India). The area extents from 20º30'N to 20º45'N latitude and 86º00'E to 86º15'E longitude. It covers an area of 60 km² (approx). The Birupa river flow from south-west to north-east and is divided into two parts i.e. Ganguti and Birupa The study area is bounded by Ganguti river is north and Birupa river in south. The eastern part of the study area is bordered by the Highway No. 5A. It connects the port of Paradeep with National highway No. 5 which in turn connects Chennai with Kolkata. In the south east part of 'Tapu' or 'Dwepa' , Birupa river rejoins with Ganguti to flow further as Birupa (Figure 2.1).

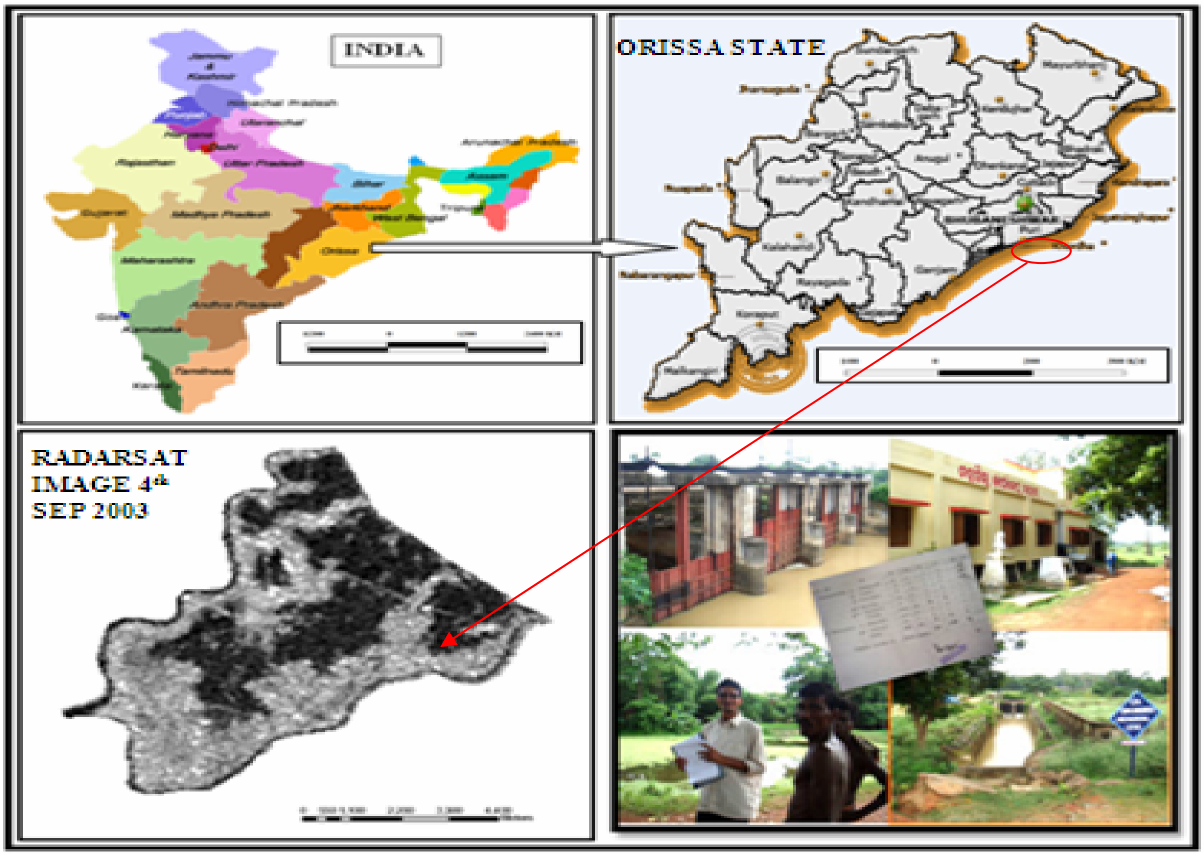

Figure 2.1 Location

Source: Maps of India.com and NRSA

2.2 Physiography and Geomorphology.

The study area is almost flat with low relief typical of a delta region. Geomorphology is the study of the configuration of the Earth surface and physical properties of materials of the features indicating which morphological process are dominant. Geomorphic features shows that more than 90% of the

area is lateritic plains, other areas are young alluvial plains with natural levee etc which are situated near to the river bed. The study area represents a young deltaic alluvial plain in between Ganguti river in north and Birupa river in south. Natural levee are found along the southern and central part adjoining Birupa river. Central and northern sections of the study area represent complex natural levees which are found along the banks of Ganguti river. Another interesting geomorphic future is paleo-channels which are scattered in the central part of the study area. These channels have been abandoned in the past and now they join with canal system within the area that helps in draining the excess water out. The eastern part of the area is characterized by a long narrow lateritic residual hill which is a prominent location for human settlement in that area (Figure 2.2).

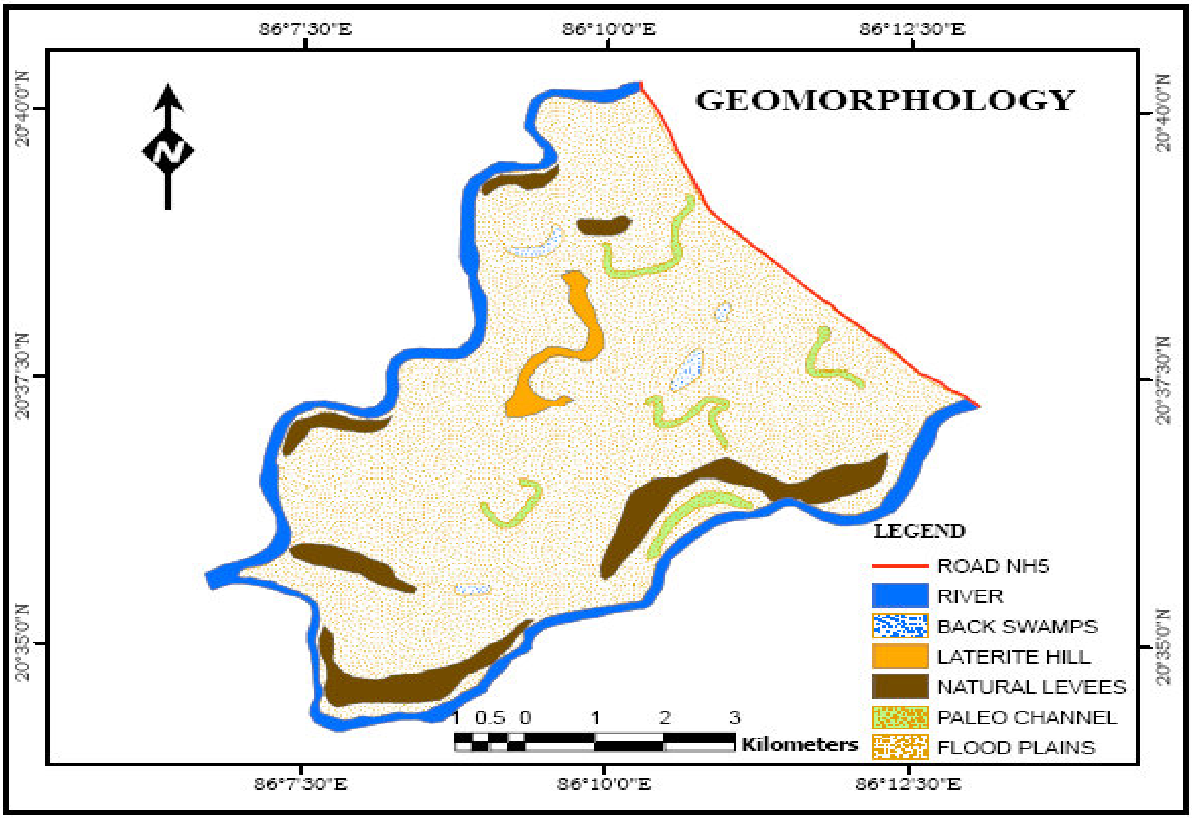

Figure 2.2 Geomorphology

Source: National Remote Sensing Agency (NRSA), India.

2.3 Drainage network and sub-basins

The study area is bounded by Ganguti river on its west and northern part and Birupa river on its southern part. It is almost flat with very low ridges which are divided into small shallow sub-basins (Figure 2.3). High rainfall intensity with long duration and overflow of the river embankment makes the way of water through the chanal network as has already happened in 2003 and 2008. At time water movement becomes complicated by influence of man-made embankments within the study area. Natural levees, paleo-channel and numerous scattered back swamps also influence the water movement.

2.4 Climatic condition

The climate of Jajpur district is tropical monsoon. Annual average rainfall is dominated by south-west monsoon and averages 120 to 140cm annually. At times tropical depressions (cyclonic storms with

strong winds reaching 85 to 135 km/hour) originate from the adjoining Bay of Bengal. The average annual temperature varies from 12ºC to 36ºC **(**Agro Industrial Corporation 2005**).**

2.5 Soil and Vegetation

Laterite and alluvial soils are main soils of this region. Aluminum and iron hydroxide are the main component of lateritic soil and it is very hard in subsoil zone. This type of soil has low fertility thus poor in agricultural production and has very low percentage of organic matter. Agricultural production can be possible with proper soil management techniques. Deltaic alluvial soils are fertile in nature and have high water holding capacity. Fertility of this soil is due to during cultivation for a long period. Deltaic alluvial soils are more suitable for rice and jute cultivation.

2.6 Agriculture

Rice is the main agricultural product and jute is the secondary crop of the region. Rice is grown in all the seasons of a year and this crop calendar is divided into three parts. First, Kharif season occurs from June to September. Second, Boro season is from March to May and third is the Rabi rice crop is cultivated from November to February. Rice is a crop of hot and humid climate. High temperature and enormous amount of water (water height not greater than the plant height up to 12 days) is needed for rice cultivation at the initial stage. Jute is the second important crop of the study area. It needs high temperatures and water. Two weeks continuous water logging is harmful for jute as well (Figure 2.3).

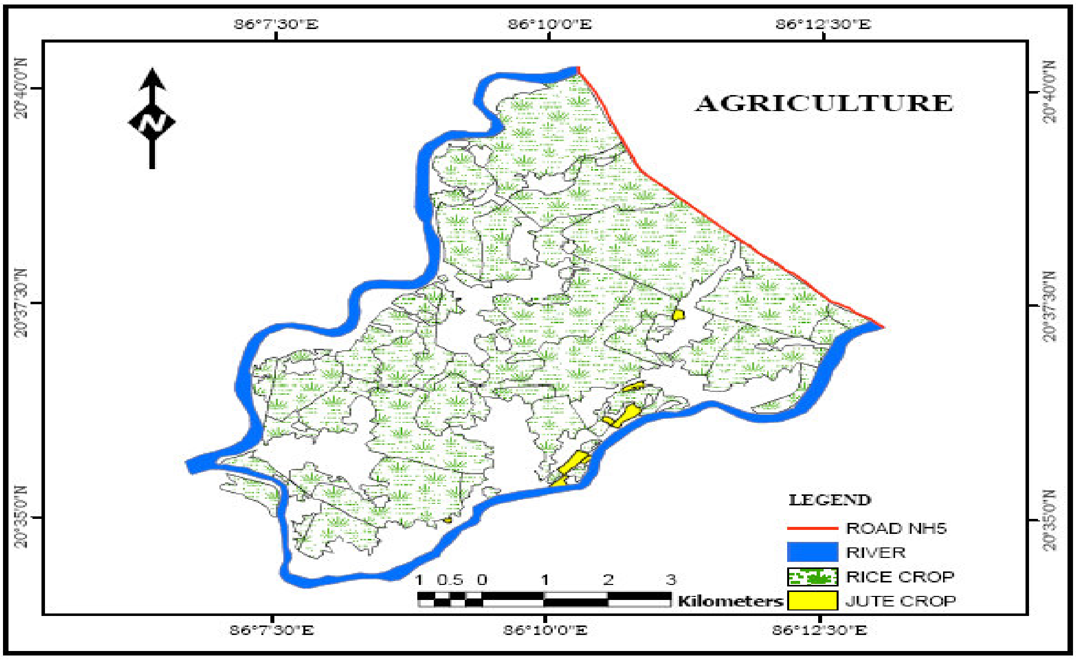

Figure 2.3 Agriculture
Source: Based on Google Image and field survey

2.7 Demography

The total population of the study area is 13708 **(**Block.Development.Office 2001**).** The Arakhpur (2040 persons), Kundal (1792 persons), Koliatha (1353 persons) have high population zone while Hargobindpur (51 persons), Bidiyadharpur (115 persons), Daulatpur (152 persons) are low population villages (Figure 2.3). The social structure is divided into General, Schedule Caste and Other Backword Caste. The percentage of general population is dominant (79%) and remaining percentage (21%) are

Schedule Caste (SC). Other Backward Caste (OBC) and Scheduled Tribe (ST) population are very few with respect to the total population. More than half (60%) of the population is below 16 years which indicates that the growth rate of population is very high that has resulted in low quality of life.

2.8 Settlements

Settlements are more protected with respect to other landuse areas (agriculture field and road) from flood event. The rural settlements in the study area are dense canopy of trees. Linear settlement pattern developed along the road, rivers (Ganguti and Birupa river) and clustered type of settlements are situated on relatively high elevated natural levees. Jaypur, Kundi, Madhupur, Dobandia, Basudeopur, Nilambarpur, Gaurpatana and Surkudeipur. Sipura, Mulbasanta, Dharamdaspur, Hansadia, Kuhunda, Kotpada, Sankhapur, Alorigram and Sahapur are the main villages of the study area (Figure 2.4).

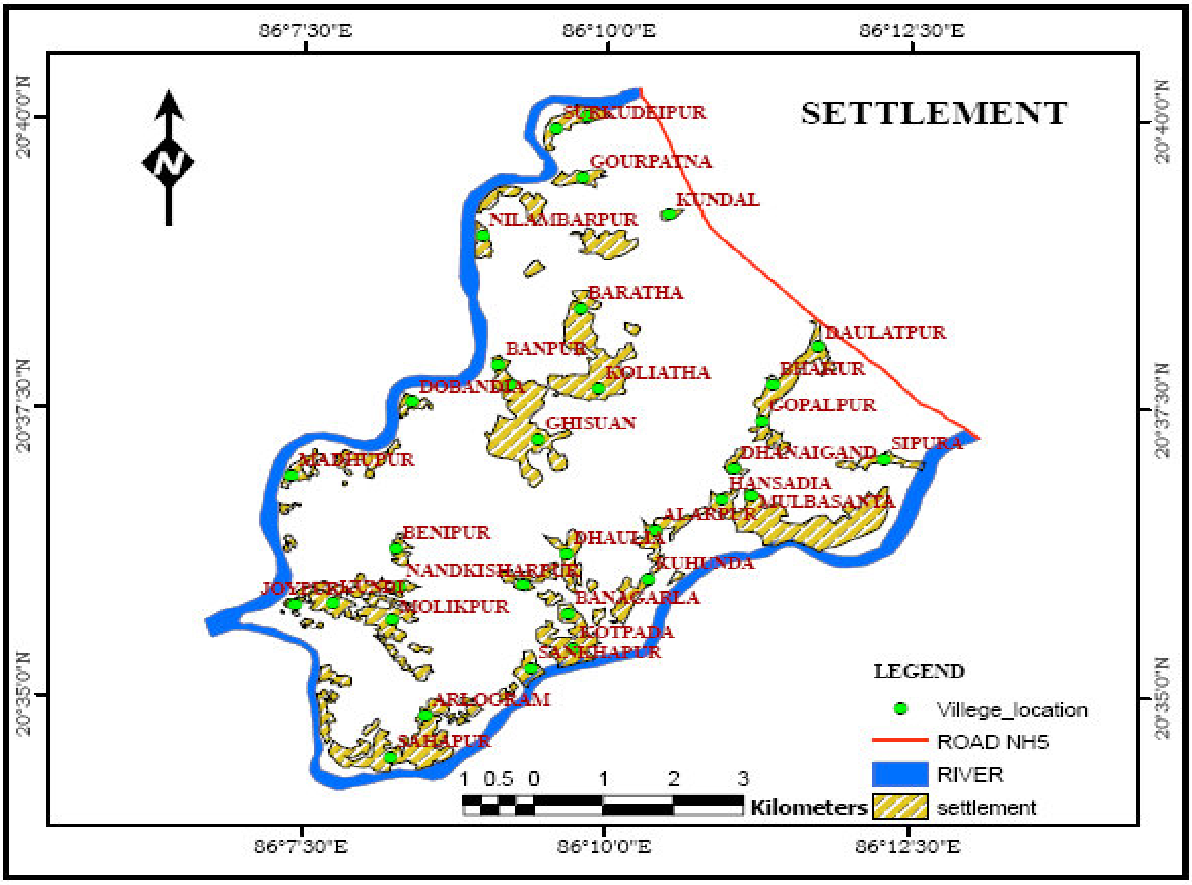

Figure 2.4 Settlement

Source: Based on Google Image and field survey

2.9 Road

Source: The National highway No. 5A is the only main road besides some other metal roads that connect major villages. National Highway No. 5A is the eastern boundary of the study area. In the eastern part of the study area, one narrow metal road runs almost parallel to National highway No. 5A which connect Gaurpatna, Arakpur, Nuahat, Barabali, Bhakur and Sipura villages. Another metal road connects the Sahapur, Achilogram, Sankhapur, Kotpada, Kuhunda, Hansadia, Dharamdaspur and Mulbasant villages along the Birupa river in the south-eastern part of the study area. South-eastern and northern metal roads are connected with each other at Gopalapur (Figure 2.5).

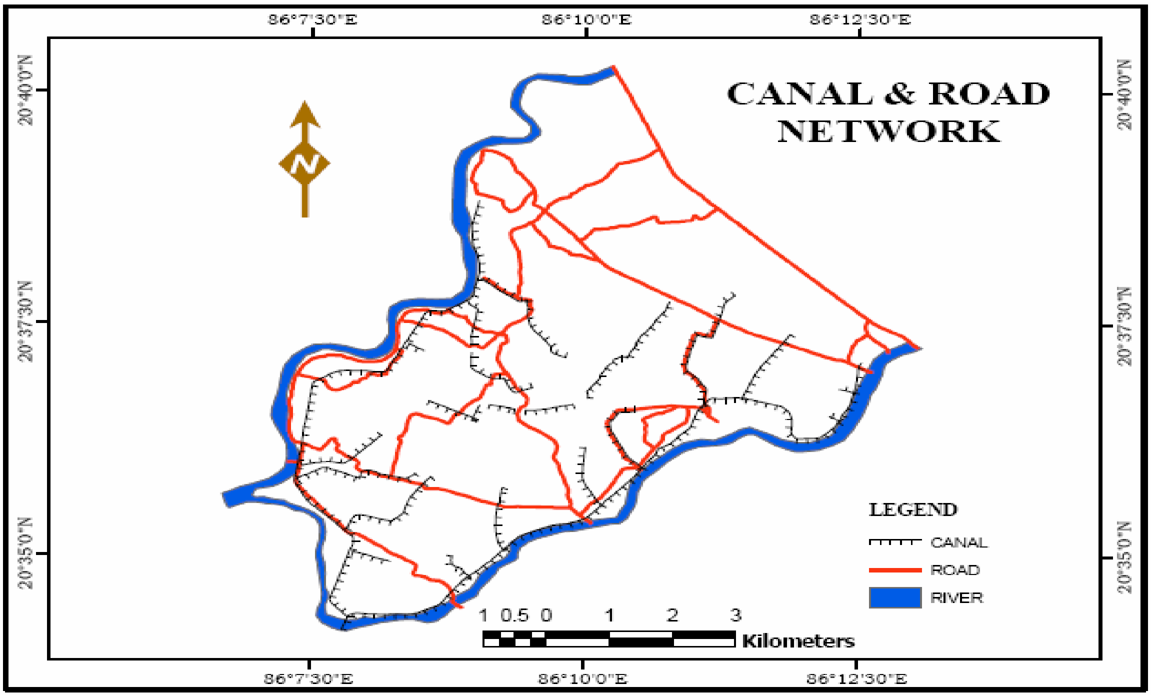

Figure 2.5 Road and Canal network

Source: Based on Google Image and field survey.

2.10 Canal Network

Source: Canal systems was developed in the area only 10 years back and is an extension of Pattamundai canal system which starts at Hirakund dam on Mahanadi at Cuttack. At Triveni on Birupa in the southern part where branch of Pattamundai canal crosses Birupa through a syphon system and splits it into two parts, one branch goes parallel to the Birupa river before ending near Sipura in the eastern part of the area and the other branch goes parallel to Ganguti towards north of the study area. Small canals have been connected with these two main canals bringing water to the areas of depression in the central part of the area. Water from these canals is used for agriculture as per requirement. The embankment plays an important role in influencing the spread of water and preventing flooding of agricultural fields (Figure 2.5).

2.11 Economy

Development of an area is largely dependent on its economic activities. Agriculture is the main source of income of around 90% population. Apart from agriculture, other small scale economic activities which are carried out are handicraft, grocery shop, service holder etc.

3. Literature Review

3.1 Concept of Hazard, Disaster, Vulnerability, Damage and risk

3.1.1 Hazard

This "Hazard" is defined as an extreme event natural or man-induced, which exceeds the tolerable magnitude within or beyond certain time limits, makes adjustment difficult, result in catastrophic losses of property, income and lives and become the headlines of different news media at world level (Shing, 2001).

"Hazard" is defined as potentially damaging phenomenon (Natural or man-made) which may cause loss of life or injury, property damage, social and economic disruption or environmental degradation. (Twigg, 2004).

Natural hazard means the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon (UNDRO, 1979 and Fournier, 1986)

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The basis of Marxist theory on hazards can be summarized as follows (Bryant, 1991).

- The forms of exploitation in Third World countries increase the frequency of natural disasters as social-economic conditions and the physical environment deteriorate.
- The poorest classes suffer the most.
- Disaster relief maintains the status quo, and works against the poor event if it is internationally directed to them; and
- Measures to prevent or minimize the effects of disasters, which rely upon high technology, re-inforce the conditions of underdevelopment, exploitation and poverty.

Different degree of flood hazard is assigned to each Geomorphologic unit, depending on slope, drainage pattern, grain size and permeability (Badilla, 2002).

3.1.2 Disaster

Measures "Disaster" caused by the natural process or human factors, is an extreme event which occurs very rarely and aggravates natural environment processes to cause disaster for human society such as sudden tectonic movements leading to earthquake and volcanic eruption, continued dry conditions leading to prolonged droughts, floods, atmospheric disturbance, collision of celestial bodies etc (Shing, 2001).

Generally a "disaster" is a singular event that results in widespread losses to people, infrastructure, and environment. Disasters originate from many sources, just as hazards do (natural systems, social systems, technology failures) (Cutter, 2001).

Disaster is an events that has negative impact on society (Death, injury, loss of properties) and take long time to recover (Twigg, 2004).

3.1.3 Assessment of vulnerability due to flood

Vulnerability is an essential part of hazards and risk research. It refers to the susceptibility of people, communities or regions to natural or technological hazards.

Vulnerability is a characteristic of a society which identifies the potential for damage to occur as a result due to different type to hazards (Capobianico, *et al.,* 1999). Flood is a natural hazard and it causes

widespread damage to society. This damage is assessed from the vulnerability of the affected socio-economic and ecological systems (Cutter. 1996 and Mitchell, 1989).

Vulnerability is broadly defined as "Potential for loss" (Cutter, 1996). He has found in different ways vulnerability i.e. vulnerability as hazard exposure, vulnerability as social response and vulnerability of places. (Cutter, *et al.,* 2003) has drawn together the different type of element that contributes to the overall vulnerability of places in the hazards-of-place model of vulnerability (Figure 3.1).

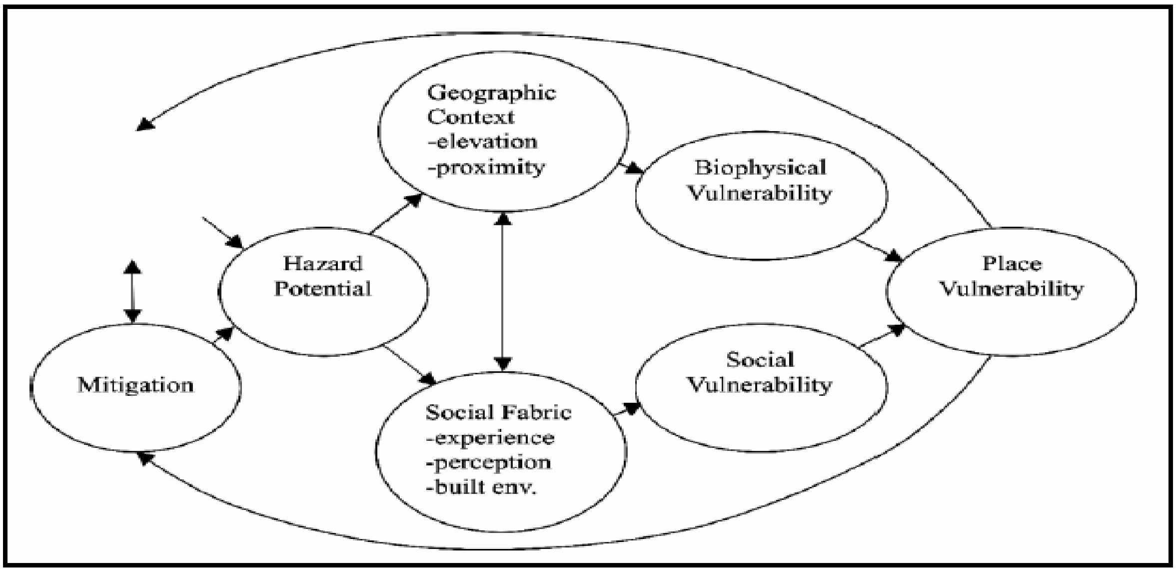


Figure 3.1 The hazard-of-place model vulnerability

Source: Cutter *et al.,* 2003 in Kumpulainen, 2006

Vulnerability is referred to as "a set of conditions and processes resulting from physical, social, environmental and economical factors, which increase the susceptibility of a community to the impact of hazards" (ISDR, 2004).

The concept of vulnerability addresses a double structure consisting of an external side (Bohle, 2001), and also that vulnerability (Pelling, and Uitto, 2001) is multi-dimensional and differential, scale-dependent and dynamic. Generally, the vulnerability of a system against a certain hazard is not easily assessed. Three routes for the assessment can be distinguished i.e. economic, social and cultural.

(Marfi, *et. al,*) has worked on vulnerability analysis and risk assessment for seismic and flood hazard in Turialba city, Costa Rica. They assessed the vulnerability of the urban areas is largely related to building design and quality since it's these houses, which collapse and injure people in respect to 25, 75 and 100 years return period of floods on basis of flood depth.

Structural damage due to flood has assessed in respect to the flood depth and velocity (Kelmen, 2002). Vulnerability of the residential properties have prepared in physical based method on the flood depth in costal, Eastern England.

3.1.4 Assessment of Damage due to flood

Damage is defined as the estimated reparation in money for detriment or injury sustained; a compensation, recompense, or satisfaction to one party, for a wrong injury actually done to him by another (ARD Dictionary).

Damage may happen due to natural and man-induced event. Flood is a natural event and flood damage assessment is very much important for the purpose of the estimation of loss caused due to flood is not

being calculated mitigation and rescue work will not be carried over properly. It also helps for planning regarding for prevention, warning, monitoring and relief along with the flood protection. Now day different government and private agencies are involved for assessment of damage due to flood (Prasad, 2007).

Harm caused by flooding means the adverse effects on humans, their health and their belongs, on public infrastructure, culture, culture heritage, ecological systems, industrial production and competitive strength of the affected economy. Flood damage effects can be categorized into direct and indirect effects. Direct flood damage is harm which relate to the immediate physical contract of flood water to humans, their property and environment. Indirect flood damage occurs as a consequence of flood like disruptions of economic and social activities (Messner, *et al.,* 2006).

Kelman (2002) applied the vulnerability scale due to flood but Nadal (2007) incorporated that scale damage for masonry of walls and glass window. This scale has categorized into five classes.

One of the most relevant study is the physical vulnerability of residence to flood disasters in costal, England by Kelman (2002). He has decided the scale of damage for masonry of walls and glass window. This scale has categorized into five classes. (Nadal, 2007)

Damage scale 0 – Represents non damage and non failure and it means no water contract with structure.

Damage scale 1 – Indicates damage but not failure and water contract only outside of the structure but not enter (Damage range is 1.2 to 15%).

Damage scale 2 – Represents damage but not failure and external failure is damage or removes by water (Damage range is 15 to 50%).

Damage scale 3 – Represents the transition from non-failure to failure in that a residence component fails. Water penetrates through a close or cover opening (Damage range is 50 to 60%).

Damage scale 4 – Represents structural failure and water penetrates through a route not including an opening a wall or roof (Damage range is 60 to 80%).

Damage scale 5 – Represents structural failure and completely damage beyond repair (Damage range is 80 to 100%).

Vinet (2002) assessed damage due to flash flood in southern France. He analyzed damage to economic sectors. Economic sector is categorized into 1. Damage to private property (vehicles and houses), 2. Damage to agriculture, 3. Damage to public works and networks and, 4. Damage to industries.

Oliveri *et al.* (2000) estimated damage to urban structure due to flood. He determined the depth damage relationship of two building types with two and four storey. As the flood depth increases the damage also increases. He analyzed the relationship between damage and flood frequency as.

$$D_f = x \sum \left(A_{if}^n\right)_f \left(P_{if}^n\right)$$

Where x represents the average property given per unit area; $\left(A_{if}^n\right)_f$ is, for a given occurrence frequency ‘f’, the surface cover by structures belonging to the nth building type 9n = 1, 2). Finally $\left(P_{if}^n\right)$ is the percent damage for the nth building type (Figure 3.2).

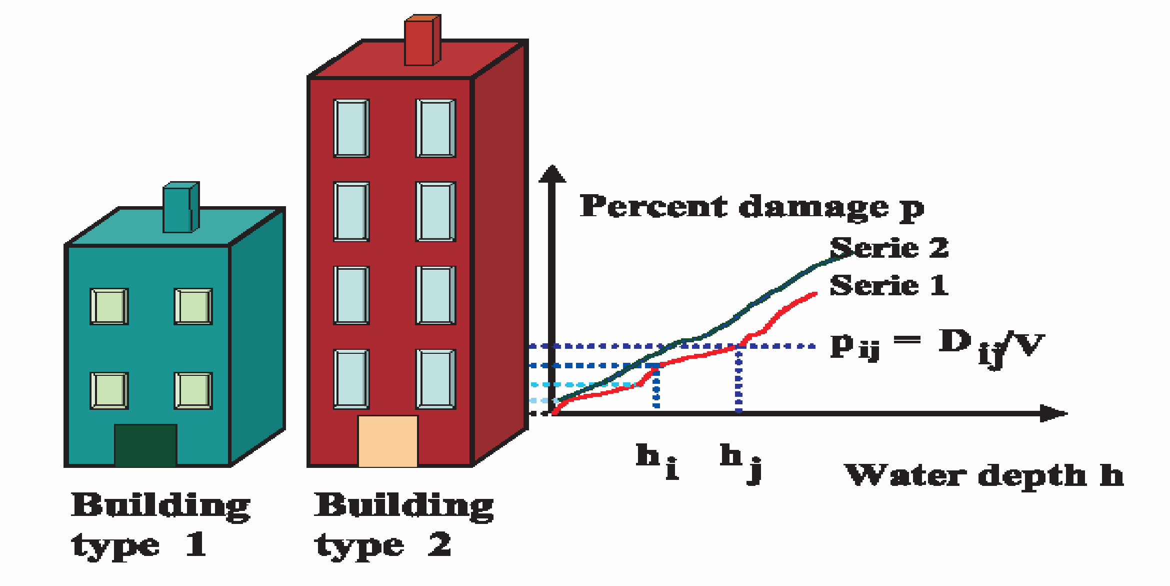


Fig. 4. Schematisation of the local depth–percent damage relationships evaluation procedure.

Figure 3.2 Depth-damage relation curve
Source: Oliveri *et al.* (2000)

Due to flood damage has been exclusively assessed in different country, but Pielke, 2000 in Vinet, 2008 said that consider all elements should not a goal. The impact of flood might be classified into direct and indirect damage. Flood damage can be divided on the basis of influencing factors like water depth flood duration, flow velocity of flood and resistance factors like type of building, road etc. preventive measures, preparedness and warning (Theiken, 2005).Damage has been assessed of percentage of damage property value which depending on water depth of flood. Structural replacement costs have been used to estimate the average value of a property (Oliver and Santoro, 2000). Total economic damage due to flood has been estimated on the basis stage damage function by simulation model and stage damage function are derived from post flood data. Through analytical descriptions of flood damage to various properties which are considering the possible damage ratio from flood depth and flood duration (Dutta, *et al.*, 2003)

3.1.5 Assessment of Risk due to flood

'Risk' is the probability of a loss, and this depends on three elements, hazard, vulnerability and exposure". If any of these three elements in risk increases or decreases, then risk increases or decreases respectively (Crichton, 1999).

Expected degree of loss due to natural phenomena is called the specific risk (R^s). The expected number of live lost, persons injured, damage to property of economic activity due to a particular natural phenomena is called total risk (R^t). Elements of risk are population property, economic activities, including public service etc. at risk in a given area (E) and natural hazard and vulnerability are H and V (Concept of Hazards and Risk, Western. C. V).

$$R^t = R^s * E = EHV$$

The Oxford English Dictionary (OED, 2002) defines risk as "the chance or hazard of commercial loss, spec. in the case of insured property or goods". Later it was modified through a quotation from 1841

which reads "In the theory of Probabilities the risk of loss or gain means such a fraction of the sum to be lost or gained as expresses the chance of losing or gaining it". This definition correlates well with the modern definition of mathematical expectation (Råde & Westergren, 1990; Turner, 1970)

$$\text{EXP}\left[f(X_r)\right] = \Sigma_{All_{Xr}}\ P\left[f(X_r)\right] X f(X_r) \quad \text{(for a discrete function)}$$

$$= \int_{All\ \ xr} \text{P}\left[f(X_r)\right]\ f(X_r)\ \text{d}\,x_r \quad \text{(for a continuous function)}$$

Although OED (2002) fails to explicitly incorporate the "specified timeframe" component into their risk definition, probability by definition always incorporates a time component. This time component tends to be expressed with standard temporal units such as seconds or years for continuous $f(X_r)$ and with the temporal units of "events" for discrete $f(X_r)$. An example of the latter occurs in calculating the probability of obtaining a certain number of tails for a coin tossed a pre-determined number of times. The coin tosses are the "events". This definition of risk as an analogue to mathematical expectation, i.e. the anticipated outcome of a probabilistic function over a specified time period, is adopted for this study. The risk definition still requires a meaningful interpretation in the context of residence vulnerability to floods because the expectation equation is generic. $f(X_r)$ may be any real function on any random variable (Kelman, 2002).

Schmidt-Thome *et al.* (2006) assessed the economic risk due to flood and earthquake. He integrated the economic vulnerability of a region (region GDP per capita, Population density) leading for the classification of the areas according to their economic risk or damage potential towards hazards. Economic vulnerability of this region increases with economic growth hence risk can be mitigated by appropriate counter measures.

3.1.6 Meso scale approach

'Scale' is a ratio in between ground or actual field and map. Scale is categorized into Macro, meso and micro scale. Macro scale analysis is applied on the national and international level that means large area will provide a low accuracy of information. Micro scale concept applied on the local level and accuracy is the best among three categories (Dillon, 2008). Meso scale is applied on the regional level like river basin costal area etc. The potential damage is assessed from aggregated data with meso scale. Macro-scale approach is the data of variables stem from official statistics in municipality level. Each valuable is assigned in different land-use categories. For example, residential capital is assigned to residential areas, manufacturing sectors are assigned to industrial areas and livestock is assigned to grassland areas. This approach is differentiating in between areas and value which indicates the potential damage value of urban area in a city center is very high and agricultural land or forest area is very low. Depth-damage function indicates that the degree of loss is increases as flood depth for the different categories of landuse increases (Messner, 2005) (Figure 3.3.)

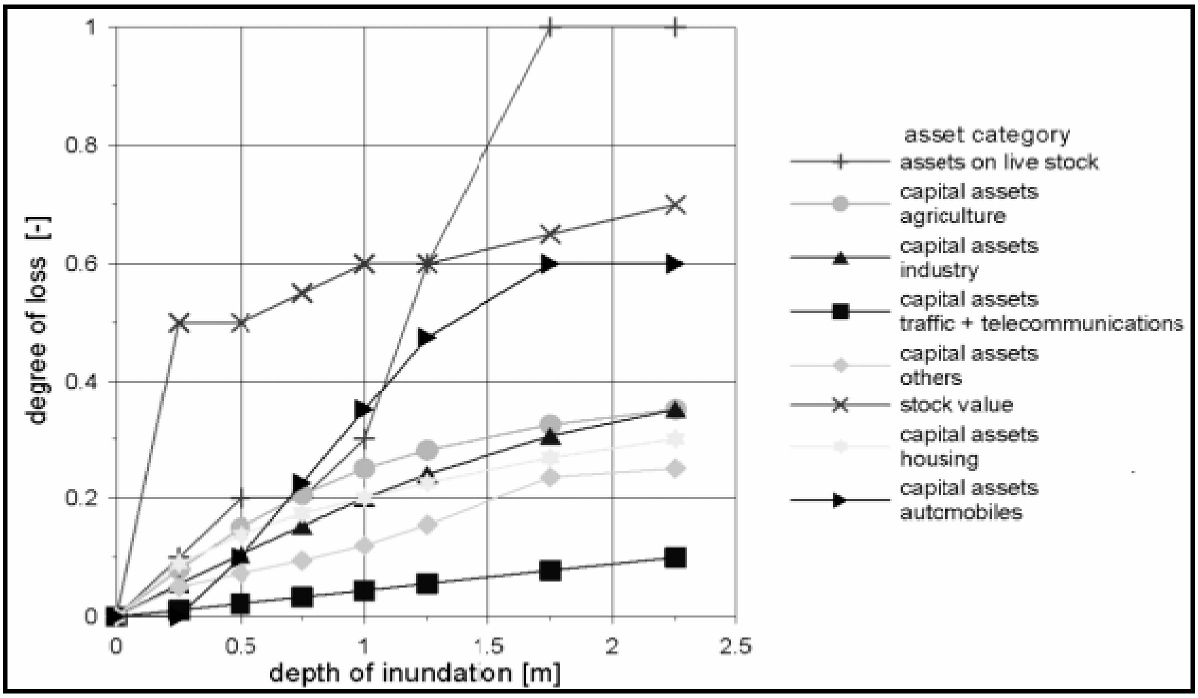


Figure 3.3 Depth-damage-function for different asset categories

Source: based on Klaus & Schmidtke 1990 in Elsner *et al.,* 2003.

3.1.7 Relationship among flood vulnerability, damage and risk:

'Scale is the damage potential of a particular area refers the maximum probable amount of damage which may occur when the area becomes inundated. Vulnerability aspects should be considered in order to estimate the proportion of the damage potentially. Vulnerability factor is derived from vulnerability indicators (inundation depth, duration etc.) which indicate the degree of damage during a flood event. In some cases vulnerability is assessed from expert knowledge and empirical data on flood damages and then indicates a scale between 0 (no loss at all) and 1 (total loss) for different categories of elements at risk (Elsner *et al*. 2003, Glade, 2003). When flood risk is low in a region may perhaps be due to the fact that flood events very rarely occur or the level of flood protection in terms of dykes and levees is very good. As a rule of thumb the low levels of flood risk perception and a low degree of preparedness of a particular region for coping with flood events tend to indicates flood damage levels above average their vulnerability to flood events trends to be high. Vulnerability factor such is a risk perception and indicates towards preparedness of communities and individuals.

4. Methods and materials

4.1 Data requirement and data avilability

The present work is based on remotely sense data, government records and the information collected after an extensive field survey. Remotely sense data required for the presently work comprises of RADARSAT images provide by NRSA (National Remote Sensing Agency), Google image provided by ITC and Cartosat-1 DEM Digital Elevation Model) generated previously by R. K. Dillon, 2008 that was provided by IIRS (Indian Institute of Remote Sensing). The RADARSAT images were used to delineate the flood extent, flood depth and flood duration over the study area. The Google image was used to identify the elements at risk and based on Google image a grid of 100*100m was prepared so that vulnerability, damage and risk can be calculated at meso scale. The Cartosat-1 DEM was used to delineate the depth of water under which different elements at risk has been submerged during the flood. The government records were looked into to verify the outputs form remotely sensed data and detailed field work was carried out for information regarding vulnerability, damage and risk was required in terms of 100*100m grid.
The details of different kind of data that have been used is tabulated in table 4.1

Table 4-1: Data requirement and data availability

Data Analysis	Data requirement	Data availability
• Permanent water body before flooding. • Flood extent and duration map.	• Catosat-1 Image. • RADARSAT images (during flood period in 2003, 2006 and 2008.	• Cartosat-1 (19 February, 2006). • RADARSAT images of September, 4, 11, 13 and 20 of 2003, August, 4, 19, 26 and September, 4 of 2006 and June, 23, July, 24 and September, 18 of 2008.
• Identify the element at risk	• Google image.	• Quickbird image of May 14 of 2004 with 0.6m resolution (source: Google).
• Analysis of elements at risk: • Physical and economical impact of floods (2003, 2006 and 2008). • Vulnerability, damage and risk assessment of	• Interviewed the number of household types and its construction of each 100×100m pixel area. • Surveyed agriculture cropping patterns (Rice and jute).	• Field work (community based approach).

elements at risk.	• Flood depth information. • Damage information of building types, agriculture and road. • Actual construction value of houses, roads and crop production.	
• Flood frequency	Maximum water level information of gauge station.	Maximum water level data at Naraj gauge station from 45 years back.
• Spatial analysis	• Boundary map, settlement map, village map agriculture map, road map, drainage map are in digital format.	Orissa State Disaster Mitigation Authority (OSDMA).

4.2 Data collection and database preparation

Use this for the body text. The present research has been carried out focusing on different aspects of the study area like road, houses, agricultural fields etc. Information has been gathered from household survey regarding flood characteristics of which depth and duration parameters are considered in case of agriculture (agriculture is affected by both depth and duration) and in case of houses and roads only depth is considered (depth is more important as compared to duration for damage to houses and roads). Field data is of vital importance in this case as information needed to be collected on basis 100*100m grid basis. The field work was carried out from 13th June to 28th June, 2008.

4.3 Pre field work

The pre-field work activities are shown by flow chart below (Figure 4.1).

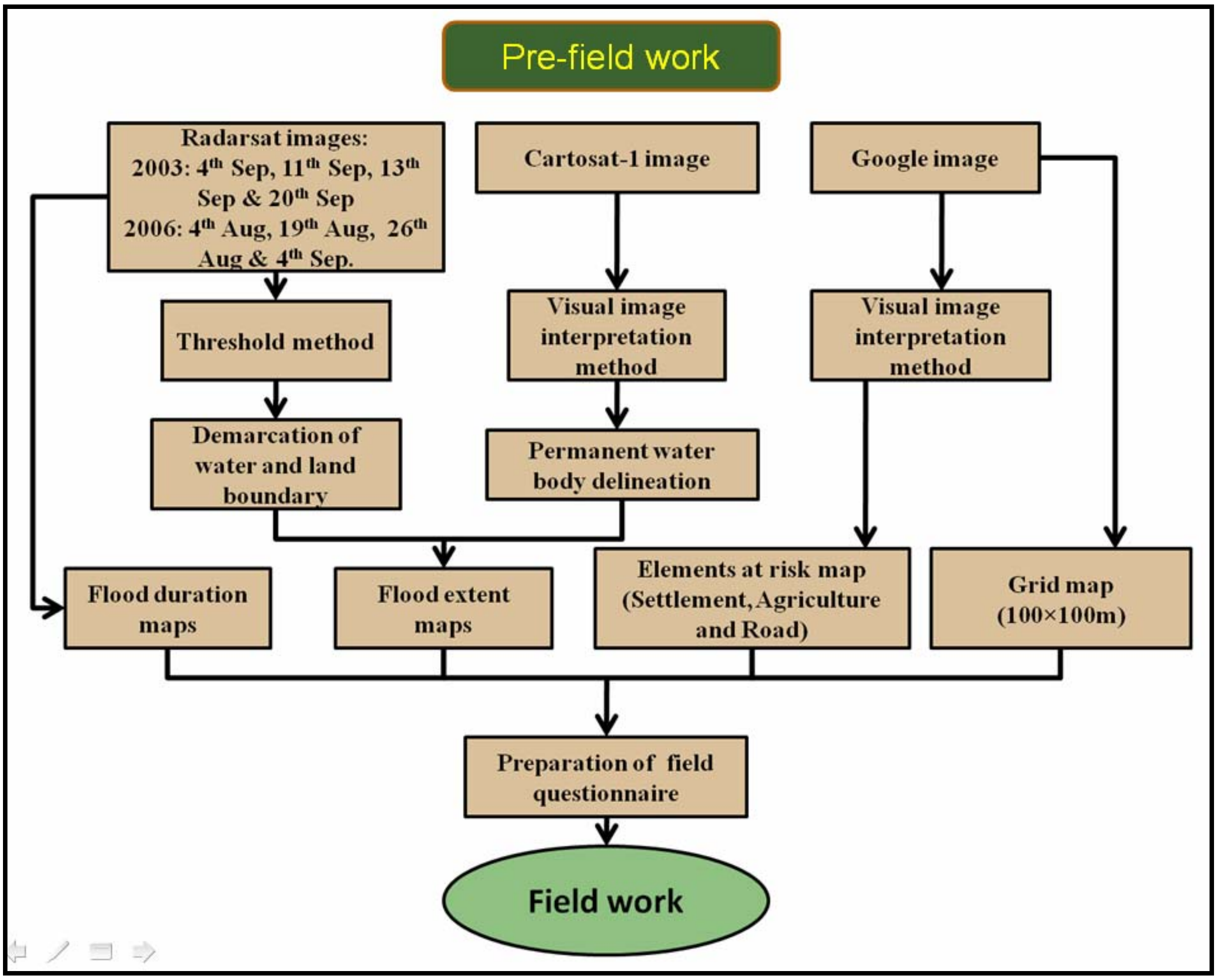
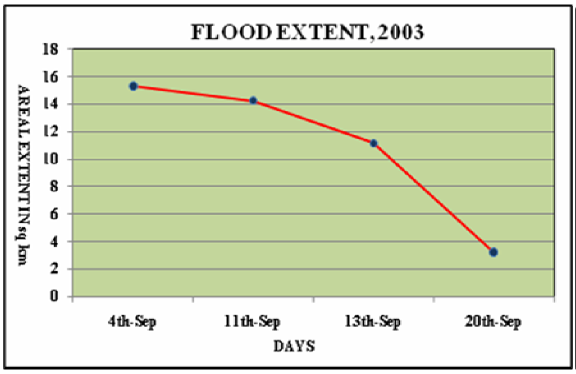
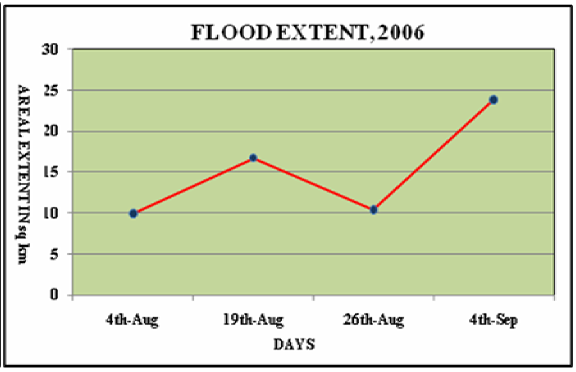


Figure 4.1: Pre-field work

4.4 Flood extent delineation

The flood extent map has been delineated from temporal RADARSAT imagery which clearly shows that 18th September has the maximum flood extent among the three images of 2008. In 2006, 04th September had the maximum flood extent while 04th August was the date of minimum extent. The other two images of 2006 shows that flood extent gradually increased from 04th August to 19th August after which the aerial extent of flood decreased from 19th August to 26th August after which there were a sudden increase in flood extent up to 04th September when the flood was at its maximum.





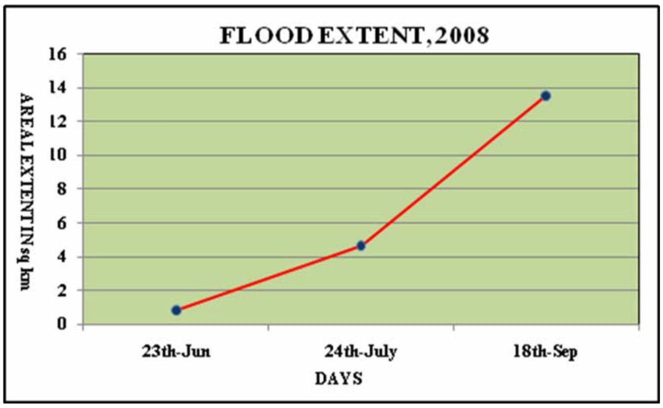
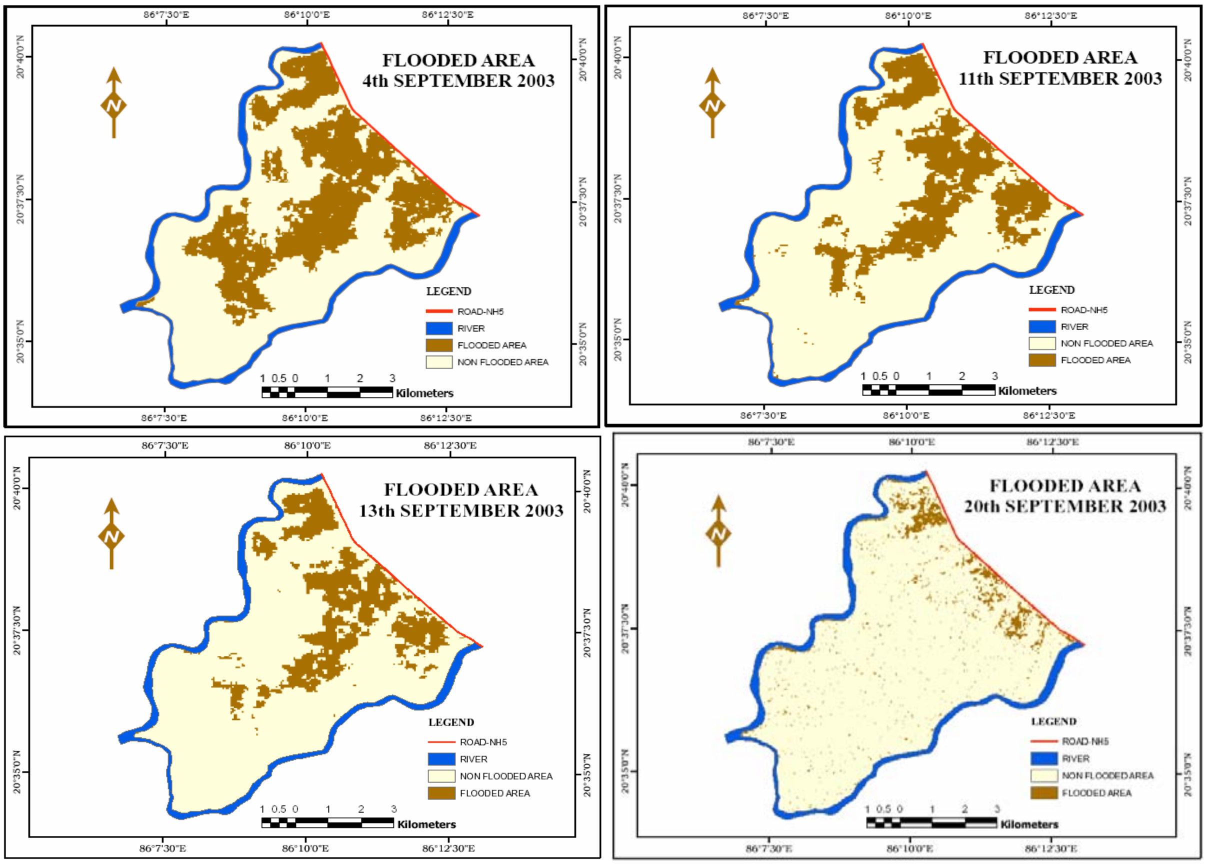


Figure 4.2: Changes of flood extent in 2003, 2006 and 2008

In 2003 flood extent was at its maximum extent on 04th September and the area gradually decreased as revealed by 11th September, 13th September and 20th September images (Figure 4.3).

Flooded and non flooded area (including permanent water body) from RADARSAT images is extended of the region with the help of ERDAS Imagine 9.0 by threshold method and Permanent water body is extracted with the help of Arc GIS 9.1 by visual image interpretation method from Cartosat-1 image during non flooded period. The actual flooded area generated for subtracting permanent water from flooded area (including permanent water body) using ERDAS Imagine 9.0



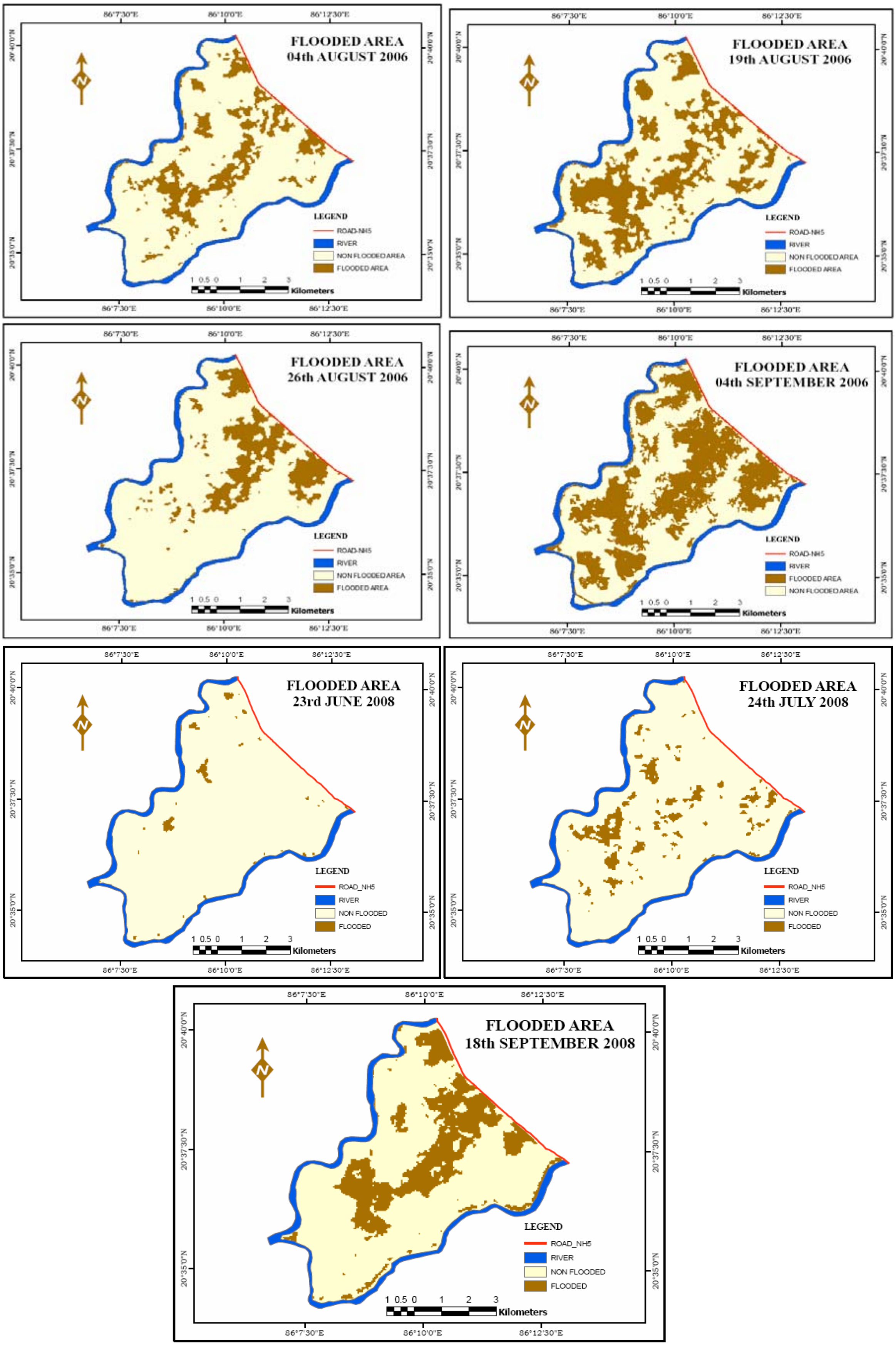


Figure 4.3: Flood extent maps

4.5 Analysis of flood depth

Flood depth is derived from highest flood level maps and DEM (Digital Elevation Model). DEM is verified with field survey by points (eight bridges points) where the height is already mentioned by government authority and the value varies between ± 1 meter (Appendix-1). Initially flood extent map was generated by threshold method and the maximum flood extent map is found among the flooded maps of a flood event, for example 18th September is the maximum flood extent among the three images of 2008. Only this area is subtracted from DEM and the maximum value of DEM is found from it. I consider this value to be maximum flood level of that flood event because there are no government records about flood level of a fixed point. Moreover as this area is plane land, I believe that this method is very much effective in finding the maximum flood height. Maximum height of the flood levels is subtracted from DEM (only maximum flooded area) for generating the flood depth of individual pixel (100×100m). This procedure has been used for three different flood events (2003, 2006 and 2008) using ERDAS Imagine 9.0 and Arc GIS 9.1 (Figure 4.4). Output flood depth value has been verified during field survey by interacting from local people. Total 112 point have been used for checking the flood depth (45 are the settlement area, 15 along metalled road, 12 along unmetalled road, 35 in rice fields and 5 in jute fields) and flood depth varies between ± 1 meter (photographs of depth verification during the field survey is attached) (Appendix-1).

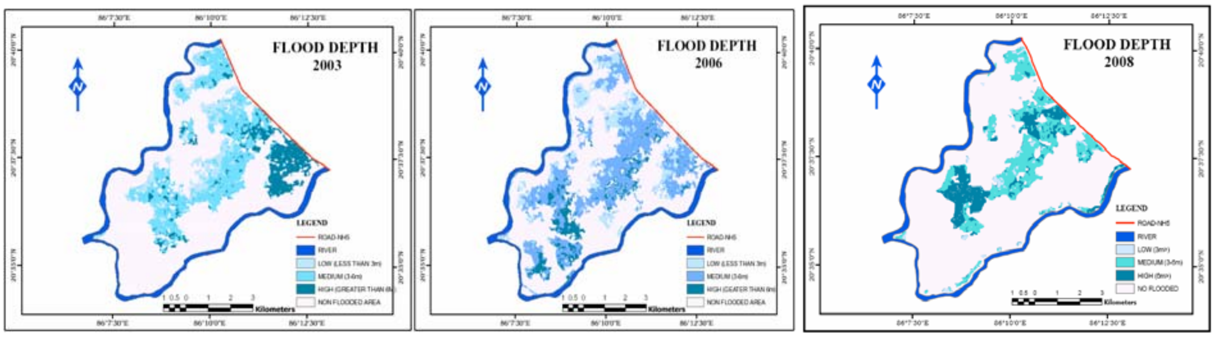


Figure 4.4: Flood depth maps

4.6 Flood duration calculation

The flood duration map has been generated from the temporal RADARSAT images for 2003, 2006 and 2008 flood events. RADARSAT images of September, 4, 11, 13 and 20 of 2003 flood, 04th August, 19th and 04th September for 2006 floods and 23rd June, 24th July and 18th September for 2008 flood event. Flood extent maps have been prepared by threshold method and it has used for preparing duration maps. 04th September is the maximum flood extent of 2003 and 2006 flood events and 18th September is the highest flood extent of 2008 flood event. Duration of the flood event has been categorized into short (less than 5 days), medium (5 to 15 days) and long (more than 15 days) consulting with the Office of Agricultural Department, government of Orissa.

Flood duration of the region is demarcated with the help of model maker in ERDAS Imagine 9.0 which provided the results after generating the flood extent map in 2003, 2006 and 2008 flood events (Figure 4.5).

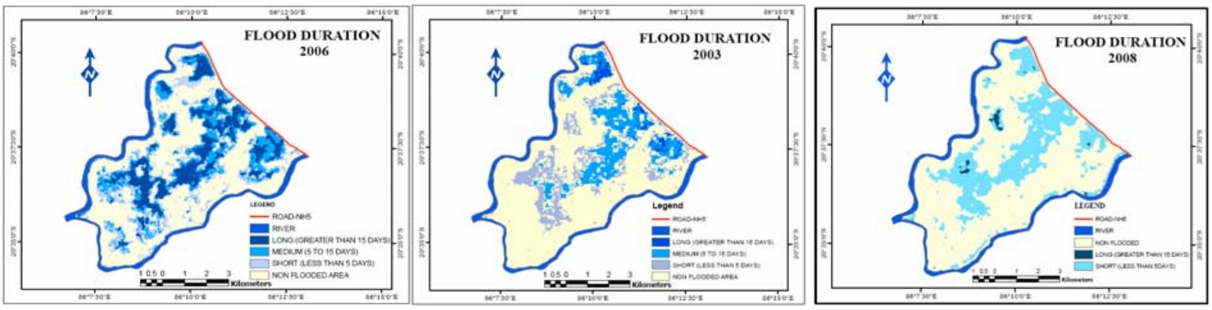


Figure 4.5: Flood depth maps

4.7 Element at risk map and landuse map

The land cover map has been generated from Quickbird image from Google with 0.6m of resolution of 14th May, 2004. Elements like houses, roads, agricultural fields etc. are generated by visual image interpretation method using Arc GIS 9.1. Agricultural lands are divided into rice and jute fields and roads into metalled and unmetalled roads (Figure 4.6).

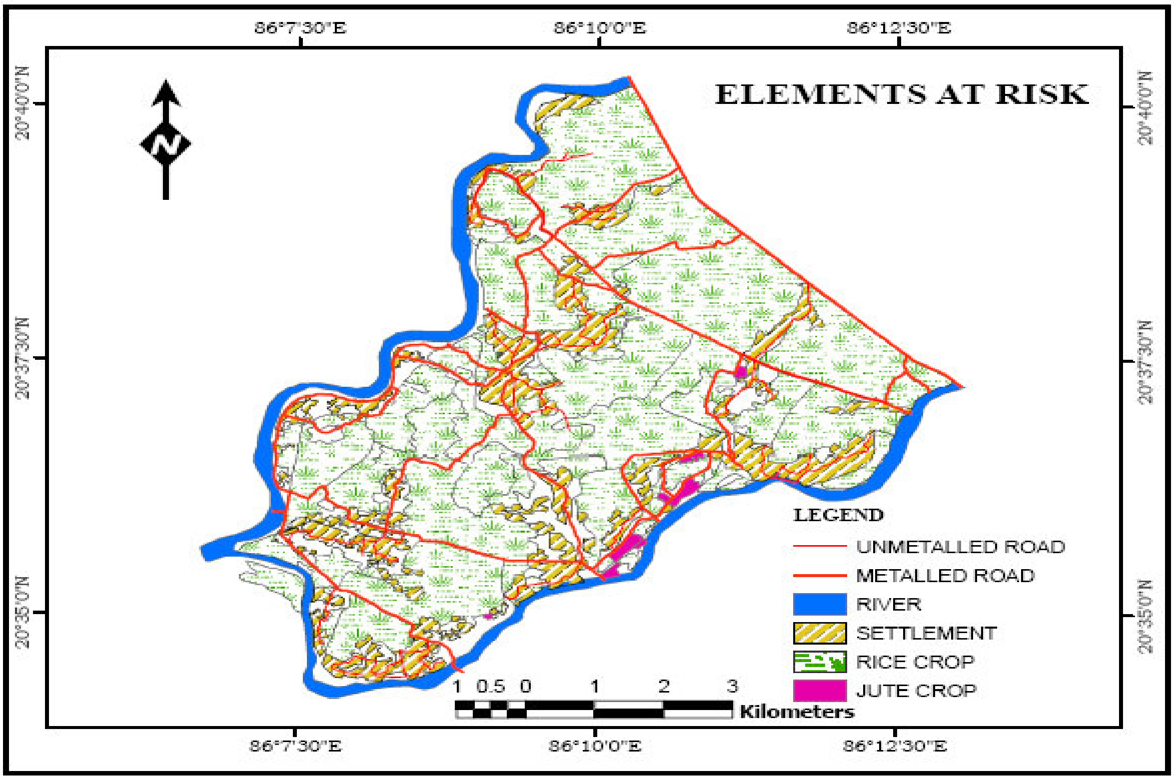


Figure 4.6: Elements at risk map

Source: Google image, road map, agriculture map and field survey.

4.8 Questionnaire

Questionnaire forms an important part in any field survey as it provides sufficient information regarding the place of interest. It gives detail information for the damage assessment. This involves the collection of data and information about flood depth, duration, various damages that results due to flood like loss of agricultural land, road and house damages. Flood depth was analyzed on the basis of human scale like knee-length or up to the chest etc. and even from the height of the water mark from houses and other permanent structure like bridges. Later it was transformed into meters and compared with DEM. Different house types were recognized from the field to assess the vulnerability like mud-

house or concrete house, number of floors, roof types, wall types, floor types etc. Roads were also surveyed for studying the damages as flood causes more damages to metalled roads than to unmetalled roads.

4.9 Field work

Field work comprised of collection of the primary and the secondary data, the proper aggregation for preparation of database for assessing the vulnerability, damage and risk. The major portion is definitely composed of primary data, but the input of secondary data is of utmost necessity to make it perfect hence secondary data collection also forms a major part of the field work (Figure 4.7).

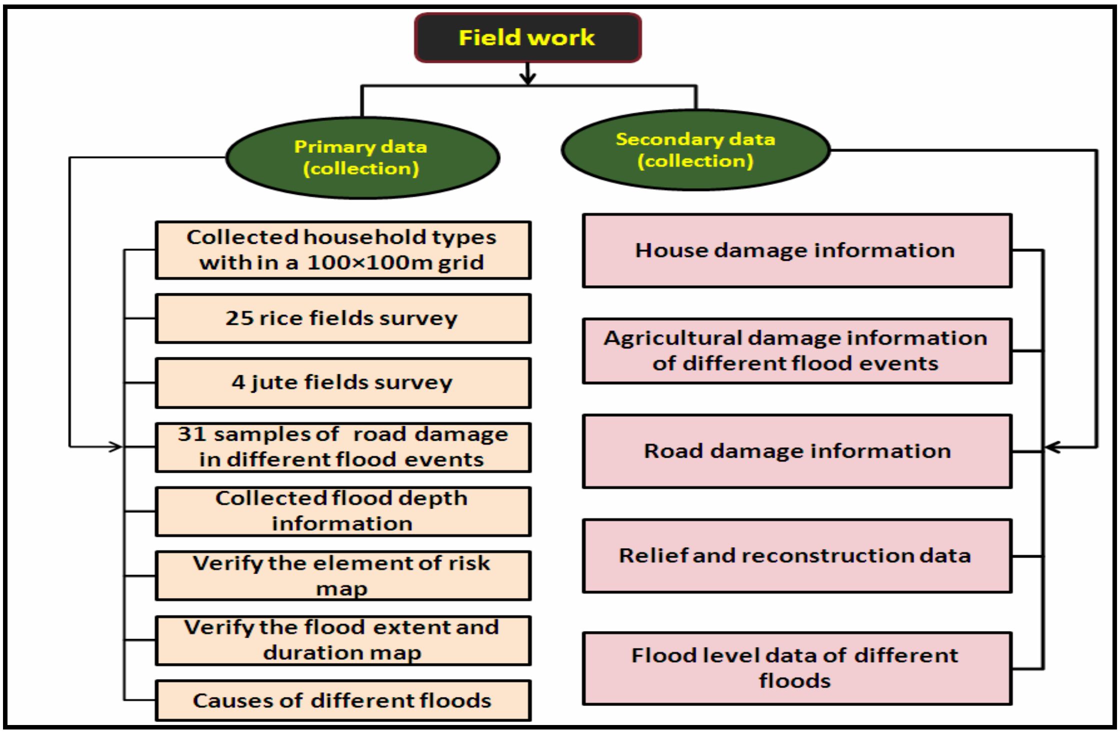


Figure 4.7: Data collection from field

4.10 Primary data collection

Primary data was collected at the meso level, by dividing the whole area into 100*100 grid size and collecting information about the house types and roads and other constructions for each pixel. Flood depth was measured from the locality and community based information was also gathered about this. Canal information was collected by surveying their links with the rivers as these forms one of the major source for flood. GPS survey helped to locate each pixel in the field, the accuracy of which is 12.5m.

4.11 Secondary data collection

Secondary data was collected from different block offices of Barchana. Data about the flood water level was obtained from the Water Resource Department of Barchana block; road damage information from the Collector's Office of Cuttack; house damage data was collected from the Mehanga and Barchana tehsil head quarters and agricultural damage maps were taken from Block Agricultural Office of Mehanga and Barchana block. The information collected through secondary data is of importance as

these have been collected and proposed by state government agencies. Their data not only can be used to fill in the gaps in the existing data but also to verify the results generated by remotely sensed data.

4.12 Methods for database preparation

In the pre-field work all the element at risk (houses, agricultural area, and roads) were identified and classified with the help of visual image interpretation in Arc GIS 9.1. 100*100m grids of the study area ware generated using ERDAS Imagine 9.0and elements at risk of each grid were marked and identified with the help of Arc-GIS. Data collected from the field like the types of houses within each pixel were then inserted and processed in Arc-GIS 9.1. Flood depth was calculated on the basis of DEM and from the information of the maximum flood level. Duration map has been generated from the temporal RADARSAT images by ERDAS Imagine 9.0. Vulnerability curve of the elements at risk like houses, roads and agricultural fields have been formed on the basis of the damage information of floods. Flood duration and depth is considered for agriculture (rice and jute) and only flood depth is considered for houses and roads for vulnerability assessment. Vulnerability is calculated on the basis of vulnerability curves which are generated from flood depth and duration information using ILWIS 3.3. Damage to each element at risk has been calculated from vulnerability and their construction cost and thematic output maps have been prepared for them using Arc GIS 9.1.

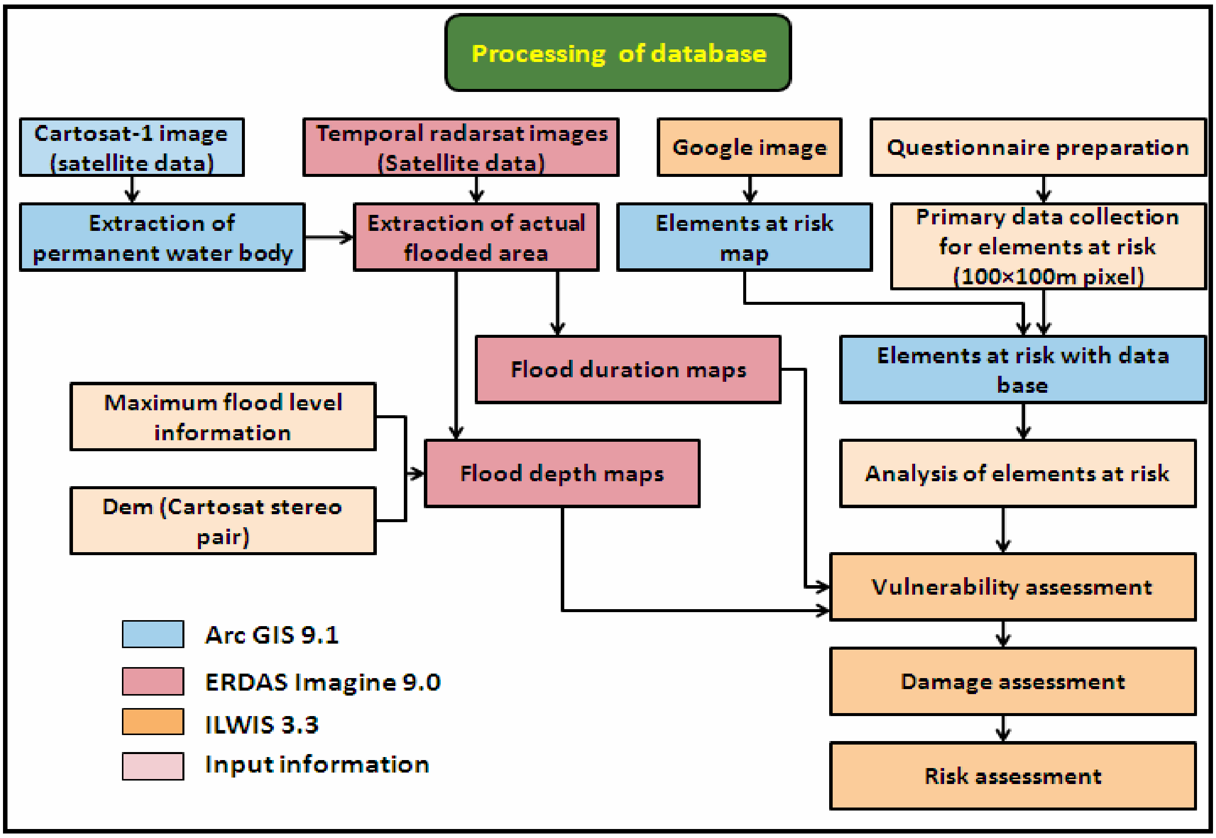


Figure4.8: Preparation of database

5. Results, Analysis and Discussion

5.1 Elements at risk

Many elements are affected by flood among which most important are houses followed by roads, agricultural fields, population, livestock. In this study only house, road and agricultural areas have been taken for assessing the vulnerability, damage and risk of three recent flood events (2008, 2006 and 2003) in the study area. Flood depth and duration are taken for assessing the vulnerability of three different flooded years.

5.1.1 House type

Building types are classified into 4 categories on the basis of their construction materials and it relation with flood water. Total numbers of house are 4234 in the study area which are made of different materials and can be classified into four categories normally, type-1, type-2, type-3 and type-4.

a. Structural type-1

Structural type-I has the more resistance power to cope up with the flood water for more number of days as these are composed of cement and brick. Therefore these are least vulnerable among all the types (Figure 5.1). Some of the buildings which are of this type are temples, schools, government offices like Water Resource Office and Irrigation Office, houses of the village heads and the upper rich class etc. These houses are also used as a shelter at the time of flood. This type of houses is 566 which indicate the 13.37% of total houses in the study area (Figure 5.3).

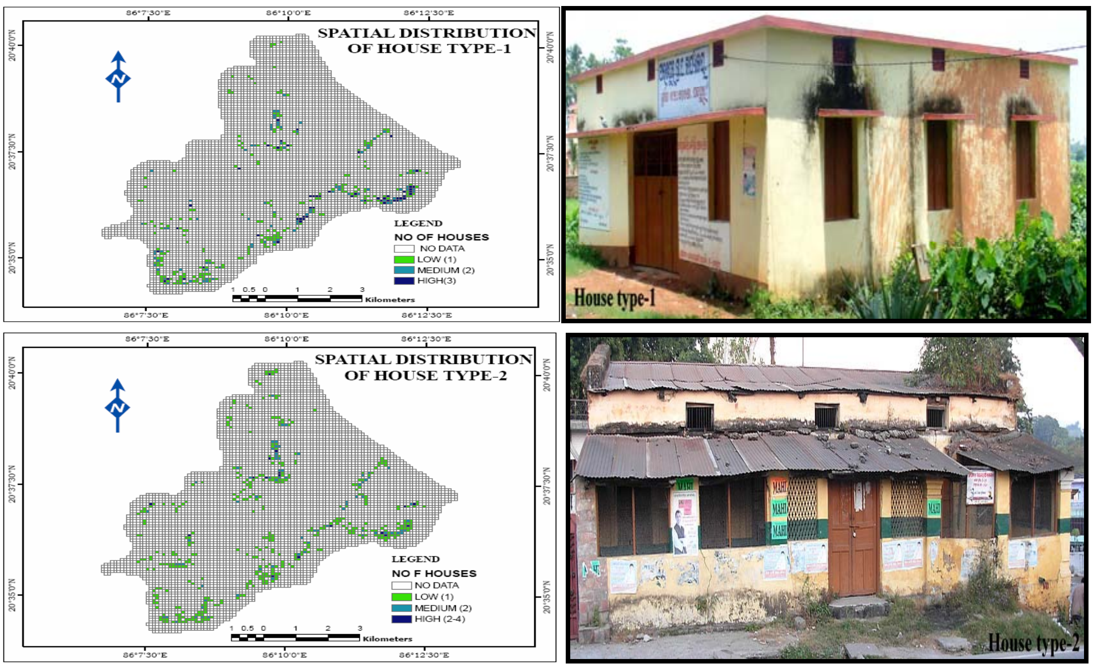


Figure 5.1: Spatial distribution of house type-1 & house type-2

b. Structural type-2

This type is less resistant to flood in comparison with the type-I as floor of the structures am made up of soil and the walls and roof with brick and cement. Therefore during flood their floors are prone to damage causing the damage of the whole building (Figure 5.1). But this type is very less in number as only floor of soil with brick and cement wall is not so acceptable. These types of buildings are 585 which indicate the 13.82% of total houses of the study area (Figure 5.3).

c. Structural type-3

This type has wooden material as its walls and floor and so they are constructed on pillars to avoid the direct water logging. This type is mainly used for shops and the Nuhat village has the highest percentage of this type of structures (Figure 5.2). But if the water logging is more or if the flood level is high for a longer period, then they are easily subjected to damage. These types of houses are 1455 which indicate the 34.36% of total houses of the study area (Figure 5.3).

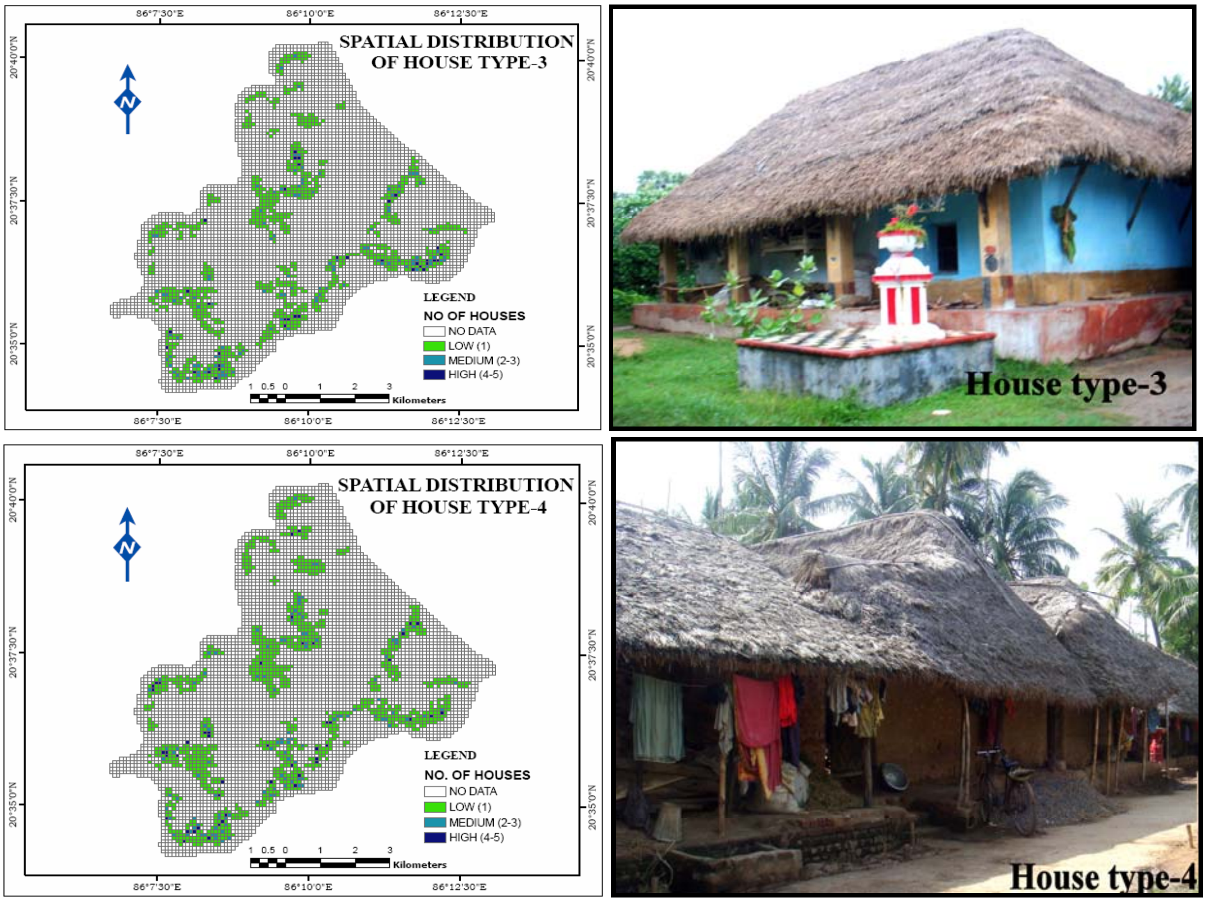


Figure 5.2: Spatial distribution of house type-3 and house type-4

d. Structural type-4

This type is composed mainly of mud and straw and so they are most vulnerable to flood. This type is of maximum number in the study area and is the dwelling of poor people only the straw is taken from bamboo and jute. Some of them are built on some raised platforms and are therefore little safe during

flood, but not for long if flood water stand for few days (Figure 5.2). These types of houses are 1628 which indicate the 38.45% of total houses of my study area (Figure 5.3).

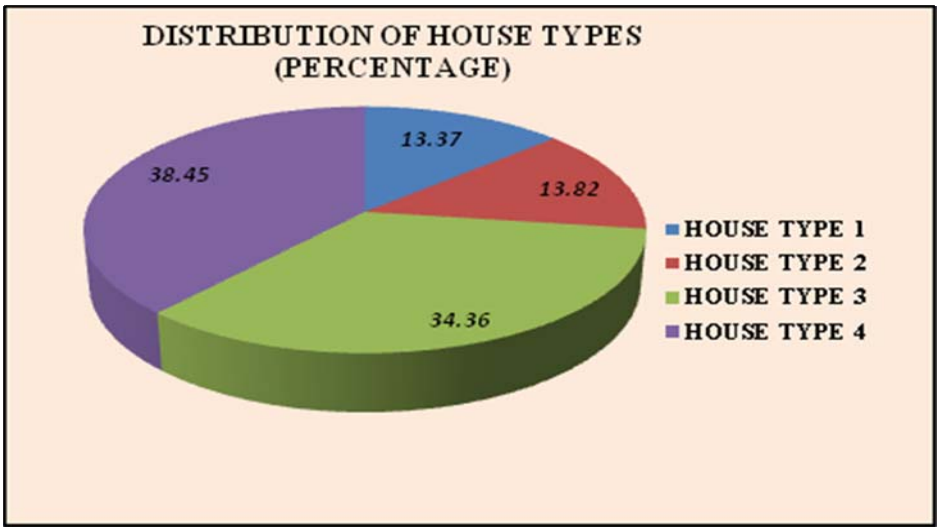


Figure 5.3: Distribution of house types

5.1.2 Agricultural type

Mainly two types of crops are grown in the study area during monsoon period (July to October), jute and rice. Total rice fields and jute field are covered by 37.90 sq km and 0.35 sq km of entire study area. This crop vulnerability information was collected directly from the field survey. Rice is grown in maximum area here. Jute is used as the constructional material for the house type III and IV. It is also used for making some handicrafts like rags etc. Canal irrigation is practiced here, but sometimes small floods with very low intensities are considered as boon to the local people as they are used as irrigational water.

a. Crop condition

Rice grows mainly in hot and humid areas (temperature should remain within 21 to 37 degrees centigrade) which are available here. It also requires standing water during first month of growth period, so flood with little water depth is not so harmful so for the rice crop. But flood with longer duration causes problem to the rice field.

Figure 5.4: Rice and jute field
Source: Field Survey

But jute is a crop which requires less water and temperature of 24 to 37 degree centigrade, so longer water logging for more than a week or two may cause harm to a jute crop. If water height is more than the plant height, then the damage will be quicker for jute (Figure 5.4).

b. Crop period

Rice is the major crop here and therefore it grows throughout the year. It is mainly a Kharif crop sown in June and harvested in September/October. Rabi crop is sown from November to March and Sowing of jute crop is generally done from March to May and harvested in August / September (Figure 5.4). From the field study it is found that sowing is done up to end of April and harvested in the mid of August.

5.1.3 Road types

Roads form an important part of an infrastructure of any place. It a major route for all sort of transportation purposes. Here, roads are mainly of concrete type but some non-concrete roads are also found. Two categories of roads have been recognized here: metalled and unmetalled roads.

a. Unmetalled road

These types of roads are of local use and made by local people. They are made up of soil and during the time of flood they get inundated and remain useless as long as water remain logged up there. They are of small lengths in comparison to the bituminous roads (Metalled road are two type like concrete and bituminous) and are maintained by panchayets. They are very muddy and hence during flood or any water logging condition there remains a fear of stuck in to mud. This type of road is 45.88 km length (long) of my study area (Figure 5.5).

b. Metalled road

Roads are mainly bituminous or concrete in the study area and are maintained and built by the government. The northern part of the study area has the National Highway number 5 which is also connects the central Orissa with the Paradeep port. Therefore this road is of great value from the economic view point. These type of roads are also less vulnerable to the flood water unless and until the depth and duration is high for 10 or 15 days. So they are accessible even during the time of flood. This type of road is 87.67 km length (long) of the study area (Figure 5.5).

Figure 5.5: Metalled and unmetalled road
Source: Field survey

5.2 Vulnerability assessment of elements at risk

Vulnerability is the degree of loss due to a particular phenomenon of single or a set of elements at risk from the occurrence of a natural phenomenon of a fixed magnitude and it vary in between 0 to 1 (UNDRO, 1991). So any flood vulnerability analysis needs information regarding some factors which can

be specified in terms of element at risk indicators, exposure indicators and susceptibility indicators (Messner, *et. al.,* 2006). Flood vulnerability analysis is the group of elements which are at risk of being harmed by floods. Elements at risk indicators are persons, household, firms, economic production, private and public building, public infrastructure, cultural assets, agriculture etc. Exposure indicator give information about location of the various elements at risk, their elevation, their proximity to the river, their closeness to inundation areas, return periods of different types of floods in the flood plain. Flood duration, sediment load, velocity and inundation depth are the exposure indicators due to flood (Alexander *et. al.,* 1993). Susceptibility indicators indicates how sensitively behaves at elements at risk and when it is conformed with some kind of hazards that means it relates to the affected social, economic and ecological systems (Messner, *et al.,* 2006).

Elements at risk chosen for this particular study area are road, house and agriculture. Among different indicators like flood duration, sediment load, velocity and inundation depth for flood exposure, only flood depth and flood duration are taken for assessing vulnerability of flood for three flood events. Flood depth has been used for the studying the houses and roads, and both flood depth and flood duration have been used for the agriculture only. Flood duration is more important in case of agriculture (jute and rice) than in the cases of house and road because agricultural crops can survive the water logged condition for some duration of time (5 to 7 days). For this purpose of assessing vulnerability, field survey data, remote sensing data and other secondary sources of data have been used.

For the vulnerability assessment of these elements at risk, vulnerability curves have been generated on the basis of the flood damage information that were collected from field and different government offices. How these elements at risk behaved at the time of flood, that information was also collected from these sources. Vulnerability curves shows the level of damage of different elements with respect to the exposure indicators (flood depth and flood duration) of certain magnitude of flood. Each curve is a combination of some small straight lines. Depth and duration of the elements at risk were replaced according to the vulnerability curves by the vulnerability values by following equation (straight line equation).

$$y = mx + c$$

'x' and 'y' are the coordinates of the points that satisfy the function; 'm' is the gradient of the straight line and; 'c' is the 'y intercept' of the straight line. By using this method, elements at risk of the flood event of three years are assessed.

Vulnerability of each element at risk are discussed and analyzed spatially below.

5.2.1 Vulnerability assessment of house type

House types of the study area are categorized into four types on the basis of which vulnerability has been assessed that have considered the flood depth, construction material of buildings (floor, roof, wall etc) of three different flood events (2003, 2006 and 2008). Four curves have been generated for four types of houses depending on their behavior at the time of the flood event. 393 houses were affected in 2008, 152 houses were affected in 2006 and 299 houses were affected in 2003 flood event with total of 4234 houses (Figure 5.6).

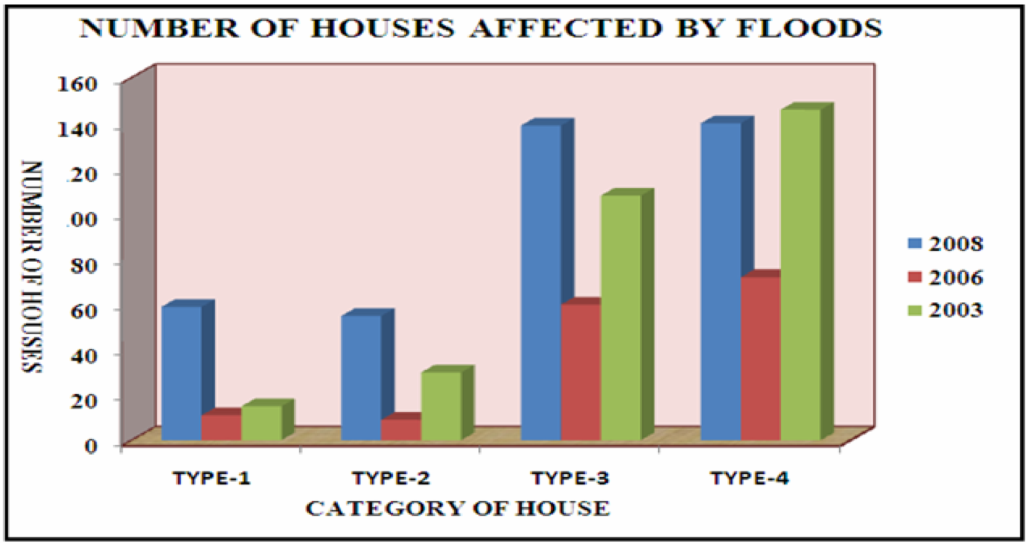


Figure 5.6: House affected by floods

Table 5-1: Vulnerability scale of house types

Vulnerability	Description
0 (no damage)	1. No damage due to flood. 2. No need for any replacement or repair.
0.2 (20% damage of a house)	1. Half damage of any one part (roof, wall and floor) of a house. 2. Damage materials needs to repair. 3. No need for any replacement.
0.4 (40% damage of a house)	1. Half damage of two part (roof, wall and floor) of a house. 2. Damage materials needs to repair. 3. No needs any replacement.
0.6 (60% damage of a house)	1. Half damage of any two part (roof, wall and floor) and full damage of one part of a house. 2. Half damage materials needs to repair. 3. Full damage materials needs to replace.
0.8 (80% damage of a house)	1. Fully damage of any two part (roof, wall and floor) and half damage of one part of a house. 2. Full damage materials needs to replace. 3. Half damage materials needs to repair.
1 (fully damage of a house)	1. All materials need to replace and make a new structure.

a. House type-1

This type is composed of brick, cement and iron and having a strong concrete floor, wall and roof. This type of house has very low vulnerability due to flood in respect to the other classes. The vulnerability will increase with the increasing flood depth and duration but only the flood depth of three different flood events (2003, 2006 and 2008) has been considered. 0.31 is the highest vulnerability when the house is completely under water due to flood. Out of 566 houses, 59 were affected in 2008, 11 in 2006 and 15 in 2003 (Figure 5.7).

House structure type-1

Flood depth in cm.	Vulnerability
20	0.05
40	0.07
60	0.09
80	0.12
100	0.15
120	0.18
140	0.21
160	0.24
180	0.26
200	0.28
220	0.29
240	0.30

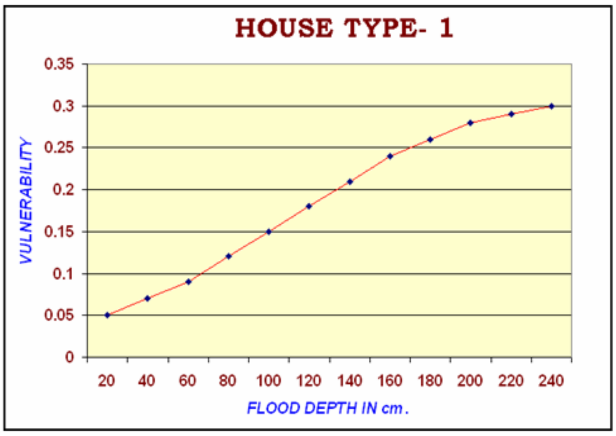


Figure 5.7: Vulnerability curve of house type-1

b. House type-2

Major portion of the structural type II is composed of brick and cement but its floor is made up of soil which may get washed away by water easily and thereby will be more prone to damage than the type I. During flood if the duration is very long then it may affect the floor. But as the wall is made up of brick, therefore the damage will be much less unless the flood level rises or stays for a long time. 0.46 is the highest vulnerability when the house will be damaged. Out of 585 houses, 55 were affected in 2008, 9 in 2006 and 30 in 2003 (Figure 5.8).

House type-2

Flood depth in cm.	Vulnerability
20	0.050
40	0.120
60	0.180
80	0.230
100	0.270
120	0.310
140	0.340
160	0.360
180	0.385
200	0.410
220	0.430
240	0.450

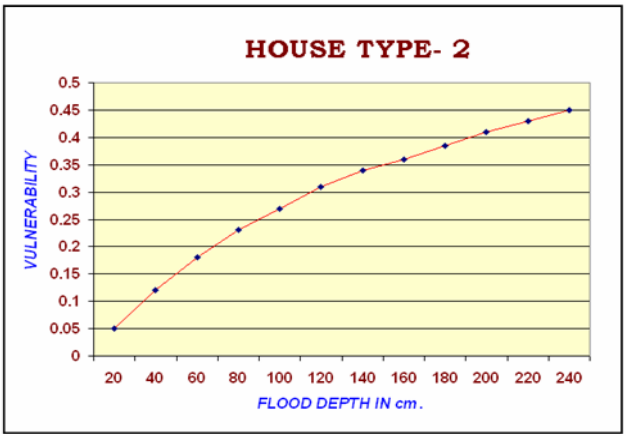


Figure 5.8: Vulnerability curve of house type-2

c. House type-3

This type is made of wood and is above a platform but they get damaged easily once flood water entree within the house. If bricks remain within the framework of wood, then they may lose strength due to this if ultimately results in the total collapse of the house when they are unable to resist horizontal forces. Wood has the tendency to absorb water which results in further damage. 0.81 is the highest vulnerability for this type. Out of 1455 houses surveyed 139 were affected in 2008, 60 in 2006 and 108 in 2003 (Figure 5.9).

House type-3

Flood depth in cm.	Vulnerability
20	0.050
40	0.150
60	0.270
80	0.380
100	0.465
120	0.550
140	0.610
160	0.660
180	0.710
200	0.750
220	0.780
240	0.800

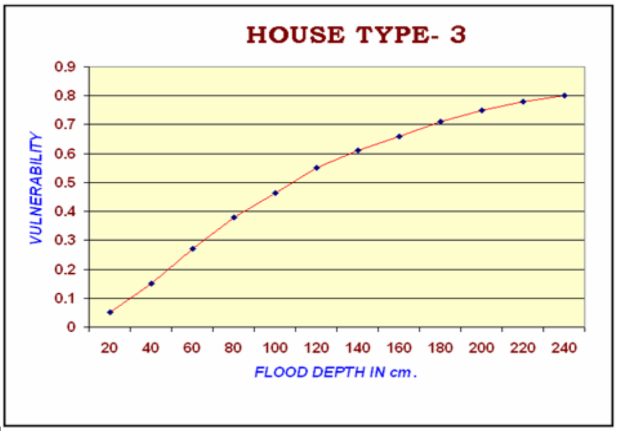


Figure 5.9: Vulnerability curve of house type-3

d. House type-4

This type is made of mud and clay and thereby is the most vulnerable. Major types of houses of the study area are of this type and hence even in short duration, like few days, it may get damaged. Soil or mud has less resistant power, so that they are eroded easily leading to the total destruction of the houses. Straw, that is used for making roofs, they are also very much vulnerable to flood water and so maximum damage occurs in this type of houses. 0.96 is the highest vulnerability for this type. Out of 1628 houses, 140 were affected in 2008, 72 in 2006 and 146 in 2003 (Figure 5.10).

House type-4

Flood depth in cm.	Vulnerability
20	0.05
40	0.20
60	0.35
80	0.50
100	0.63
120	0.72
140	0.78
160	0.85
180	0.90
200	0.95

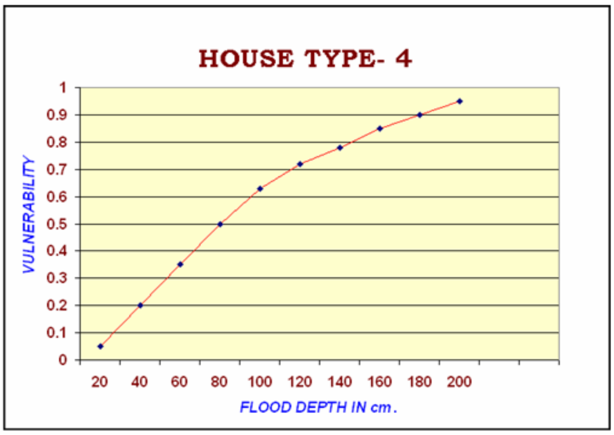


Figure 5.10: Vulnerability curve of house type-4

Comparative studies for different types of houses are shown in a single graph by the vulnerability curves (Figure 5.11).

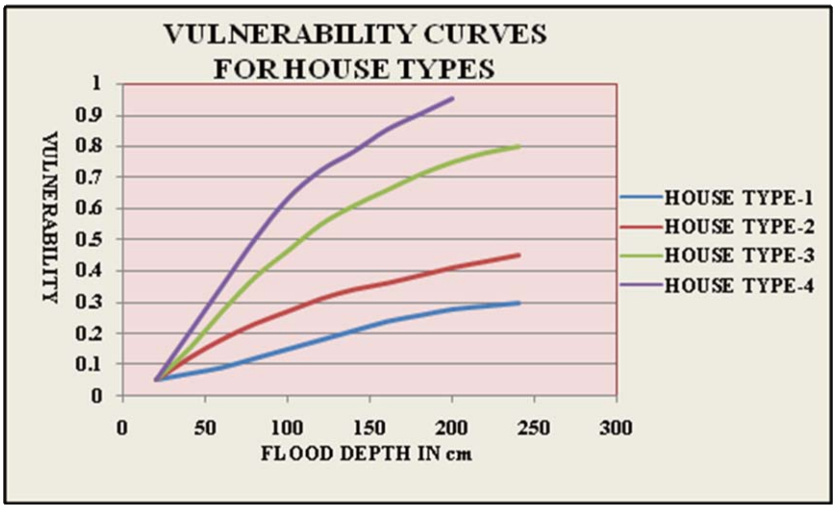
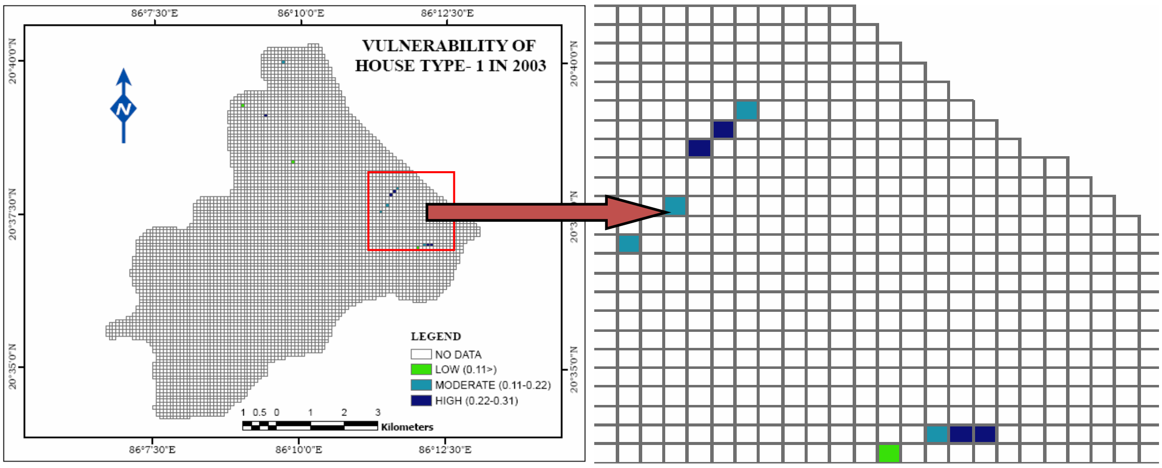


Figure 5.11: Vulnerability curves for houses

Type-I houses in 2003 are least affected. They are situated in the northern and eastern part, so it can be said that the flood depth was low in that area. Few moderately affected houses are found in the eastern part and the highly affected ones, i.e. the areas with maximum flood depth are found scattered in the eastern part. In the year 2006, highly affected houses are found in the southern part of the study area. In 2008 flood, most of the affected houses are scattered in east and south (Figure 5.12). The area has been categorized into low, medium and high by equal interval of vulnerability. In these three years of flood, i.e. in 2003, 2006 and 2008, lowest category was less than 0.11 and the highest vulnerability was within 0.22 to 0.31.



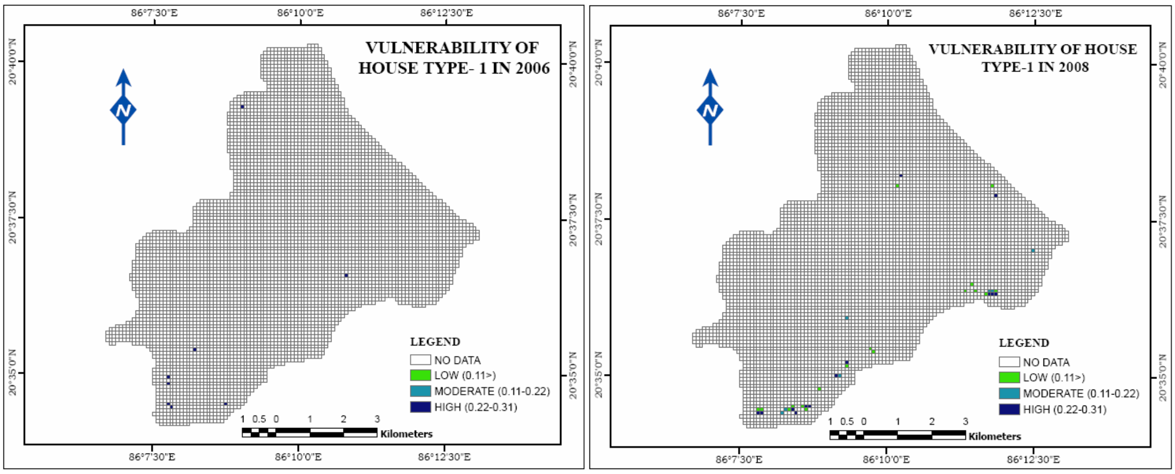


Figure 5.12: Spatial distribution of vulnerability for house type-1 (2003, 2006 & 2008)

In the type-2 houses of 2003, least affected houses are found scattered in northern part. Moderately affected houses are found in northern and eastern part while the highly affected are found mainly in the eastern and north eastern part. In 2006, highly affected are found in southern part. In 2008, affected houses are scattered in all areas except in the west, but highly affected areas were distributed in southern, eastern and south-eastern part with low and moderate category (Figure 5.13). The area has been categorized into low, medium and high vulnerability. The lowest vulnerability in these three years was below 0.16 and the highest vulnerability was within 0.32 to 0.46.

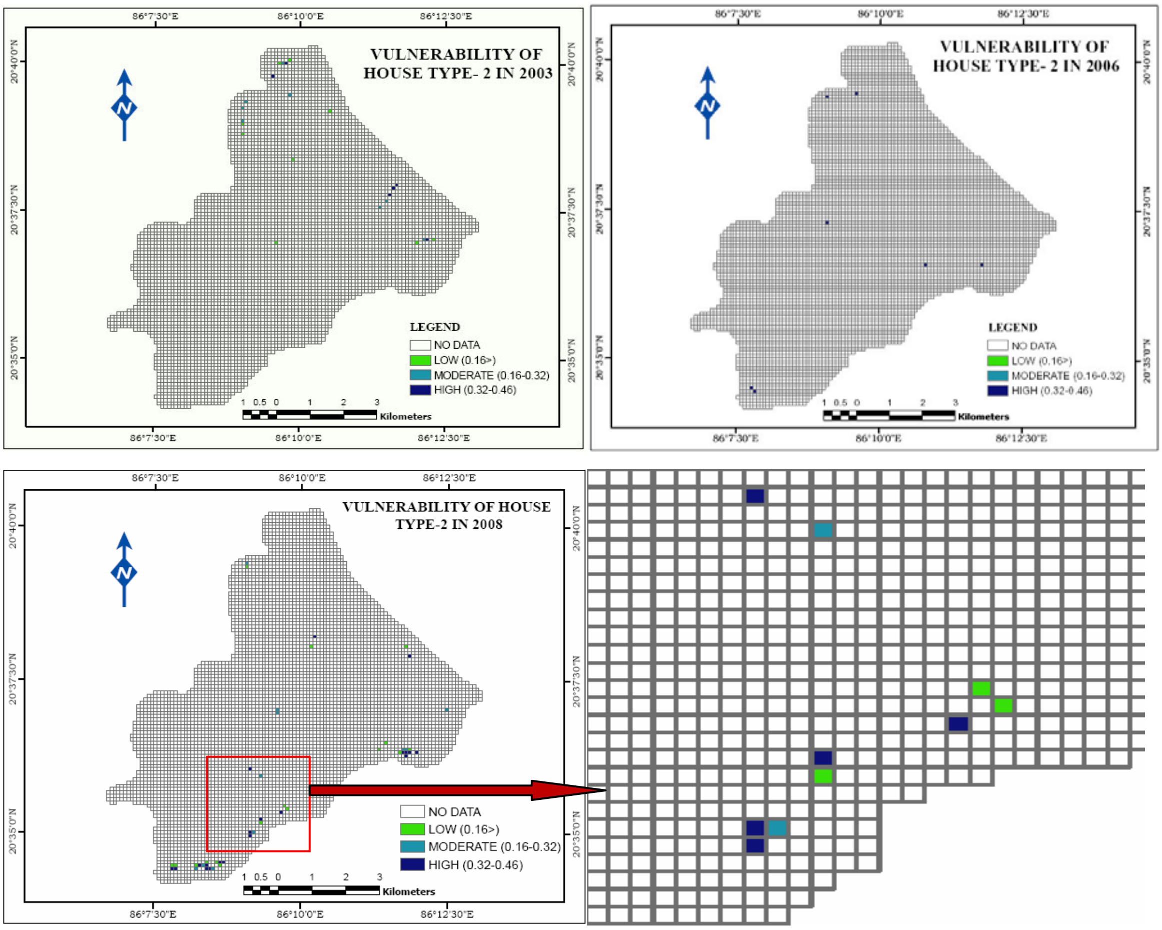


Figure 5.13: Spatial distribution of vulnerability for house type-2 (2003, 2006 & 2008)

In the house type-3 in 2003, least affected houses are found mostly in central and north-west part, moderate in the northern, eastern and north-eastern and the highly affected are found in the northern and eastern from which it can be said that flood depth was maximum in the northern and eastern part in the study area. In 2006, least affected houses are very low found in the central and western part and highly affected are found scattered throughout the area. In 2008, highly affected of houses are found in south, south-east, eastern and the central part with low and moderate category (Figure 5.14). The area has the lowest vulnerability of less than 0.27 and the highest vulnerability within 0.54 to 0.81.

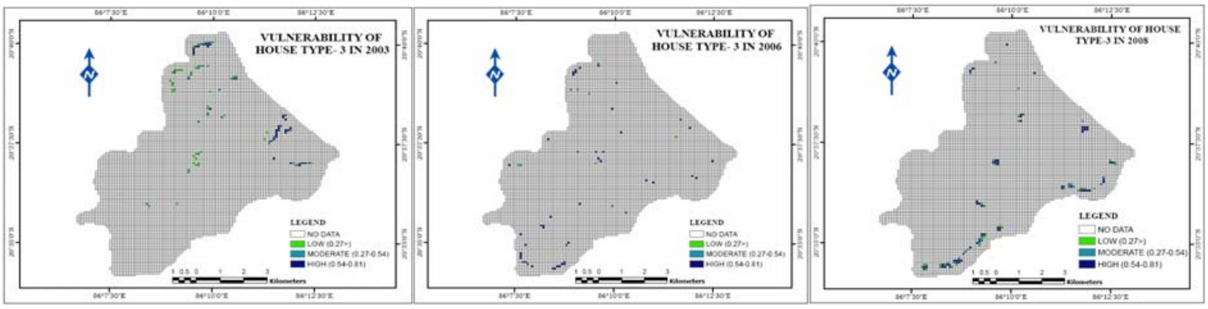


Figure 5.14: Spatial distribution of vulnerability for house type-3 (2003, 2006 & 2008)

In the house type-4 of 2003, least affected are found in the northern and central part, moderately affected houses are very low in number found scattered in the northern and central part and highly affected in the northern, eastern and north-east. During 2006 flood, most of the houses that are highly affected are scattered everywhere. In 2008, highly affected houses are found in east, south and the central part with low and medium category (Figure 5.15). The lowest vulnerability of less than o.32 has occurred in 2003, 2006 and 2008 and the highest vulnerability was within 0.64 to 0.96.

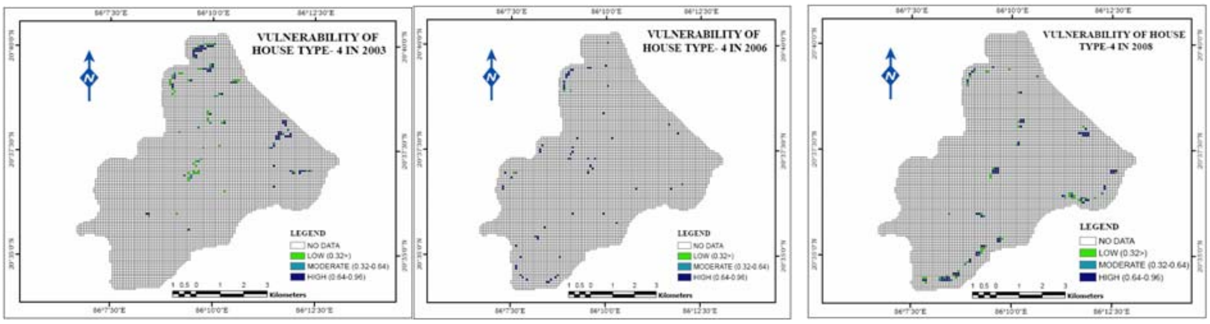


Figure 5.15: Spatial distribution of vulnerability for house type-4 (2003, 2006 & 2008)

5.2.2 Vulnerability of road types

Road damage occurs at the time of flood as stagnant water cause the inaccessibility of road and also the overall damage as well. Some are very low-lying roads. Unmetalled road is made up of mud and thereby highly vulnerable and the metalled roads are made up of concrete and so much more stable.

Table 5-2: Vulnerability scale for roads

Vulnerability	Description
0	No damage.
0.2	Very low damage and forms hole which are small size on road. Repairing needs very minimum.
0.5	Some parts of road wash out and forms large hole on road. No needs any replacement. Repairing of damage parts takes medium amount of cost.
0.8	Some parts of road wash out. Some portion needs to replace. Some portion needs to repair. Repairing of damage parts takes large amount of cost.
1	The road fully collapses. The road needs to make a new structure.

a. **Unmetalled road**

Unmetalled roads are of soil and mud which when flood occurs get totally damaged. It gets blocked up by water and develops humps and pits which was repaired by the community. With the flood depth of 0.5m, vulnerability was almost 0.5. During this stage little repair may control the situation. While at the flood depth of 4 m vulnerability is almost 0.9 and with the further increase, it leads to total damage. Total length of the road is 45875m (generated by visual image interpretation method). In the year 2008, total affected part was about 6090m, in 2006 it was 3615m and in 2003, it was 5735m. This curve has been generated from the field survey by comparing the depth of flood of a particular area (Figure 5.16).

Unmetalled road

Flood depth in meter	Vulnerability
0.5	0.7
1	0.8
1.5	0.87
2	0.945
2.5	0.98
3	0.98

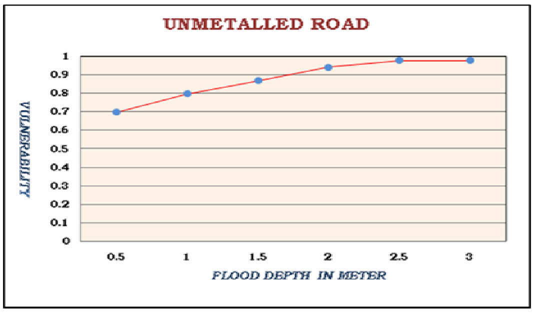


Figure 5.16: Vulnerability curve of unmetalled road

b. **Metalled road**

This type of road is made up of bituminous and concrete and so vulnerability is much less than the unmetalled roads. With the vulnerability of 0.4 damages will be less and it may not cause much problem. But with the increasing flood depth of about 5 to 5.5 m vulnerability also increases causing problems. Out of the total length of 87640m, 27235m was affected in 2008, 19775m was affected in 2006 and 15915m was affected in 2003 (Figure 5.17).

Metalled road

Flood depth in meter	Vulnerability
0.50	0.050
1.00	0.400
1.50	0.600
2.00	0.680
2.50	0.730
3.00	0.760
3.50	0.790
4.00	0.810
4.50	0.820
5.00	0.825
5.50	0.830
6.00	0.850

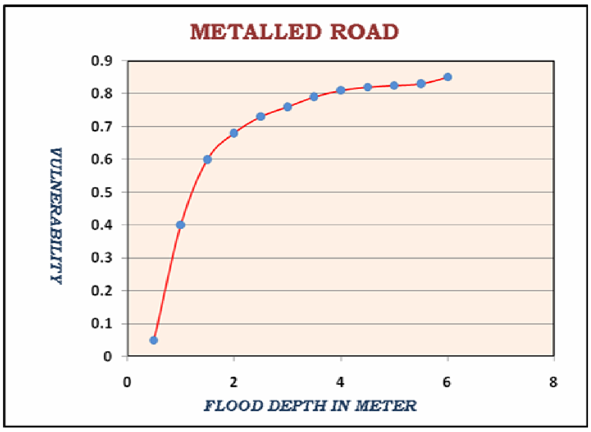


Figure 5.17: Vulnerability curve of metalled road

COMPARISON BETWEEN BOTH TYPES

Unmetalled road is definitely more vulnerable than the metalled road and that is why metalled road can survive even at the flood depth of 6m while unmetalled road cannot persist so long under such flood depth. A comparative study between both the roads is shown below in a graph by vulnerability curves (Figure 5.18).

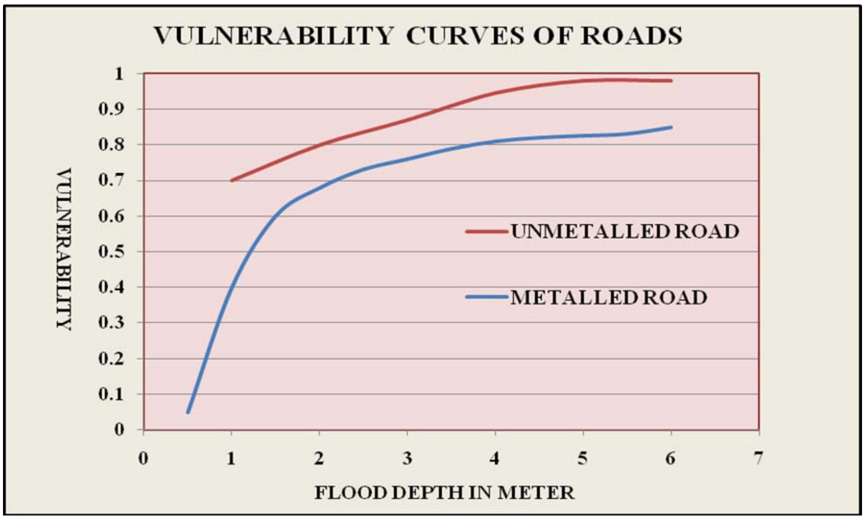


Figure 5.18: Vulnerability curves for roads

In case of unmetalled road, it can be observed from the map of 2003 that roads are highly vulnerable in the north eastern and the eastern part, with less vulnerability in the central and the north western part. In 2006, flood affected roads are almost scattered in the northern, southern and the eastern part. Some moderately affected roads are also found in the central part. In the year 2008, less affected roads are found in north western part while highly affected roads are found in the eastern and southern part. As areas in the northern are comparatively higher elevations (Figure 5.19). The lowest vulnerability in case of 2003 was less than 0.32 while that of 2006 had less than 0.31 and 2008 had less than 0.33. The highest vulnerability of 2003 was within 0.64 to 0.95, 2006 had 0.62 to 0.93 and 2008 had 0.66 to 0.98.

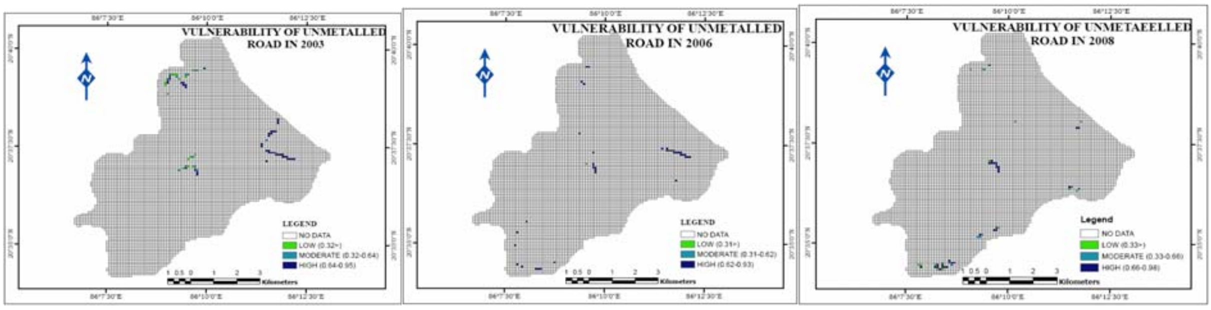


Figure 5.19: Spatial distribution of vulnerability for unmetalled road (2003, 2006 & 2008)

In case of metalled roads, in 2003, it was observed that highly affected roads are found scattered in all areas, while less affected roads are found in the western part. In 2006, roads are highly affected throughout the area with some less affected parts in the western part. And in the year 2008, highly affected roads are found in the central part, mostly, with less affected parts in the northern and western part (Figure 5.20). Here, the lowest vulnerability for 2003, 2006 and 2008 was less than 0.29 and the highest vulnerability was within 0.58 to 0.86.

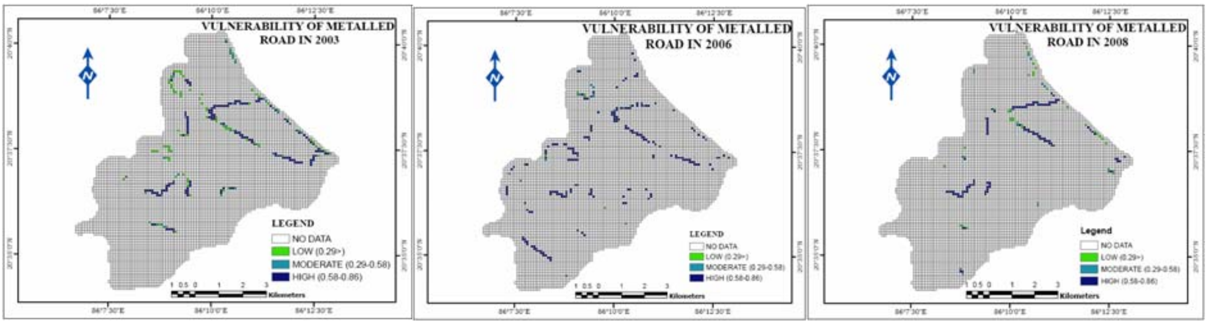


Figure 5.20: Spatial distribution of vulnerability for metalled road (2003, 2006 & 2008)

5.2.3 Vulnerability of agricultural crops

Flood depth and duration were taken for assessing the vulnerability of agricultural crops. Rice and jute are main crops. Flood duration is categorized into short duration (less than 5 days), medium duration (5 to 15 day) and long duration (greater than 15 days) with flood depth and generated the vulnerability curves of jute and rice of three different flood events. In 2008, total agricultural area is affected is 15.20sq km area from three RADARSAT images, in 2006, total agricultural area is affected by 25.01 sq km area from four RADARSAT images and in 2003, total agricultural area affected is 15.99 sq km from four RADARSAT images during flooded period. 10.60m, 08.90m and 10.17m are the maximum flood depth in 2008, 2006 and 2003 flood events. Vulnerability scale for rice crop is given below in a chart:

Table 5-3: Vulnerability scale for rice

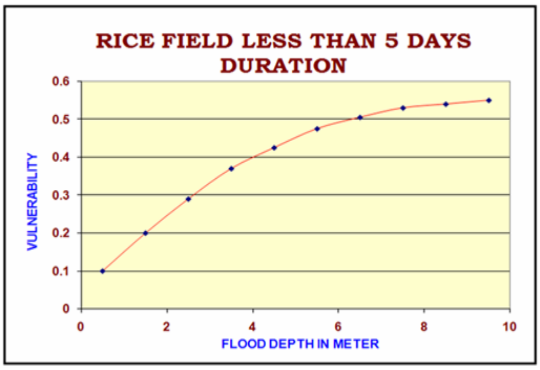
Duration of flood				
Serial No.	Water depth in meters	0 to 5 days duration	5 to 15 days duration	Greater than 15 days duration
1	0 to 1.5m	Less than 20% loss	Less than 30% loss	Less than 40% loss
2	1.5 to 3m	20 to 35% loss	30 to 50% loss	40 to 65% loss
3	3 to 4.5m	30 to 45% loss	40 to 65% loss	65 to 80% loss
4	4.5m to 6m	45 to 50% loss	65 to 75% loss	80 to 90% loss
5	6 to 7.5m	50 to 53% loss	75 to 80% loss	90 to 95% loss
6	7.5m<	Up to 55% loss	Up to 85% loss	Total crop loss

5.2.3.1. Vulnerability of rice

Flood depth and duration is more important factor for vulnerability assessment of rice. At early period of rice production, rice field can be completely inundated by water during a short period (less than 5 days) and it will not be more vulnerable. Because its need water all the time and rice is fully inundated. At inundated stage, vulnerability increases with duration for rice crop.

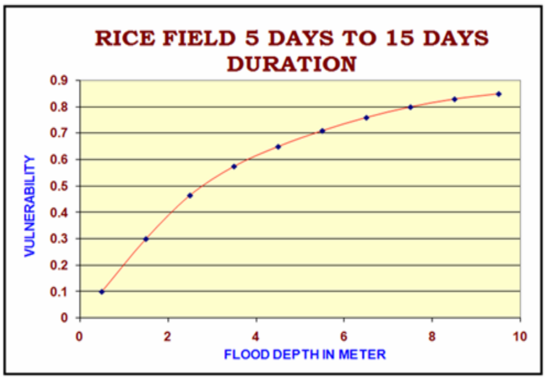
Rice short duration (less than 5 days)

Flood depth in metre	Vulnerability
0.5	0.100
1.5	0.200
2.5	0.290
3.5	0.370
4.5	0.425
5.5	0.475
6.5	0.505
7.5	0.530
8.5	0.540
9.5	0.550



Rice medium duration (5 to 15 days)

Flood depth in metre	Vulnerability
0.5	0.100
1.5	0.300
2.5	0.465
3.5	0.575
4.5	0.650
5.5	0.710
6.5	0.760
7.5	0.800
8.5	0.830
9.5	0.850



Rice medium duration (greater than 15 days)

Flood depth in metre	Vulnerability
0.5	0.100
1.5	0.400
2.5	0.600
3.5	0.720
4.5	0.800
5.5	0.870
6.5	0.910
7.5	0.930
8.5	0.930
9.5	0.950

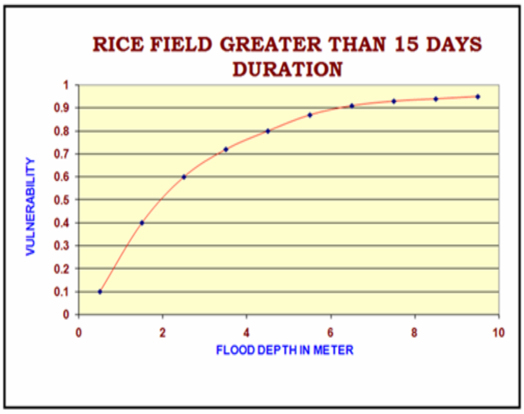


Figure 5.21: Vulnerability curves for rice crop

Loss of crop due to flood has been calculated on the basis of total production cost. Duration of rice was categorized into short, medium and long after consulting Agricultural Office of Govt. of Orissa (AOGO). The relationship is shown between flood depth and rice crop vulnerability and is represented in different duration of flood (Figure 5.21).

A comparative study of the effect of flood on rice in these three durations is shown below by the vulnerability curves in one graph (Figure 5.22).

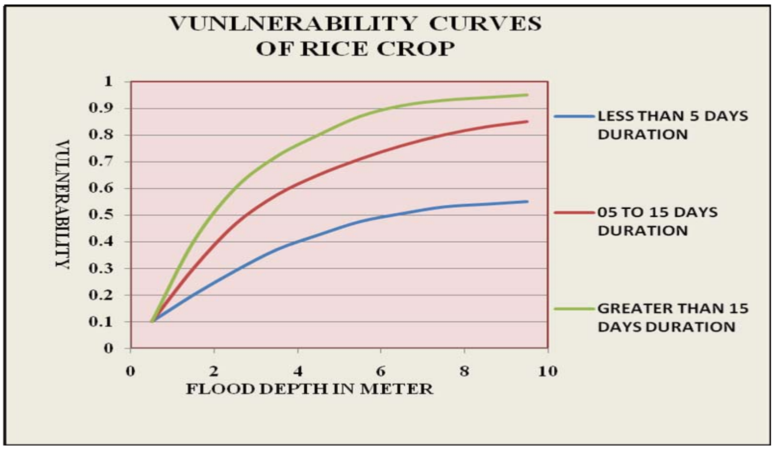


Figure 5.22: Vulnerability curves of rice crops

For short flood duration, total affected area was 6.69sq km in 2003. Vulnerability of rice was high in the east and the southern part with low to moderate effect in the west. In 2006, total area affected was 8.06sq km. highly affected rice is found in entire region with very low portion of less affected fields in the west, in 2008 (Figure 5.23). The lowest vulnerability for 2003 was less than 0.19 while 2006 and 2008 had the same lowest value of less than 0.18. The highest vulnerability for 2003 and 2008 was almost same within 0.38 to 0.55 and 0.36 to 0.55 respectively. 2006 had the highest vulnerability within 0.36 to 0.54.

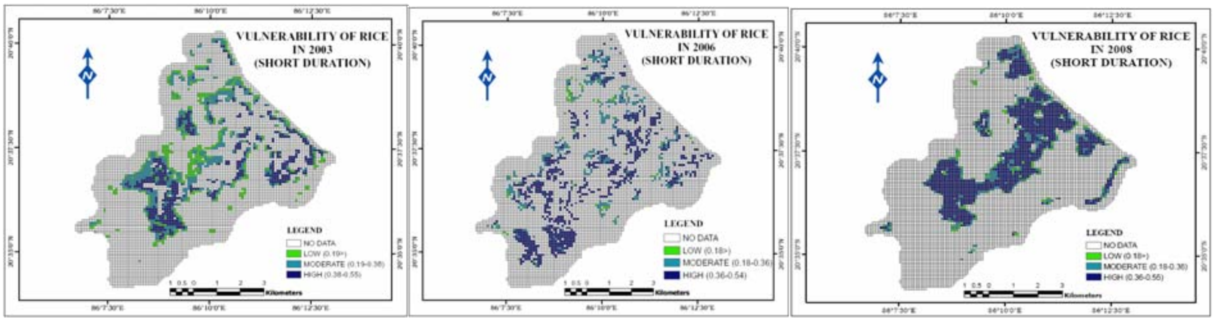


Figure 5.23: Spatial distribution of vulnerability for rice of short duration (2003, 2006 & 2008)

For medium flood duration, total area under the influence of flood water was 7.74sq km in 2003. Vulnerability of rice was very high in northern, central and eastern part along with some moderately affected areas due to the water was entering the area breach in river embankments. In 2006, total affected area was 7.94sq km, most of the rice fields were highly affected in the region with less to moderately affected areas in the western part in 2008 (Figure 5.24). In 2003, the lowest vulnerability was less than 0.29 and that of 2006 was less than 0.28 and the highest vulnerability of 2003 was within 0.58 to 0.86 and 2008 had 0.56 to 0.84.

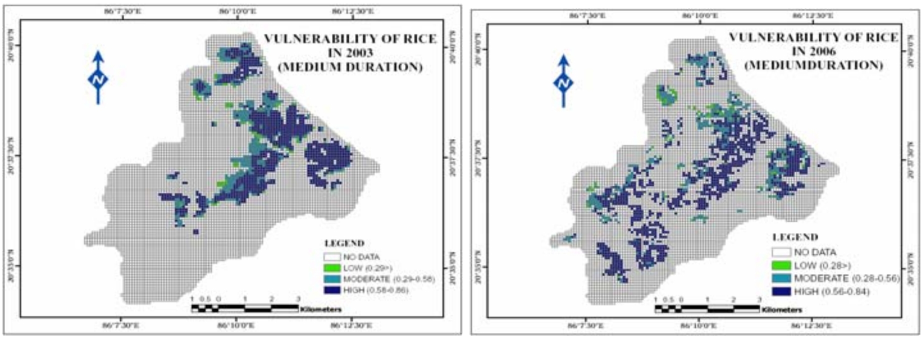


Figure 5.24: Spatial distribution of vulnerability for rice of medium duration (2003, 2006 & 2008)

For long flood duration, total flood affected area in 2003 was 1.5348sq km. Rice was highly vulnerable and was mostly concentrated in the northern and the north eastern part. In 2006, total area under flood was 9.09sq km when most of the rice fields were vulnerable and thus were much affected throughout the region with very little areas of moderately affected areas in the west in 2008 (Figure 5.25). The lowest and the highest vulnerability of 2003 and 2008 was same, it was less than 0.32 and within 0.64 to 0.96 respectively. 2006 had the lowest vulnerability of less than 0.31 and the highest was within 0.62 to 0.94.

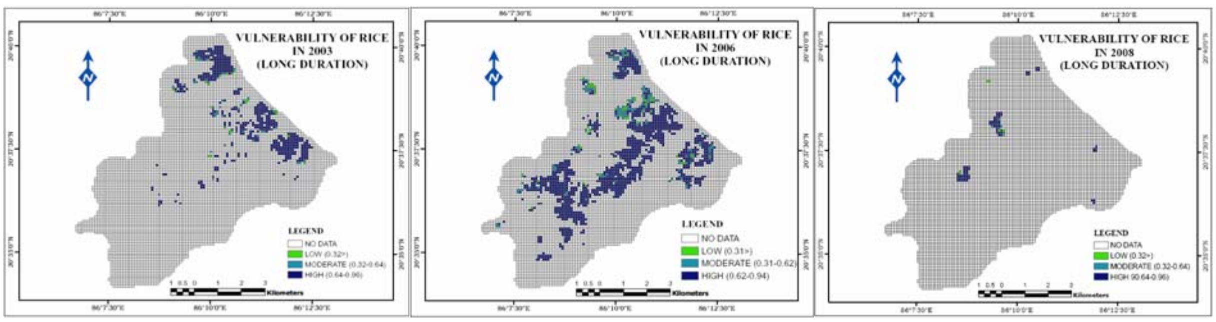


Figure 5.25: Spatial distribution of vulnerability for rice of long duration (2003, 2006 & 2008)

5.2.3.2. Vulnerability of jute

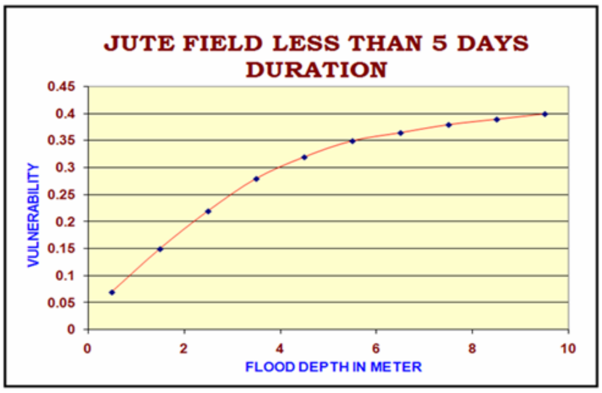
Jute is a secondary crop in the study area and very small area (0.35 sq km) is used for jute cultivation. Jute crop resists more time than rice and all time it needs to water for growing. At a time when jute crop is fully inundates due to flooded water during a long period (more than 10 days) only then it will be damaged (Figure 5.26). Vulnerability scale for jute crop is given below in a chart:

Table 5-4: Vulnerability scale for jute

Duration of flood				
Serial No.	Water depth in meters	0 to 5 days duration	5 to 15 days duration	Greater than 15 days duration
1	0 to 1.5m	Less than 15% loss	Less than 30% loss	Less than 35% loss
2	1.5 to 3m	15 to 25% loss	30 to 55% loss	35 to 75% loss
3	3 to 4.5m	25 to 30% loss	55 to 65% loss	75 to 95% loss
4	4.5m to 6m	45 to 35% loss	65 to 75% loss	Total crop loss
5	6 to 7.5m	35 to 40% loss	75 to 80% loss	Total crop loss
6	7.5m<	Up to 45% loss	Up to 85% loss	Total crop loss

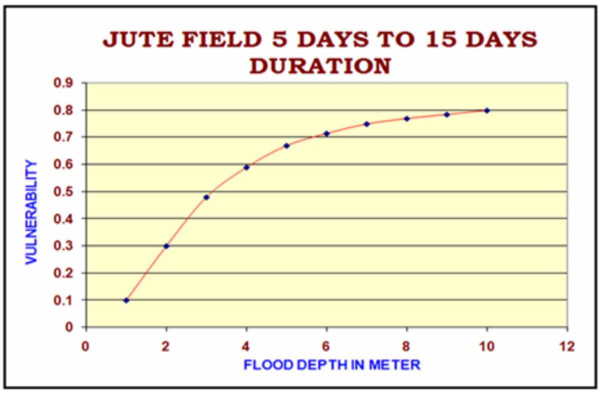
Jute short duration (less than 5 days)

Flood depth in metre	Vulnerability
0.5	0.070
1.5	0.150
2.5	0.220
3.5	0.280
4.5	0.320
5.5	0.350
6.5	0.365
7.5	0.380
8.5	0.390
9.5	0.400



Jute medium duration (5 to 15 days)

Flood depth in metre	Vulnerability
0.5	0.100
1.5	0.300
2.5	0.480
3.5	0.590
4.5	0.670
5.5	0.715
6.5	0.750
7.5	0.770
8.5	0.785
9.5	0.800



Rice medium duration (greater than 15 days)

Flood depth in metre	Vulnerability
0.5	0.100
1.5	0.370
2.5	0.650
3.5	0.850
4.5	0.950
5.5	0.100
6.5	0.100
7.5	0.100
8.5	0.100
9.5	0.850

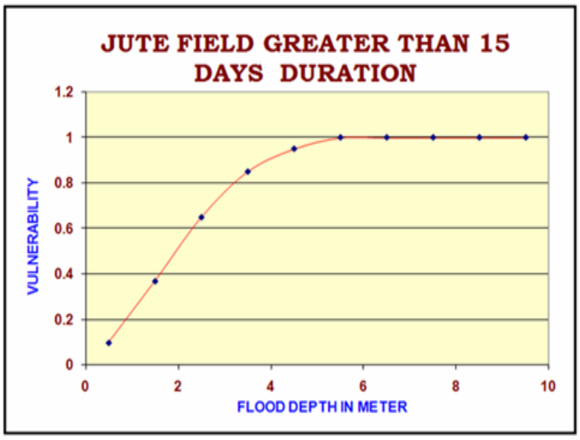


Figure 5.26: Vulnerability curves for jute crop

Duration for jute is categorized in to short, medium and long like rice crop. The relationship is shown in between flood depth and jute crop vulnerability is represented in different duration of flood of a comparative study of the effect of flood on jute is shown by vulnerability curves for three different durations in one graph below (Figure 5.27).

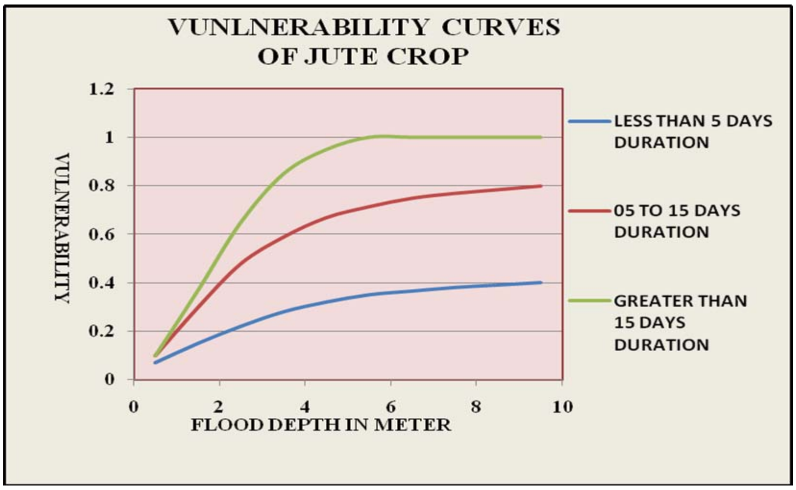


Figure 5.27: Vulnerability curves of jute crop

In short duration of flood, the total affected area of jute in 2006 was 0.33 sq km. Medium affected area was found in the eastern part with little portion of highly affected area. In 2008, total flood affected area was 0.39 sq km with some highly affected areas together with medium and less affected areas are found in the south eastern part. Because jute cultivated area was concentrated in eastern and southern part of the study area (Figure 5.28). The lowest vulnerability of 2006 and 2008 was same, i.e. below 0.11 and the highest vulnerability of 2006 was within 0.22 to 0.33 and 2008 had within 0.22 to 0.35.

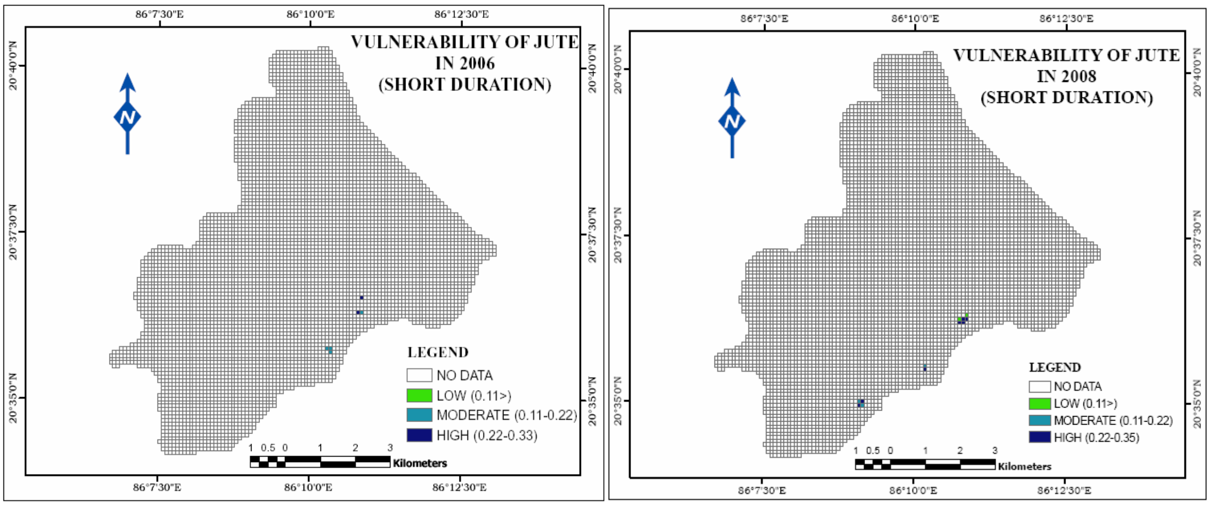


Figure 5.28: Spatial distribution of vulnerability for jute of short duration (2003, 2006 & 2008)

5.3 Damage assessment of elements at risk

Damage refers to all harmful affect on human, their health and their belongings public infrastructure, cultural heritage, industrial production, ecological systems which have affected on economy. When this damage occurs due to flood then it call flood damage (Messner, *et al.,* 2006). Persons, household, firms, economic production, private and public building, public infrastructure, cultural assets, agriculture are the elements at risk and flood duration, sediment load, velocity and inundation depth are the parameter of damage due to flood.

Elements at risk which are selected for this particular study area are road, house and agriculture and among different parameter like flood duration, sediment load, velocity and inundation depth for flood parameter, only flood depth and flood duration are taken for assessing damage due to flood for three flood events (2003, 2006 and 2008). Flood depth and flood duration have been used for the agricultural damage and flood depth has been used the house and road damage due to flood. Same data sets and other secondary sources like vulnerability assessment have been used for assessing the damage and only construction cost of elements at risk has been used as an extra. Costs of elements at risk are shown bellow as a tabular format.

Damage assessment of elements at risk has been assessed from their vulnerability of three different flood events and their construction cost. Damage value is expressed in rupees (Indian currency) from multiplication vulnerability value and construction cost of each elements at risk. All damage value of elements at risk has been added for assessing the total damage of a flood event.

$$\text{Sum } (Rd = V*C)$$

'Rd' is specific damage of element at risk; V and C are vulnerability and cost of element at risk.

Vulnerability of each element at risk are discussed and analyzed spatially below.

5.3.1 Damage of house types

Four different categories houses have been generated the damage from vulnerability and cost in rupees of three different flood events (2003, 2006 and 2008). Recover cost of flood affected houses are Rs. 0.4, Rs. 0.075, Rs. 0.018 and Rs. 0.005 million for house type-1, house type-2, house type-3 and house type-4. These have been discussed in below.

Table 5-5: Damage statistics of house type-1 (2003, 2006 & 2008)

TYPE OF HOUSES	TOTAL HOUSES	DAMAGE IN RUPEES (2008)	DAMAGE IN RUPEES (2006)	DAMAGE IN RUPEES (2003)
Type-1	566	3845878	3313600	3349840
Type-2	585	1099127	297600	437100
Type-3	1455	1325179	1216638	1417422
Type-4	1628	431947	451255	592805

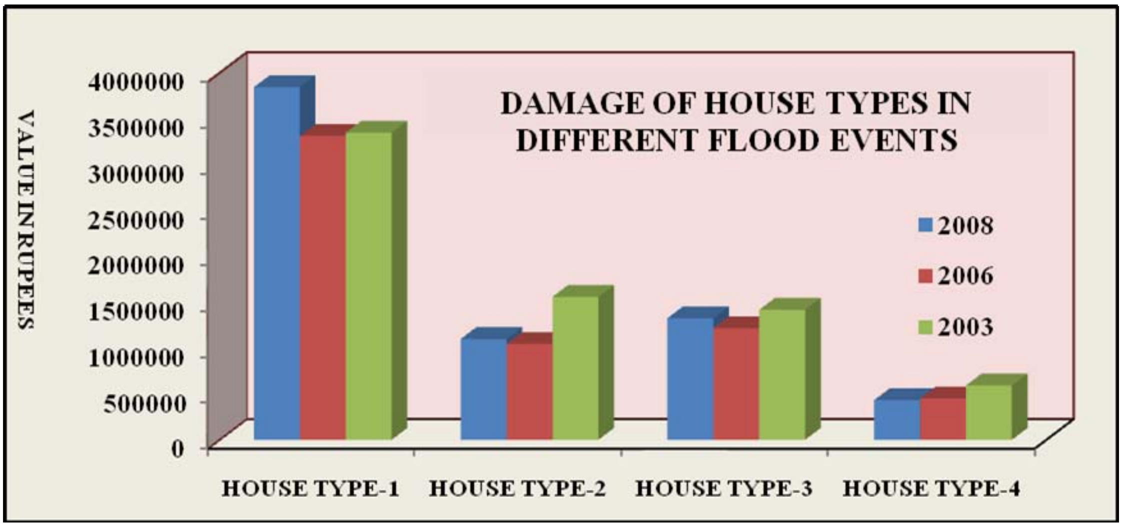


Figure 5.29: Damage of house types if different flood events

a. House type-1

Damage of the house type-1 was Rs 3.85, Rs 1.24 and Rs 1.07 million in 2008, 2006 and 2003 flood events respectively. But areal extent of flood was the maximum at 04th Sep in 2006 and damage was the maximum of house type-1 in 2008. Because the maximum affected area was agricultural area in 2006. In 2008, areal extent of flood was the minimum but damage of house type-1 was the maximum among three flood events, because settlement area was more affected with high depth of flood. 59 houses were affected in 2008, 11 in 2006 and 15 in 2003 (Figure 5.29).

In the type-1 houses in 2003, it is observed that affected houses are situated in the northern, eastern and north-eastern part mostly; medium and high category of damage was found due to high flood depth. In 2006, southern part was more affected with high category of damage and other areas were affected with low damage. In 2008, the low and medium categories of damages ware observed due to low depth of flood. The medium category is concentrated in the eastern part due to medium category of flood depth (Figure 5.30).

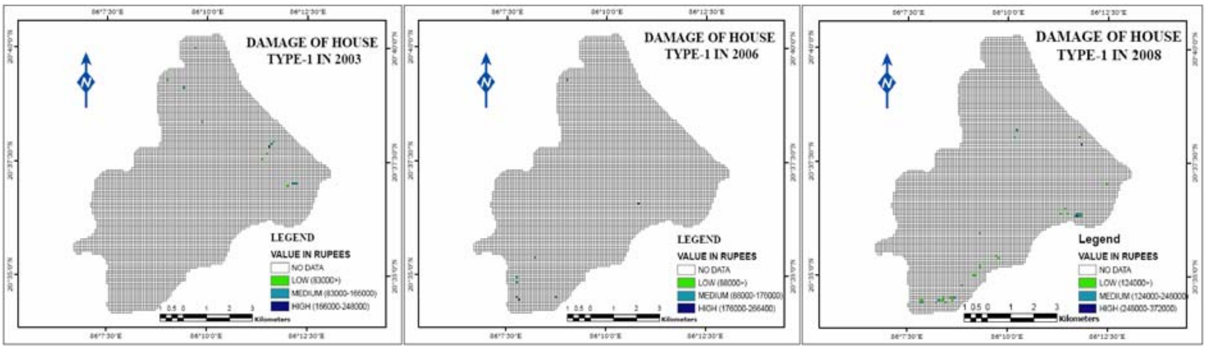


Figure 5.30: Spatial distribution of damage for house type-1 (2003, 2006 & 2008)

b. House type-2

Damage of the house type-2 was Rs 1.10, Rs 0.35 and Rs 0.34 million in 2008, 2006 and 2003 flood events respectively. But areal extent due to flood was the maximum at 04th Sep in 2006 and damage was the maximum at 18th Sep in 2008 of house type-2 due to high flood depth and the number of affected houses were maximum. Agricultural areas were affected in maximum in 2006. In 2008, damage of house type-2 was the maximum along with the minimum areal extent of flood. 55 houses were affected in 2008, 9 in 2006 and 30 in 2003.

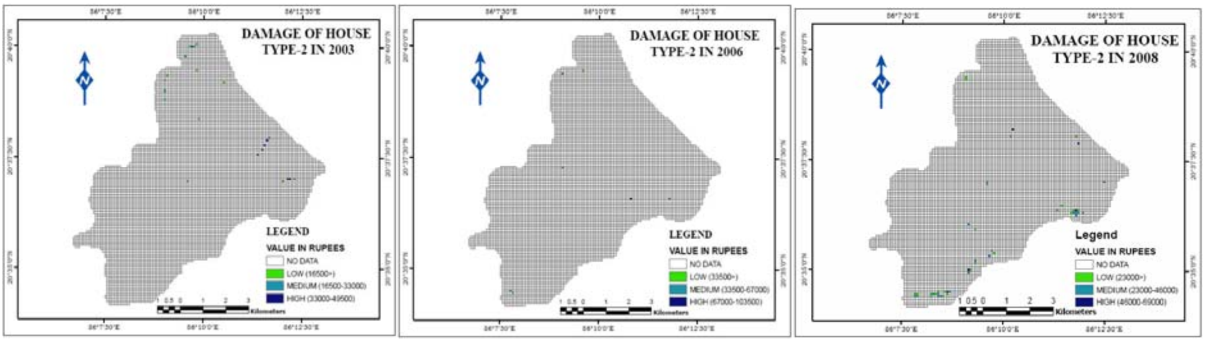


Figure 5.31: Spatial distribution of damage for house type-2 (2003, 2006 & 2008)

In 2003, damage was medium to less in the eastern, northern and north-eastern part with little highly affected areas. In 2006, the affected areas were mostly concentrated in the south which was high and medium affected areas. In 2008, flood affected areas were found in the eastern and south-eastern boundary of the study area which were mostly medium and less affected areas with few highly affected areas in the central part (Figure 5.31).

c. House type-3

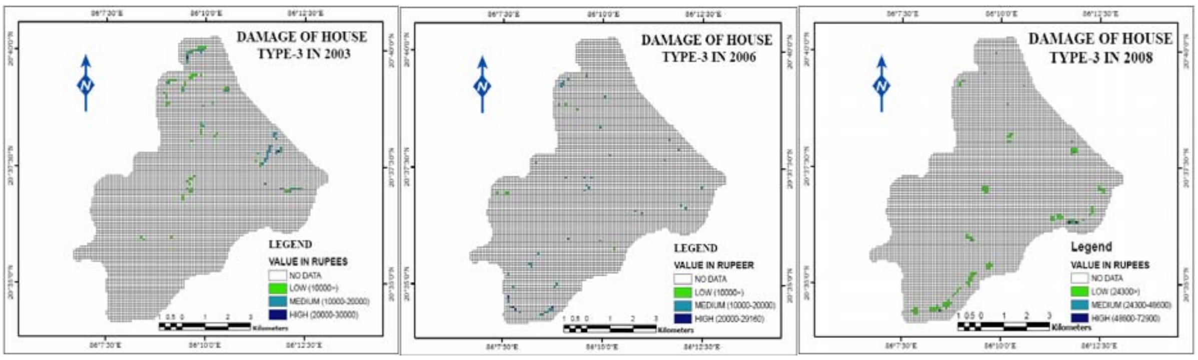


Figure 5.32: Spatial distribution of damage for house type-3 (2003, 2006 & 2008)

Damage of the house type-3 was Rs 1.33, Rs 0.76 and Rs 0.82 million in 2008, 2006 and 2003 flood events respectively. In 2008, damage was very high in case of houses. Number of type-3 houses was destroyed due to heavy flood. Damage of house type-3 was the maximum along with the minimum areal extent of flood. 139 houses were affected in 2008, 60 in 2006 and 108 in 2003.

In the type-3 houses, in 2003, low to medium affected houses are found in the north, central, eastern and the north-eastern part, highly affected houses are less in number found in the north and north-eastern part. In 2006, medium affected houses are scattered throughout the region with less affected areas in the western part and highly affected areas in the southern part. In 2008, less affected areas are dominant in the eastern and south-eastern boundary of the study area with very little highly affected area in the eastern part (Figure 5.32).

d. House type-4

Damage of the house type-4 was Rs 0.43, Rs 0.32 and Rs 0.40 million in 2008, 2006 and 2003 flood events respectively. In 2008, damage was very high in case of houses. Many type-4 houses were destroyed due to this event. Damage of house type-4 was the maximum along with the minimum areal extent of flood. 140 houses were affected in 2008, 72 in 2006 and 146 in 2003. Although, the areal extent was less in 2008, but more number of houses were affected due to more depth of flood. And so, this affects the houses extremely.

1n 2003, highly affected zones are found in the northern and the north-eastern part while less to medium affected parts were found in the western, central and the eastern part. In 2006, less affected houses were dominant in the region with very little medium and highly affected houses in the southern part. In 2008, less affected houses were dominant in the eastern boundary of the study area with very few highly affected houses in the southern part (Figure 5.33).

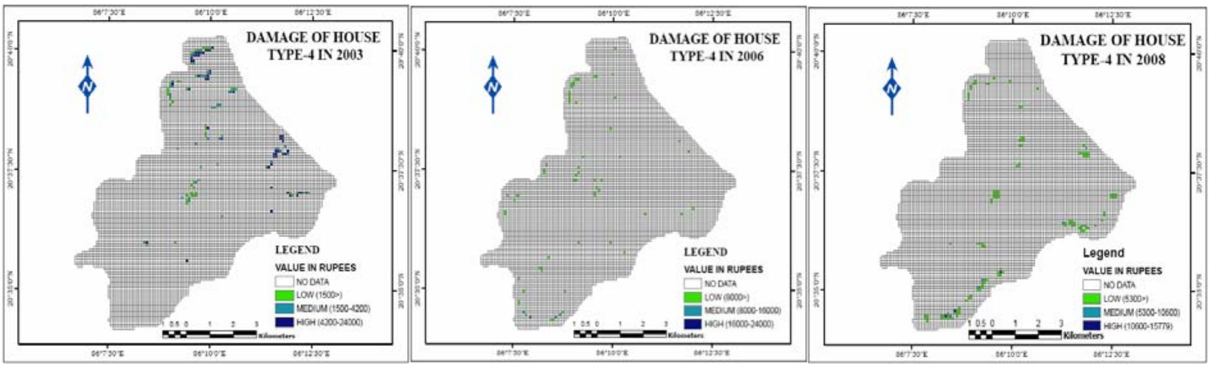


Figure 5.33: Spatial distribution of damage for house type-4 (2003, 2006 & 2008)

5.3.2 Damage of roads

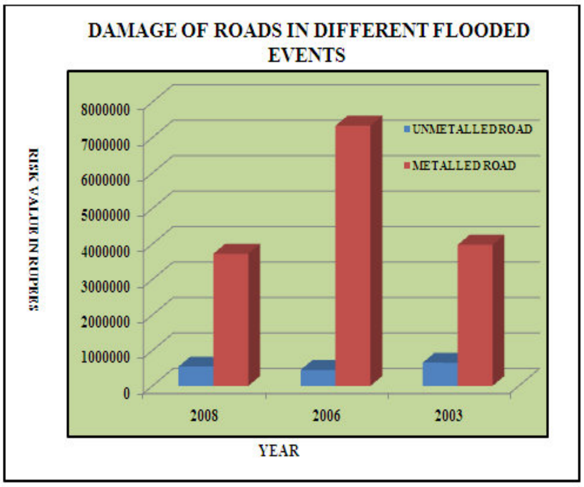
Two different categories of roads have been generated in terms of materials and damage in term of cost has been described as below (Figure 5.34). Recover cost of flood affected metalled road and unmetalled road are Rs. 0.30and Rs. 0.15 million per kilometer length when roads are fully damaged.

Table 5-6: Damage of roads (in rupees) due to floods

ROAD TYPE	DAMAGE OF ROAD IN RUPEES (2008)	DAMAGE OF ROAD IN RUPEES (2006)	DAMAGE OF ROAD IN RUPEES (2003)
UNMETALLED ROAD	547623	451443	656618
METALLED ROAD	3727884	7335260	3977940

Table 5-7: Damage of roads in length due to floods

ROAD TYPE	TOTAL LENTH OF ROAD IM METER	AFFECTED OF ROAD (LENGTH) IN METER (2008)	AFFECTED OF ROAD (LENGTH) IN METER (2006)	AFFECTED OF ROAD (LENGTH) IN METER (2003)
UNMETALLED ROAD	45875	6090	3615	5735
METALLED ROAD	87640	27235	19775	15915



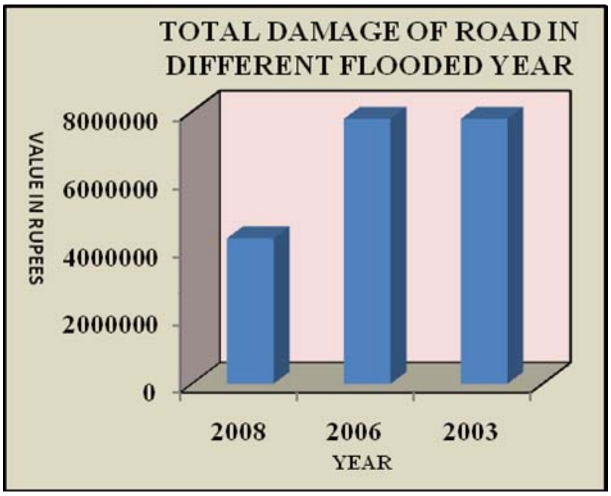


Figure 5.34: Damage of roads in different floods events

a. Unmetalled road

Damage of unmetalled road was Rs. 0.55, Rs. 0.45 and Rs. 0.66 million in 2008, 2006 and 2003 respectively. The affected length of road in 2003 was less than in 2008, but the cost of damage was the maximum in 2003, because in 2003, the depth of flood on the roads was higher than in 2008. Total affected road length in 2008 was 6.09 Km; in 2006 it was 3.61km and 5.73 km in 2003.

In 2003, less to medium affected categories was found in the western and central region while the highly affected areas were found in the eastern part. In 2006, highly affected category was found in the central and eastern region with less to medium affected roads in the southern and the western part. In 2008, highly affected roads were found in the southern and the central part with less affected in the southern and western part (Figure 5.35).

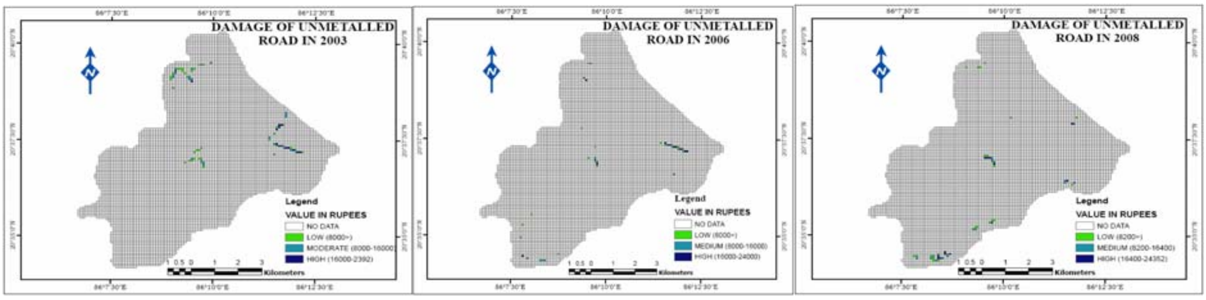


Figure 5.35: Spatial distribution of damage for unmetalled (2003, 2006 & 2008)

b. Metalled road

Damage of metalled road was Rs. 3.73, Rs. 7.34 and Rs. 3.98 million in 2008, 2006 and 2003 respectively. The affected length of road in 2006 was less than in 2008, but the cost of damage was the maximum in 2006, because in 2006, the depth of flood on the roads was higher than in 2008. Total affected road length in 2008 was 27.235 km; in 2006 it was 19.775 km and 15.915 km in 2003.

In 2003, three damage categories were spread in the western, north-western, northern, north-eastern, eastern middle and central region while the highly affected areas were dominated in the eastern and central part due to high flood depth. In 2006, highly affected category was found in the central and eastern region with less to medium affected roads in the southern, central, north-eastern and the western part, but all categories were found like disperse of entire study area. In 2008, highly affected roads were found in the central and north-eastern part with less affected in the southern, northern and eastern part (Figure 5.36).

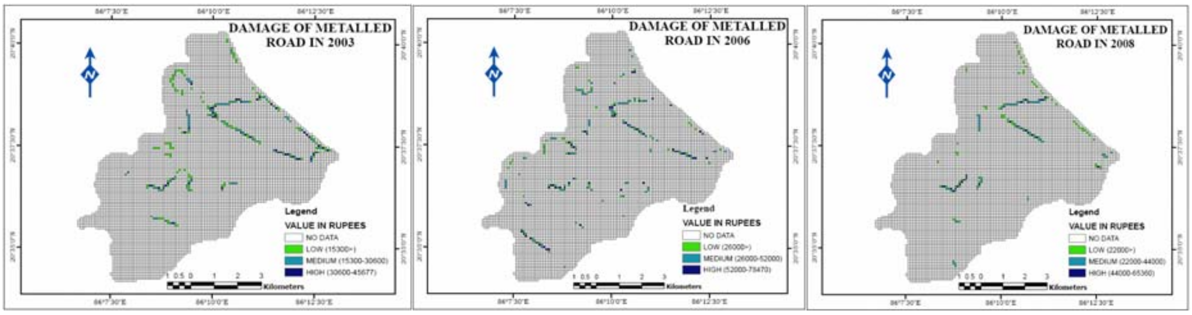


Figure 5.36: Spatial distribution of damage for metalled (2003, 2006 & 2008)

5.3.3 Damage of agriculture crops

Rice and jute are two types of agricultural crop have been assessed the damage due to flood in 2003, 2006 and 2008 which has been described as below. Value of flood affected rice crop is Rs. 0.0358 million per sq hectare meter when it was fully damaged.

A. Rice crop

Damage of rice crop was assessed on the basis of flood depth and duration in three different flood events. Damage has been assessed from short (less than 05 days), medium (05 to 15 days) and long (greater than 15 days) duration. These are discussed in below (Figure 5.37).

Table 5-8: Damage statistics of rice due to floods

FLOOD CATEGORY	DAMAGE OF RICE IN RUPEES (2008)	DAMAGE OF RICE IN RUPEES (2006)	DAMAGE OF RICE IN RUPEES (2003)
LONG DURATION	991624	22244664	4521875
MEDIUM DURATION	-	14693922	17566841
SHORT DURATION	19783545	6695036	8059820

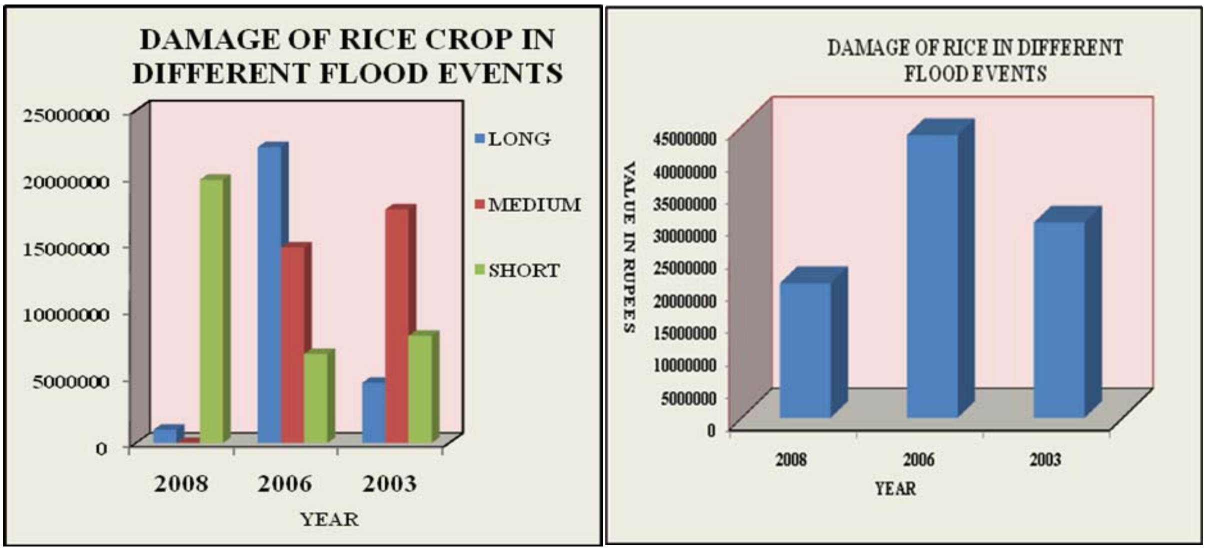


Figure 5.37: Damage of rice crop due to floods

a. Short duration

Damage of rice crop was Rs. 19.78, Rs. 6.68 and Rs. 6.32 million in 2008, 2006 and 2003 respectively from short duration (less than 05 days) due to flood. Total affected area of rice in 2008 was 14.50 sq km; in 2006 it was 08.06 sq km and 05.40 sq km in 2003. In 2008 was the maximum affected area and damage in respect to others floods, but high category was more dominated also.

In 2003, less category of damage was shown in central, eastern and south-western part of the study area, but high category of damage was found only south-western, eastern and central part. In 2006, Damage categories were distributed equally over whole study area, but high damage category was concerned in southern and northern part. In 2008, damage areas were found in central, northern and north-eastern part of the study area, but high category of damage was dominated whole damage area except boundary part (damage area) (Figure 5.38).

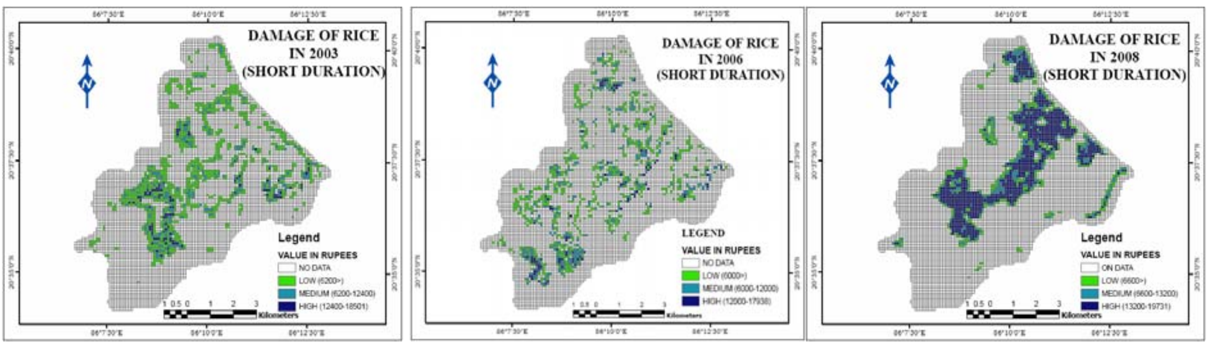


Figure 5.38: Spatial distribution of damage for rice of short duration (2003, 2006 & 2008)

b. Medium duration

Damage of rice crop was Rs. 14.68 and Rs. 17.58 million in 2006 and 2003 respectively from medium duration (05 to 15 days) due to flood. Damage of 2008 flood was not carried out the medium duration category of flood due to lack of data (RADARSAT image) during flooded period. Total affected area of rice in 2006 was 07.94 sq km and 07.74 sq km in 2003.

In 2003, less category of damage was shown at edge area and high category of damage was at centre of damage affected areas in medium duration which was shown in eastern, north-eastern and central part of the study area. In 2006, Damage categories were spread like scatter over whole study area, but high damage category was concerned in eastern and north-eastern part (Figure 5.39).

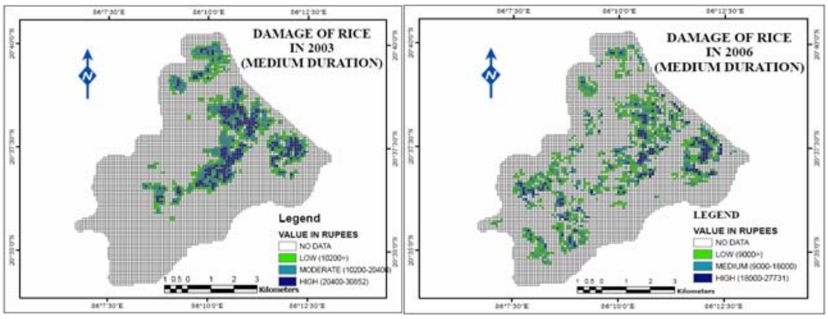


Figure 5.39: Spatial distribution of damage for rice of medium duration (2003, 2006 & 2008)

c. Long duration

Damage of rice crop was Rs. 0.99, Rs. 22.24 and Rs. 4.51 million in 2008, 2006 and 2003 respectively from long duration (greater than 15 days) due to flood. Total affected area of rice in 2008 was 00.34 sq km; in 2006 it was 09.09 sq km and 01.53 sq km in 2003. In 2006 was the maximum affected area and damage in respect to others floods, but high category was more dominated here.

In 2003, less category of damage was shown in central, eastern and north-eastern part of the study area, but high category of damage was found only eastern and northern part. In 2006, Damage categories were distributed in central, eastern, north-eastern and south-western part of the study area. High category of damage was at centre of damage affected areas in long duration. In 2008, damage areas were found in western and very less area in northern and eastern part of the study area, but high category of damage was dominated western part (Figure 5.40).

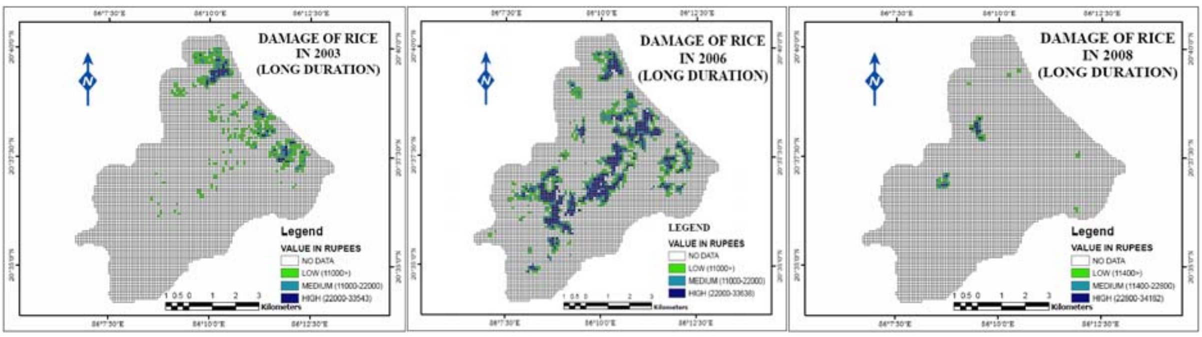


Figure 5.40: Spatial distribution of damage for rice of long duration (2003, 2006 & 2008)

B. Jute crop

Damage of jute crop was assessed on the basis of flood depth and duration in three different flood events like rice crop. Damage has been assessed from three different duration of flood. These are discussed in below. Value of flood affected rice crop is Rs. 0.052 million per sq hectare meter when it was fully damaged.

a. Short duration

Damage of jute crop was Rs. 0.59 and Rs. 0.00 91 million in 2008 and 2006 respectively from short duration (less than 5 days) due to flood. Total affected area of rice in 2008 was 00.39 sq km and in 2006 it was 00.33 sq km. In 2006, damage was more due to high flood depth in respect to 2008. Damage area was in eastern side in 2006 and 2008 flood events.

Damage was not occurred in medium and long duration of my study area in 2003, 2006 and 2008 flood events.

Comparative analysis of total damage in 2003, 2006 and 2008

Total damage has been calculated from sum of damages of each element at risk in a year due to flood for three different flood events (2003, 2006 and 2008) from vulnerability and cost. The total damage of elements at risk is 32.35, 53.31 and 39.75 million (rupees) in 2008, 2006 and 2003 floods. Low damage areas are concentrated in the boundary part of the flooded area, high damaged areas lie in the central part and medium category lies in between low and high of three different flood events. Sometimes, high damage zone is found in boundary part due to affected metalled road whose repair or construction cost is very high. Total risk is very high in 2006, due to maximum areal extent of flood in comparison to 2003 and 2008 flood events (Figure 5.41).

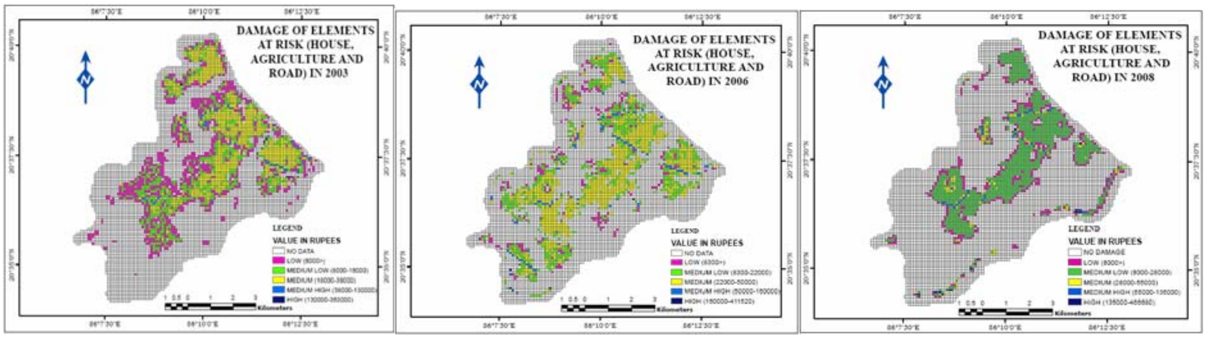


Figure 5.41: Comparative analysis of total damage in 2003, 2006 and 2008

5.3.4 Risk assessment of elements at risk

Risk is defined as expected degree of loss due to a particular natural phenomenon (Earth quake, flood, cyclone, forest fire, volcanic eruption etc). It is expressed by the product of hazard (H), Vulnerability (V) and Cost (C). When risk is assessed from a single natural phenomenon of particular elements at risk, it is called specific risk (Rs), but expected number of lives lost, persons injured damages to property or disruption of economic activity due to all natural events is called the total risk. It is the sum of the specific risks for all return period and all type of events (Westen. C. V).

$$Rs = H*V*C$$

$$SUM (Rs = H*V*C)$$

For risk assessment purpose, houses, agriculture and road are selected on the basis of 2003, 2006 and 2008 flood events.

a. Flood frequency analysis

Flood frequency analysis of a basin is a hydrologic process and it is difficult to assess analytically, because it depends on characteristics of basin, rainfall, antecedent condition, each one of these factors is depend on a host of constituent parameters (Subramanya, 2006).

There are four methods for estimating the flood magnitude of peak. These are mentioned below.

1. Rational method
2. Empirical method
3. Flood frequency analysis
4. Unit hydrograph method.

For a certain magnitude of food event, the time period it takes to re-occur after its preceding occurrence is called return period or frequency of that flood. The magnitude of a flood is inversely related with frequency. There are four methods for calculating the flood frequency analysis.

1. Method of plotting position.
2. Log normal distribution.
3. Log person type-111 distribution and
4. Gumbel’s extreme value distribution

Gumbel’s distribution is selected for present study for calculating the flood frequency analysis.

b. Gumbel’s extreme distribution method

This methods is introduced the distribution of extreme value by Gumbel (1941) and commonly known as Gumbel’s distribution. This method can be applied for prediction of flood pick, maximum rainfall, maximum wind speed etc. According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value x_0 is

$$P(X \geq x_0) = 1 - e^{-e^{-y}}$$

$$x_T = \bar{x} + K\sigma_{n-1}$$

Where σ_{n-1} = standard deviation of the sample of size N.

$$\sigma_{n-1} = \frac{\sum (x - \bar{x})^2}{N - 1}$$

K = Frequency factor is expressed as

$$K = \frac{y_T - \bar{y}_n}{S_n}$$

y_T = Reduced variate, a function of T and is given by

$$y_T = -\left[\ln.\ln\frac{T}{T-1}\right]$$

$$y_T = -\left[0.834 + 2.303 \log\log\frac{T}{T-1}\right]$$

$\bar{y}_n$ = Reduced mean, a function of sample size N and these are constant for a particular return period.

s_n = Reduced standard deviation, a function of sample size N and these are constant for a particular return period.

$\bar{y}_n$ And s_n values start from 10 years. But below 10 years, maximum height of water has been calculated for 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100 years return period. Then these values are plotted on Gumbel probability paper and drawn the 'XY' line. Probability of reoccurrence values has been calculated of 2003, 2006 and 2008 flood events from 'XY' curve on the basis of maximum water level (Figure 5.42).

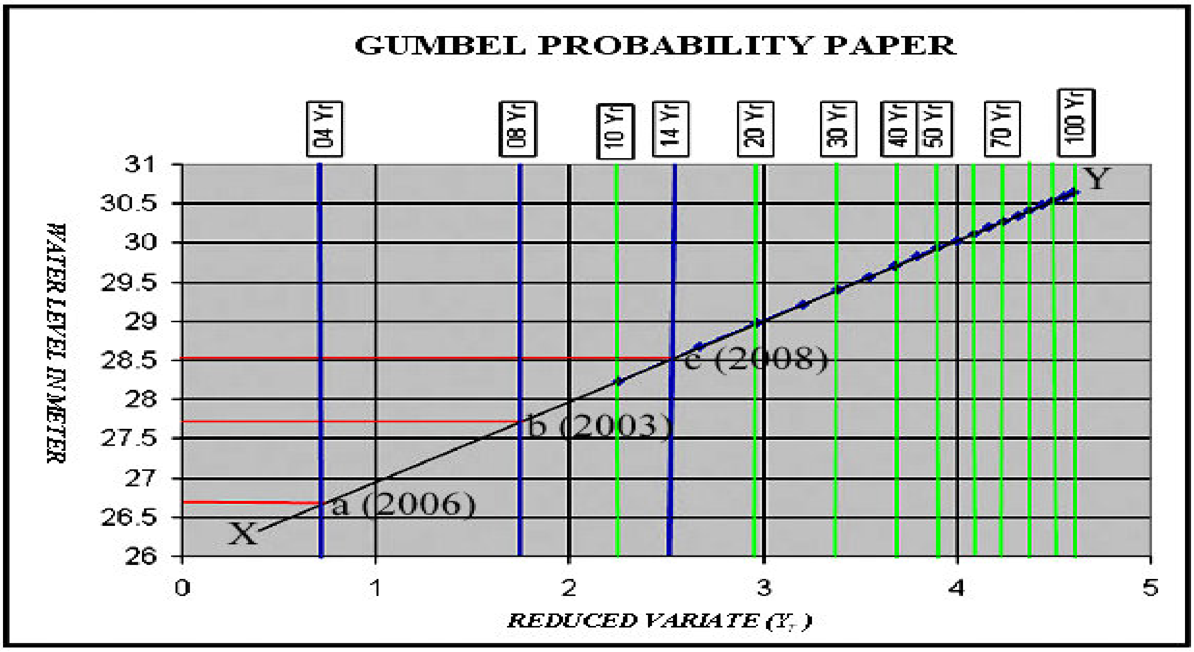


Figure 5.42: Probability curve of maximum water level

Flood frequency has been calculated from 45 years data of maximum flood level height by Gumbel distribution method of Naraj Gauging site at south-west part of my study area where the main source of water comes from. Plotting position method was applied for flood frequency analysis from maximum water level data (Sreyasi, 2007). Return period of 2008 flood event was 14.33 years (this magnitude of flood will come every 14.33 years with in one time). Similarly the return period for 2006 and 2003 are 3.21 and 7.79 years respectively. The probability of occurrence per year of 2008, 2006 and 2003 are 0.070, 0.311 and 0.128 respectively (Appendix-2).

c. Risk curve

Risk curve has been generated from probability of occurrence of floods and damages in three different flood events (2003, 2006 and 2008). Probability of occurrence in 2008 flood was 0.070 per year, in 2006, 0.311 per year and in 2003, 0.128 per year and damage was Rs 32.34, Rs 54.07 and Rs 35.66 in rupees. Probability of occurrence has been calculated on the basis of maximum water level on Naraj gauging site by Gumbel distribution method from 45 years data. As per result, probability of occurrence due to floods was more frequent (Figure 5.43).

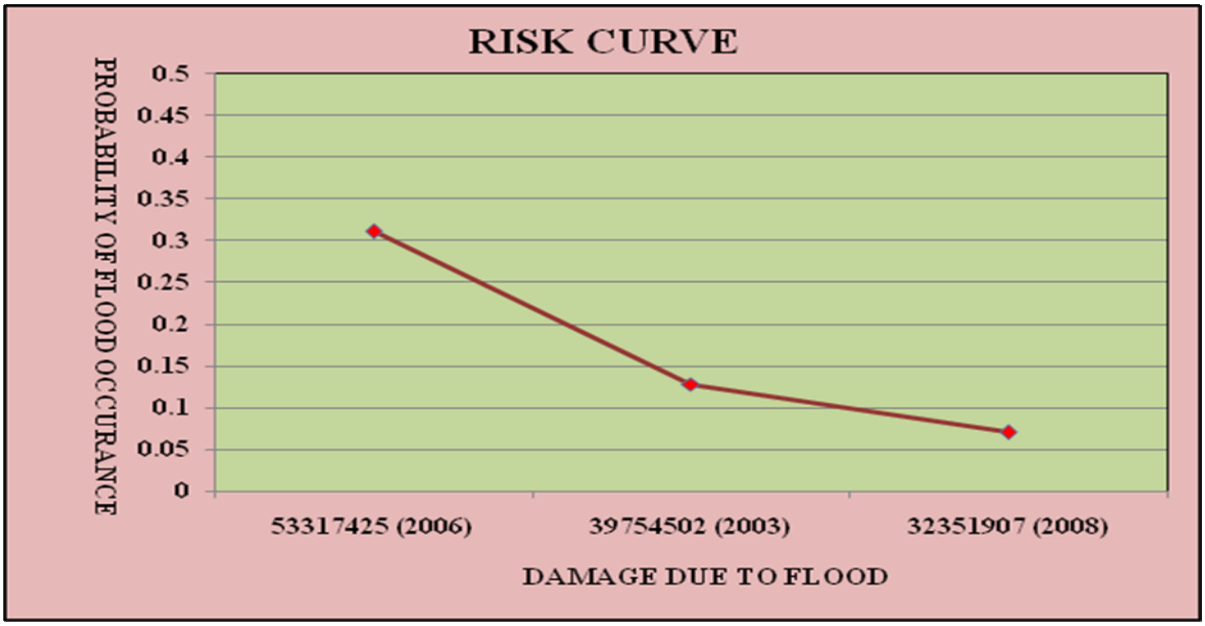


Figure 5.43: Risk curve of three different flood events

5.3.5 Risk of house types

The risk of four different categories of houses has been assessed from vulnerability, cost and probability of flood occurrence in rupees from three different flood events (2003, 2006 and 2008). These have been discussed below (Figure 5.44).

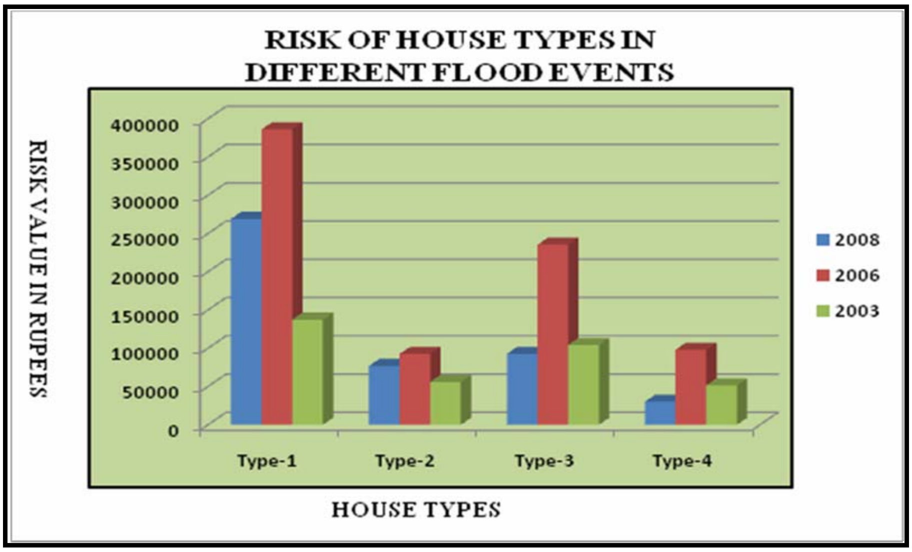


Figure 5.44: Risk of houses in different flood events

Table 5-9: Risk statistics of house types (2003, 2006 & 2008)

TYPE OF HOUSES	TOTAL HOUSES	RISK VALUE IN RUPEES (2008)	RISK VALUE IN RUPEES (2006)	RISK VALUE IN RUPEES (2003)
Type-1	566	269212	386138	137472
Type-2	585	76937	92554	55949
Type-3	1455	92763	235480	104357
Type-4	1628	30236	98090	51538

a. House type-1

Risk of the house type-1 was Rs. 0.27, Rs. 0.39 and Rs. 0.14 million in 2008, 2006 and 2003 flood events respectively. But areal extent of flood was the maximum on 04^{th} Sep in 2006 due to high rainfall intensity. Risk was the maximum of house type-1 in 2006 because the probability of 2006 flood occurrence was 0.311 per year. In 2008, areal extent of flood was the minimum and damage was the maximum among three flood events, but risk was second highest due to probability of occurrence is 0.070. The area has been categorized into low, medium and high by equal interval of risk value in rupees. In 2003 the lowest category was less than 10600 while in 2006 it was less than 27600 and in 2008 it was less than 8680. Therefore the risk was much higher in 2006 and lowest in 2008 as the total loss of money was greater in 2006. The highest category of loss in 2003 was 21200 to 31744, in 2006 it was between 55200 to 82851 and in 2008 it was between 17360 to 26040. So it has been found that the risk was the minimum in 2008 as the loss was less and the risk was the maximum in 2006 with the highest loss of money. So it can be said that the risk was maximum in 2006.

In the type-1 houses in 2003, it is observed that affected houses are situated mostly in the eastern and northern part; medium and high risk zones are found in the eastern part with scattered areas of low risk zone I both in the of east and north parts. In 2006, maximum concentration of risk factor is found in the southern part with high and medium risk zone and a single risk zone in the east and a medium risk zone in the north-west. In 2008, the concentration of low and medium risk zone is found in the south and south-eastern part and a high risk zone in the north-eastern part (Figure 5.45).

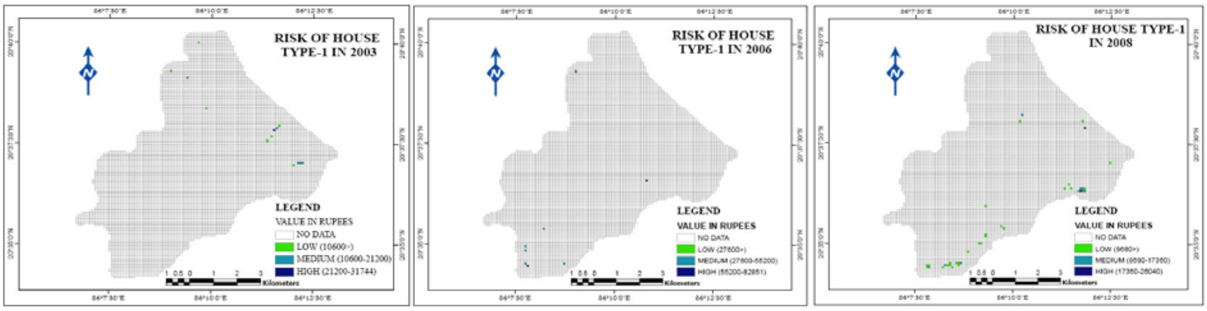


Figure 5.45: Spatial distribution of risk for house type-1 (2003, 2006 & 2008)

b. House type-2

Risk of the house type-2 was Rs. 0.077, Rs. 0.093 and Rs. 0.056 million in 2008, 2006 and 2003 flood events respectively. The highest risk was found in 2006 flood due to probability of occurrence. In 2003 the lowest category was less than 2100 while in 2006 it was less than 10700 and in 2008 less than 1610. Therefore the risk was much higher in 2006 and very low in 2008 as the total loss of money was greater in 2006. The highest category of loss in 2003 was 4200 to 6336, in 2006 it was 21400 to 32189 and in 2008 it was 3220 to 4830. From this study it has been found that the risk was the mini-

mum in 2008 as the loss was less and the risk was the maximum in 2006 with the highest loss of money and 2003 has the medium loss.

In the type-2 houses in 2003, it is observed that affected houses are situated mostly in the eastern and northern part; medium and high risk zones are found in the eastern part and northern part with few low risk zones in the west and north-east. In 2006, maximum concentration of risk factor is found in the southern part with high and medium risk zone and a single risk zone in the east and a medium risk zone in the north-west. In 2008, the concentration of low risk zone is found in the south and south-eastern part and scattered areas of high and medium risk zone in the central and north-eastern part (Figure 5.46).

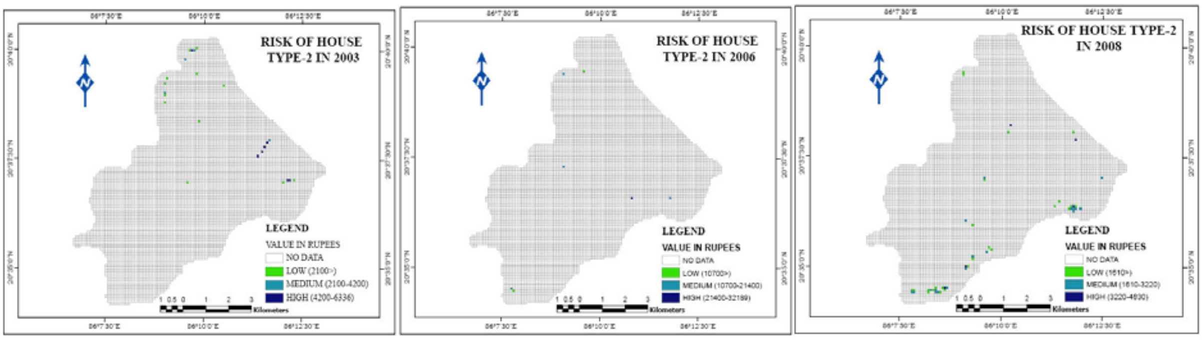


Figure 5.46: Spatial distribution of risk for house type-2 (2003, 2006 & 2008)

c. House type-3

Risk of the house type-3 was Rs. 0.093, Rs. 0.24 and Rs. 0.104 million in 2008, 2006 and 2003 flood events respectively. In 2003 the lowest category was less than 1250 while in 2006 it was less than 3020 and in 2008 it was less than 1700, therefore the risk was highest in 2006 and lowest in 2003. The highest category of loss in 2003 was 2500 to 3733, in 2006 it was 6040 to 9069 and in 2008 it was 3400 to 5103. From these it is found that the risk was the minimum in 2003 in this particular house type unlike the other cases while it is equally high in case of 2006.

In the type-3 houses in 2003, it is observed that affected houses are situated mostly in the north-eastern and northern part; medium and high risk zones are found in the eastern part and northern part with many low risk zones in the north-west, central and east. In 2006, medium and high risk zones are found scattered throughout the region and few low risk zones are found in the north-western, south-western and central part. In 2008, the concentration of low risk zone is found in the south and eastern boundary and very few areas of high risk zones in the eastern part (Figure 5.47).

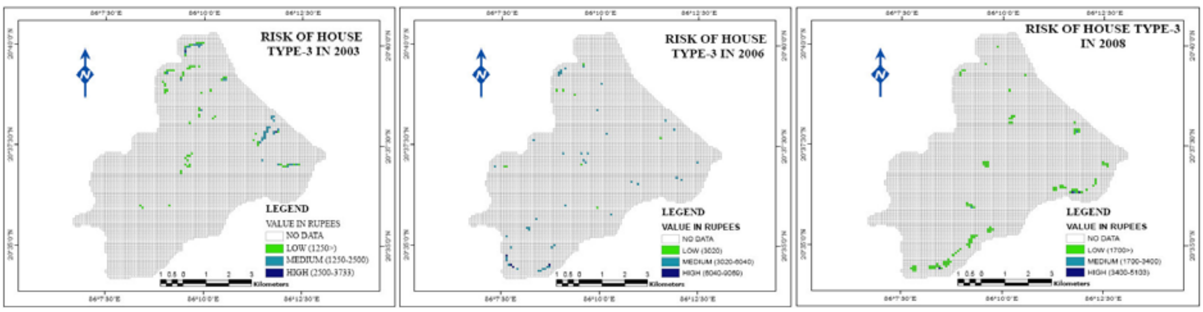


Figure 5.47: Spatial distribution of risk for house type-3 (2003, 2006 & 2008)

d. House type-4

Risk of the house type-4 was Rs. 0.03, Rs. 0.098 and Rs. 0.052 in 2008, 2006 and 2003 flood events respectively. In 2003 the lowest category was less than 1025 while in 2006 it was less than 2500 and in 2008 it was less than 370. Therefore the risk was highest in 2006 and lowest in 2008. The highest category of loss in 2003 was 2050 to 3072, in 2006 it was 5000 to 7465 and in 2008 it was 740 to 1105. From these it is found that the risk was the minimum in 2008 and minimum in 2006.

In the type-4 houses in 2003, it is observed that affected houses are situated in the north-eastern and northern part mostly; low risk zones are dominant in all areas with a high risk zone in the north-eastern part. In 2006, low risk zones are maximum in the entire area with very few high and medium zones in the southern part. In 2008, low risk zone is found scattered in the area with few high risk zone in the southern part (Figure 5.48).

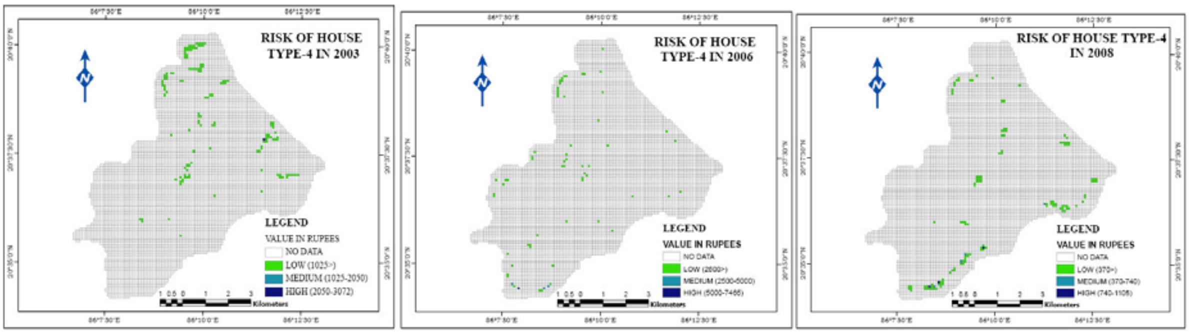


Figure 5.48: Spatial distribution of risk for house type-4 (2003, 2006 & 2008)

5.3.6 Risk of road types

Metalled and unmetalled road have been assessed the risk from vulnerability, cost and probability of flood occurrence in rupees from three different flood events (2003, 2006 and 2008). This is discussed below (Figure 5.49).

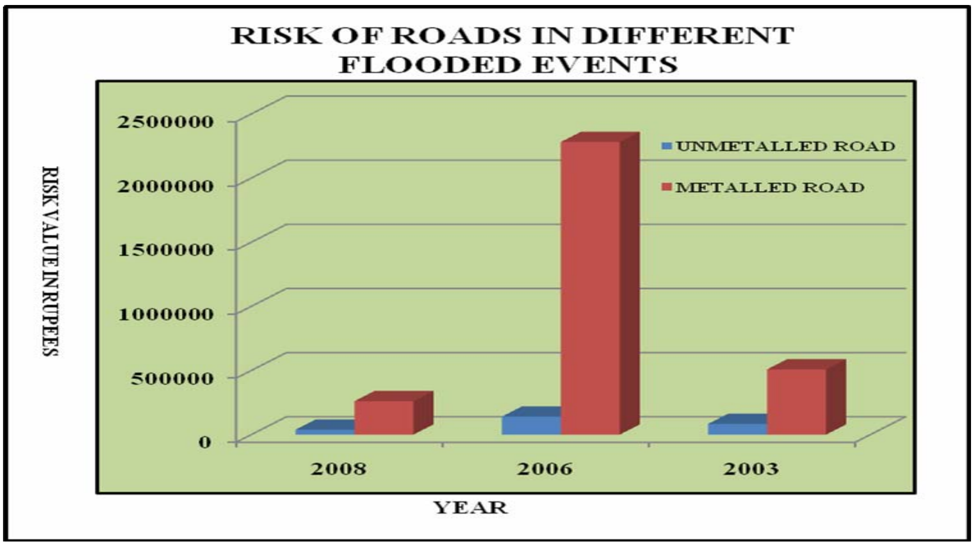


Figure 5.49: Risk of roads in different flood events

Table 5-10: Risk of roads in different flood events

ROAD TYPE	RISK OF ROAD IN RUPEES (2008)	RISK OF ROAD IN RUPEES (2006)	RISK OF ROAD IN RUPEES (2003)
UNMETALLED ROAD	38334	140399	84074
METALLED ROAD	260952	2281266	509176

a. Metalled road

Risk of metalled road was Rs 0.26, Rs 2.28 and Rs 0.51 million in 2008, 2006 and 2003 flood events respectively. In 2008 the lowest category was less than 1525 while in 2006 it was less than 8140 and in 2003 it was less than 1950. Therefore the risk was highest in 2006 and lowest in 2008. The highest category of loss in 2008 was 3050 to 4575, in 2006 it was 16280 to 24405 and in 2003 it was 3900 to 5847.

In the metalled road in 2003, it is observed that affected houses are situated mostly in the central, western, north-eastern and northern part; low risk zones are dominant in all areas with a high risk zone in the north-eastern and eastern part. In 2006, low risk zones are the maximum in the entire area with high and medium zones. In 2008, high risk zone are found over north-eastern and central part with medium and low zone (Figure 5.50).

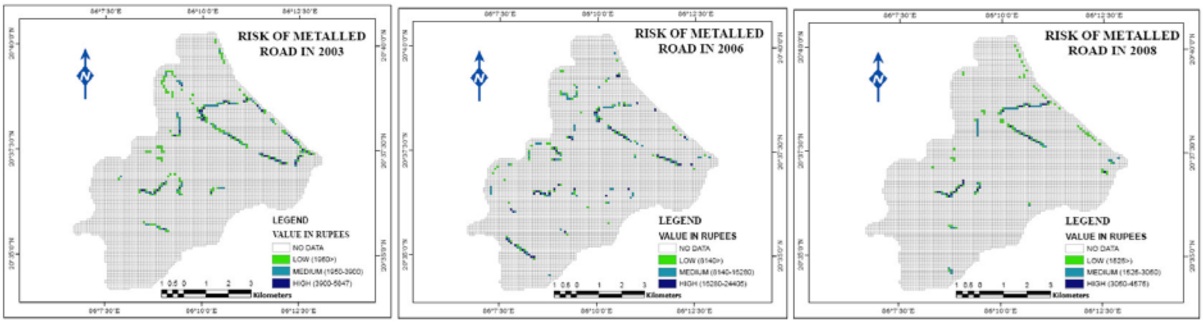


Figure 5.50: Spatial distribution of risk for metalled (2003, 2006 & 2008)

b. Unmetalled road

Risk of unmetalled road was Rs. 0.038, Rs 0.14 and Rs. 0.084 million in 2008, 2006 and 2003 flood events respectively. In 2008 the lowest category was less than 570 while in 2006 it was less than 2475 and in 2003 it was less than 1020, therefore the risk was highest in 2006 and lowest in 2008. The highest category of loss in 2008 was 1140 to 1705; in 2006 it was greater than 4950 to 7431 and in 2003 it was 2040 to 3060.

In the metalled road in 2003, it is observed that affected houses are situated mostly in the central, eastern and northern part; high risk zones are dominant in eastern part of the study area. In 2006, high risk zones are the maximum in the eastern and central with low and medium zones. In 2008, high risk zone is found over northern, south and central part with medium and low zone (Figure 5.51).

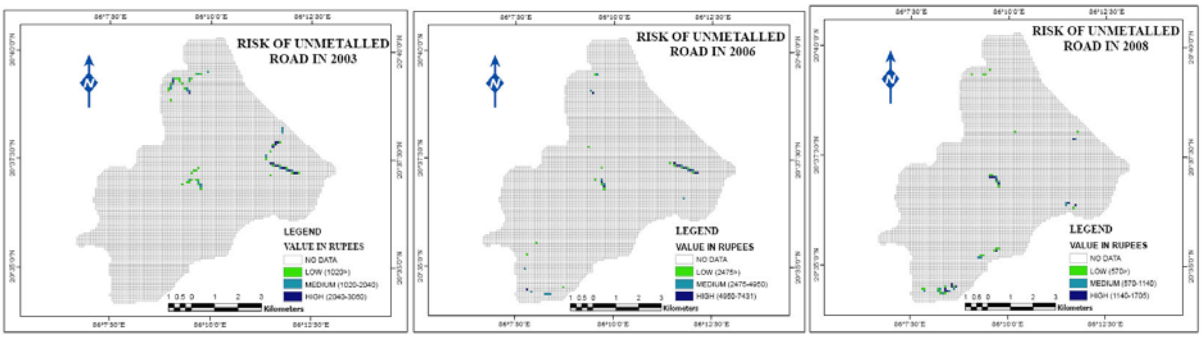


Figure 5.51: Spatial distribution of risk for unmetalled road (2003, 2006 & 2008)

5.3.7 Risk of agricultural crops

The risk of rice and jute crops has been assessed from vulnerability, cost and probability of flood occurrence in rupees due to three different flood events (2003, 2006 and 2008). This is discussed below.

a. **Rice crop**

Risk of rice crop has been assessed on the basis of flood depth and duration and duration of the floods are categorized into short, medium and long.

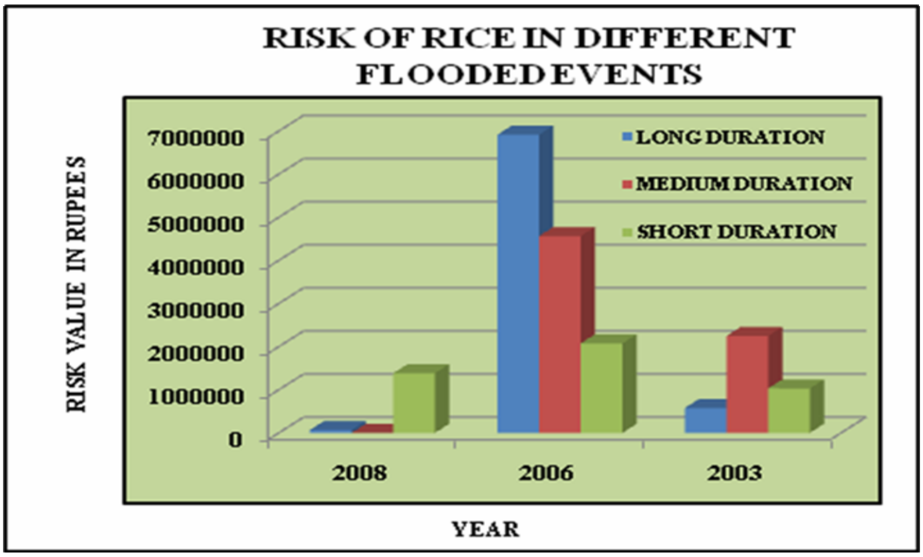


Figure 5.52: Risk of rice in different flood events

Table 5-11: Risk of rice in different flood events

FLOOD CATEGORY	RISK VALUE FOR RICE IN RUPEES (2008)	RISK VALUE FOR RICE IN RUPEES (2006)	RISK VALUE FOR RICE IN RUPEES (2003)
LONG DURATION	69414	6916997	578799
MEDIUM DURATION	-	4566567	2248556
SHORT DURATION	1384848	2078006	1031657

Short duration

Risk of rice due to short duration was Rs. 1.38, Rs. 2.08 and Rs. 1.03 million in 2008, 2006 and 2003 flood events respectively (Figure 5.52). In 2008 the lowest category was less than 460 while in 2006 it was less than1860; it was less than 805 in 2003, therefore the risk was highest in 2006 and lowest in 2006. The highest category of loss in 2008 was between 960 and 1382. In 2006 it had a range between 3720 to 5579 which is greater than 2008 and 2003 as well when the range is 1610 to 2416.

In 2003, it is observed that affected agricultural areas are situated in the central, eastern, north-western and northern part mostly; high risk zones are dominant in northern and southern part of the study area. In 2006, high risk zones are the maximum in the eastern and central while medium and low categories are distributed in entire area. In 2008, high risk zone is found northern, north-eastern and central with medium and low zone (Figure 5.53).

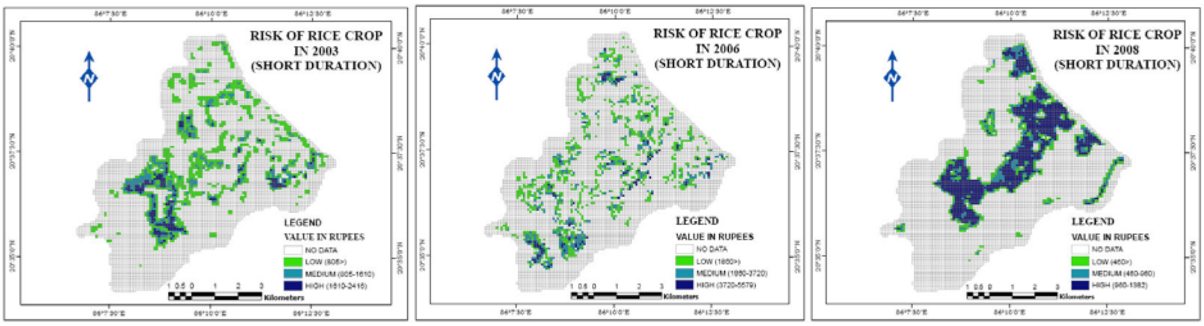


Figure 5.53: Spatial distribution of risk for rice of short duration (2003, 2006 & 2008)

Medium duration

Risk of rice due to medium duration was Rs. 4.57 and Rs. 2.25 million in 2006 and 2003 flood events respectively (Figure 5.2). In 2006 the lowest category was less than 2875 while in 2003 it was less than 1316; therefore the risk was highest in 2006. The highest category of loss in 2006 was 5750 to 8625 and in 2006.

In 2003, it is observed that affected agricultural areas are situated in the central, eastern, and north-eastern part mostly; high risk zones are dominant in north-eastern, eastern and central part of the study area. In 2006, high risk zones are found in eastern part with less area in comparison to other categories distributed over entire area (Figure 5.54).

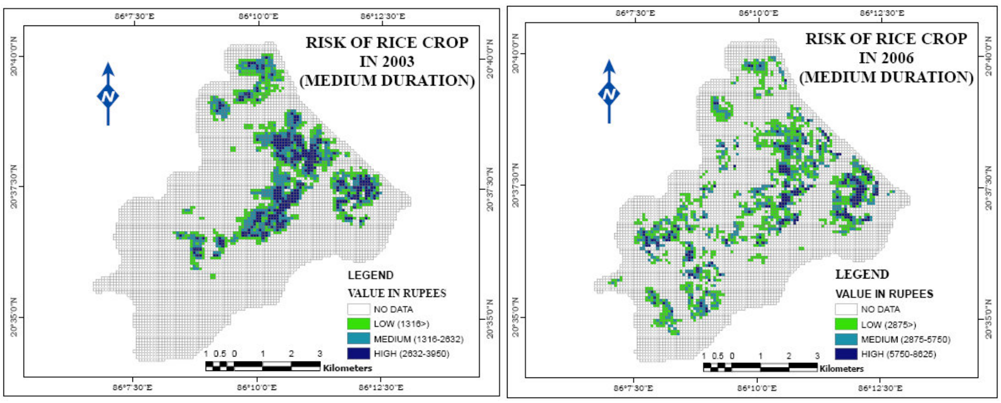


Figure 5.54: Spatial distribution of risk for rice of medium duration (2003, 2006 & 2008)

Long duration

Risk of rice due to long duration was Rs. 0.069, Rs. 6.92 and Rs. 0.58 million in 2008, 2006 and 2003 flood events respectively. In 2008 the lowest category was less than 800 while in 2006 it was less than 3500 and in 2003 it was less than 1430, therefore the risk was highest in 2006 and lowest in 2008. The highest category of loss in 2008 was 1600 to 2393, in 2006 it was greater than 7000 to 10462 in 2003 it was 2860 to 4294 (Figure 5.52).

In 2003, it is observed that affected agricultural areas are situated in the central, eastern, and northern part mostly; high risk zones are dominant in northern part of the study area. In 2006, high risk zones are the maximum in the eastern, north-eastern, western and central while medium and low categories are distributed over entire area. In 2008, high risk zone is found north-western and western with medium and low zone with very less area (Figure 5.55).

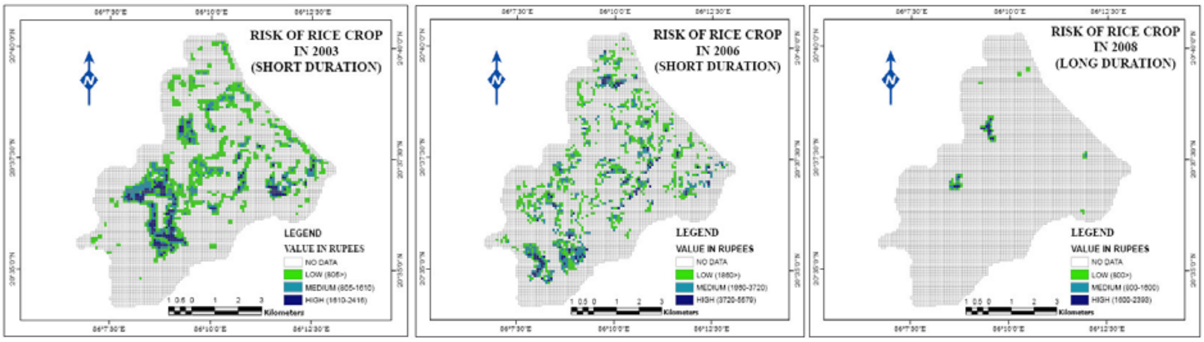


Figure 5.55: Spatial distribution of risk for rice of long duration (2003, 2006 & 2008)

a. **Jute crop**

Risk of jute crop has been assessed on the basis of flood depth and duration as rice crop of the floods are categorized into short, medium and long, but risk areas are affected by 2006 and 2008 flood events during short duration. Risk value of jute is Rs. 0.041 and Rs. 0.0028 in 2008 and 2006 at short duration period. In 2008, high risk zones are found in western part of my study area with medium and high category. In 2006, very less area is affected in eastern pert (Figure 5.56).

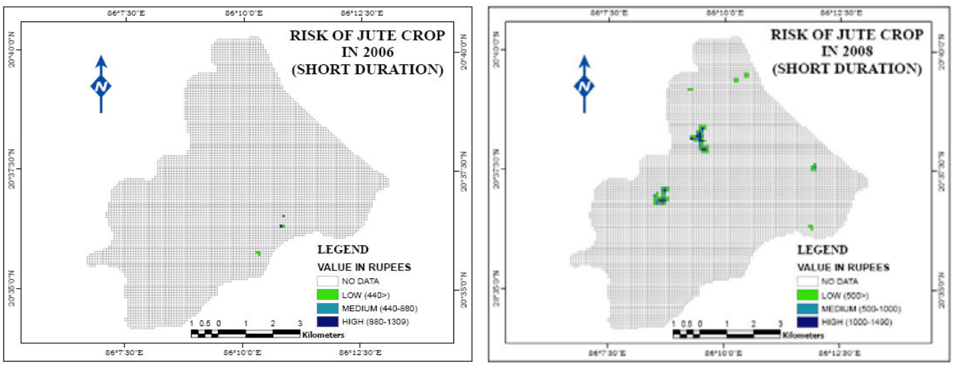


Figure 5.56: Spatial distribution of risk for jute of short duration (2003, 2006 & 2008)

Comparative analysis of total risk in 2003, 2006 and 2008 flood events

Total risk has been calculated from sum of risk of each element at risk in a year due to flood for three different flood events (2003, 2006 and 2008). The total risk of elements at risk is Rs. 2.26, Rs. 16.80

and Rs. 4.80 million (rupees) in 2008, 2006 and 2003 floods. It was perceived that high risk was calculated even though water level in river was low. Possible explanation of this was found during the field survey major sources of water were river and canal system. The source of canal is itself the Birupa river. At times of high flood river water divided into the canal which means excess water of the river is being distributed through canals. This explains the condition when river water is at low level while excess water of the same river is being canalized into the area through canals. This further explains the condition when risk can be high even through the water level in river is low. Low risk areas are concentrated in the boundary part of the flooded area, high areas are the central part and medium category lies between low and high of three different flood events. Sometimes high risk zone is found in boundary part due to affected of metalled road which repair or construction cost is very high. Total risk is very high in 2006 and 2008, due to depth and duration are high in respect to 2003 flood event (Figure 5.57).

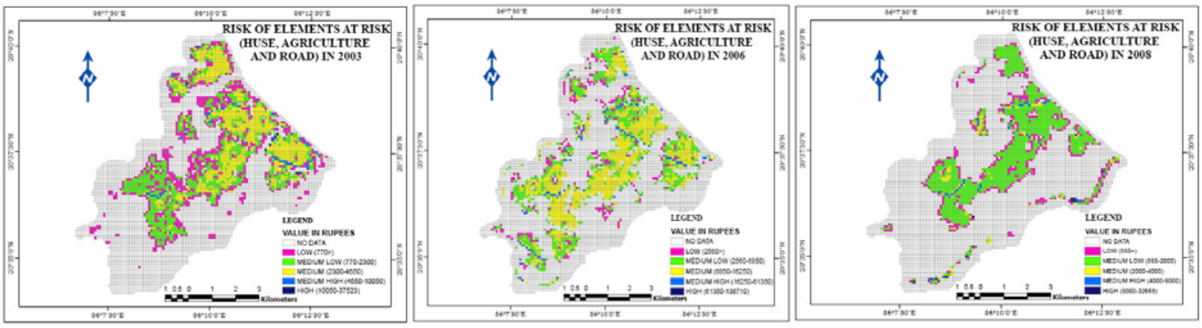


Figure 5.57: Comparative analysis of total risk in 2003, 2006 and 2008 flood event

6. Conclusion

Flood risk assessment on meso scale, based on the floods of 2001, 2003 and 2006 in Birupa river basin was the main objective of present research using remote sensing and GIS techniques. Sub-objectives and related research questions was selected on the basis of main objective which have been discussed below.

First specific objective **“derive nature of floods (Extent, depth, duration and frequency)”** and its related research question is ***a) “How to assess the flood properties of the 2003, 2006 and 2008 floods at meso scale? b) On what basis and with what accuracy can the flood depth be recorded for the three flood events (2003, 2006 & 2008) on meso scale?”***

To obtained this specific objective, flood extent map (includes flooded and permanent water bodies) has been generated from RADARSAT images during flooded period by threshold method for three different flood events, river and other permanent water bodies were extracted from Cartosat-1 and Google image by visual interpretation for evacuating the actual flooded area from to the flooded area (includes flooded and permanent water bodies). Flood depth was calculated from Cartosat-1 DEM (Digital Elevation Model with 5m. accuracy) and maximum flood level information. It is applied on the maximum areal extent among the different areal extent of different dates of a single flood event for example 04 September in 2003 from 11, 13 and 20 September, 2003. Cartosat-1 DEM shows that the ground height from mean sea level for each point (5m*5m), but it is to be subtracted from Maximum flood level value for generating the flood depth map (5m*5m). Flood duration maps have been generating from flood extent maps of different dates during a single flood event temporal RADARSAT images like 04, 11, 13 and 20 September in 2003 (during flooded period). Flooded areas have been classified into short (less than 05 days), medium (05 to 15 days) and long (greater than 15 days) duration and derive the area of each category from flooded areas which have been generated from temporal RADARSAT images in a flooded year during flooded period. These are broadly discussed in chapter number 4 (methods, materials, data requirements and data availability).

Second specific objective “**Define Land use map/ Elements at risk map (aggregated data)**” and its related research question is “***What information is to be extracted from the Quick bird image of 14/05/2004 (source: Google) in order to prepare the land use map***?” To obtain this specific objective, landuse maps or elements at risk map have been prepared by visual interpretation method from Quickbird image which is available from Google site. Earth objects have different reflectance characteristic in satellite imagery. Size, shape, tone, shadow, pattern, texture, site and resolution are the basic characteristics by which each object is extracted from satellite imagery like agricultural land can be identified on the basis of shape, Tune, texture etc (Lillesand & Kiefer, 1999). Settlements, agricultures and roads (elements at risk) have been extracted by visual interpretation method and verified with field and put in a 100m*100m grid. Finally, how much area has been occupied in each 100m*100m pixel was calculated using cross operation in Arc GIS 9.1. House, agriculture and road can be located and identified in a 100m*100m grid.

Third specific objective “**Derive vulnerability maps on basis of flood depth and flood duration of the three flood events (2003, 2006 and 2008)”** and its related research question is “***How to adapt and incorporate the vulnerability curves of the research of Dhillon. R.K. 2008 in to the meso scale flood risk assessment?***” To obtain this specific objective, Vulnerability curves of houses and road have been

derived on the basis of flood depth and agricultural crop on the basis of flood depth and flood duration. For houses, damage status of three different flood events was collected from field and it is related with construction material of houses. Finally, each type of house as it behaved in different depth of flood on basis of which vulnerability curves have been generated for houses. For roads, same method has been applied for generating the vulnerability curves. For agricultural crops, damage status changes with respect to flood depth in a duration of three different flood events which has been collected from field was used for preparation of vulnerability curves for rice and jute in different duration of flood. One pixel has a single average value of flood depth after link with pixels (100m*100m) by 'zonal' statistics' operation in Arc GIS 9.1. Flood depth values have been replaced by corresponding vulnerability value of elements at risk. A curve forms by small straight lines and same concept applied here. A curve has been split up in to small straight line and has followed the straight line equation. In this way flood depth value has been replaced by vulnerability value of three different elements at risk in a pixel (100m* 100m).

Forth specific objective "**Determination of value of assets of the elements at risk (aggregated data).**" and its related research question is "***What are the methods to be used in order to assess the value of element at risk on meso scale?***" To obtain the specific objective, value of elements at risk is decided on the basis of primary and secondary data which was collected from field and government offices and other authorized organization. For houses, values were collected from their construction cost of four categories of house from local peoples at field and also consulting with Thshil office Mahanga district in Orissa. Average values of house type-1, house type-2, house type-3 and house type-4 are 400000, 75000, 18000 and 5000 in rupees. For Roads, values are collected from Transport Corporation in Orrisa. Construction value of metalled and unmetalled roads is 300000 and 150000 in rupees per a kilometer length (3m width) respectively. For agricultural crop, Production cost of rice and jute are collected from agricultural office in Orrisa on the basis of last 10 years production and its cost. In a pixel (100m*100m), how much elements at risk are situated that have been carried out and added to the all values after transforming their (elements at risk) corresponding values. Finally we get a value at a pixel base that indicates the total elements cost within that pixel.

Fifth specific objective "**Damage calculation of the 2003, 2006 and 2008 floods.**" and it related research question is "***How accurately can the damage be assessed from three flood events (2003, 2006 & 2008)?***" To obtain the specific objective, Damage of elements at risk has been calculated from vulnerability value which was generated on the basis of flood depth and duration and their construction cost for three different flood events. For houses, one pixel (100m*100) which is affected due to flood has a vulnerability value on basis of flood depth for a single event, Construction values of the house and number of house. Damage value has been calculated from vulnerability, number of house and construction cost by multiplication. For roads, one pixel (100m*100m) has a vulnerability value, construction cost per unit length and length of road occupy in that pixel. Damage of roads is calculated from vulnerability value, construction cost per unit length and length of road occupy in that pixel by multiplication. Flood affected on agricultural crop has a vulnerability value, affected area and production cost per unit area within a pixel (100m*100m). Total damage of elements at risk has been calculated from sum of individual damage of element at risk which occupy in a pixel.

Sixth specific objective **"Determine the risk curve"** To obtain the specific objective, Risk curve has been derived from probability of flood occurrence and damage in 2003, 2006 and 2008 flood events. Damage of elements at risk has been classified on basis of vulnerability of elements at risk and cost which are necessary for coping. Construction cost of elements at risk has been collected from Govt.

and other authorized organizations. Information of related damage and vulnerability has been collected from extensive field survey. This information is all about the effected elements at risk due to floods with 100*100m pixel base. Flood depth and flood duration have been derived from Cartosat-1 DEM and temporal RADARSAT images during flooded period. This DEM was verified with some field points where elevation from mean sea level was already marked by Govt authority. The maximum error in this case is 1m. Finally, it can be assumed that the assessment of damage due to flood is accurate on meso scale. This portion has been broadly discussed in chapter number 5. Finally the risk curve is derived from damage of elements at risk and corresponding probability of reoccurrence of floods (more discuss in chapter 5.3.4).

6.1 Contribution of this research

This research makes some contribution which is discussed below.

1. This methodology can be used of any current flood event for assessing the risk using aggregated data of elements at risk at meso scale level.
2. Vulnerability and damage assessment procedure can be applied on any other flood event.
3. This methodology also can be used for risk trend due to flood from comparative assessment of elements at risk at meso scale level.
4. Depth and duration procedure can be used in any flood event using temporal RADARSAT imagery and DEM

6.2 Research limitation

This research has been completed despite of the presence of some limitation.

1. RADARSAT image is not available at peak flood session.
2. Temporal RADARSAT images are not available in equal duration during flooded period.
3. Accuracy of Cartosat-1 DEM is 5m.
4. Information about research was dependent on answer which has been collected from people.

6.3 Title Paragraph Recommendation of Orissa Disaster Management Authority

Some recommendation has been discussed below which are carried out in the present research.

1. At more vulnerable zone, people should not select for constructing new houses.
2. Dykes have to be strong for protecting the flood where the source of the flood is.
3. Jute cultivation may be increased as it is less vulnerable crop in respect to other crop.

6.4 Recommendation for further research

Recommendation for further research has been given below.

1. Flood depth, inundated area, water discharge data and flood extent from RADARSAT images can helps for flood inundation model like 1D model and 2D model.
2. Flood depth, damage information, risk information of three different flood events (2003, 2006 and 2008) can be used as an input of risk prediction model.
3. Other parameter can included for assessing the vulnerability assessment of elements at risk like flood velocity.
4. This result of the present work can be used for cope management in flood prone areas can input for coping mechanism in relation to flood, capacity in dealing with flood and policy research on flood risk management.

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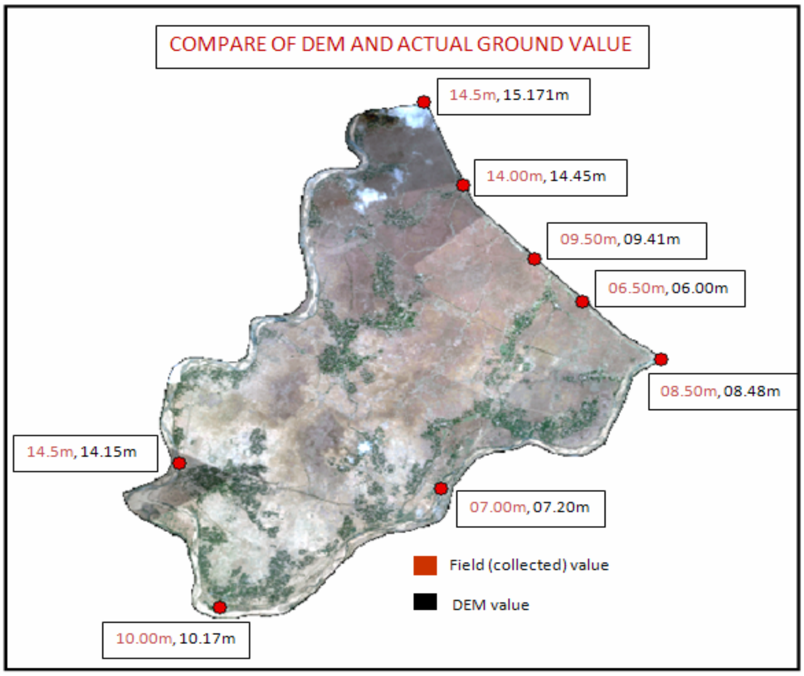
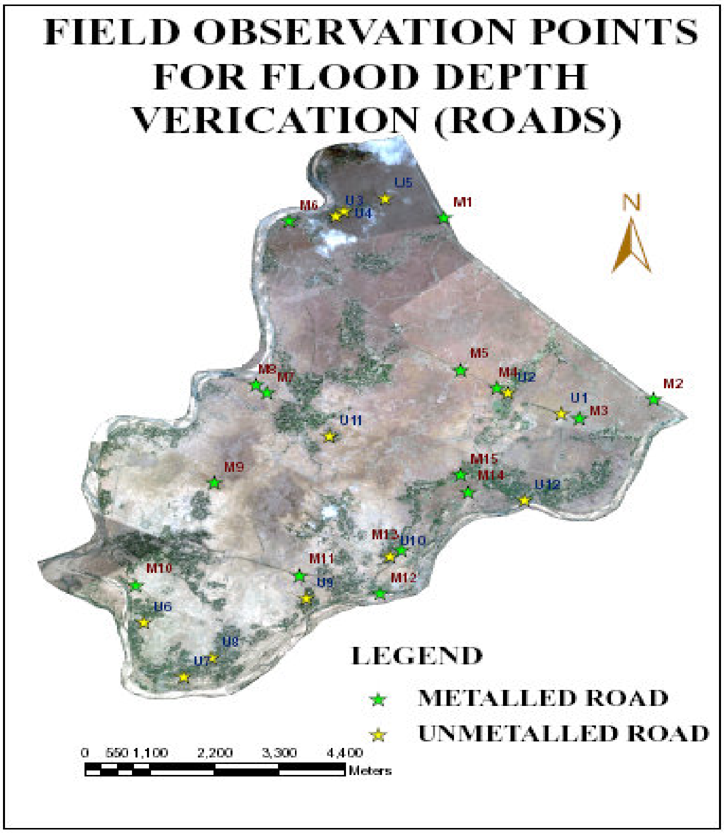
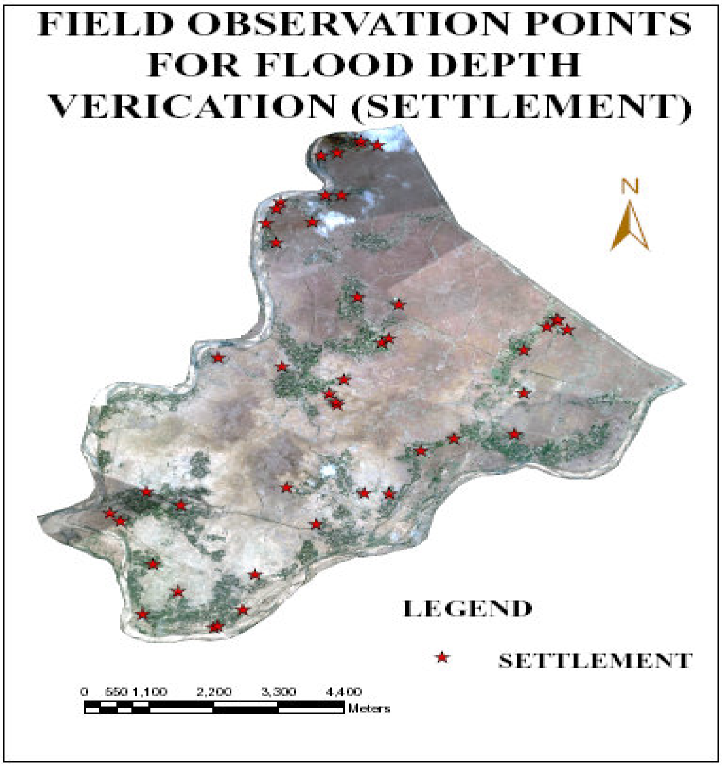
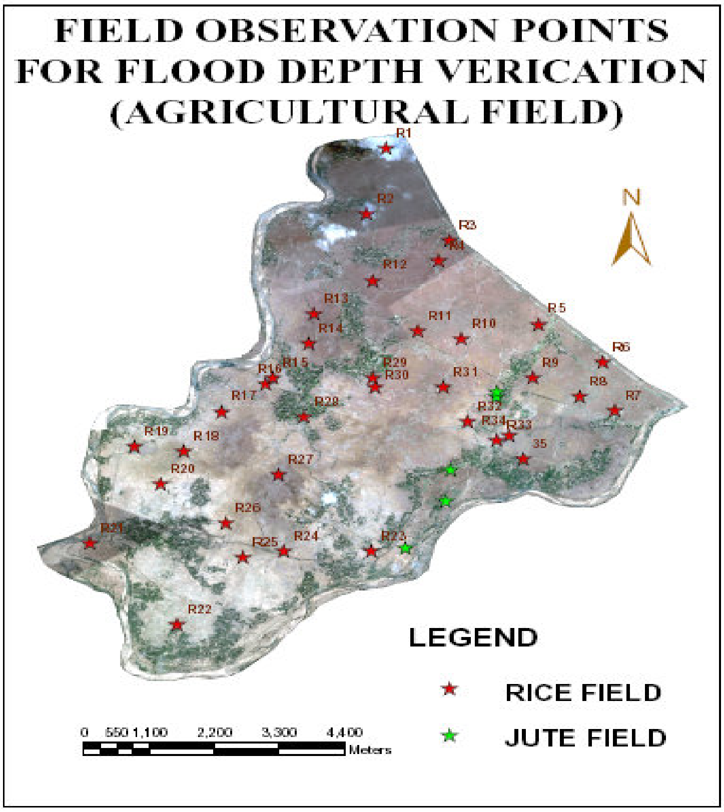
Appendix:

Appendix-1






FIELD OBSERVATION POINTS FOR FLOOD DEPTH VERICATION (SETTLEMENT)
N
LEGEND
SETTLEMENT
0 550 1,100 2,200 3,300 4,400
Meters


FIELD OBSERVATION POINTS FOR FLOOD DEPTH VERICATION (AGRICULTURAL FIELD)
N
LEGEND
RICE FIELD
JUTE FIELD
0 550 1,100 2,200 3,300 4,400
Meters

Appendix-2

Date	Flood (m) Guage		
31.08.1982	28.52	16.08.1968	26.15
20.07.2001	27.21	10.08.1971	26.37
30.08.2003	27.74	06.09.1990	26.19
22.09.1980	27.8	15.09.1972	26.09
21.08.1992	27.37	08.07.1964	29.41
14.08.1991	27.13	28.08.1970	26.49
06.09.1994	27.22	11.08.1999	25.64
29.08.1978	26.96	10.08.1979	25.66
01.08.1969	27.02	11.08.1981	25.66
25.07.1995	26.72	14.09.2002	25.46
14.09.1977	26.73	31.07.1966	28.74
15.08.1976	26.73	23.08.1996	24.88
28.09.1973	26.87	24.07.1987	24.52
22.07.1986	26.63	09.08.1988	24.35
07.08.1985	26.62	31.07.1965	27.13
09.09.1983	26.61	19.08.1989	23.8
06.08.1997	26.52	28.07.2000	23.45
17.08.1984	26.45	12.08.2004	25.93
24.08.1975	26.46	31.07.2005	26.14
28.08.1993	25.99	31.08.2006	26.7
13.09.1998	26.26	24.09.2007	25.85
07.08.1967	27.08	20.09.2008	28.53
19.08.1974	26.37		

Source: Bakimchandra. O, 2006 (Reconstruction of the 2003 daya river flood, using multi-resolution and multi-temporal satellite imagery).

Appendix-3

ID_NO	Type-1	Type-2	Type-3	Type-4	Flood depth in 2003 (Field)	Flood depth in 2003 (Cal-culated)	Flood depth in 2006 (Field)	Flood depth in 2006 (Calcu-lated)
3762	3	3	5	2				
5264	1	1	5	5				
1216	3	3	5	1				
1373	2	3	1	5				
4686	3	1	2	5				
1321	2	2	5	2				
3951	3	2	5	1				
3858	3	1	1	5				
2137	2	2	5	1				
4227	3	1	5	1				
1984	2	2	5	1				
4040	3	3	3	1				
4044	3	1	5	1				
1884	1	1	2	5				
4765	1	1	2	5				
1520	1	1	2	5	0	0	0	0
5815	2	1	1	5				
5865	1	1	2	5				

5529	3	1	2	3				
1801	1	1	5	2				
5418	1	1	5	2				
1376	2	2	3	2				
3952	1	2	5	1				
1113	2	1	5	1				
4136	2	1	5	1				
4041	1	2	5	1				
3568	2	1	5	1				
1881	0	2	1	5				
5948	1	1	1	5				
5421	1	1	1	5				
4436	1	0	2	5				
1518	0	1	2	5				
1692	2	0	1	5				
273	0	1	2	5				
5891	1	1	1	5				
2344	0	1	2	5				
3098	0	1	2	5				
4350	0	1	2	5				
2620	0	0	5	3				
2736	3	2	1	2				
3924	3	2	1	2				
3923	3	1	2	2				
3737	3	2	1	2				
5784	3	1	2	2				
4975	0	1	5	2				
4038	3	2	1	2				
5314	0	1	5	2				
3936	1	1	5	1				
5263	1	1	5	1				
5315	1	1	5	1				
1873	2	3	2	1				
1877	3	3	1	1				
1733	3	3	1	1				
4135	3	3	1	1				
1956	3	2	2	1				
4811	3	3	1	1				
4045	3	2	2	1				
5871	1	1	5	1				
5975	1	1	5	1				
2891	3	3	1	1				
5898	1	1	5	1				
2297	0	0	2	5				
3950	0	0	2	5				
4939	0	0	2	5				
4766	0	0	2	5				
5543	1	0	1	5				
4349	0	1	1	5				
5870	1	1	2	3				
5753	0	0	5	2				
5670	0	0	5	2				
1663	0	2	3	2				
3946	3	1	2	1				
3925	3	2	1	1				
3935	3	1	2	1				
4970	3	2	1	1				
2809	2	3	1	1				
3738	2	3	1	1	0	0	2.5	2.55

1164	2	2	2	1				
3831	0	1	5	1				
3828	0	1	5	1				
1806	2	3	1	1				
1883	3	2	1	1				
4138	3	1	2	1				
4386	3	2	1	1				
4259	3	2	1	1				
4748	3	2	1	1				
4046	3	2	1	1				
4128	3	2	1	1				
4709	0	1	5	1				
4074	2	3	1	1				
1637	3	2	1	1				
4687	3	2	1	1				
2986	2	3	1	1				
5939	3	1	2	1				
5952	2	1	3	1				
5914	3	2	1	1				
5919	3	1	2	1				
5922	0	1	5	1				
5918	1	1	5	0				
5966	0	0	1	5				
5755	0	0	1	5				
4039	0	0	1	5				
2906	0	0	1	5				
2905	0	0	1	5				
4110	0	0	1	5				
4109	0	0	1	5				
302	0	0	1	5	1.0	0.55	0	0
5843	0	0	1	5				
5006	0	0	1	5				
4669	0	0	1	5				
5889	0	0	1	5				
5769	0	0	1	5				
5067	0	0	1	5				
3001	0	0	1	5				
5363	0	0	1	5				
4830	0	0	1	5				
5349	0	0	1	5				
4833	0	0	1	5				
1664	0	2	1	3				
5923	1	2	1	2				
5912	1	1	2	2	0	0	4	3.68
1319	2	1	1	2				
1165	0	1	3	2				
1114	1	2	1	2				
1590	1	2	1	2				
1832	1	2	1	2				
5569	1	0	3	2				
62	1	1	2	2				
1958	2	1	1	2				
5318	2	1	1	2				
3922	3	1	1	1				
1436	3	1	1	1				
1268	2	2	1	1				
3949	0	0	5	1				
1275	2	2	1	1				
3760	3	1	1	1				

5197	3	1	1	1				
1016	2	2	1	1				
1017	2	2	1	1				
5317	1	3	1	1				
1215	0	0	5	1				
3841	3	1	1	1				
1872	2	2	1	1				
4133	3	1	1	1				
1761	1	2	2	1				
4137	3	1	1	1				
4230	0	0	5	1				
1909	1	2	2	1				
1519	2	1	2	1				
4747	3	1	1	1	0	0	0	0
4749	3	1	1	1				
4810	2	1	2	1				
1492	2	1	2	1				
4043	2	2	1	1				
5872	1	1	3	1				
80	1	3	1	1				
3547	2	1	2	1				
5951	2	1	2	1				
3570	3	1	1	1				
5370	2	2	1	1				
5371	3	1	1	1				
2890	2	2	1	1				
5926	2	1	2	1				
3665	3	1	1	1				
5465	2	1	2	1				
5720	2	2	1	1				
706	2	2	1	1				
5485	1	0	4	1				
3664	2	1	2	1				
5913	2	2	1	1				
3569	3	2	1	0				
4746	0	0	0	5				
4581	0	0	0	5				
5864	0	0	2	3				
3844	0	1	1	3				
1065	1	1	1	2				
1428	2	0	1	2				
1800	0	1	2	2				
4031	0	1	2	2				
1908	2	0	1	2				
3133	0	1	2	2				
2870	0	2	1	2				
4874	2	1	1	1				
1375	1	2	1	1				
3939	1	2	1	1				
3953	1	1	2	1				
2541	1	2	1	1				
4971	1	2	1	1				
4966	2	1	1	1				
3763	2	1	1	1				
5313	1	1	2	1				
1115	1	2	1	1				
5074	2	1	1	1				
5040	1	1	2	1				
3842	2	1	1	1				

3839	2	1	1	1				
3859	1	1	2	1				
4202	1	2	1	1				
4553	2	1	1	1				
1878	1	2	1	1				
4132	1	1	2	1				
4134	2	1	1	1				
4139	2	1	1	1				
2023	2	1	1	1				
2060	1	2	1	1				
2136	3	1	0	1				
4472	2	1	1	1				
1955	1	1	2	1				
4229	2	1	1	1				
4732	2	1	1	1				
4127	2	1	1	1				
1720	1	1	2	1				
4622	2	1	1	1				
4626	1	1	2	1				
4716	2	1	1	1				
5530	2	1	1	1				
5970	2	1	1	1				
5968	1	2	1	1				
5967	1	1	2	1				
5499	1	2	1	1				
3652	2	1	1	1	0.5	0	0	0
3548	1	1	2	1				
3643	2	1	1	1				
3546	2	1	1	1				
5662	1	2	1	1				
5947	2	1	1	1				
3099	1	1	2	1				
5965	2	1	1	1				
5953	1	1	2	1				
5636	2	1	1	1				
5807	2	1	1	1				
5414	2	1	1	1				
5759	1	1	2	1				
272	1	2	1	1				
5814	1	2	1	1				
5367	2	1	1	1				
5789	2	1	1	1				
5927	1	2	1	1				
3666	2	1	1	1				
5470	1	1	2	1				
707	1	2	1	1				
5928	2	1	1	1				
3662	2	1	1	1				
5721	2	1	1	1				
5738	2	1	1	1				
5925	1	2	1	1				
4228	2	1	2	0				
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5924	0	0	1	3				
5369	0	0	1	3				
5899	0	0	1	3				
3948	0	0	1	3				
5770	0	0	2	2				
5921	0	0	2	2				

2738	0	0	2	2				
4373	0	0	2	2				
4167	0	1	1	2				
1833	1	0	1	2				
4540	0	1	1	2				
5542	0	1	1	2				
627	0	1	1	2				
2085	0	1	1	2				
4706	0	1	1	2				
4608	0	1	1	2				
2916	0	1	1	2				
1947	0	1	1	2				
4800	0	0	2	2				
2572	0	2	1	1				
4898	0	0	3	1				
4875	1	1	1	1				
3942	1	1	1	1				
3940	1	1	1	1				
2574	0	2	1	1				
4020	1	1	1	1				
4838	0	1	2	1				
1429	1	0	2	1				
4972	0	2	1	1				
4965	1	1	1	1				
5260	1	1	1	1				
5261	1	1	1	1				
2776	1	1	1	1				
3761	1	1	1	1				
5265	1	1	1	1				
5198	1	1	1	1				
2770	0	2	1	1				
5202	1	1	1	1				
3742	1	1	1	1				
2816	1	1	1	1				
5316	1	1	1	1				
5066	1	1	1	1				
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2634	1	1	1	1				
5071	1	1	1	1				
5041	1	1	1	1				
1064	1	1	1	1				
3856	0	1	2	1				
5131	0	2	1	1				
4542	2	0	1	1				
4191	1	1	1	1				
1834	1	1	1	1				
4204	0	0	3	1				
1807	1	1	1	1				
2296	1	1	1	1				
1868	1	1	1	1				
1794	1	1	1	1				
1874	1	1	1	1				
1759	1	1	1	1				
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2033	1	1	1	1				
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4226	1	1	1	1				
4435	1	1	1	1				
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2008	0	2	1	1				
1957	1	1	1	1				
4742	1	1	1	1				
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1464	1	1	1	1				
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1485	1	1	1	1				
4798	1	1	1	1				
4799	1	0	2	1				
4612	1	1	1	1				
4111	1	0	2	1				
4627	1	1	1	1				
1575	1	1	1	1				
4677	1	1	1	1				
1633	1	1	1	1				
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5528	2	0	1	1				
664	1	1	1	1				
5971	1	1	1	1				
5969	1	1	1	1				
5687	1	1	1	1				
2992	1	1	1	1				
648	1	1	1	1				
2984	0	1	2	1				
2987	1	1	1	1				
5929	1	0	2	1				
5513	1	1	1	1				
5895	1	0	2	1				
3452	1	1	1	1				
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3451	1	1	1	1				
5940	1	1	1	1				
5663	1	1	1	1				
5949	1	1	1	1				
5944	1	1	1	1				
3081	1	1	1	1				
5886	1	1	1	1				
5938	1	1	1	1				
3100	0	2	1	1				
5964	1	1	1	1				
5557	1	1	1	1				
5637	1	1	1	1				
3064	1	2	0	1				
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2892	1	1	1	1				
5783	1	0	2	1				
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5722	1	1	1	1				
5785	1	1	1	1				
5739	1	1	1	1				
5897	1	1	1	1				
61	1	1	1	1				
4190	2	1	1	0				
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5671	2	1	1	0				
5686	1	1	2	0				
5800	2	1	1	0				
4387	3	0	1	0				
4826	2	1	1	0				
4967	2	1	1	0				
1810	0	0	1	2	0	0	0.5	0
1066	0	0	1	2				
1576	0	0	1	2				
5920	0	0	1	2				
5916	0	0	1	2				
5466	0	0	1	2				
5950	0	0	1	2				
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5954	0	0	1	2				
4541	0	0	1	2				
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4032	0	0	1	2				
5845	0	0	1	2				
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5000	0	0	1	2				
1632	0	0	1	2				
3454	0	0	1	2				
5558	0	0	1	2				
2991	0	0	1	2				
4679	0	0	1	2				
628	0	0	1	2				
5786	0	0	1	2				
1267	0	0	1	2				
5777	0	0	1	2	0	0	0	0
4610	0	0	1	2				
2087	0	0	1	2				
5512	0	0	1	2				
5890	0	1	0	2				
4703	0	0	1	2				
4607	0	0	1	2				
4895	0	0	1	2				
4768	0	0	1	2				
2808	0	0	1	2				
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5319	0	0	1	2				
4220	0	0	1	2				
5977	0	0	1	2				
5235	0	0	1	2				
2215	0	0	1	2				
4260	0	0	1	2				
5422	0	0	1	2				
1882	0	0	1	2				
2575	0	1	1	1				
4832	1	0	1	1				
1408	0	1	1	1				
4976	0	0	2	1				
4999	0	1	1	1				
1374	0	1	1	1				
4016	0	0	2	1				
3941	0	0	2	1				

4864	0	1	1	1				
3943	0	1	1	1				
5005	0	1	1	1				
4896	1	0	1	1				
4841	0	1	1	1				
2539	0	1	1	1				
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1431	1	0	1	1				
2535	0	1	1	1				
1274	0	1	1	1				
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5258	0	1	1	1				
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2810	0	1	1	1				
3741	1	0	1	1				
5343	1	0	1	1				
3745	1	0	1	1				
2813	0	1	1	1				
5203	1	0	1	1				
3748	1	0	1	1				
2819	0	1	1	1				
2637	0	1	1	1				
2641	0	1	1	1				
5038	0	1	1	1				
5039	0	1	1	1				
3830	1	0	1	1				
3840	1	0	1	1				
2720	0	1	1	1				
5174	1	0	1	1				
2674	1	0	1	1				
3855	0	1	1	1				
2675	0	1	1	1				
3857	1	1	0	1				
5135	0	1	1	1				
5136	1	0	1	1				
3851	0	0	2	1				
3850	0	1	1	1				
4537	0	1	1	1				
1831	0	0	2	1				
4193	0	1	1	1				
1809	0	1	1	1				
1879	0	1	1	1				
1880	0	1	1	1				
2261	0	1	1	1				
4602	1	0	1	1				
1732	0	0	2	1				
1734	0	1	1	1				
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2010	0	1	1	1	0	0	0	0
4284	1	1	0	1				
2025	0	1	1	1				
2103	0	1	1	1				
2058	1	0	1	1				

2102	0	1	1	1				
1945	1	0	1	1				
2216	0	1	1	1				
1954	0	1	1	1				
1949	0	1	1	1				
1907	1	0	1	1				
4473	1	0	1	1				
1982	0	1	1	1				
1959	0	1	1	1				
2435	0	1	1	1				
2442	1	0	1	1				
2441	0	1	1	1				
1549	1	0	1	1				
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2475	1	1	0	1				
4829	0	1	1	1				
2474	0	1	1	1				
4030	0	1	1	1				
1488	0	1	1	1				
1487	0	1	1	1				
4042	0	1	1	1				
2381	0	0	2	1				
4646	0	1	1	1				
1697	0	0	2	1				
4641	0	1	1	1				
4710	0	1	1	1				
4711	1	0	1	1				
4708	1	0	1	1				
4714	1	0	1	1				
1603	0	0	2	1				
1577	0	1	1	1				
1591	0	1	1	1				
1589	0	1	1	1				
4715	0	1	1	1				
4676	0	0	2	1				
4700	0	0	2	1				
4684	0	0	2	1				
5348	0	1	1	1				
665	0	1	1	1				
668	0	1	1	1				
3552	1	0	1	1				
663	1	0	1	1				
2989	0	1	1	1				
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5033	0	0	0	1				
5034	0	0	0	1				
5028	0	0	0	1				
1213	0	0	0	1				
5035	0	0	0	1				
5045	0	0	0	1				
3825	0	0	0	1				
3754	0	0	0	1				
2716	0	0	0	1				
5140	0	0	0	1				
3853	0	0	0	1				
5129	0	0	0	1	3	2.35	0	0
3849	0	0	0	1				
3854	0	0	0	1				
4205	0	0	0	1				
1811	0	0	0	1				
1886	0	0	0	1				
2258	0	0	0	1				
1870	0	0	0	1				
1867	0	0	0	1				
4606	0	0	0	1				
2346	0	0	0	1				
1729	0	0	0	1				
1735	0	0	0	1				
1798	0	0	0	1				
1796	0	0	0	1				
4153	0	0	0	1				
1736	0	0	0	1				
1763	0	0	0	1				
4295	0	0	0	1				
2032	0	0	0	1				
4297	0	0	0	1				
2178	0	0	0	1	0	0	4.5	4.50
2163	0	0	0	1				
2021	0	0	0	1				
2089	0	0	0	1				
2084	0	0	0	1				
4348	0	0	0	1				
2217	0	0	0	1				
4434	0	0	0	1				
4319	0	0	0	1				
1961	0	0	0	1				

1962	0	0	0	1				
1517	0	0	0	1				
1521	0	0	0	1	1	0.66	0	0
4770	0	0	0	1				
4764	0	0	0	1				
2434	0	0	0	1				
2439	0	0	0	1				
2440	0	0	0	1				
4778	0	0	0	1				
4776	0	0	0	1				
4741	0	0	0	1				
4734	0	0	0	1				
4073	0	0	0	1				
4750	0	0	0	1				
4738	0	0	0	1				
1543	0	0	0	1				
1532	0	0	0	1				
1547	0	0	0	1				
4812	0	0	0	1				
2472	0	0	0	1				
4828	0	0	0	1				
1484	0	0	0	1				
1486	0	0	0	1				
4801	0	0	0	1				
4654	0	0	0	1				
4643	0	0	0	1				
2379	0	0	0	1				
4108	0	0	0	1				
1651	0	0	0	1				
1666	0	0	0	1				
4648	0	0	0	1				
4621	0	0	0	1				
4131	0	0	0	1				
4098	0	0	0	1				
1722	0	0	0	1				
1605	0	0	0	1				
1602	0	0	0	1				
4680	0	0	0	1				
1635	0	0	0	1	1	0.88	0	0
4672	0	0	0	1				
4691	0	0	0	1				
4683	0	0	0	1				
4675	0	0	0	1				
1634	0	0	0	1				
102	0	0	0	1				
101	0	0	0	1				
3549	0	0	0	1				
100	0	0	0	1				
669	0	0	0	1				
3107	0	0	0	1				
452	0	0	0	1				
647	0	0	0	1				
650	0	0	0	1	0	0.14	3	3.69
3108	0	0	0	1				
3648	0	0	0	1				
3131	0	0	0	1				
3650	0	0	0	1				
425	0	0	0	1				
243	0	0	0	1				

242	0	0	0	1				
3653	0	0	0	1				
85	0	0	0	1				
3640	0	0	0	1				
96	0	0	0	1	0.5	0	0	0
5942	0	0	0	1				
494	0	0	0	1				
495	0	0	0	1	0.5	0.16	0	0
3089	0	0	0	1				
5884	0	0	0	1				
3566	0	0	0	1				
3090	0	0	0	1				
569	0	0	0	1				
5580	0	0	0	1				
548	0	0	0	1				
488	0	0	0	1				
547	0	0	0	1				
5605	0	0	0	1				
3038	0	0	0	1				
3080	0	0	0	1				
160	0	0	0	1				
5887	0	0	0	1				
5656	0	0	0	1				
5893	0	0	0	1				
3036	0	0	0	1				
5603	0	0	0	1				
3034	0	0	0	1				
459	0	0	0	1				
622	0	0	0	1				
5560	0	0	0	1				
3102	0	0	0	1				
2995	0	0	0	1				
5544	0	0	0	1				
119	0	0	0	1				
120	0	0	0	1				
630	0	0	0	1				
629	0	0	0	1				
591	0	0	0	1				
590	0	0	0	1				
468	0	0	0	1				
3013	0	0	0	1				
587	0	0	0	1				
3231	0	0	0	1				
607	0	0	0	1				
466	0	0	0	1				
118	0	0	0	1				
3008	0	0	0	1				
3162	0	0	0	1				
2908	0	0	0	1				
3474	0	0	0	1				
5435	0	0	0	1				
2914	0	0	0	1				
3471	0	0	0	1				
5761	0	0	0	1				
3376	0	0	0	1				
363	0	0	0	1				
275	0	0	0	1				
361	0	0	0	1				
276	0	0	0	1				

362	0	0	0	1				
3161	0	0	0	1				
2912	0	0	0	1				
2875	0	0	0	1				
5813	0	0	0	1				
827	0	0	0	1				
3580	0	0	0	1				
5364	0	0	0	1				
299	0	0	0	1	0	0	5.5	5.39
5362	0	0	0	1				
2887	0	0	0	1				
3196	0	0	0	1				
3195	0	0	0	1				
338	0	0	0	1				
3197	0	0	0	1				
306	0	0	0	1				
327	0	0	0	1				
337	0	0	0	1				
3326	0	0	0	1				
531	0	0	0	1				
248	0	0	0	1				
533	0	0	0	1				
247	0	0	0	1				
2938	0	0	0	1				
5473	0	0	0	1				
67	0	0	0	1	2	2.25	4.5	5.00
711	0	0	0	1				
703	0	0	0	1				
3134	0	0	0	1				
5632	0	0	0	1				
180	0	0	0	1				
178	0	0	0	1				
5838	0	0	0	1				
5758	0	0	0	1				
5836	0	0	0	1				
5752	0	0	0	1				
2936	0	0	0	1				
396	0	0	0	1				
3677	0	0	0	1				
5450	0	0	0	1				
750	0	0	0	1				
751	0	0	0	1				
4114	0	1	0	0				
3453	0	0	1	0				
4126	0	0	1	0				
4282	0	0	1	0				
4189	0	0	1	0				
3852	0	0	1	0				
3860	0	0	1	0				
3846	0	0	1	0				
3663	0	0	1	0				
3843	0	0	1	0				
3837	0	0	1	0				
3645	0	0	1	0				
3755	0	1	0	0				
3758	0	0	1	0				
3740	0	0	1	0				
3735	0	0	1	0				
3565	0	0	1	0				

3554	0	0	1	0				
3551	0	0	1	0				
4095	0	0	1	0				
3965	0	0	1	0				
3583	0	1	0	0				
5451	0	0	1	0				
5417	0	0	1	0				
5413	0	0	1	0				
5567	0	0	1	0				
5593	0	0	1	0				
5266	0	0	1	0				
5888	0	0	1	0				
5894	0	0	1	0				
5902	0	0	1	0	0	0	0.5	0
5868	0	0	1	0				
5866	0	0	1	0				
5955	0	0	1	0				
5917	0	0	1	0				
5805	0	0	1	0				
5819	0	0	1	0				
5856	0	0	1	0				
5861	0	0	1	0				
5911	0	0	1	0				
5988	0	0	1	0				
5963	0	0	1	0				
5978	0	0	1	0				
5657	0	0	1	0	0	0	6	5.59
5685	0	0	1	0				
5692	0	0	1	0				
5688	0	0	1	0				
5602	0	0	1	0				
5639	0	0	1	0				
5787	0	0	1	0				
5696	0	1	0	0				
5697	0	0	1	0				
5740	1	0	0	0				
5718	0	0	1	0				
4556	0	0	1	0				
4531	0	0	1	0				
4539	0	0	1	0				
4535	0	0	1	0				
4690	0	0	1	0				
4688	0	1	0	0				
4685	0	0	1	0				
4740	0	0	1	0				
4736	0	0	1	0				
4619	1	0	0	0				
4625	0	0	1	0				
4623	0	0	1	0				
4611	0	0	1	0				
4651	0	0	1	0				
4647	0	0	1	0				
4375	0	0	1	0				
4456	0	0	1	0				
5031	0	0	1	0				
5030	0	0	1	0				
5036	0	1	0	0				
5070	0	0	1	0				
5004	1	0	0	0				

5007	1	0	0	0				
5002	0	0	1	0				
5141	0	0	1	0				
5142	0	0	1	0				
5095	0	0	1	0				
5138	0	0	1	0				
5137	0	0	1	0				
4803	0	0	1	0				
4835	0	0	1	0				
4842	0	0	1	0				
4769	0	0	1	0				
4773	0	0	1	0				
4743	0	0	1	0	0	0	0	0.61
4802	0	0	1	0				
4797	0	1	0	0				
4941	0	0	1	0				
4936	0	1	0	0				
4968	0	1	0	0				
4960	0	0	1	0				
4959	0	0	1	0	0.5	0	0	0
4977	0	0	1	0				
1063	0	0	1	0				
1015	0	0	1	0				
1163	0	0	1	0				
1112	0	0	1	0				
870	0	0	1	0				
969	0	0	1	0				
970	0	0	1	0				
1573	0	0	1	0				
1607	0	0	1	0				
1318	0	0	1	0				
269	0	0	1	0				
245	0	0	1	0				
398	0	0	1	0				
332	0	0	1	0				
333	0	0	1	0				
358	0	0	1	0				
59	0	0	1	0				
103	0	0	1	0				
82	0	0	1	0				
730	0	0	1	0				
688	0	0	1	0				
691	0	0	1	0				
824	0	0	1	0				
748	0	0	1	0				
783	0	0	1	0				
781	0	0	1	0				
432	0	0	1	0				
451	0	0	1	0				
2792	0	1	0	0				
2775	0	0	1	0				
2734	0	0	1	0				
2715	0	0	1	0				
2894	0	0	1	0				
2571	0	0	1	0				
3202	0	0	1	0				
4892	0	0	1	0				
3063	0	0	1	0				
3082	0	0	1	0				

1944	0	0	1	0				
1910	0	0	1	0				
1981	0	0	1	0				
1804	0	0	1	0				
1835	0	0	1	0				
1766	0	0	1	0	7.5	7.11	4	3.84
1758	0	0	1	0				
1760	0	0	1	0				
2138	0	0	1	0				

Appendix-4

Field survey data for rice crop in 2003

Grid No.	Flood depth (Field survey)	Flood depth (Calcu-lated)	Short Duration (Field survey)	Medium duration (Field survey)	Long duration (Field survey)	Short Duration (Calcu-lated)	Medium duration (Calcu-lated)	Long duration (Calcu-lated)
1209	4.5	4.32	Yes			Yes		
1536	3.5	3.67	Yes			Yes		
2097	0	0.02				Yes		
3297	0	0.00						
3402	3	2.92	Yes			Yes		
5184	6.5	6.12		Yes		Yes		
5139	0	0.00						
5777	0.5	0.00	Yes					
49	2	1.84	Yes			Yes		
563	2.5	1.80	Yes			Yes		
881	1.5	1.22	Yes			Yes		
2393	10	9.67	Yes				Yes	
1847	11.5	9.04		Yes			Yes	
2205	7	6.68		Yes			Yes	
1504	4.5	4.04			Yes			Yes
2193	3	2.81			Yes			Yes
718	3.5	3.43	Yes			Yes		
4719	4	4.05	Yes			Yes		
3899	5	4.87		Yes		Yes		
4068	0	0.00						
2063	8	7.48			Yes			Yes
3166	0	0						
404	5	4.81			Yes			Yes
1352	7	6.48		Yes			Yes	
2867	0	0						
3652	0	0						
1757	3	2.66	Yes			Yes		
3261	0	0						
2414	4.5	4.66	Yes			Yes		
4956	1	0.93	Yes			Yes		
2739	0.5	0	Yes					
2036	0	0						
2091	0	0						
338	5	4.67		Yes			Yes	
2691	7.5	7.43			Yes		Yes	

Field survey data for rice crop in 2006

Grid No.	Flood depth (Field survey)	Flood depth (Calculated)	Short Duration (Field survey)	Medium duration (Field survey)	Long duration (Field survey)	Short Duration (Calculated)	Medium duration (Calculated)	Long duration (Calculated)
1209	0	0						
1536	0	0						
2097	3	2.83			Yes			Yes
3297	0	0						
3402	3.5	3.27			Yes			Yes
5184	6	5.60		Yes		Yes		
5139	0	0						
5777	0	0						
49	0	0						
563	0.5	0	Yes					
881	0	0						
2393	4.5	4.71		Yes			Yes	
1847	4.5	4.09		Yes			Yes	
2205	0	0						
1504	6	6.03			Yes			Yes
2193	4	3.90	Yes			Yes		
718	3	2.66	Yes			Yes		
4719	0	0						
3899	0	0						
4068	0	0						
2063	3.5	3.07	Yes				Yes	
3166	0.5	0	Yes					
404	4	3.56	Yes			Yes		
1352	0	0						
2867	0	0						
3652	0	0						
1757	0.5	0	Yes					
3261	0	0						
2414	0	0					Yes	
4956	2.5	2.38		Yes				
2739	0	0						
2036	0	0						
2091	0	0						
338	2	1.87		Yes			Yes	
2691	4.5	4.65		Yes		Yes		

Appendix-5

Field survey data for metalled road

Grid No.	Flood depth in 2006 (Field survey)	Flood depth in 2006 (calculated)	Flood depth in 2003 (Field survey)	Flood depth in 2003 (calculated)
351	0	0	0.5	0
2319	0	0	0	0
2057	0	0	0	0
3739	2	2.54	0	0
4942	1	1.21	0	0
2585	5	4.74	8.5	8.92
3793	5	5.54	6	5.37
1750	6	5.66	5	5.26
359	0	0	1	0.22
2016	2	2.27	0	0.01
2096	3.5	3.30	0.5	0.21
4026	5.5	5.12	0	0
5254	4.5	4.731	0	0
5334	3	2.84	0	0
5426	0	0	0	0

Field survey data for unmetalled road

Grid No.	Flood depth in 2006 (Field survey)	Flood depth in 2006 (calculated)	Flood depth in 2003 (Field survey)	Flood depth in 2003 (calculated)
302	0	0	1	0.55
2137	0.5	0	0	0
2483	4	4.55	9	8.48
4223	0	0	0	0
5007	0	0	0	0
5465	0	0	0	0
5970	0.5	0	0	0
5870	0	0	0.5	0
5638	0	0	0	0
2941	0	0.18	0	0.03
299	5.5	5.39	0	0
333	4.0	3.73	3	2.53