APPLICATION OF GEOINFORMATICS FOR FLOOD STUDY AT TARAPUR UNION OF GAIBANDHA

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It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree.

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ABBREVIATIONS

ADRO	Applications Development Research Opportunity
BBS	Bangladesh Bureau of Statistics
BWDB	Bangladesh Water Development Board
CEGIS	Centre for Environmental and Geographic Information Services
cm	Centimeter
DEM	Digital Elevation Model
EMSS	Emergency Medical Support Space
FAP	Flood Action Plan
FFWS	Flood Forecasting and Warning System
FIA	Federal Insurance Administration
GIS	Geographic Information System
HD	Hydrodynamic
HYV	High Yielding Varieties
HEC-RAS	Hydraulic Engineering Center's River Analysis System
ICID	International Commission on Irrigation and Drainage, Bangladesh National Committee
ILWIS	Integrated Land and Water and Information System
IWFM	Institute of Water and Flood Management
IWM	Institute of Water Modeling
NOAA	National Oceanographic and Atmospheric Administration
PPCC	Probability Plot Correlation Coefficient
PWM	Probability Weighted Moment
Kg	Kilogram
Km	Kilometer
RAPIDS	Real-time Acquisition and Processing - Integrated Data System
RMSD	Root Mean Square Deviation
SAR	Synthetic Aperture Radar
SPARRSO	Space Research and Remote Sensing Organization
WARPO	Water Resources Planning Organization
m	Meter
SOB	Survey of Bangladesh
Sq. km	Square Kilometer
UFDSM	Urban Flood Dynamic Simulation Model
VRSAP	Vietnam River Systems and Plains

GLOSSARY

Acre	Unit of land measure; 0.41 hectare
Aman	Rice grown in Kharif-2 season
Aus	Rice grown in Kharif-1 season
B. Aman	Deep water rice sown during Kharif-1 and harvested in Kharif-2 season
B. Aus	Broadcast variety of rice grown in Kharif-1 season
Boro	Rice grown during the winter season
Double crop	Only two crops cultivated on the same land in one year
Dry season	6 months; December-May inclusive
Gross cropped area	The aggregate area of various crops raised in the same farmland during the census year
Homestead area	Homestead area means the area residence of the holder's with all its structures, courtyard, and the land occupied by the passage enter and exit
Household	A family unit who share common resources for cooking and eating
Intermediate holding	A farm holding having operated area 2.50-7.49 acres
Intensity of Cropping	It represents the ratio in which total area of temporary crops to the net temporary cropped area.
Kharif	Cropping season between March October, often divided into Kharif-1 (March-June) and Kharif-2 (July-October)
Operated area	The area owned by the holder plus the area rented from others minus the owned given to others for operation.
Permanent crop area	The part of net sown area with permanent crops or planted with fruit trees which occupy the land for a long period of time and do not need for many years after each harvest.
Pre-Kharif	March-April period
Rabi	Cropping season between November and February
Rabi crops	Crops grown in the Rabi season such as pulses, oilseeds, spices, etc
Single crop	Only one crop cultivated on the same land in one year
Small holding	A farm holding having operated area 0.05-2.49 acres, with minimum of 0.05 acre as cultivated area.
T. Aman	Transplanted variety of rice grown in Kharif-2 season
Temporary crop area	The part of net sown area where crops whose growing cycle or length of life is less than one year
Thana	Administrative unit comprising a number of Unions
Union	Lowest administrative unit comprising a few village
Triple crop	More than two crops cultivated on the same land in one year

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ABSTRACT

This study has been taken to develop vulnerability maps for agriculture using Remote Sensing (RS) and Geographic Information System (GIS) regarding different return period for flood hazard vulnerability assessment in a flood prone area, Tarapur union of Sundarganj thana under Gaibandha district of Bangladesh. The study mainly focuses on the development of a vulnerability function for preparing vulnerability maps for agriculture.

For the development of vulnerability function depth-damage relation has been followed. For establishing relationship between flood depth and agricultural damage, an extensive field survey has been carried out in the study area. Satellite images and other related data are also widely analyzed for establishing the relation more fruitfully. A Landsat and a Radarsat image of the study area have been used to identify agricultural land and for identification of flooded and non-flooded area.

Although the study area is located in a floodplain locality but the terrain is not so much flat. Due to this, depth of flood level varies in different location corresponding to a fixed level rise of water level. In this regard for the development of a depth-damage function, the study area has been divided into four categories based on the elevation. In monsoon (July to September), one meter rise of water level leads 100 % damage of all the crops in the very low lying river associated land. Whereas about 2 meter rise of water level causes 100 % damages of all the crops in low land and 2.5 meter and 3 meter rise of water levels causes 100 % damages in all medium and high land crops of the study area respectively.

For the development of flood inundation and flood depth map, Digital Elevation Model (DEM) and water level data of the study area have been collected form Bangladesh Water Development Board (BWDB). Water levels are used based on flood frequency analysis for 2-, 5-, 10-, 20-and 50-year return periods.

The agricultural land of the study area has been found in between the elevation>22.9 to <25.91 meter. Vulnerability function was based upon these land areas. The magnitude of vulnerability for agriculture of Tarapur union is found to increase linearly up to three meter depth of water and then it becomes horizontal.

From the vulnerability maps it has been observed that for all the return periods, the study area is very much vulnerable. And area close to river bank is relatively more vulnerable compared to the area far away from the river bank. Flood level due to 20- and 50-year return periods damages 100 % damages of crops.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Flood is the major disaster affecting many countries in the world year after year. It is an inevitable natural phenomenon occurring from time to time in all rivers and natural drainage systems. It causes damage to lives, natural resources and environment as well as the loss of economy and health. The impacts of floods have been increased due to a number of factors such as increased development activities on floodplain.

Floods cause widespread sufferings and severe stresses on sustainable and equitable development. Such disasters exacerbate poverty through disruption of livelihoods, environmental degradation, destruction of vital infrastructure and services and loss of economic investment in agriculture, aquaculture and personal property.

'Flood Disaster' derives most of its meaning from 'disaster', which is the term often given to the harmful event that occasionally arises as a consequence of hazard. Thus according to Parker and Cannon (2002), a hazard is a perceived natural event which threatens both life and property and a disaster is the realization of this hazard. In other words, natural hazard is the probability of occurrence of a potentially damaging phenomenon within a specified period of time and within a given area.

Flood disasters are extraordinary events that cause great destruction of property and may result in death, physical injury and human suffering. Flood disaster is an event which afflicts a community, the consequences of which are beyond the immediate financial, material or emotional resources of the community. Disaster has also been defined as usually overwhelming events and circumstances that test the adaptational responses of community or individual beyond their capability, and lead at least temporarily to massive disruption or function for community or individual (Parker and Cannon, 2002). This definition implies that communities and individuals have differential resilience or capacity to cope with disasters, and this again highlights the importance of the concept of vulnerability.

Dutta and Hearth (2004) presented an analysis of flood disaster trends in Asian countries during the last 30 years. The analysis was carried out to understand the changing characteristics of flood disasters in Asian countries in the past three decades with the rapid change in socio-economic conditions. It shows that flood disasters in most of the Asian countries are increasing significantly, especially in the last few years Asia witnessed a rapid increase of flood disasters.

With the increase of population, industrial growth, more and more settlements and development in floodplains, flood hazards in Bangladesh have become ever-increasing natural disasters resulting in highest economic damage among all kinds of natural disasters. In order to formulate flood management and control policies, a thorough understanding of flood problems and how it can be solved is required. This can be done through data collection and analysis along with flood impact assessment (Aziz et al., 2002).

The magnitude and duration of floods have changed during the last few decades. The duration of 1998 flood was over 70 days. In 1999 a prolonged flooding condition prevailed throughout much of the monsoon season.

The total area covered by major floods has been steadily increasing since 1974, with an exception of 1984 floods. The land area affected by major floods has increased from 35% in 1974 to 68% in 1998.

Riverine floods occur when the amount of runoff originating in a watershed exceeds the carrying capacity of natural and constructed drainage system. Flooding can occur due to river overflow or surface runoff. There are two types of floods which occur in Bangladesh: annual floods *(barsha)* that inundate up to 20% of the land area; and low frequency floods of high magnitude that inundate more than 35% of the area *(bonna)*. While the annual floods are essential and desirable for overall growth of the

Bangladesh delta and the economy, the major floods that occurred in1954, 1955, 1974, 1984, 1987, 1988, 1993, 1998, 1999, and 2000 were very much destructive.

The rivers in the extreme northern area (Teesta, Dudkumar and Dharla) have steeper gradients (1 in 2000) than elsewhere and most of their catchments lie in India and Bhutan. These rivers frequently cause flash floods. The part of the region along Brahmaputra suffers severely from river flooding caused by breaches, mainly in the main Brahmaputra River and to limited scale in the Teesta River. The severity of flooding may be exacerbated by rainfall within the region. (ICID, 1997).

Riverbed aggradation is so pronounced in Bangladesh that changes in riverbed level can be observed during one's lifetime. Riverbed aggradation reduces the water carrying capacity of rivers, causing floods due to bank overflow. This recent increase in riverbed levels has undoubtedly contributed to the increased flooding propensity in Bangladesh.

Flood control measures in Bangladesh are mainly limited to building of earthen embankments, polders, and drainage. Embankments and polders have reduced floodplain storage capacity during floods, leading to an increase in water level and discharges in many rivers. Earthen embankments can easily breach and can be damaged by riverbank erosion. Most of the embankments in Bangladesh have experienced breaching and erosion more than once since their completion. Embankments have created a false sense of security among residents living within embanked areas. The effectiveness of embankments is being questioned in other countries as well.

Agriculture is the essential source of income in the developing countries like Bangladesh. Especially, the poor people suffer the most from flood disasters because they tend to live in marginal areas and depend on high-risk, low return livelihood systems such as rainfed agriculture and face many sources of vulnerability. The preferred areas for agriculture are river banks and floodplains due to their natural high productivity and availability of water, but during flood events high percentages of the harvest often gets damaged.

The study area Tarapur union of Sundarganj thana under Gaibandha district is subjected to flood almost every year from both the boundary rivers of the Teesta and the Brahmaputra, with both beneficial and adverse effects. In the year 2004 a heavy rain fall for six to seven consecutive days in July and upstream river flow caused a devastating flood in the locality. The river Teesta is responsible for both types of flash flood and monsoon flood in the study area. The river Brahmaputra also has a significant impact on both types of flood in Tarapur union. Riverine monsoon flood is very much destructive and occurs very frequently in the study area. Flash flood is also destructive but does not occur so frequently. Normally monsoon flood occur in July to September.

The economy of the study area is mainly agrobased and almost 82% area of Tarapur union is now being used as agricultural land. Among the crops, paddy occupies about 74% of the gross cropped area and normally grown in the low-laying areas (BBS, 1996). Monsoon flood leads a huge damage to agriculture almost all the year.

Considering that damage to agriculture in Tarapur union is most significant of the total damage, emphasis is given in this study to assess flood hazard vulnerability of agriculture for monsoon flood.

For an effective management of flood in low lying flood-prone areas, Geographic Information System (GIS) and Remote Sensing (RS) technology is proving to be a useful and efficient tool (Wagner, 1989; Wu and Xia. 1990; Rahman, 1992). The existing inadequate communication system and high accessibility of remote sensing in case of extraction of information make it a useful tool for flood study. Satellite images can be used for preparing flood inundation map, monitoring of flood and estimation of flood damage.

For flood disaster risk management, it is important to analyze and assess vulnerability of different elements at risk. The flood inundation maps are very much useful for an effective management of flood while the flood hazard vulnerability maps for agriculture are also useful for flood risk management. Vulnerability function relates hazard magnitudes with vulnerability and is the basic ingredient of flood hazard vulnerability maps. Hence for better management of flood and for selection of location for agricultural and other activities, flood hazard vulnerability maps of could be used.

In this study geoinformatics is applied to assess flood hazard vulnerability in a flood prone area Tarapur union. Flood hazard vulnerability of agriculture are assessed for different flood magnitudes through development of flood inundation maps, flood depth maps and vulnerability function.

1.2 Rationale of the Study

Flooding cannot be completely avoided, but damages from severe flooding can be reduced if effective flood mitigation scheme is implemented. This can be achieved if the sufficient information regarding flood can acquired both in time and in quality. Hydrologic applications of GIS and Remote Sensing range from synthesis and characterization of hydrologic tendencies to the prediction of response to hydrologic events. The payoff comes from the multiple ways in which the data can be used once it is made to be digitally accessible in a GIS format. Use of GIS and Remote Sensing will provide supplementary data in hydrology for such analysis and will lead to easier interpretation and understanding of flood phenomena and characteristics.

1.3 Objectives of the Study

The major objectives of the study are as follows:

1. To develop flood inundation maps of the study area.
2. To assess flooding (areal extent, depth) for different flood magnitudes.
3. To develop flood hazard vulnerability function of agriculture.
4. To assess flood hazard vulnerability of agriculture for different flood magnitudes.

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

The people of Bangladesh are repeatedly confronted by natural and human-made catastrophes such as flooding. While some of these environmental degradations and calamities are not directly related to human activities and landuse practices (such as earthquakes. tornadoes. and cyclones), others are related to human interactions with the nature. Flooding is one water-related environmental problem that is directly related to human activities. The magnitude and intensity of flooding are very much dependent on landuse practices in the watershed of each rivers or streams. Finding solutions to the flooding problem is imperative. It is important to understand the processes that influence flooding in Bangladesh, before any solution to the flooding problem is prescribed (Khalequzzaman, 2000).

The literature review is primarily directed to an overview of application of Remote Sensing (RS) and Geographic Information System (GIS) in present and past flood study in Bangladesh as well as in other parts of the world. The aim of this research is to develop a methodology using geo-informatics (RS and GIS) for vulnerability assessment for agriculture. For developing vulnerability function it is needed to realize damages caused by flood. Again for flood hazard vulnerability assessment an understanding about the risk analysis and the concept of hazard factors and vulnerability factors should be clear. So the review of literature includes here all the factors along with Remote Sensing and GIS.

2.2. Brief History of GIS and RS in Bangladesh

The complex and dynamic environment of Bangladesh, its susceptibility to natural hazards and heavy dependency on natural resources makes spatial information a crucial ingredient for the development process (Huque, 2000). The existing communications infrastructure is inadequate to support efficient collection and dissemination of information regarding management of natural calamities like flood.

Therefore, activities related to photogrammetry, Remote Sensing and spatial information science have been developing over the past three and a half decades (Huque. 2000). Regarding this. in this chapter. especial emphasis is given on the application of Geographic and Information System (GIS) and Remote Sensing in flood management.

Photogrammetry and Remote Sensing in Bangladesh has been growing at a moderate pace but was limited to specialized national agencies until recently. During the nineties, increasing numbers of development activities within the country and tremendous technological advances worldwide have caused a major increase in the use of these technologies. Practical applications of Remote Sensing products started filling the gaps in available up-to-date information. Huge amounts of spatial and attribute information are being digitized in order to make best use of GIS technology for enhancement of planning and management capabilities in the country. The nineties have also seen a large increase in local professionals capable of dealing with these technologies. However, the activities are still mostly limited to government organizations and donor funded projects. The major agencies that have been working in these fields are Space Research and Remote Sensing Organization (SPARRSO), Survey of Bangladesh (SOB) and Centre for Environmental and Geographic Information Services (CEGIS).

2.3 Use of GIS and RS in Flood Study

Khatun (2005) conducted a study to develop a methodology for socio-economic vulnerability assessment and to create a loss map using GIS and developed vulnerability indices for a scenario flood event for urban flood disaster risk management in Hanoi and Bangkok. the capitals of Vietnam and Thailand respectively.

Shrestha et al. (2004) mapped flood risk and vulnerability using GIS. Hydrologic analysis was combined with socioeconomic resources and constraints with the help of

GIS data processing software ArcInfo and ArcView 3.1. Landsat imagery at 30 m resolution and time series areal photographs were used to detect change in river morphology and to identify flood plains. DEM was incorporated into Hydraulic Engineering Center's River Analysis System (HEC-RAS) software for flood elevation estimates. Primary data on past hazards, socio-economic condition. vulnerability and response capability in the recent past were collected to develop vulnerability and risk map. For vulnerability four sets of parameters were chosen: Houses, Built-up area, Landuse and land cover and Road Infrastructure. To develop the vulnerability map, parameter maps were transformed into weight maps by assigning a weightage to each class of parameter. Risk was obtained by the multiplication of cost, vulnerability and recurrence interval of the natural phenomenon.

Gupta et al. (2004) reviewed flood damage assessment in the Mekong delta, Vietnam. The Vietnam River Systems and Plains (VRSAP) model was calibrated with the year 2000 flood data to predict depth, duration and extent of inundation at different return periods.

Dutta and Tingsanchali (2003) developed loss functions in some selected regions of Bangkok for urban flood risk analysis. Questionnaire surveys were carried out in two selected districts on residential and non-residential buildings for gathering data and information for development of loss functions. Based on the estimated damage to residential and non-residential buildings due to hypothetical floods of different durations, hypothetical loss functions were established for the following four categories.

- Category1: Damage to building structures,
- Category2: Damage to building contents/ stocks,
- Category3: Damage to outside properties,
- Category4: Emergency and cleaning costs due to floods.

In this study it was observed that damages to different categories significantly varied with the duration of floods and due to that flood duration is considered as one variable in loss function development.

Dutta et al (2003) presented an integrated mathematical model for distributed modeling of flood inundation and damage. Based on the landuse patterns and nature of damage they developed mathematical flood damage models for three types of landuse as Urban, Rural and Infrastructure. The hydrologic model considers major processes of the water cycle through physically based governing equations. The loss estimation model is formulated based on stage-damage relationships between different flood inundation parameters and landuse features. For urban and rural damages, the damage estimation models are formulated as grid based model and are developed for each category. This model was applied in Ichinomiya River Basin, Chiba, Japan.

Dutta (1999) presented the methodology for flood damage assessment using GIS and Distributed Hydrology Model and a case study in Ichinomiya River Basin, Chiba, Japan. The Hydrologic Model which includes four major components such as overland flow, river flow, unsaturated zone flow and saturated zone flow were used in his study for flood modeling.

Hutchison and Watt (1978) presented a systemic approach to the flood risk mapping. In that study it was concluded that, flood risk mapping was the cornerstone of the new, comprehensive approach to the reduction of flood damage both in Canada and in the United states. Ngoc (2003) presented the implementation of GIS technology in Urban Flood Dynamic Simulation Model (UFDSM). The main characteristics of UFDSM are simulation of the detailed flood process. therefore, the results can be applied in many aspects such as flood loss calculation, flood hazard map, regional planning, flood insurance, flood control planning etc.

2.3.1 Application of GIS and RS in Flood Study in Bangladesh

2.3.1.1 GIS and RS in Flood Mapping and Monitoring

In Bangladesh, during the last decade several initiatives have been taken up by the Flood Action Plan (FAP-19) in order to monitor the flood process by using geographical information.

In 1993 the use of time-series of ERS-1 images led to classification of flooded and non-flooded area. The results have been published in internal reports (FAP-19, 1995) and at several symposia and in the European Space Agency (ESA) quarterly journal. In 1996 Radarsat images have been used in the Applications Development Research Opportunity (ADRO) research programme for a feasibility study on flood monitoring. In the study detailed measurements with Radarsat Fine beam images (8 m resolution) and Radarsat Wide beam images (25 m resolution) have been generated. Under European Space Agency Data User Porgramme (ESADUP) funding a transportable ground receiving station was temporarily installed at SPARRSO in 1999. During the monsoon several SAR images were acquired and processed in near real time for flood applications with help of Centre for Environmental and Geographic Information Services (CEGIS). The data was processed near real time into flood information products and has served as an eye-opener based on which a number of other promising applications were investigated briefly (Valkengoed et al., 2001).

Floods inundate 30 percent of the country in normal monsoon years. and occasional excessive floods inundate more than 60 percent of the country (BWDB, 1998). Because of dense cloud-cover during the monsoon flooding period, (Synthetic Aperture Radar) SAR has proven to be the most reliable tool for mapping and monitoring the dynamics of the flooding process. EGIS carried out research in 1993 (FAP19, 1995), 1996 (EGIS, 1997) and 1997 (EGIS, 1998) using the European ERS-1 and Canadian RADARSAT-1 SAR images (under ADRO funding) and develop a methodology to map open water flooding. Results from RADARSAT SAR show over 90 percent agreement with field observations for the open water class derived from digital classification. During the catastrophic floods of 1998, RADARSAT ScanSAR Wide and ScanSAR Narrow images, covering almost the entire country. were used in near real time mode. Flood maps showing open water flooded areas and percentage of area flooded were produced for disaster management and relief distribution.

In 1998, SPARRSO conducted a flood mapping and monitoring project with RADARSAT images under an Applications Development Research Opportunity (ADRO) project of the Canadian Space Agency. Following the flood a project was conducted, again using RADARSAT data to study the progress in post-flood agricultural rehabilitation.

In 1998, a pilot study area in north central Bangladesh was selected and methodologies have been developed for computing flood extent, depth and duration using a time series of ten RADARSAT F3 SAR images, digital elevation model, GIS data and hydrological information. Land use/land cover patterns were generated from the SAR images with the support of ground truth information. The output of this study can be used to assist in the planning and management of floodplain resources in Bangladesh.

Real-time Acquisition and Processing-Integrated Data System (RAPIDS), a low-cost, small sized, easily transportable, PC based ground receiving station was set up for the monsoon of 1999 for nine months to receive ERS SAR images for demonstrating near real time flood mapping and monitoring. A large archive of multi-temporal ERS-2 images both in ascending and descending mode were collected for a major part of the country and processed in near real time. The images were applied in flood extent, flood depth, crop and shrimp farm mapping. The station was set up at SPARRSO and the project was carried out in collaboration with SPARRSO, National Aerospace Laboratory (NLR) and SYNOPTICS of the Netherlands with funding from the European Space Agency.

From 2002 onwards EGIS is aiming to be an independent organization for environmental and geographical services in the near future. The centre is continuing to provide services for several applications in coastal and river areas in the field of flood and agricultural monitoring. Co-operation with several partners (Resource Analysis, Synoptics, NLR) in internationally funded projects has resulted in methodologies to map flood extent, depth, duration, flooding directions and crop classification on the basis of space borne SAR and optical imagery. During the monsoon season, typically from July-November, radar (SAR) satellites provide guaranteed imagery as opposed to optical satellites. The acquisition of SAR images is not hampered by cloud coverage and ground receiving station can guarantee frequent data availability. The immediate handling of images, covering the whole of Bangladesh in times of emergency, is essential for fast response measures by local authorities and validation in the field.

Estimating the extent of floods in Bangladesh a study was conducted by Blasco et al. (1992). In that study SPOT Satellite images were used for continuous monitoring of flood through measuring the area inundated regarding different time period. Sado and Islam (1997) conducted a study on satellite Remote Sensing data analysis for flooded area identification of Dhaka city, Bangladesh. Rahman (1992) carried out a research work by using GIS, Remote Sensing and Models for flood studies in Bangladesh. This was an analytical study in a flood prone polder in Bangladesh. The study mainly focused on monitoring of flood. Rasid and Pramanik (1990) conducted a study on visual interpretation of satellite imagery for monitoring floods in Bangladesh.

2.3.1.2 GIS and RS in Flood Risk and Hazard Mapping

Barua and Nagasawa (2003) reviewed risk assessment and empowering community healthcare facilities in coastal cities of Bangladesh. This study focused on the disaster risk caused by flood and cyclone, its post-disaster diseases and emergency medical support system that needed within the existing shelter-cum-community healthcare for sustainable development. The assessment result shows that the community healthcare facilities with Emergency Medical Support Space (EMSS) can play an effective role as a part of long-term disaster mitigations with the other recovery activities.

Islam and Sado (2000 a, b) studied flood hazard in Bangladesh using NOAA AVHRR data with GIS. In that study hazard assessment was made considering two major flood hazard parameters (depth of flooding and duration of flooding). Satellite images were used for the prediction of flood depth and duration. Finally, hazard map was developed considering combined effect of both parameters. The flood hazard map provides information for the development of counter measures and preparation of high risk areas, on a priority basis, against flood damage. Physiographic divisions, geological divisions, land cover categories and drainage network data were used as GIS components.

Islam and Sado (2000 c) also carried out a research work on Satellite Remote Sensing data analysis for flood damaged zoning with GIS for flood management. Pramanik (1994) conducted a study on Remote Sensing Applications in Disasters Monitoring in Bangladesh. This study mainly discusses the applications of Space Sciences, Remote Sensing and GIS by various agencies in Bangladesh

Ochi et al. (1991) conducted a study on flood risk evaluation in Bangladesh using Remote Sensing and GIS. This study deals by using NOAA-10 AVHRR imagery with other thematic maps by Geographic Information System (GIS) to estimate flood damage area in 1988 and also calculate some thematic information inundated by floods.

2.3.1.3 Application of GIS and RS in Flood Study in Meghna - Dhonagoda Polder

Brouder (1994) of International Institute for Aerospace Survey and Earth Sciences, Netherlands conducted a research on Flood Study in the Meghna - Dhonagoda Polder, Bangladesh. In this study spatial data in the digital data base of the GIS, such as digital elevation model (DEM) were used to predict the effects of future events. SPOT Multispectral CCT of 10^{th} October 1988, also was taken during the period of flooding provide an effective means of mapping the extent of the flooded areas.

The main objective of that study was to assess GIS and RS as tools for managing flood - prone areas in Bangladesh. In that study a comparison of the 1988 flood maps of the study area obtained by satellite imagery and the DEM was shown. And a calculation of the acreage of the area flooded and the depth and volume of the flood water of the study area for the 1988 flood were shown. The effect of flooding (area extent, depth and volume) assuming different high water level and different locations of dike failure was also identified in that study.

As the flood level on 10th October 1988 was between 3.00 and 3.50 m a.m.s.l. two flood maps were created in that study. One for a water level of 3.00 m and one for a water level of 3.50m. Figure 2.1 shows the flood map resulting from the operation on the DEM due to 3.00m water level. At a water level 3.00 m 83% of the area was estimated to be flooded.

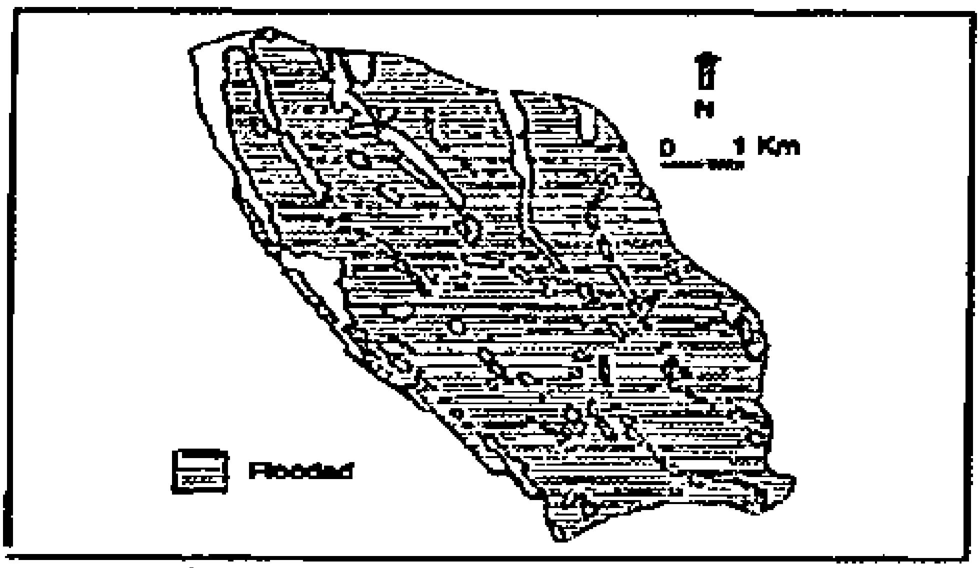


Figure 2.1 Estimated flooded area, using a DEM (High water level of 3.00m)
[Source: Brouder (1994)]

By using the simple technique of density slicing (SPOT image of 10th October 1988) flooded and non-flooded areas were differentiating in that study. Figure 2.2 shows the flooded and non-flooded areas obtained by slicing the near infrared band image of 10 October 1988. It appeared that 83% of the area was flooded.

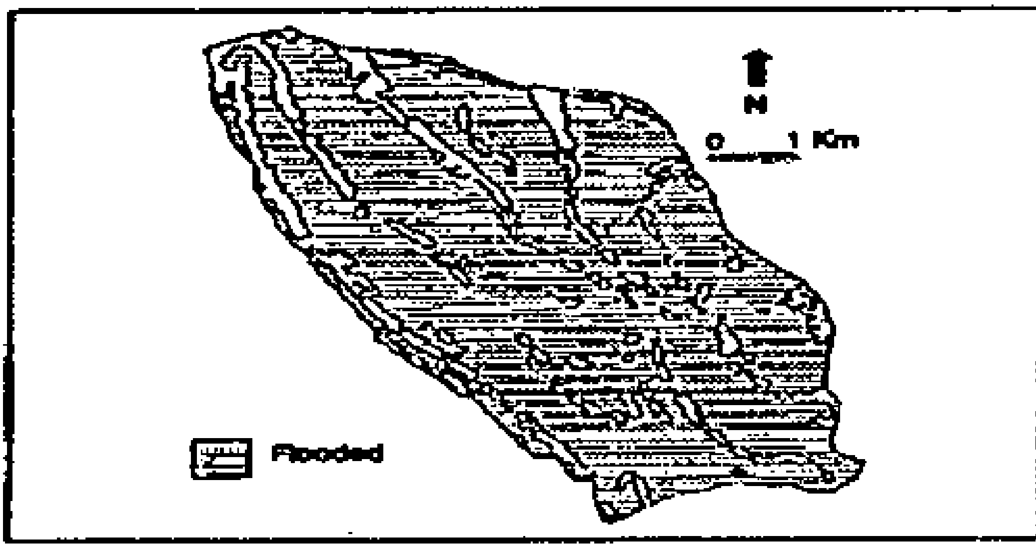


Figure 2.2: SPOT image classified as flooded and non-flooded areas, using density slicing. [Source: Brouder (1994)]

In order to compare the flood maps obtained by processing of the SPOT imagery and the DEM, these two products were overlayed (Figure 2.3) and the differences and similarities were analyzed.

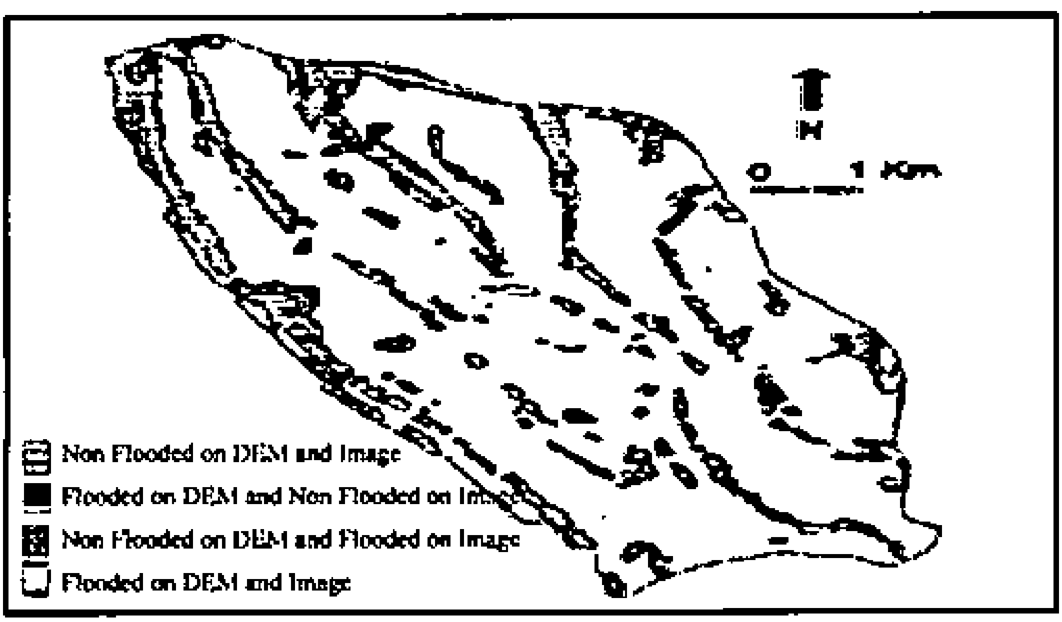


Figure 2.3: Comparison between flooded areas on image and DEM (flood level 3 m) [Source: Brouder (1994)]

Flood statistics is essential for the management of flood prone areas and to assess the expected consequences of possible flooding events. Flood statistics for a flood level of 3.00 m and 3.50 m found in that study is given below.

Table 2.1: Flood statistics for a flood level of 3.00 m and 3.50 m found in that study is given below.

Flood level (m)	Area Flooded (million ha)	Volume of flood waters (million m^3)
3.00	2.89	1634799
3.50	3.16	2443454

Source: Brouder (1994)

2.3.1.4 Flood Study on Sundarganj Thana

Aziz et al. (2002) conducted a research on Sundarganj Upa-Zilla of Gaibandha district to develop an integrated approach to disaster mitigation in Bangladesh through dynamic flood warning system. In that study Hydrodynamic model MIKE 11-FF (NAM. HD and FF) was successfully integrated with GIS in the Arc view GIS environment. Flood inundation maps were being created for Sundarganj thana by overlaying landuse features and infrastructures to delineate flooded areas using dynamic spatial modeling.

2.4 Vulnerability and Risk

Vulnerability depends on the magnitudes of hazard like depth of flood water. An understanding about the relationship among vulnerability, risk perception and damages due to hazard and an appropriate estimation of damage is essential for assessment of vulnerability of an area through vulnerability function. Risk perception, hazard magnitudes and status of damages largely determine the nature or characteristics of vulnerability function. Flood damage, vulnerability and risk perception confer specific information about hazardous threats to the various elements at risk. (e.g., Alexander 1993; Heyman et al.1991).

2.4.1 Vulnerability

Vulnerability is a set of prevailing or consequential conditions composed of physical, socio-economic or political factors which increase a community's susceptibility to calamity or which adversely affect its ability to respond to events. In general view vulnerability indicates the degree of loss to a given elements or set of elements at risk. Vulnerability can be considered in terms of five components.

1. Initial well-being
2. Self protection
3. Social protection
4. Livelihood resilience
5. Social capital

The actual amount of flood damage of a specific flood event depends on the vulnerability of the affected socio-economic and ecological systems, i.e., broadly defined, on their potential to be harmed by a hazardous event (Cutter 1996; Mitchell 1989). Generally speaking, an element at risk of being harmed is more vulnerable, the more it is exposed to a hazard and the more it is susceptible to its forces and impacts. Therefore, any flood vulnerability analysis requires information regarding these factors, which can be specified in terms of element-at risk indicators, exposure indicators and susceptibility indicators. In this regard, natural and social science indicators are highly significant.

2.4.1.1 Element-at-Risk Indicators

The subject matter of any flood vulnerability analysis is the group of elements which are at risk of being harmed by flood events. Element-at-risk indicators specify the amount of social, economic or ecological units or systems which are at risk of being affected regarding all kinds of hazards in a specific area, e.g. persons, households, agri-firms, economic production, private and public buildings, public infrastructure, cultural assets, ecological species and landscapes located in a hazardous area.

The elements are at risk of being affected by flood events, the magnitude of damage can be estimated in monetary and non-monetary units, which are reflected in total the maximum possible flood damage. This is also called damage potential. And because every element at risk is more or less exposed to flood events and more or less susceptible to them, exposure and susceptibility indicators are always related to element-at-risk indicators and contribute significantly to the analysis of flood vulnerability.

2.4.1.2 Exposure Indicators

Indicators supply information about the 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 floodplain. Taken together, these indicators inform us of the frequency of floods in floodplains and of the threat to the various elements at risk of being inundated. Indicators of the second category focus on general flood characteristics like duration, velocity, sedimentation load and inundation depth.

2.4.1.3 Susceptibility Indicators

Susceptibility indicators measure how sensitively an element at risk behaves when it is confronted with some kind of hazard. Regarding social and economic systems, an important group of indicators refer to susceptibility in a narrow sense, measuring the absolute or relative impact of floods on individual elements at risk. For example, the impact of inundation depth and flood duration on crops is frequently a major issue of damage analysis and research, attempting to identify crops types that feature similar susceptibilities. And this makes sense, because paddy is much more susceptible to floods than jute. Vulnerability can be defined in terms of functional relationships between expected damages regarding all elements at risk and the susceptibility and exposure characteristics of the affected system, referring to the whole range of possible flood hazards.

2.4.2 Flood Risk Analysis

2.4.2.1 Risk Perception

The notion of risk perception refers to the intuitive risk judgments of individuals and social groups in the context of limited and uncertain information (Slovic, 1987). These judgments vary between individuals due to different levels of information and uncertainty, due to different intuitive behaviour, and also due to specific power constellations and positions of interest. As a consequence, the individuals of a community may assess the risk of being flooded very differently, because they do not have the same information about the probability of flood hazard events in their region, about flood mitigation measures and their effectiveness, and they perhaps have a different historical background regarding the experience of living in a floodplain and of being flooded. In case of the very diverse risk perceptions within society, a communication process on flood risk and flood risk perception should be encouraged as a basis for policy. If prevailing perceptions and value concepts become transparent and open to public debate, a common perception of communities may evolve and contribute to an increased acceptance of flood protection policies and for development a vulnerability function for any field.

2.4.2.2 Risk Assessment

Risk assessment means the integration of specific risk of a hazardous system of activity and its significance in an appropriate context. United Nations (1991) outlined a methodology of risk assessment for mitigating natural disasters in a manual for policy makers and planners. As per this manual, the risk is expressed by the product of specific risk and elements at risk.

2.4.2.2.1 Specific Risk (Rs)

The specific risk (Rs) means the expected degree of loss due to a particular natural phenomenon as a function of both natural hazard and vulnerability.

2.4.2.2.2 Total Risk (Rt)

Total risk indicates the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon and expressed as the multiplication of elements at risk and specific risk. The intensity of natural hazard depends on flood depth while vulnerability depends on population density. This methodology was used for risk assessment to prepare comprehensive disaster management program under relief Ministry of the Government of Bangladesh.

2.4.3 Relationship among Flood Damage, Vulnerability and Risk Perception

2.4.3.1 Relationship between Flood Damage and Vulnerability

Flood damage analysis aims at quantifying flood damages for specific future scenarios with different flood events and flood policies in order to quantify the benefits of flood protection measures and, thereby, support policy decisions. In this context the concept of damage potential is crucial. The damage potential of a specific area represents the maximum possible amount of damage which may occur if the area becomes inundated. In these analyses vulnerability aspects must be considered in order to estimate the proportion of the damage potential which will finally materialize, *i.e.* to determine expected damages. In some vulnerability analyses, such a factor is derived from expert knowledge and empirical data on flood damages and then expressed on a scale between 0 (no loss at all) and 1 (total loss) in order to quantify the expected damage reduction for several categories of elements at risk (e.g., Elsner et al., 2003; Glade, 2003). The most important vulnerability indicator for estimating damages in current flood damage analyses is the exposure indicator inundation depth.

2.4.3.2 Relationship between Risk Perception and Vulnerability

With regard to the social and economic features of vulnerability, the notion of risk perception is crucial, too. If (average) flood risk perception is low in a region there would probably be taken any action to decrease the risk or to prepare for flood damage, vulnerability and risk of flooding. Conversely, if people are well aware of a flood risk – perhaps because they experience a flood with varying severity time and again – they tend to be better informed and prepared (Messner and Meyer, 2005). As a rule of thumb it can be stated that regions with low levels of flood risk perception and a low degree of preparedness for coping with flood events tend to experience flood damage levels above average and vulnerability to flood events is usually high.

2.4.4 Flood Damage Estimation

The loss estimation due to any natural disaster is a hypothetical, quantitative description of the effects of a future disaster (s) upon geographical area – a city, region, state or nation. There are many flood variables which affect damages caused to agricultural lands, for example: water depth, duration of inundation, time of the year. The relative importance of those factors will vary between different crops with varying growing and harvesting cycles (Ngoc, 2003).

With different types of research works several types of flood damage are generally recognized (e.g. Higgins 1981; Parker et al. 1987). First it is customary to distinguish between tangible and intangible damages based on whether or not monetary values can be assigned to the consequences of flooding.

Tangible damages are those, which can be evaluated in terms of monetary value. But, intangible damages are difficult to express in monetary values such as ill health, anxiety, inconvenience and disruption of social activities. Tangible damages are of two types, direct and indirect damages. Direct damages are caused by physical contact of floodwater such as damage to crops. Indirect damages result from the interruption of community activities, including traffic flows, trade and industrial production (Khatun, 2005)

Tangible damages, both direct and indirect, are measured in terms of monetary values in two ways. One is by developing stage-damage functions. It relates flood parameters (ex. duration of flood, depth of inundation, etc.) with damage extent to different types of properties (ex. crops, houses etc). These stage-damage functions are derived either from past flood data analysis or through analytical descriptions of flood damage to various properties.

Today digital landuse data like the digital landscape model is frequently used for flood damage estimation which allows its spatial implementation by means of Geographic Information System (GIS). By intersecting maps of inundation area and damage potential in a GIS and relating them accordingly, the amount of valuables or people affected can be determined. The vulnerability factor of the valuables, i.e. the share that is expected to be damaged, is in most cases exclusively related to inundation depth. Hence, relative depth-damage functions are used to calculate the expected damages

Gupta et al (2004) reviewed flood damage assessment in the Mekong delta, Vietnam. The Vietnam River Systems and Plains (VRSAP) model has calibrated here with the year 2000 flood data to predict depth, duration and extent of inundation at different return periods. Direct damages, indirect damages such as economic losses due to interruption of economic activities, intangible damages , such as anxiety, inconvenience, ill health and loss of cultural significance were considered. Based on these results, damage-frequency functions were developed; functions were of linear form for residential and commercial sectors and are of power form for the agriculture and infrastructure sectors.

Khatun (2005) presented a procedure for measuring tangible damage through field survey. In surveying procedure questionnaire surveys were conducted in flood affected area among affected people to estimate loss to properties. Extensive research works was conducted for deriving stage-damage functions from flood damage analysis.

In case of the great variety of methods of damage analysis, the choice of an appropriate method does not only depend on the size of the area under consideration, but also on other factors like the availability of necessary data. time. manpower and/or money resources and not least on the goal of the respective study and the management level for which it should provide decision-making support.

The major considerations for estimating the flood damages in Bangladesh by return period (JICA, 2003) are as follows:

- The people of Bangladesh are accustomed to protect their properties in their long life experience to minimize the damages. They do not always consider the flood to bring the damages to them as the negative benefits but rather they assumed to have utilized the positive effects of flood such as natural water supply by flood for irrigation, new soil flew from upstream to fertile their farm lands, fishing in the flooded field or river and so on.
- The crops are planted in the proper season to minimize the flood damages by taking account of the characteristics of crops.
- There are very slight flood damages in the flood of short term return period such as 2-and 5-year. Then it was assumed that only the indoor movables and crops would be damaged in flood prone area of 2-year of return period.
- The flood damages in catastrophic conditions, like the flood that happened in 1998 of 50-year return period, tend to be drastically increased.
- The flood damages for infrastructure in the short return period are negligibly smaller than those of longer return period.
- The flood damages are related to the years of return period and flood prone area by return period.

CHAPTER THREE
METHODOLOGY

3.1 Reconnaissance Survey

Reconnaissance survey is essential for conducting a research, for understanding the flood status of the locality and its impacts on different sectors like agriculture. It is also essential for setting a outline for the overall study. For this study reconnaissance survey was undertaken with individual respondents, although a number of respondents occasionally might be interviewed at the same time. The objective of the survey was to quickly obtain basic information in developing an understanding of the area and helped ensuring that the formal questionnaire was designed in a manner understandable and relevant to agricultural damage due to flood, farmers' circumstances and sensitive local issues related to flood.

In addition to this, informal discussions were conducted with officers of Bangladesh Water Development Board (BWDB), Institute of Water Modeling (IWM), Bangladesh Space Research and Remote Sensing Organization (SPARRSO), the agricultural officers and some farmers about the existing situation of the area.

3.2 Selection of Study Area

The study area Tarapur union of Sundarganj thana under Gaibandha district is one of the worst flood affected region of Bangladesh. From the reconnaissance survey and literature review, it is found that the characteristics of flood of Tarapur union are almost same with the floods of other parts of Bangladesh. So a flood study on Tarapur union using GIS and Remote Sensing will be a representative for the whole Bangladesh.

Moreover as one of the basic requirements of the study area is a Digital Elevation Model (DEM) and a prepared DEM of the study area Tarapur union by BWDB was helpful in taking the decision of selection of the study area. In selection of the study area, availability of satellite image of the area for a required time period is also essential. In this aspect Tarapur union was suitable. Moreover in case of other study related information, existing communication system and smooth law enforcement Tarapur union is more suitable for conducting the research work.

3.3 Primary Data Collection

A semi-structured questionnaire was prepared to collect the primary data (Appendix-A). The questionnaire was prepared on the basis of the objectives of the study mainly for the development of vulnerability function curve for agriculture. In this regard for selection of the interviewers, framers were given more priority. And the age of the interviews was not less than 40 years because the questionnaire was used to obtain information on the situation of the study area in the past. And wider range time frame information about flood of the study area will be more helpful in developing a more precise vulnerability function for agriculture.

The total number of sample was selected randomly and 48 No. of sample was distributed randomly among the villages of Tarapur union.

3.4 Secondary Data Collection

Digital Elevation Model (DEM) of the study area was collected from Flood Forecasting and Warning Center of Bangladesh Water Development Board (BWDB). The resolution of DEM is 50 meter. DEM was used to develop flood inundation maps. Satellite images were collected from Space Research and Remote Sensing Organization to develop flood inundation map and landuse map. In this regard, ILWIS software was used (ILWIS 3.0 Academic, 2001). Water level data of the year 1988 to 2004 of Teesta and Brahmaputra River at different station (Dalia, Noonkaoa, Bahadurabad station) (Appendix B-I) was collected from IWFM library and from BWDB for flood frequency analysis. For flood frequency analysis yearly maximum levels of water were used.

3.5 Flood Frequency Analysis

Frequency analysis is merely a procedure for estimating the frequency of occurrence or probability of occurrence of past or future events. To determine the water level of Tarapur in response to 2-,5-,10-,20- and 50-year return periods flood frequency analysis was conducted based on the water level data of the year 1988 to 2004. To select the appropriate distribution a total of five distributions were compared in this study. These are Log Normal Distribution, 3-Parameter Log Normal Distribution, Pearson Type III Distribution, Log Pearson Type III Distribution and Gumble Distribution. The comparison is based upon goodness-of-fit analysis. Based on 2, 5, 10, 20 and 50- year return periods, depth of flood were used for preparation of flood inundation and flood depth maps. Detail calculation for estimating the flood flow using the above five distributions are given in Appendix B-II.

3.5.1. Goodness-of-Fit Analysis

Good ness-of-fit study based upon probability plot correlation coefficient (PPCC) is useful for assessing whether a proposed distribution is consistent with the at-site data sample (Stedinger et al.. 1993). Another goodness-of-fit analysis based upon probability plot (plotting position) is the root mean square deviation (RMSD) in fit. Goodness-of- fit analysis based upon PPCC is employed in this study.

The adequacy of a fitted distribution can be evaluated by the PPCC which is essentially a measure of the linearity of probability plot. It gives the correlation between the ordered observations and the corresponding fitted quantiles determined by a plotting position. If Y denotes the observed i-th flow, W the computed flow at the i-th plotting position, $\overline{Y}$ the average value of observations and $\overline{W}$ the average value of computed flows, then the PPCC of the fitted distribution for n sample size at a site is given by

$$\rho = \sum_{i=1}^{n}(Y_i - \overline{Y})(W_i - \overline{W}) / [\sum_{i=1}^{n}(Y_i - \overline{Y})^2 \sum_{i=1}^{n}(W_i - \overline{W})^2]^{0.5}$$

The maximum value of PPCC can be equal to one. Among fitted distributions to a sample of data, the one with the largest PPCC has the best fit to the data. For selection of the best fitted method of flood frequency analysis for Tarapur point, the above procedure was used (Appendix B-III).

3.5.2. Determination of Flood Level

The Pearson Type III distribution was found to be the best distribution that describes the flood frequency at Tarapur (Appendix B-IV). Hence for determination of flood levels regarding different return periods Pearson Type III distribution was used.

3.6 Development of Flood Inundation and Flood Depth Maps

Flood Inundation or Flood Extent Map and Flood depth map was prepared form Digital Elevation Model (DEM). A Radarsat image on 23rd July, 2004 was used for Screen Digitizing in order to differentiate between flooded and non-flooded areas. The water level on the date of acquisition of satellite imagery was used to develop flood inundation map using DEM so that, it can be compared with flood inundation map obtained from satellite imagery. All the above operations were done by using ILWIS software (ILWIS 3.0 Academic, 2001).

3.7 Multispectral Image Classification

Multi-spectral image classification is used to extract thematic information from satellite images in a semi automatic way. Different methods for image classification exist; some of them are based on the theory about probabilities. In order to make the classifier work with thematic classes, some "knowledge" about the relationship between classes and feature vectors must be given. Theoretically, this could be done from a database in which the relationships between (thematic) classes and feature vectors are stored.

At a certain image pixel in M bands simultaneously, M values are observed at the same time. Using multi-spectral (SPOT) images, where M=3, three reflection values per pixel are found. For instances, (34, 25, 117) in one pixel, in another (34, 24, 119) and in a third (11, 77, 51). The values found for 1 pixel in several bands are called feature vectors. It can be recognized that the first two sets of values are quite similar and that the third is different from other two. The first two probably belong to the same (land cover) class and third one belongs to another class.

In this study Multi-spectral image classification through ILWIS 3.0 software was used to classify land cover. In this regard for identifying agricultural and non-agricultural land a Landsat image on 24th February, 2005 of the study area was used.

3.8 Screen Digitizing

In ILWIS it is furthermore possible to digitize a satellite image or scanned photograph with the mouse pointer on computer screen. Screen digitizing is the process of creating or editing a segment (line) or point map while an existing raster map is displayed as a background in a map window. The raster map can be for instance a band of satellite image, a color composite, a scanned map, or a scanned photograph. The background map or photo needs to have a georeference of type: Tie-points: for satellite image; Direct Linear: when the photograph is taken with a normal camera; Orthophoto: when the aerial photograph is taken with a professional photogrammetric camera and has fiducial marks. For the direct linear orthophoto georeferences a DEM should be available. An orthophoto is a rectified (north- oriented raster map with square pixels) scanned photogrammetric aerial photograph with corrections for tilt and relief displacement.

In this study screen digitizing was used to identify flooded and non-flooded area of the study area through visual observation of the Radarsat image in order to compare flood inundation map based on DEM and Satellite image. Map through screen digitizing was also used for giving an overview of flood damages of the study area.

3.9 Development of Flood Hazard Vulnerability Function for Agriculture

Vulnerability function expresses the degree of loss on a scale between 0 for no damage and 1 for complete damage. Vulnerability function for agriculture was developed from the field survey and existing reports analysis. A depth-damage relation was followed for the development of vulnerability function.

3.10 Development of Flood Hazard Vulnerability Maps of Agriculture

Flood hazard vulnerability maps for agriculture was developed from land use or specified agricultural land use map (based on DEM), flood depth map and vulnerability function by using ILWIS software.

3.11 Overall View of the Methodology

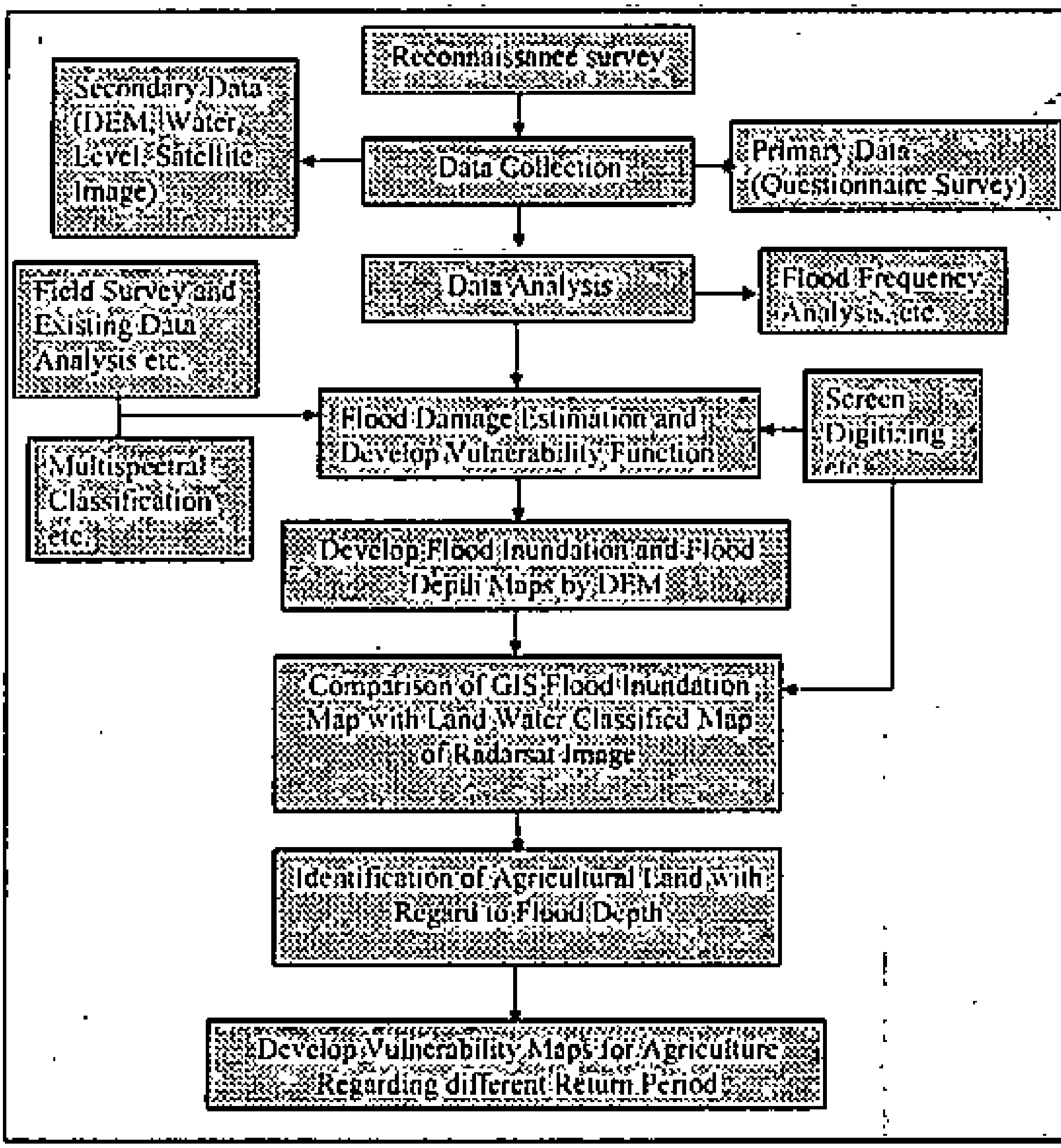


Figure. 3.1: Overall view of the methodology

CHAPTER FOUR

OVERVIEW OF THE STUDY AREA

4.1 Study Area

Tarapur union of Sundarganj thana under Gaibandha district in Bangladesh has been selected as study area. It is located in the northern part of the country (Figure 4.1 and Figure 4.2). Two major rivers bound Sundarganj thana, Brahmaputra (Jamuna) in the eastern side and Teesta in the northern part of Bangladesh. Tarapur union is situated between 25°34′ and 25°39′ north latitudes and between 89°29′ and 89°33′ east longitudes.

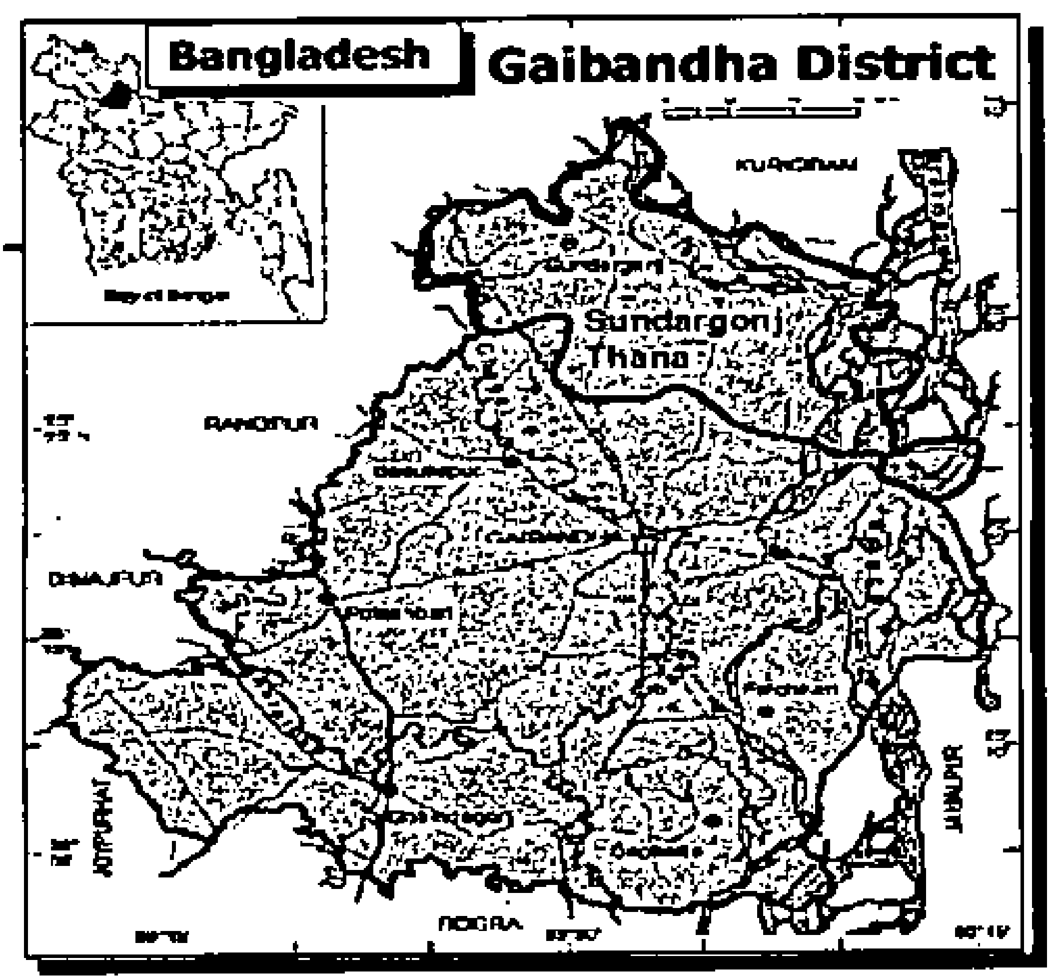


Figure 4.1: Study area map

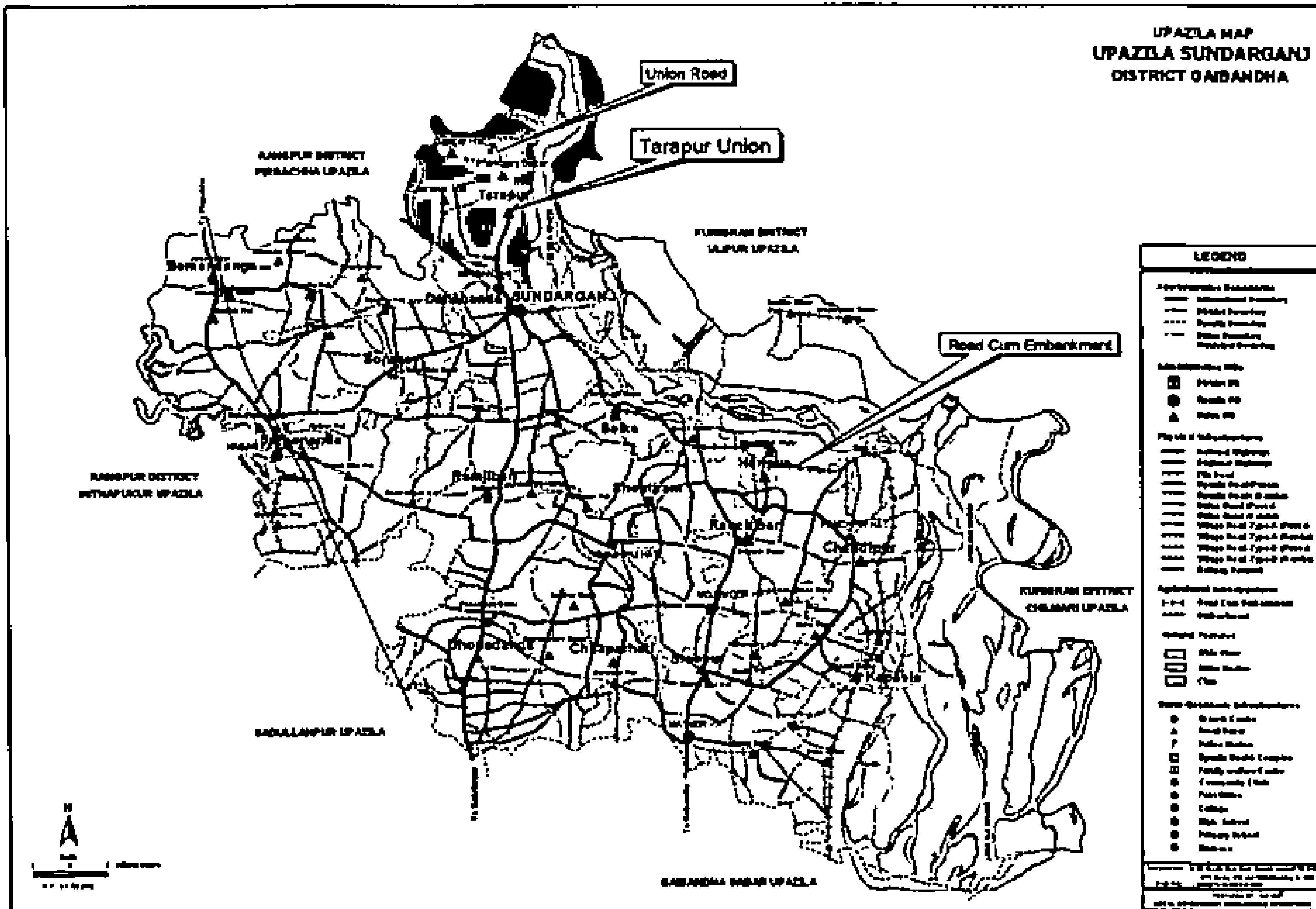


Figure 4.2: Study area map of Tarapur union

The size of urban area of Sundarganj thana is 5.0 Sq. km and population is 9, 940. Total area of Tarapur union is about 30 Sq. km. Homestead area of Tarapur union is 6.42 Sq. km. and population is 25,796 (BBS, 1994).

4.2 Climatic Condition

The climatic condition of the district is mild with equable temperature, high humidity and plenty of rainfall. The summer season commences in April and lasts up to early June. The monsoon usually sets in early July and continues till the end of September. The winter season sets in early November and lasts upto the end of February. In the months of January and February relatively severe cold is experienced in the district due to its proximity to the Himalayas and Garo hills. The average maximum temperature recorded in the district during summer is 34.2^0C while the average minimum temperature recorded in the locality in winter is 10.1^0C. During the hot months humidity is high (about 90%) and remains high until December when it falls sharply to reach a low in April. The maximum rainfall is generally observed during the months of July and August. The annual rainfall in the locality is 2872 millimeters.

4.3 Soil Condition

The soil of the district is mainly divided into two groups i.e. Khiar (Brand tract) and Poli (alluvium). The Barind tract in the northern region of the district contains brown and gray silty clay loam soils of the Older Teesta Meander Floodplain. Along the Teesta river valley, active and Young Teesta Meander Floodplain soil is also prevailing in the region. In the eastern part of the district, soil along the Jamuna river valley is active young floodplains with grey silty loam.

4.4 Topography and Hydrology

The topographical condition of the area is low gradient of the terrain and subjected to floods almost every year. As the river courses change continuously, the terrain is not much stable and is basically alluvium flood plain. This area is classified as shallow depressions and valleys of moribund river channels formed by long morphological history of changes in the river courses. Flash flood is caused by the river Teesta and the river flooding by the river Teesta and Brahmaputra. Excessive precipitation in the upstream, localized drainage congestions and insufficient capacity of hydraulic structures are the causes of flooding in this area.

4.5 Major River System of the Study Area

There are a number of rivers and rivulets in Gaibandha Zilla. These rivers are the little Jamuna, the Gaigat, the Manas, the Teesta, the Bengali, the Karatoya , the Akhira and Brahmaputra flows through eastern border of the study area. All these rivers are non-tidal and are not navigable during all seasons (BBS, 1996). Among these rivers Teesta and Brahmaputra play significant role in maintaining the flood level and characteristics of flood of the study area.

4.5.1 Teesta River

The River Teesta plays a significant role in maintaining the hydrologic characteristics of North West region of Bangladesh; carving out verdant Himalayan temperate and tropical river valleys. The emerald colored river then forms the border between Sikkim and West Bengal before joining the Brahmaputra as a tributary in Bangladesh. The river originates in the Cho Lhamu Lake at an elevation of 5,330 m (17.500 feet) above MSL in the Himalayas.

4.5.2 Brahmaputra River

The Brahmaputra is a major international river covering a drainage area of 580 000 sq. km. of which 50 percent is in China, 34 percent in India, 8 percent in Bhutan and 8 percent in Bangladesh (Goswami, 1998). The gradient of the river in the gorge section ranges from about 4.3 m to 16.8 m/km. On entering India, the Tsangpo, now called Dihang, traverses 226 km. of a mountainous course before it emerges onto the Assam plain near Pasighat (elevation 155 m). Near Kobo, 52 km. south of Pasighat, the Lobit River joins the Dihang, and the combined flow, called the Brahmaputra, moves westward through Assam for 720 km. until near Dhubri.

The Brahmaputra originates in the great glacier mass of the Kailas range in southern Tibet at an elevation of 5300 m. In Tibet, where it is called Tsangpo, the Brahmaputra flows eastward for 1100 km. At the extreme eastern end of its course in Tibet, the

Tsangpo enters a deep narrow gorge (elevation 3500 m) and continues southwards across the Himalayan range where it swerves to the south and enters Bangladesh. The Brahmaputra has a gradient of 0.09 to 0.17 m/km near Dibrugarh at the head of the valley and is further reduced to about 10 cm/km near Pandu (Goswami, 1985). The slope near Bahadurabad reduces to 7.5 cm/km and the average width of the river within Bangladesh is about 11 km with a depth of about 5 meters. The river carries sediment of about 590 million tons per year (EGIS 1997 and WARPO, 2002).

The Brahmaputra is the main source of fresh water in the dry season and also causes flooding during the monsoon. The river starts rising in March/April due to snowmelt in the Himalayas and reaches a peak in June. It rises again and reaches the annual peak in late July until mid August. The river net-work system of the study area is shown in Figure 4.3.

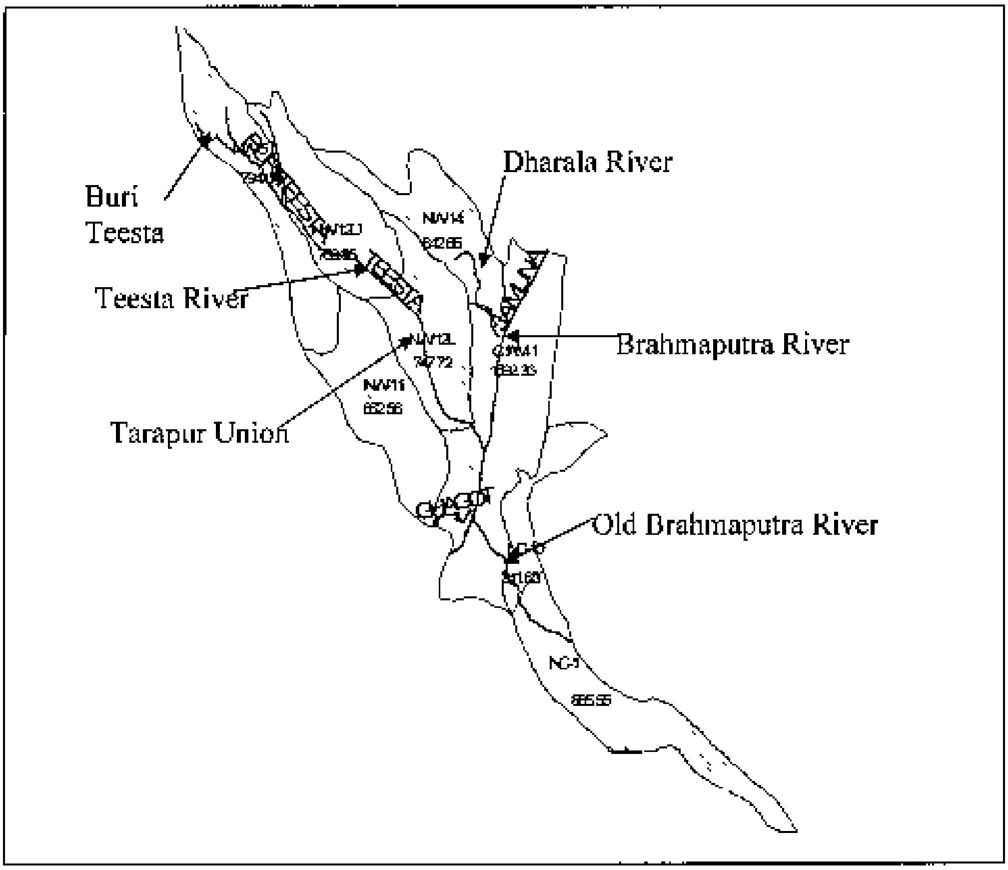


Figure 4.3: The river net-work system of the study area.

4.6 Natural Disaster

Although floods and few other disasters occur frequently in the locality but flood is more devastating and occurs very frequently. Both flash flood and monsoon flood occur in the locality. Flash flood occur normally in the month May-June where as monsoon flood occur in the month July-September. Although Teesta is responsible for both types of floods but the river Brahmaputra also has a significant influence in flood characteristics of the locality. Excessive precipitation, localized drainage congestions and insufficient capacity of hydraulic structures are the causes of flooding in this area. Flood types based on NOAA Satellite imagery for all over Bangladesh are given in the Figure 4.4.

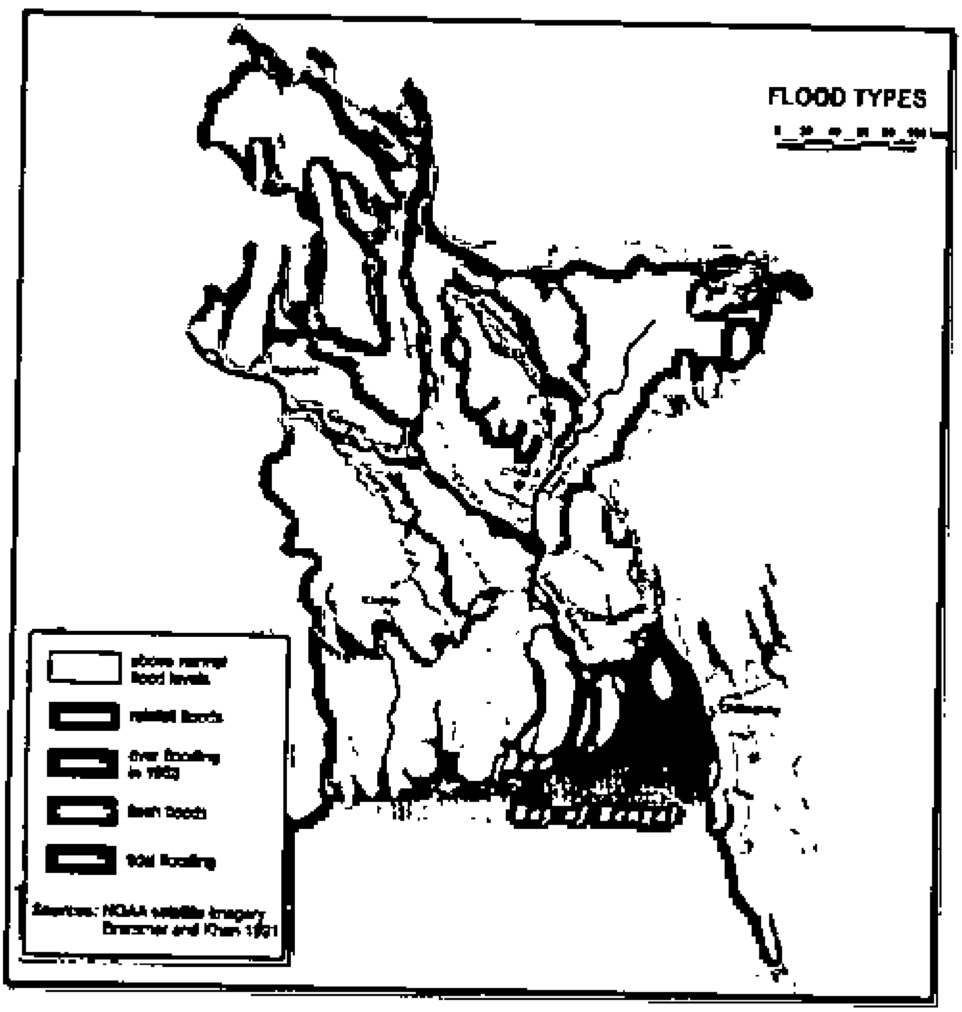


Figure 4.4: Types of flood and extent map

4.7 Agriculture

The economy of the study area Tarapur is mainly agrobased. About 62.97% holdings are farms that produce varieties of crops namely local and HYV rice, wheat, jute, mustard, potato, sugarcane, different kinds of vegetables and others (BBS, 1996). High soil fertility, climatic condition and silt deposition make the study area agricultural dependent.

Gross cropped area of the study area is 7974 acre and net temporary cropped area is 3972 acre, single crop 12.29%, double crop 74.29% and triple crop land 13.42% and cultivable land under irrigation is 70%. Among the peasants 38% are landless, 29% small, 23% intermediate and 10% rich and cultivable land per head is 0.10 hectare (BBS, 1996). Area under different landuse practices and crops in the study area are shown in Tables 4.1 and 4.2.

Table 4.1: Homestead and cropped area of Sundarganj thana (Area in acres)

Classification	All holdings	Operated area	Homestead area	Temporary crop area	Permanent crop area	Col 5/ Col 3 in %
1	2	3	4	5	6	7
All Holdings	77376	67649	5258	55779	1809	82.5
Non-Farm Households	28911	2039	1112	25	52	1.2
Total Farm Holdings	48465	65610	4146	55754	1757	85.0

Source: BBS (1996)

Table 4.2: Area under different crops of Tarapur union (Area in acres)

Name of Villages	Net Temporary Cropped	Gross Cropped	HYV Aman Paddy	Local Paddy	Wheat	Jute	Vege-tables
Chachina Mir..	840	1738	386	955	97	146	143
Ghagoa	779	1660	315	918	117	167	134
Khurda	230	452	55	191	47	91	65
Latshala	414	778	18	299	113	192	154
Nachanigoa	238	597	168	219	53	86	58
Nohati Chachi..	377	700	133	347	67	73	72
Nizam Khan	464	984	162	316	109	114	164
Tarapur	630	1065	36	534	137	228	122

Source: BBS (1996)

Table 4.3 represents the basic characteristics of agricultural landuse practices of Sundarganj Thana.

Table 4.3: Basic characteristics of agricultural landuse practices of Sundarganj thana (Area in acres)

Items	All holdings	Total farm holdings
Homestead area	5258	4146
% of farm holding	100	78.85
Net cultivated area	58258	58170
% of operated area	86.1	88.7
Area under permanent crop	1809	1758
Net temporary cropped area	55780	55755
% of net cultivation area	95.7	95.8
Net irrigated area	41264	41249
% of cultivated area	70.8	70.9

Source: BBS (1996)

4.8 General Information of the Study Area

Among the total population of the study area males are 51.84% and female 48.16%; population density per sq km is 1988 (BBS, 2001). Administration of Sundarganj thana was established in 1875. It became an Upa-Zilla 1983. Average literacy rate is 24.1%; male 31.9% and female 16.5%. Agriculture is the main occupations for

48.57% people, agricultural laborer 29.64%, wage laborer 2.06%, commerce 6.63%, service 2.59%, fishing 1.25% and others 9.26% (BBS, 2001).

Communication facilities include roads: 46 km. pucca roads semi pucca 3 km. and mud road 650 km; railways 8 km; waterways 8 nautical mile.

CHAPTER FIVE
DEVELOPMENT OF VULNERABILITY FUNCTION

5.1 Introduction

Vulnerability functions relate hazard intensity to vulnerability (Maathuis and Schlerf, 2004). Vulnerability function determines the status of vulnerability or risk of an area which normally uses to prepare vulnerability map. Vulnerability function depends on the status of damages corresponding to hazard magnitude like flood depth, duration and number or amount of elements at risk.

For the development of vulnerability function of agriculture for Tarapur union to assess the flood hazard vulnerability the relation between flood depth and agricultural damages has been followed in this study. The function has been developed on the basis of damage to agriculture with the flood level. For establishing the relationship between flood depth and agricultural damage an extensive social field survey has been carried out in the study area. Based on this survey data and existing secondary data a depth-damage relationship between flood level and agriculture has been established in this study.

5.2 Vulnerability Function for Agriculture of Tarapur Union

From the above study, it is found that development of vulnerability function for agriculture due to flood depends on the appropriate damage estimation corresponding to rise of water level. So previous data of damages to agriculture due to flood is necessary for development vulnerability function of an area. Due to insufficient data of flood damages to agriculture of the study area, different procedures were applied in this study to estimate previous flood damage. Following steps were followed for estimating flood damage to agriculture with respect to water level.

First an identification of cropping area, types and pattern was carried out through existing secondary data analysis and multispectral classification of Landsat image.

Then classification of land of the study area based on elevation was carried out. By comparing Landsat image with land water classified map of Radar image (through screen digitizing) and on the basis of existing data of flood affected area, an overall view of flood affected agricultural land was found. Finally all of these results were compared with the collected field survey data.

5.2.1 Identification of Cropping Area and Pattern

The vulnerability function to agricultural products due to flood is closely related to different variables like the cropping pattern, location of agricultural land, flood depth, land class and duration of standing water. Identification of agricultural land is very essential for assessing the flood affected cropping area and for measuring its susceptibility to hazard. In few cases limited extent of floods become necessary or beneficial for agriculture. In general flood depth and damage to agriculture is considered as directly proportional. For identification of cropping area existing secondary data were used. Table 5.1 shows that almost 82% of the study area is now using as agricultural land.

Table 5.1: Land classification of Sundarganj thana

Sl. No.	Types of land	Area (hectare)
1	Agricultural land (currently in use)	27,052.00
2	Temporary fallow land	1950.00
3	Permanent fallow land	5370.00
4	Homestead area	3831
5	Road, Infrastructure and others	3630.14
6	Total agricultural land	34316
7	Total area	41833.14
8	% of agricultural land of total area	82

Source: Sundarganj Upa-Zilla Agricultural Department

For identification of agricultural land of the study area a Landsat image on 24th February, 2005 of the study area was used. Figure 5.1 shows vegetation or agricultural land of the study area based on multispectral classification of that image.

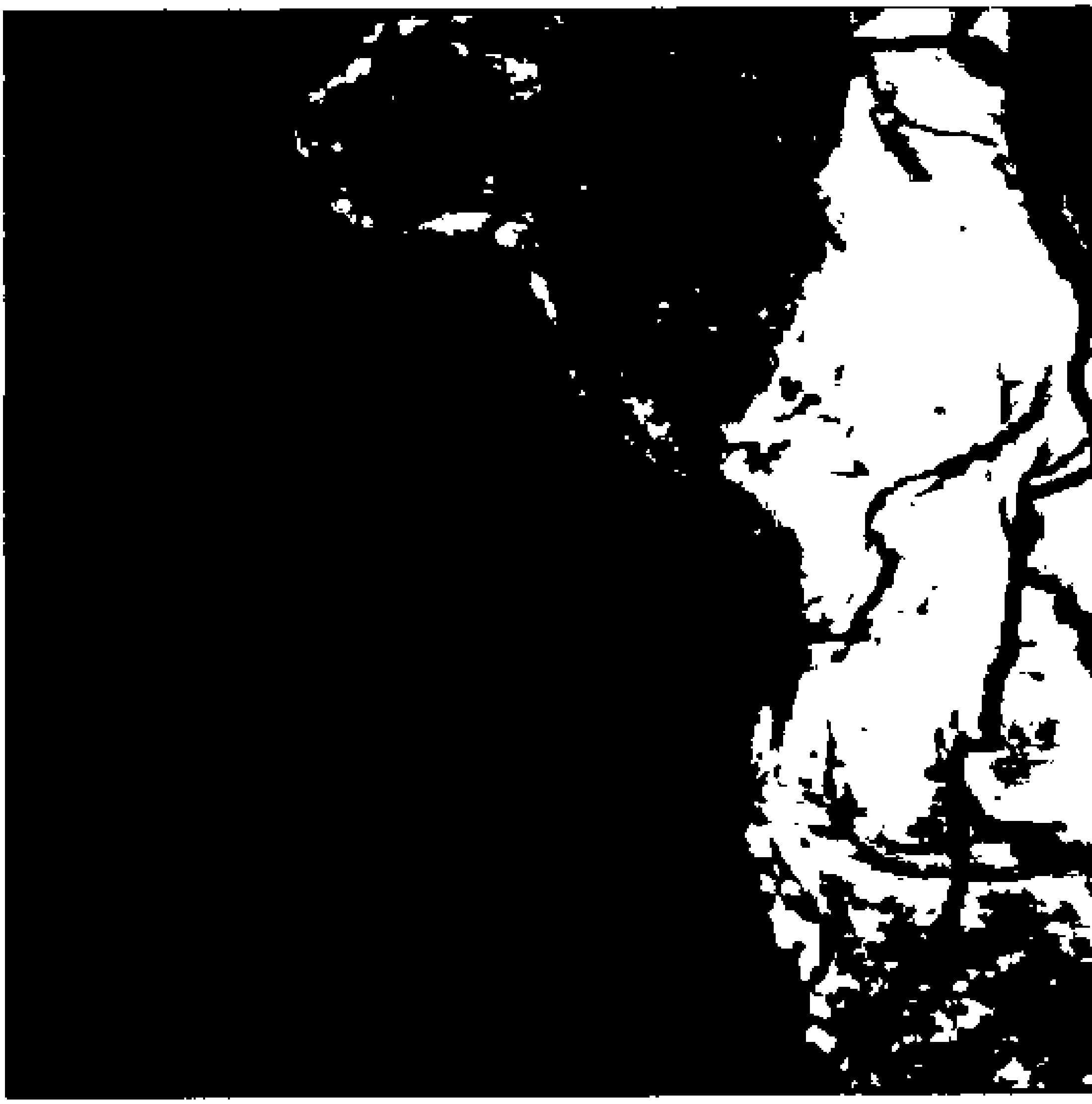


Figure 5.1: Agricultural land of the study area (Multispectral classification of Landsat image)

Visual interpretation of the classified image shows that about two third portion of the study area is covered with green vegetation and this portion is very much closely associated with the bank of the Teesta River. According to BBS (1996), the agricultural land of the study area Sundarganj thana is about 82% (Table: 5.1) which almost supports the visual interpretation of the image regarding the total cropping area.

Vulnerability to agriculture largely depends on types of crops and cultivation period. High water tolerance species is less susceptible compared to low water tolerance species. For this reason crop calendar is very important for determination agricultural vulnerability due to flood. Table 5.2 shows the crop calendar of the study area. More information of cropping area and pattern of the study area and a comparison of landuse practices of Sundarganj thana are given in Appendix-C.

Table 5.2: Crop calendar of the study area

Name of Crop	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
T. Aman - KharifII	■	■	■	■	■	■						
HYV Boro - Rabi							■	■	■	■	■	
Wheat - Rabi						■	■	■	■		■	■
Mustered - Rabi					■	■	■	■				
Pulse – Rabi					■	■	■	■				
Sugarcane - Rabi							■	■	■	■	■	■
Winter Vegetable – Rabi				■	■	■	■	■	■			
HYV T. Aus – Kharif I											■	■
HYV T. Aus – Kharif I										■	■	■

Source: BRRI, Bangladesh

5.2.2 Classification of Land based on Elevation

Sundarganj Upa-Zilla Agricultural Department prepared a land classification regarding flood inundation (Table 5.3). This table represents the land classification for the whole Sundarganj thana. Tarapur union is the worst flood affected area compared to others fifteen unions of Sundarganj thana. In field survey, maximum portion of very low and low lands were observed in three unions along with Tarapur.

Table 5.3: Land classification regarding flood inundation of Sundarganj thana

Sl. No.	Types of Land	Area (Hectare)
1	High Land (Not inundated in normal monsoon flood)	8485.00
2	Medium High Land (Inundated maximum 90 cm in normal monsoon flood)	14285.00
3	Medium Low Land (Inundated 90-180 cm in normal monsoon flood)	7978.00
4	Low Land (Inundated 180-275 cm in normal monsoon flood)	3535.00
5	Very Low Land (Inundated more than 275 cm in normal monsoon flood)	932.00
6	Total	35,215.00

Source: Sundarganj Upa-Zilla Agricultural Department (2004)

Of about 1350 hectares of currently uses Kharif-II crops area of Tarapur union about 25% area becomes inundated with flood water over 250 cm depth due to monsoon flood (Table 5.3). Moreover based on DEM of Tarapur the land classification is given in Table 5.4.

Table 5.4: Inundated agricultural land of Tarapur union based on DEM

Sl. No.	Rise of water level	Overall depth of water level	% of area inundation
1	100 cm	23.91(m)	20
2	200 cm	24.91(m)	65
4	3 00 cm	25.91(m)	90

5.2.3 Identification of Flooded and Non-flooded Agricultural Land

The study area Tarapur union experienced the worst damage due to monsoon flood in July, 2004. A Radarsat image on 23rd July, 2004 of the study area was also used to identify flooded and non-flooded area through screen digitizing (Figure 5.2).

By merging both the images (agricultural land classified Landsat image and flooded and non-flooded area classified Radarsat image) flood affected agricultural land can be identified. From visual interpretation of both the images, it was found that almost all the agricultural land was inundated.

Flooded Area 78 %   Non-Flooded Area 22%

Figure 5.2: Flooded and non-Flooded Area. (Screen digitizing of Radarsat image of the study area)

Data or information regarding damages due to the monsoon flood was not sufficient in the study area. Only an estimation of overall natural disaster affected agricultural land of the year 2004-05 was carried out by Upa-zilla Agricultural Department. The available damage data for the year 2004-2005 to agriculture of the study area is given in table 5.5.

Table 5.5: Flood and other disasters affected cropping area of Sundarganj thana

(Hectare)

Sl. No.	Types of Crops	Area Cultivated	Area Affected	% of affected area
1	Kharif-II	18800	15228	81
2	Jute	990	342	35
3	Oil Seeds	1010	382	38
4	Wheat	800	75	9
5	Vegetables	280	99	36

Source: Sundarganj Upa-Zilla Agricultural Department (2004 -2005)

According to the Upa-Zilla Agricultural Department of Sundarganj the overall flood affected agricultural land is 81% (Table 5.5) which is very close to the overall flood affected area (78%) found in land water classified map of Radarsat image. So based on this data (both image and Agricultural Department) of flood affected area due to monsoon flood and level of water (25.51m PWD) on the date of Radarsat image acquisition 23rd July, 2004 a depth-damage relation for agriculture of study area can be established. For the development of depth-damage function of agriculture for Tarapur union, all of these data are widely analyzed with field survey data to establish the relationship more fruitfully and more logically.

5.3 Development of Vulnerability Function for Agriculture through Depth-Damage Relation

Although the study area is located in a floodplain locality but the terrain is not so much flat. Due to this depth of flood water level varies in different location corresponding to a fixed level rise of water level. In this regard for the development of a depth damage function, the study area has been divided into four categories based on the elevation. This land classification has been done on the basis of extensive field observations and existing data analysis (Table 5.4) of Tarapur union of Sundarganj Upa-Zilla Agricultural Department.

The field survey was conducted on the basis of a questionnaire through personal interview with the villagers of Tarapur union. About 48 villagers of different villages of the study area, and a group of three officials of Upa-Zilla Agricultural Department headed by Upa-Zilla Agricultural Officer were interviewed in the survey.

From the field survey and existing data analysis it is found that in monsoon (July to September), one meter rise of water level leads to 100 % damage to all crops in the very low lying river associated land. Where as about 2 meter rise of water level causes 100 % damage to all crops in low land crops and a 2.5 meter and 3 meter rise of water level causes 100 % damages in all medium and high land crops of the study area, respectively.

From the above data analysis it could be summarized that in monsoon (July to September) about 30% of the total agricultural crops of the study area is damaged due to 1 (one) meter or about 3.5 feet rise of monsoon flood water where as about 50% crops is damaged if the level of water rises by 2 meter or about 7 feet. Again another 0.5 meter rise of water level leads to over all 80% damage of crops and finally overall 3 meter rise of water level leads to 100% damage of all kinds of crops of the locality.
Table 5.6 shows overall view of depth-damage relation of agriculture for Tarapur. Based on this table the function of agricultural damage due to monsoon flood for Tarapur union has been developed.

Table 5.6: Overall view of depth-damage relation of agriculture for Tarapur union

Sl.No.	Rise of flood water level (m)	% of damage to agriculture
1	1	30
2	2	50
3	2.5	80
4	3	100

Vulnerability function of agriculture for Tarapur union based on field survey and existing data analysis is given in Figure 5.3.

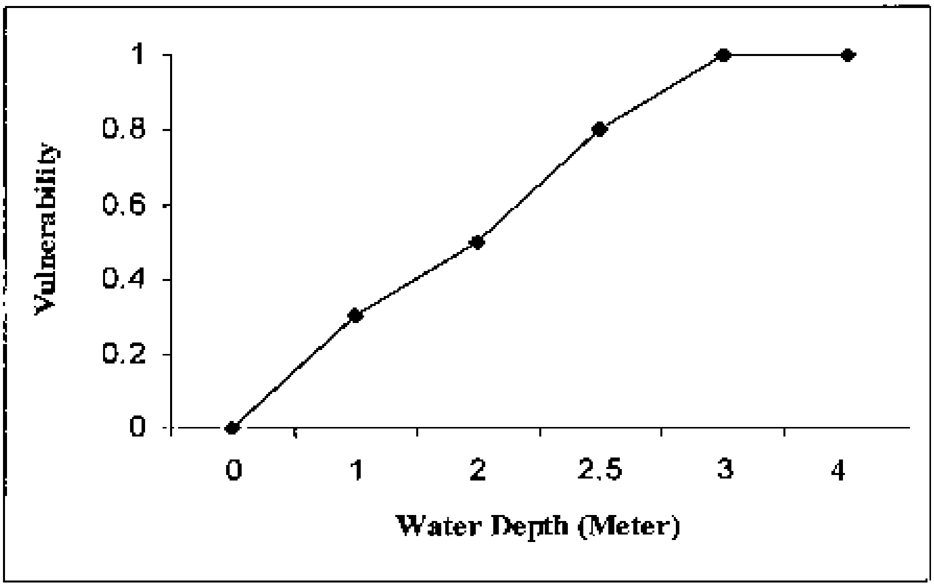


Figure 5.3: Vulnerability function for agriculture of Tarapur union

Vulnerability function shows more or less a linearly increase trends up to three meter depth and then it becomes horizontal as three meter rise of water level brings 100% or complete damage to crops. The increase of vulnerability from 0 to 1 meter depth and 1 to 2 meter depth was sharper than that from 1 to 2 meter depth.

This vulnerability function has been used to generate vulnerability maps from flood inundations and flood depth maps for different return periods.

CHAPTER SIX
ANALYSIS AND DISCUSSION

6.1 Introduction

Flood occurs in different magnitudes in each year in Bangladesh. The recent flood of 2004 was abnormal in character and magnitude. Huge damages to crops, property and infrastructure and losses of life had occurred. The damages to agricultural products are closely related to the cropping pattern and flood depth. The choice of crops to be grown in an area is determined to a large degree by flooding characteristics. The depth, timing, duration and rate of rise and fall of water levels are important factors influencing when and what crops can be grown. Judging from the relationship among crops, land class and flood depth, flooding does not always result in crop damage and there is a phenomenon that the floods and crops have been co-existing. Here it should be noted that floods do not only result in damage but can also benefit crops and farmers through an appropriate study. Hence development of flood hazard vulnerability map is essential, and helps devise an appropriate management policy. For better management of flood and for reducing the intensity of flood damages and for selection of location for agricultural and other activities, flood vulnerability map regarding different return periods could be important tools. In this section flood hazard vulnerability maps have been developed through flood inundation maps, flood depth maps and vulnerability function by using geoinformatics to assess flood hazard vulnerability for flood different magnitudes.

6.2 Determination of Water Level at Tarapur

In order to develop flood vulnerability map due to monsoon flood of the study area, water level data for the monsoon period (July to September) of the river Teesta at Tarapur is needed. As no water gauge station of the river Teesta at Tarapur is available, the water level of Teesta at Tarapur has been determined through interpolation based on distance.

To determine the water level at Tarapur, the rivers Buri-Teesta (00 to 35.00 km), Naotara. (00 to 10.00 km), Teesta (13.50 to 121.00 km), Dharala (21.5 to 48.00 km), Ghagot (132.27 to 138.00 km), Jamuna (8.00 to 84.50 km) and Brahmaputra (00 to 31.00) have been considered. Actually Tarapur area lies on the bank of the river Teesta at the chainage of 103.19 km from Dalia. The Teesta faces influence on its stage/inflow during flood period by the other rivers as considered in this network. Figure 6.1 shows the basic network mentioning the name of rivers.

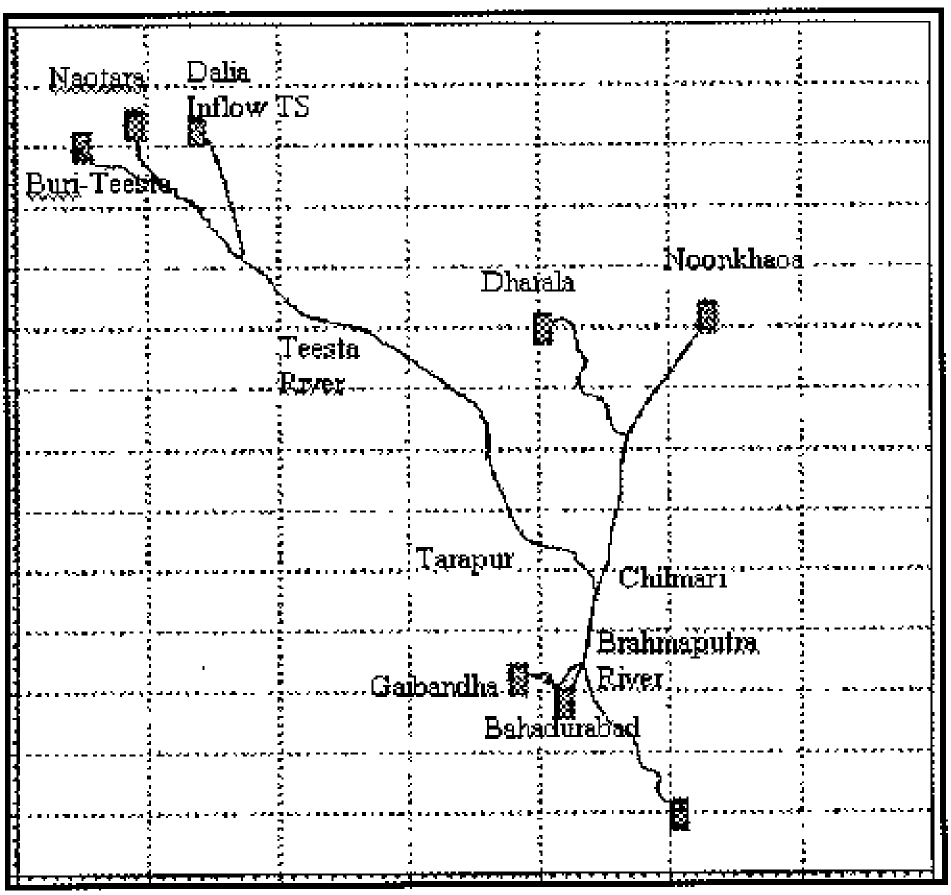


Figure 6.1: River network system of the area

Based on the water level of Dalia and Chilmari, the water level of Tarapur has been determined through interpolation as Tarapur is located in between these two stations. The interpolated value then compared with others very closely associated water gauge stations. Figure 6.2 shows maximum yearly (July to September) water level of different stations.

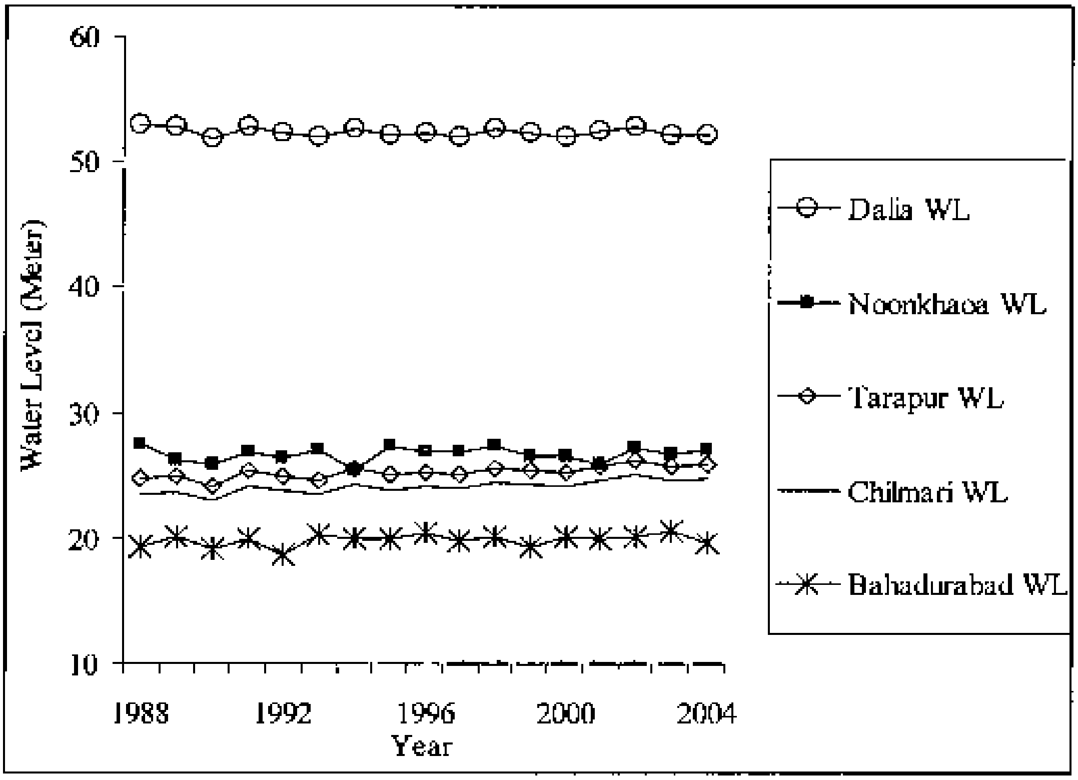


Figure 6.2: Maximum water level of Tarapur through interpolation (July to Sept.)

6.3 Flood Frequency Analysis

For preparing flood extent, depth and vulnerability map of the study area, water level are considered based on different return periods. To determine the water level of Tarapur in response to 2-,5-,10-,20-and 50-year return periods flood, frequency analysis was conducted based on the water level data of the year 1988 to 2004. Based on the most appropriate Pearson Type III distribution, water levels for different return periods are given in the Table 6.1.

Table 6.1. Water levels from flood frequency analysis

SI. No.	Return Period (Year)	Water Level (Meter)
1	2	25.31
2	5	25.71
3	10	25.91
4	20	26.07
5	50	26.24

6.4 Digital Elevation Model

Digital Elevation Model (DEM) is one of the essential data for flood study of an area using ILWIS This study is very much dependent on DEM of the study area. The DEM of Tarapur is given in the Figure 6.3. The resolution of the DEM is 50 m

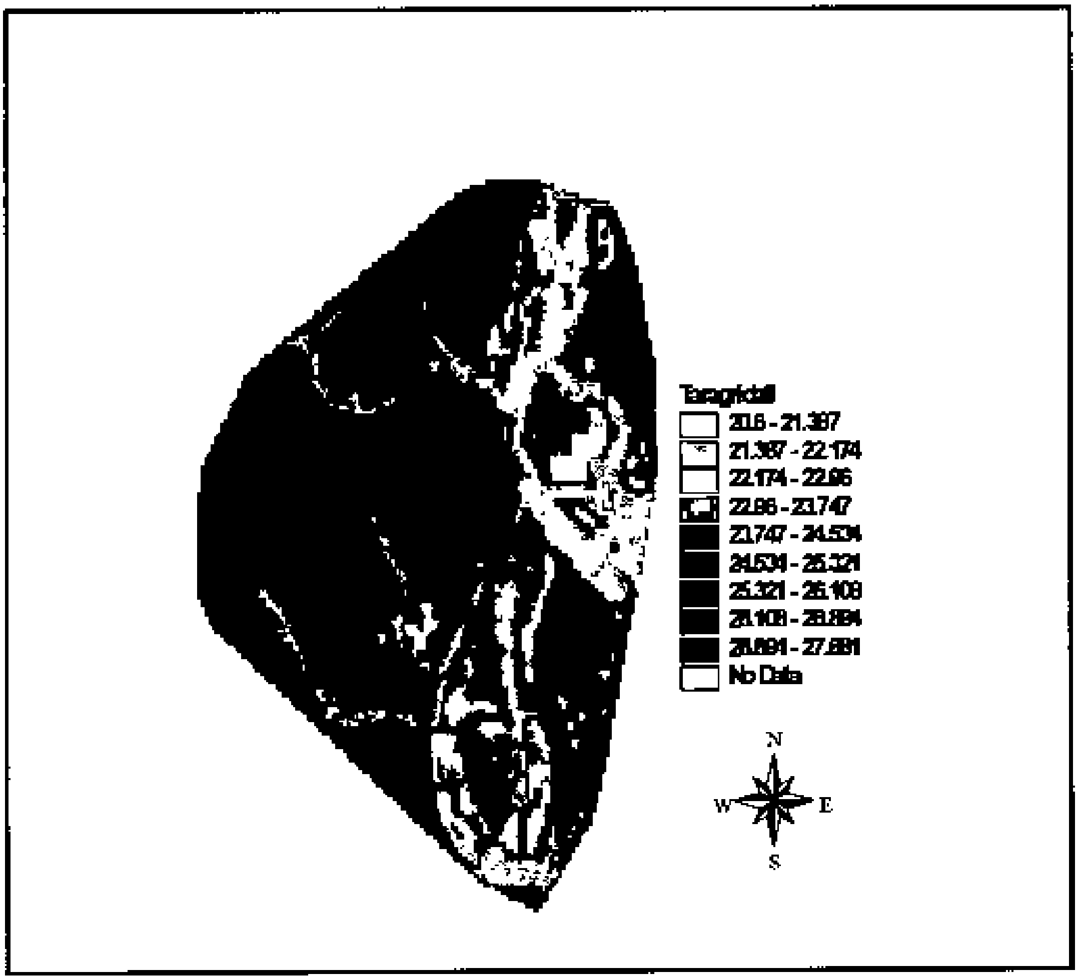


Figure 6.3: Digital Elevation Model (DEM) of Tarapur area

The DEM of Tarapur, prepared by BWDB, has been used for this study for spatial analysis to assess the flood extent and flood depth map for five return periods. The DEM is also used for identification of agricultural land use, homestead area and for preparation of vulnerability map for agriculture. The DEM can also be used for determination of homestead damages, planning of flood mitigation and economical analysis for feasibility of the flood mitigation project.

6.5 Flood Inundation Map

Flood inundation or extent maps have been prepared based on the Tarapur DEM using the flood level 25.31m, 15.71m. 25.91m, 26.07m and 26.24m corresponding to 2-, 5-, 10-, 20- and 50-year return periods. In this procedure, assuming one breach location at the outlet of the existing river system a map named 'start' has firstly been prepared. The flood inundation maps have been computed using neighbourhood functions where pixels assigned as flooded are at or below the flood levels and connected to the breach location, to prevent areas that are lower than the specified flood levels but are not connected to the affected area from taking in to consideration. The output maps are flood inundation maps indicating flooded and non-flooded areas for each particular flood water level. Flood inundation maps have been calculated by iteration. Displaying the breach location map: start. It is found the Value '?' stands for background (undefined); and Value '1' stands for breach location,

In the output flood inundation or flood extent map for 2-year return water level has been considered 25.31 meter above the mean sea level. The output flood inundation map with a value ranging from 0 to 1 and precision of 1, is the flood inundation map defining the 2-year return period flood inundation map. The process in words: if the altitude in the used Digital Elevation Model is more than 25.31 meter, then return the pixel values of raster map Start (which are undefined, as is indicated by the ?) otherwise, assign the maximum value of the neighbouring pixels found in raster map Start (which is the value of 1). In the first iteration there is only one pixel that has value 1 (the starting pixel). In every iteration, the neighbouring pixels that satisfy the conditions (altitude < 25.31 meter) will get the same value as that starting pixel. This will continue until the next neighbouring pixels have an altitude of more than 25.31 meter. If there is no connecting pixels <25.31 meter exists, then the process stops and the results are displayed. The flood inundation map for 2-year return period is shown in Figure 6.4

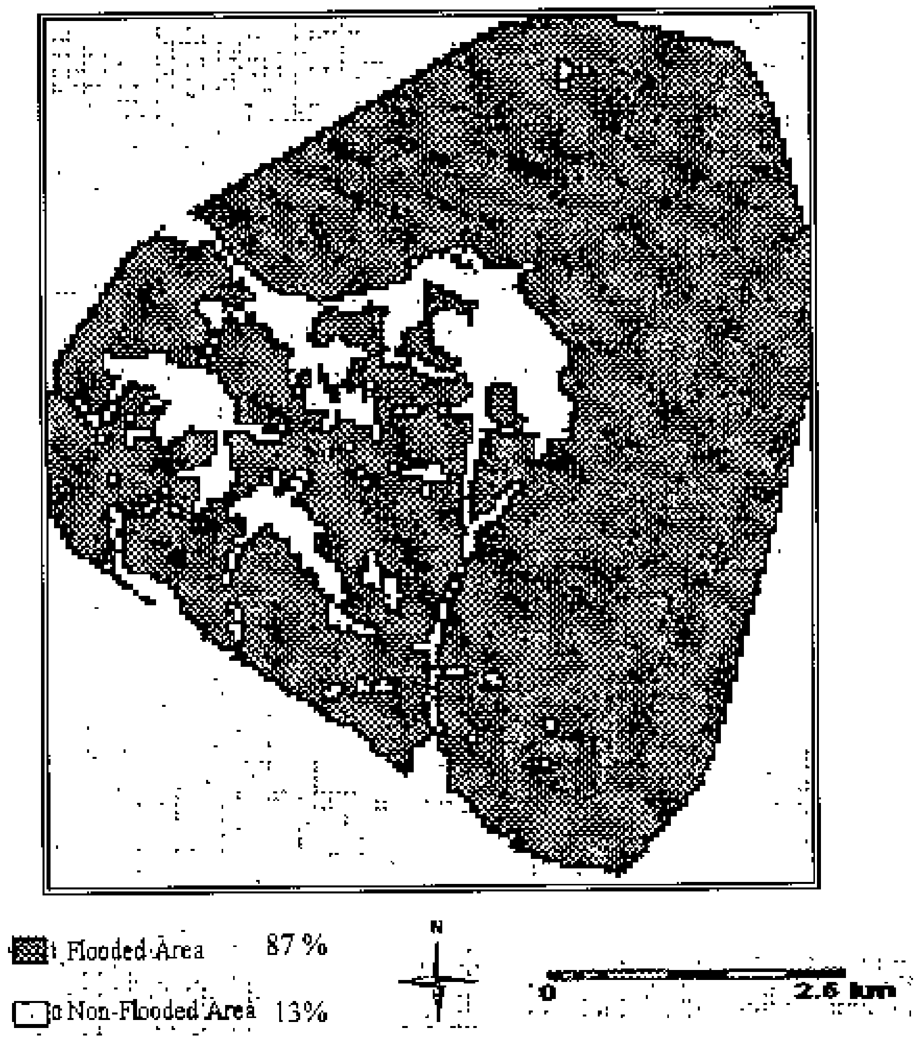


Figure 6.4: Flood inundation map for 2-year return period

Following the same procedure flood extent map for 5-,10-, 20- and 50- year return periods corresponding to 25.71m, 25.91m, 26.07m, and 26.24m depth of water levels are shown in Figures 6.5, 6.6, 6.7 and 6.8, respectively.

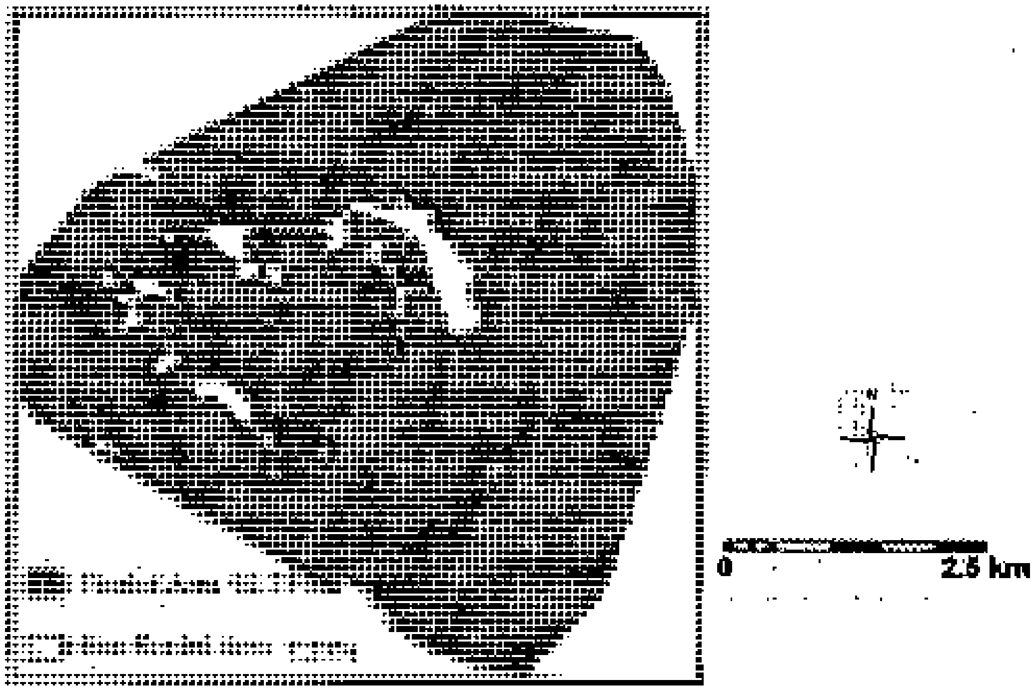


Figure 6.5: Flood inundation map of 5-year return period

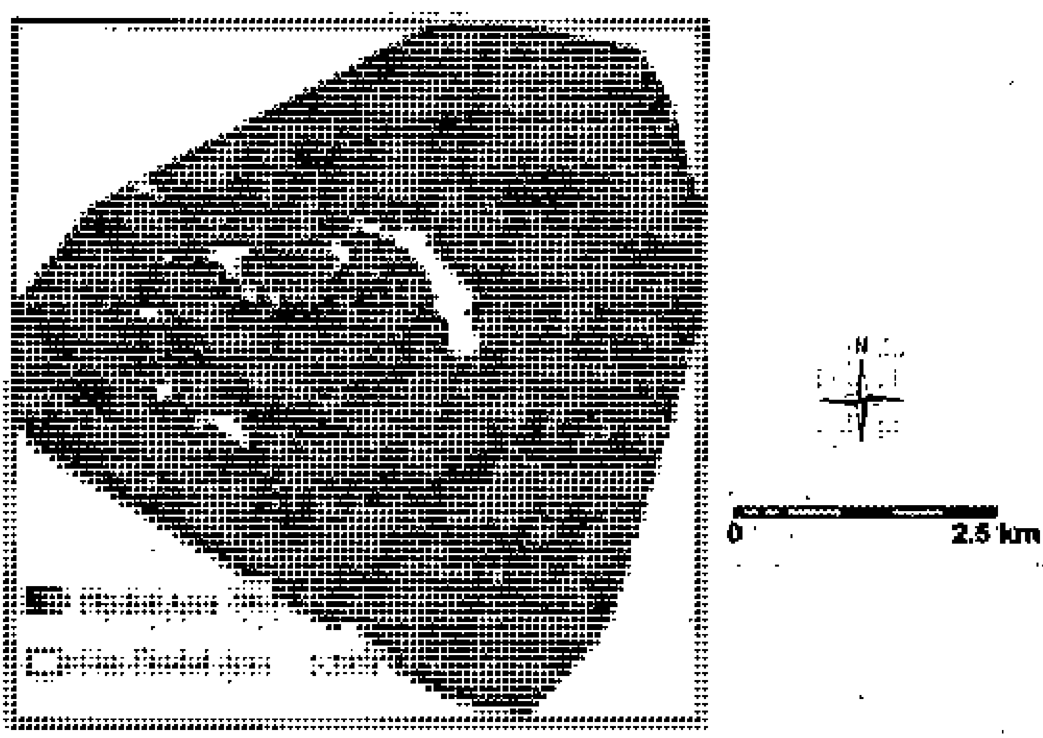


Figure 6.6: Flood inundation map for 10-year return period

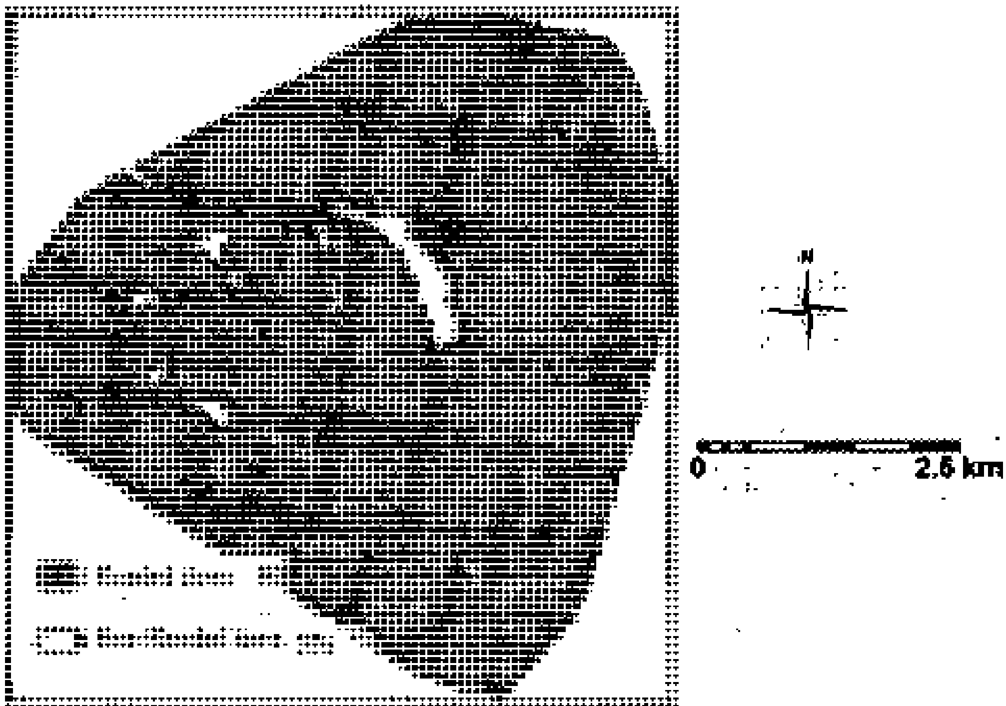


Figure 6.7: Flood inundation map for 20-year return period

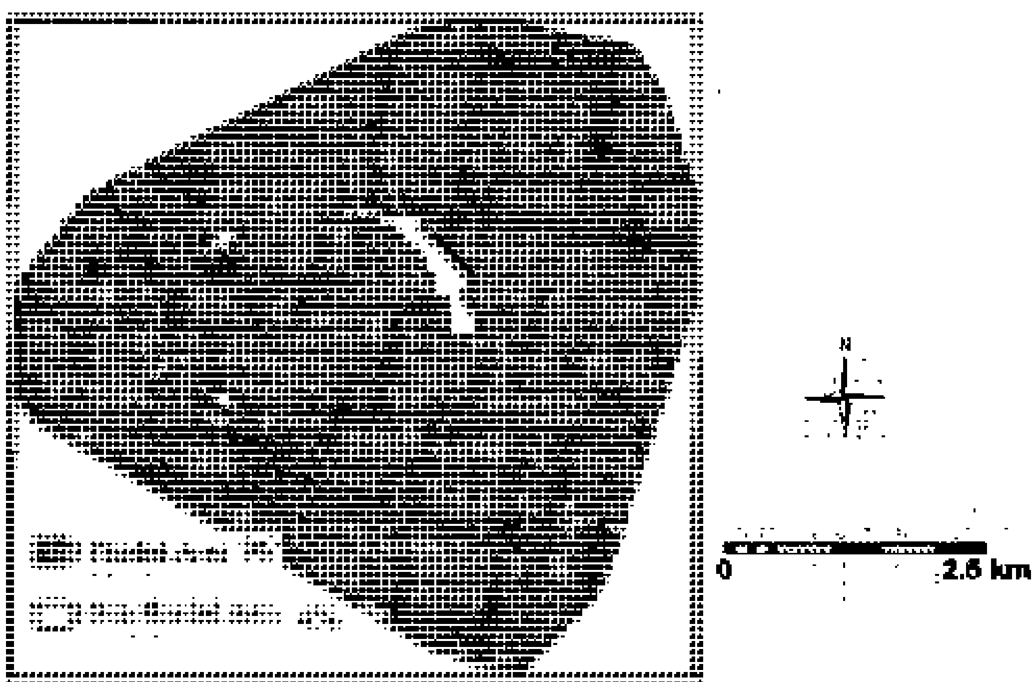


Figure 6.8: Flood inundation map of 50-year return period

6.6 Comparison of Flood Inundation Map based on DEM and Satellite Image

Flood inundation maps based on DEM and water level 25.5m on the date of satellite image acquisition on 23rd July, 2004 and land-water classified map of the study area based on screen digitizing of Radarsat Image on the date 23rd July, 2004 are shown in the Figures 6.9 and 6.10, respectively.

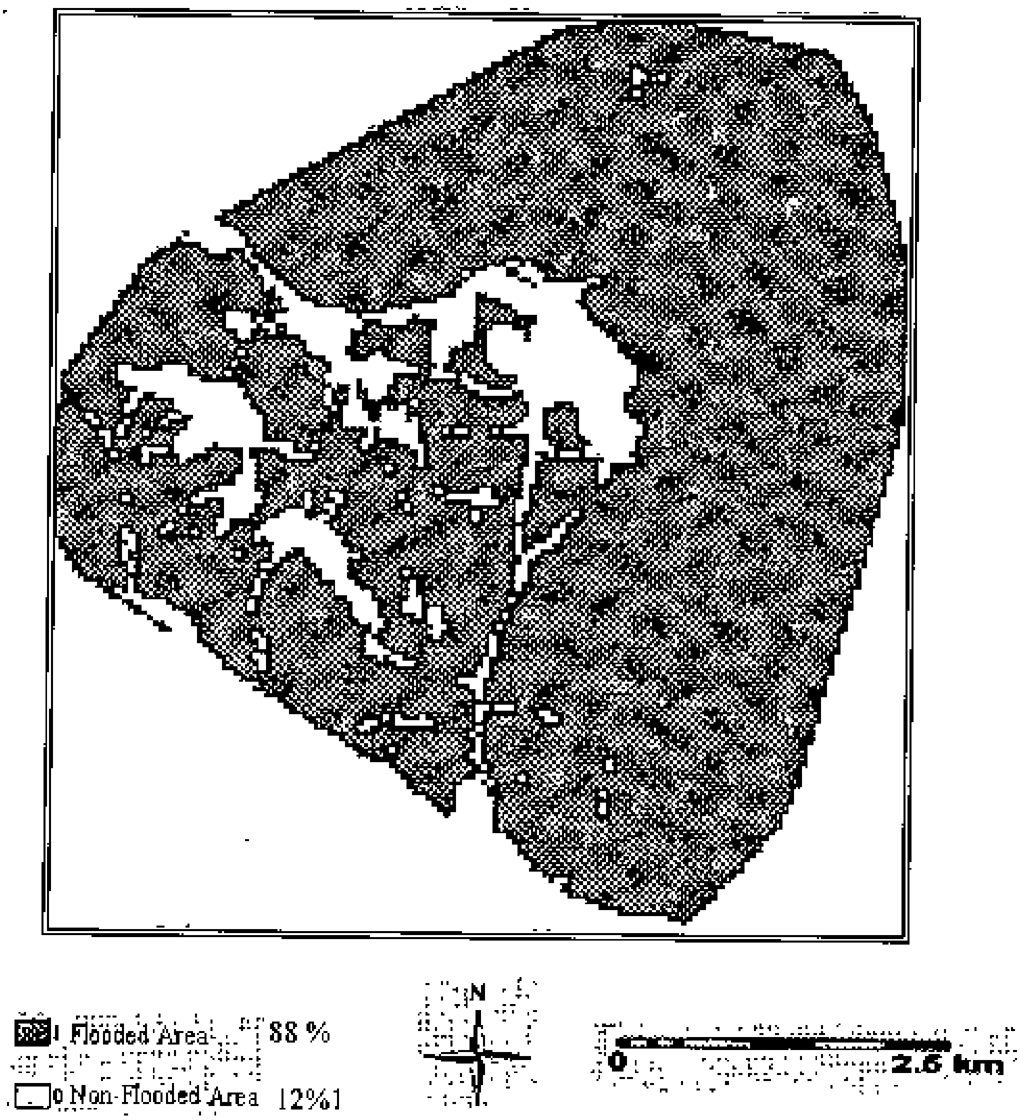
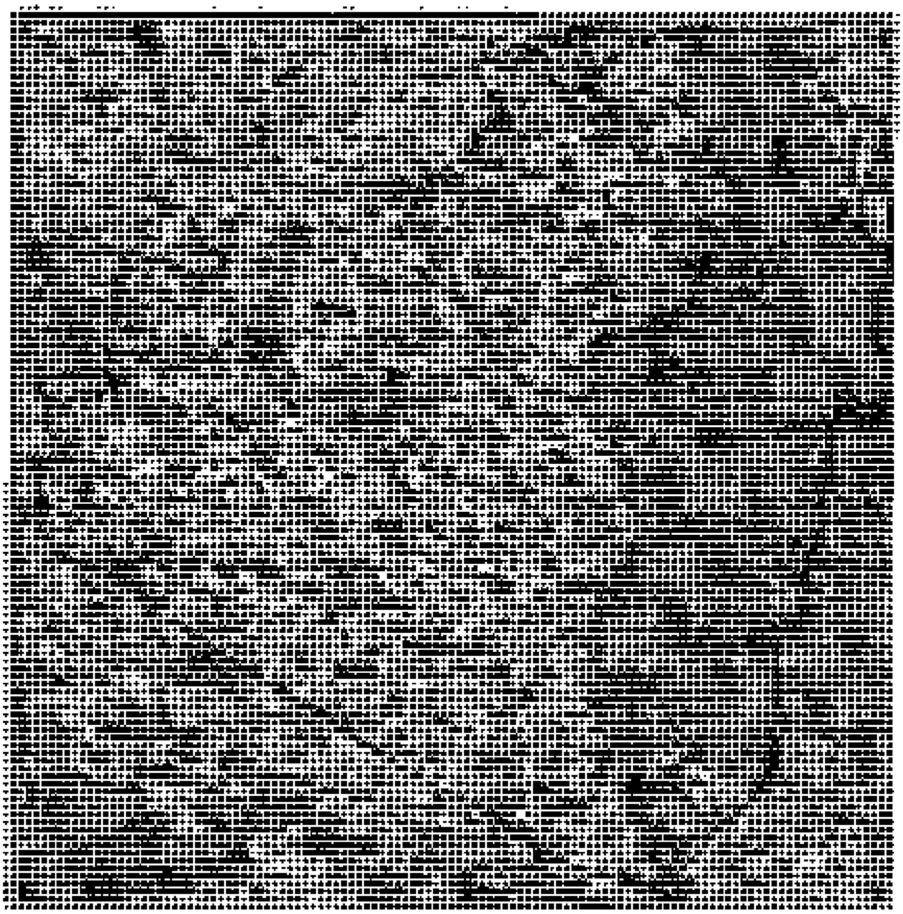


Figure 6.9: Flood inundation map based on DEM and water level data on the date of satellite image acquisition (23rd July, 2004).



Flooded Area 78% (approx.) Non-Flooded Area 22% (approx.)

Figure 6.10: Land water classified map based on screen digitizing of Radar image on 23rd July, 2004.

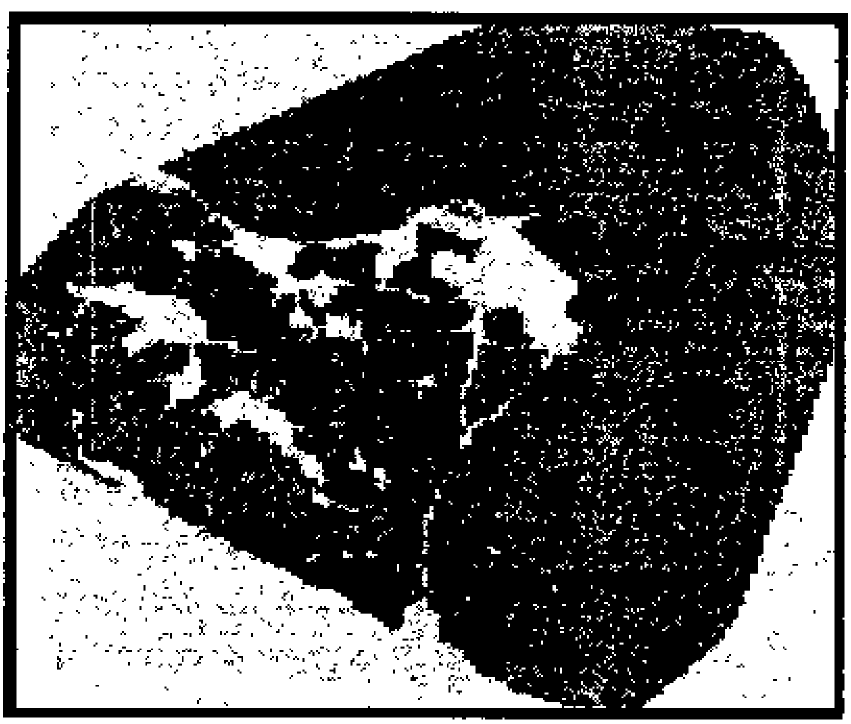
The water level at Tarapur on 23rd July, 2004 was found to be 25.5 meter on the basis of interpolation of water level data of the boundary rivers of the study area. The interpolated water level closely represents original data. This is why a little bit of dissimilarity between flood inundation map based on DEM (88% flooded) and land-water classified map based on screen digitizing of Radar Image on 23rd July, 2004 (78% flooded) was found (Table 6.2). The dissimilarity may also be due to quality of DEM. But from the satellite image it is found that the maximum land area was inundated on 23rd July, 2004. Flood inundation map based on DEM represent the same.

Table 6.2: Overall view of the flooded and non-flooded area

Sl. No.	Types of inundation map	Depth of water	% of area flooded	% of area- non flooded
1	2-year return period	25.31	87	13
2	10-year return period	25.91	94	6
3	20-year return period	26.07	95	5
4	50-year return period	26.24	96	4
5	Satellite image	-	78	22

6.7 Flood Level Map

As the undefined pixels in the calculated flood extent maps are not flooded the value of 0 will be defined instead of using undefined pixel values. To eliminate the undefined pixels preparation of flood level map is needed. Flood level maps based on different return periods are given below:



Undefined area   Defined area

Figure 6.11: Flood level map for 2-year return period

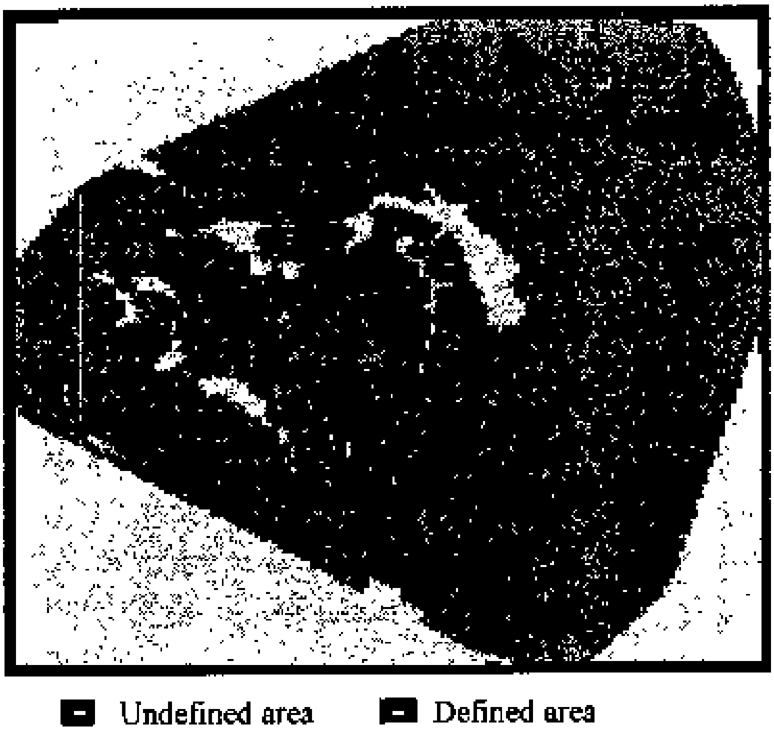


Figure 6.12: Flood level map for 5-year return period

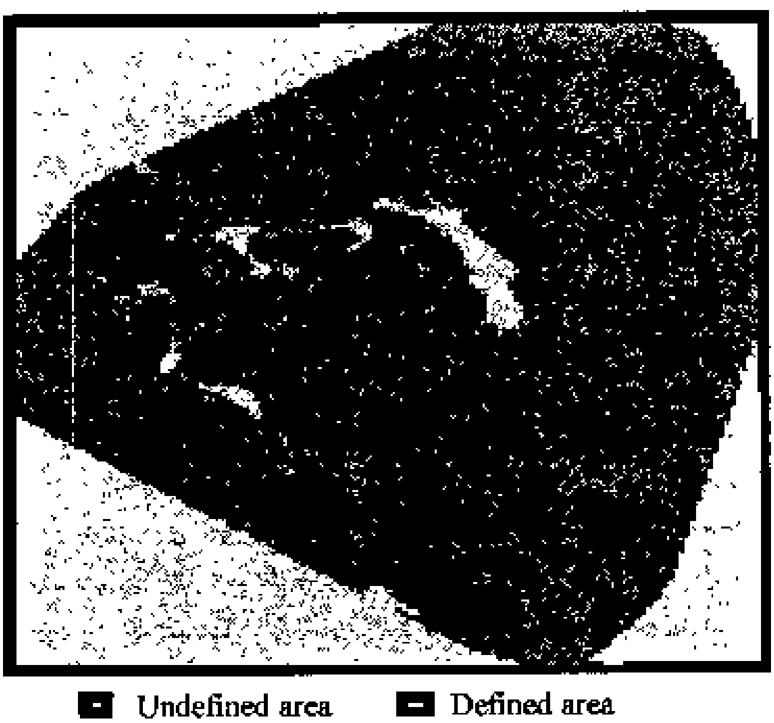
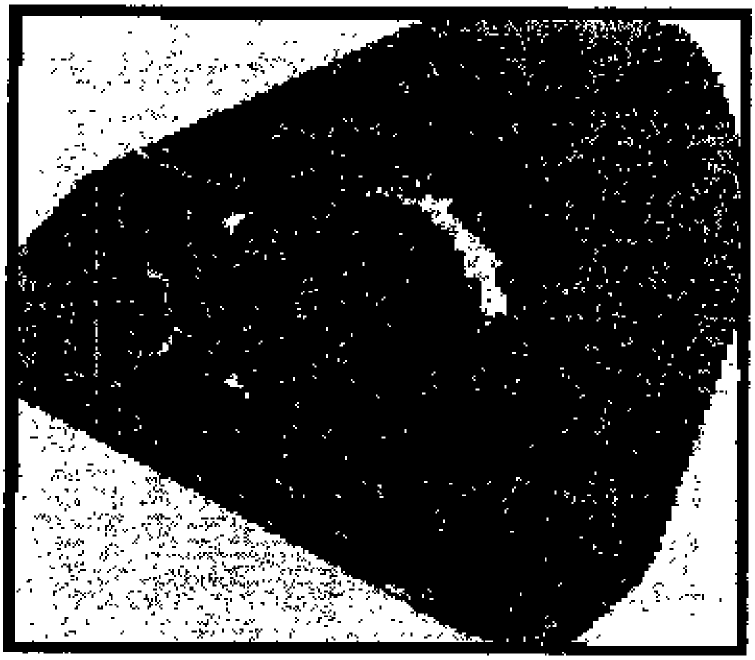


Figure 6 13: Flood level map for 10-year return period

Undefined area Defined are

Figure 6.14: Flood level map for 20-year return period

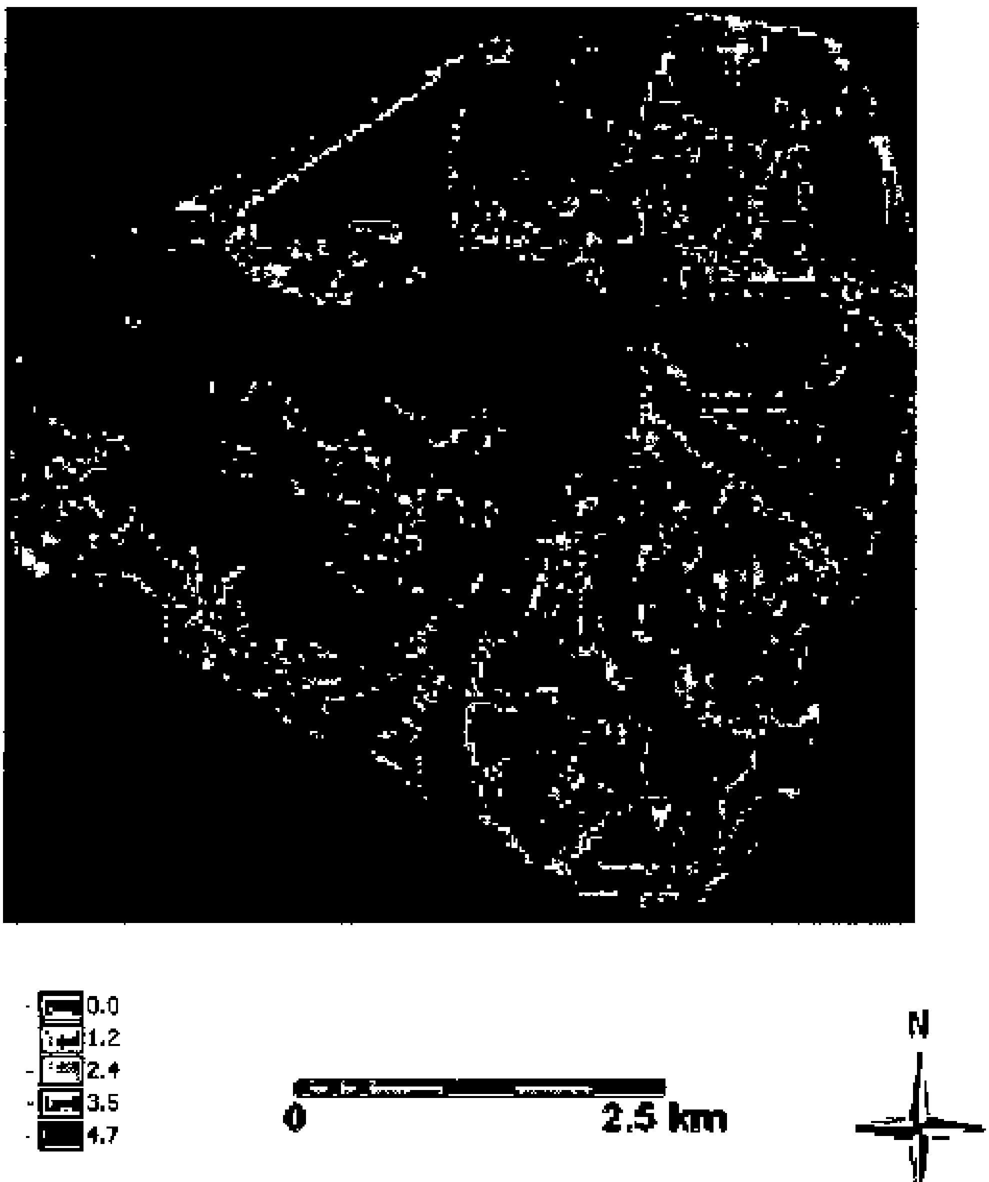


Undefined area Defined area

Figure 6.15. Flood level map for 50- year return period

6.8 Flood Depth Map

Flood depth map represents the depth of flood water in different location due to flood. To calculate the flood depth map, the elevation (from the DEM) of each flooded raster cell has been subtracted from the corresponding flood level from the different scenarios. The flood depth maps have been prepared using map calculation command from operation list of ILWIS software



Flood Depth (Meter)

Figure 6 .16: Flood depth map for 2-year return period

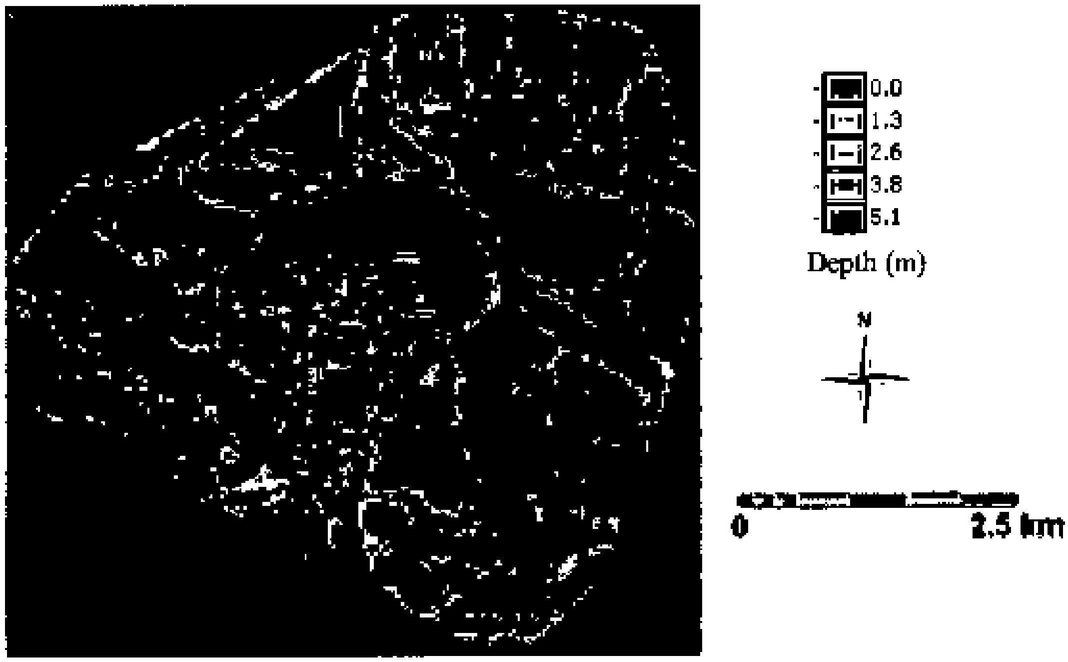


Figure 6.17: Flood depth map for 5-year return period

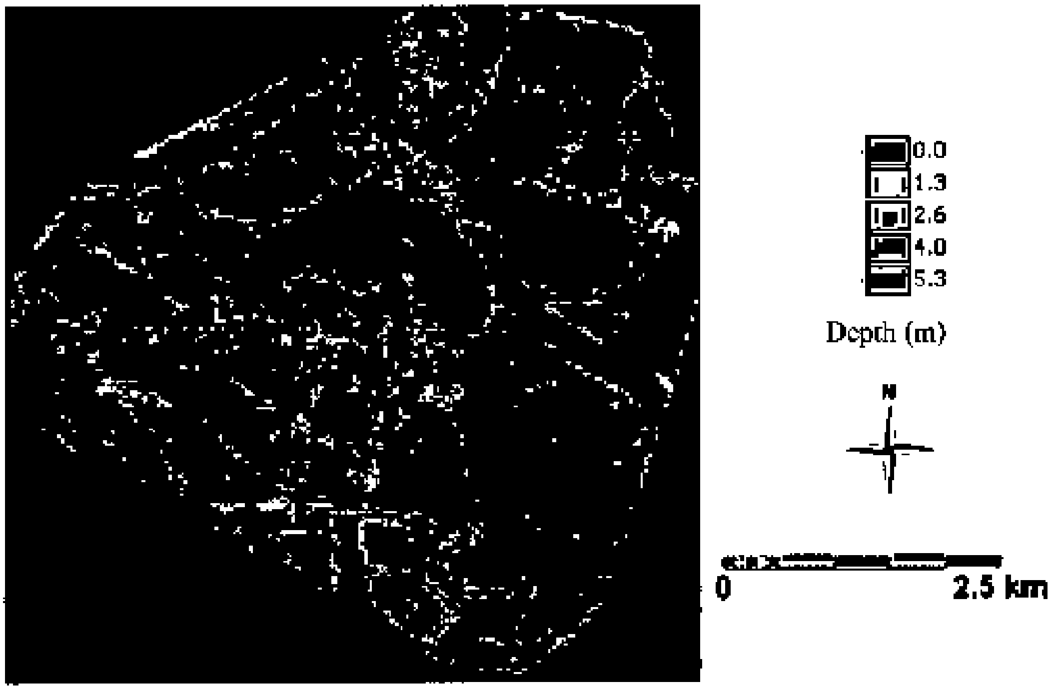


Figure 6.18: Flood depth map for 10-year return period

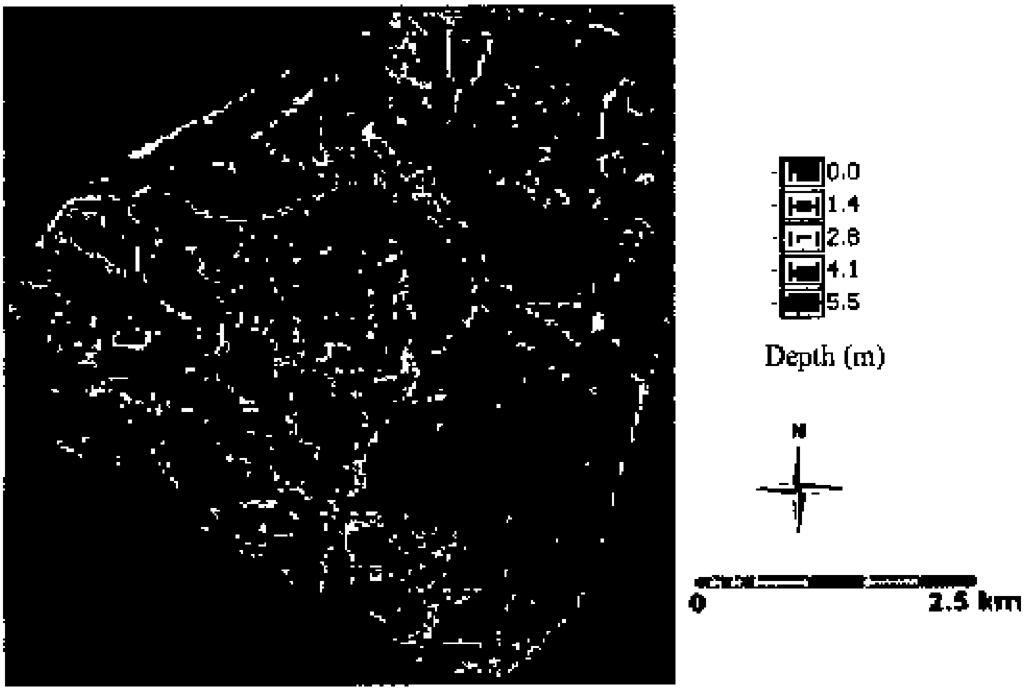


Figure 6.19: Flood depth map for 20-year return period

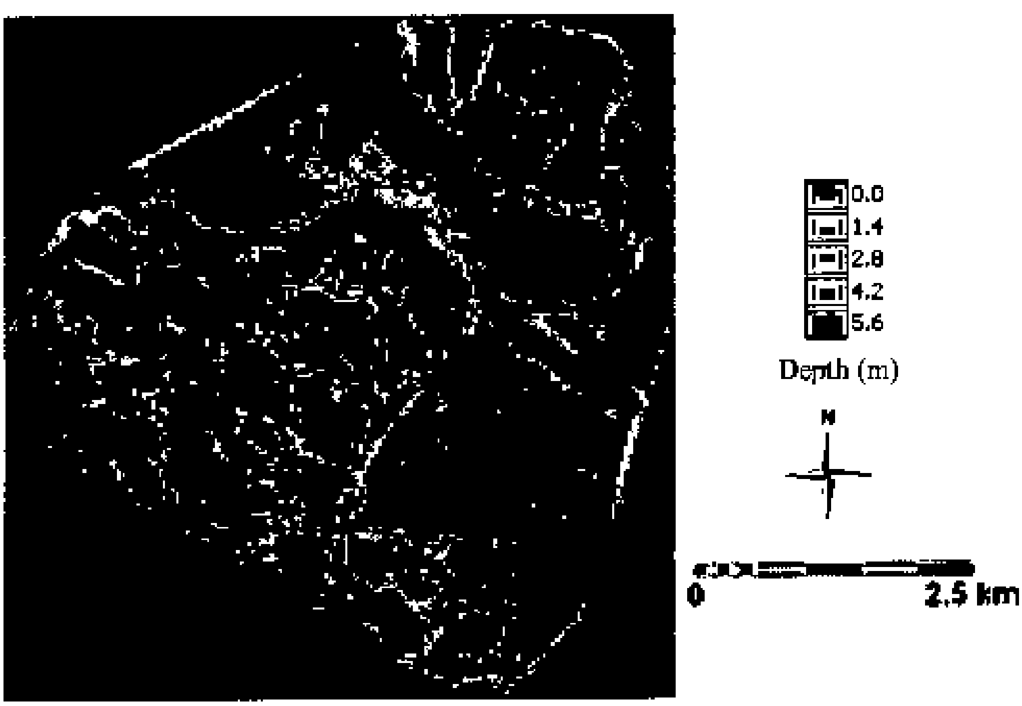


Figure 6.20: Flood depth map for 50-year return period

Table 6.3 represents overall view of flood depth observes in flood depth maps regarding different return periods.

Table 6.3: Overall view of the variation of flood depth

Sl. No.	Types of flood depth map	Maximum depth of water
1	2-year return period	4.7 (m)
2	5-year return period	5.1 (m)
3	10-year return period	5.3 (m)
4	20-year return period	5.5 (m)
5	50-year return period	5.6 (m)

6.9 Identification of Agricultural Land and Homestead Area and Infrastructure

From the water level data analysis of the major boundary rivers of Tarapur union of about 17 years for the period July to September, it is found that on average the minimum water level at Tarapur location during this period is 22.91 meter. This water level indicates that at the monsoon period all the crops are cultivated in Tarapur union above this land. So the agricultural land, homestead area and infrastrucuure of the study area Tarapur union will be >22.91 meter land as shown in Figure 6.21.

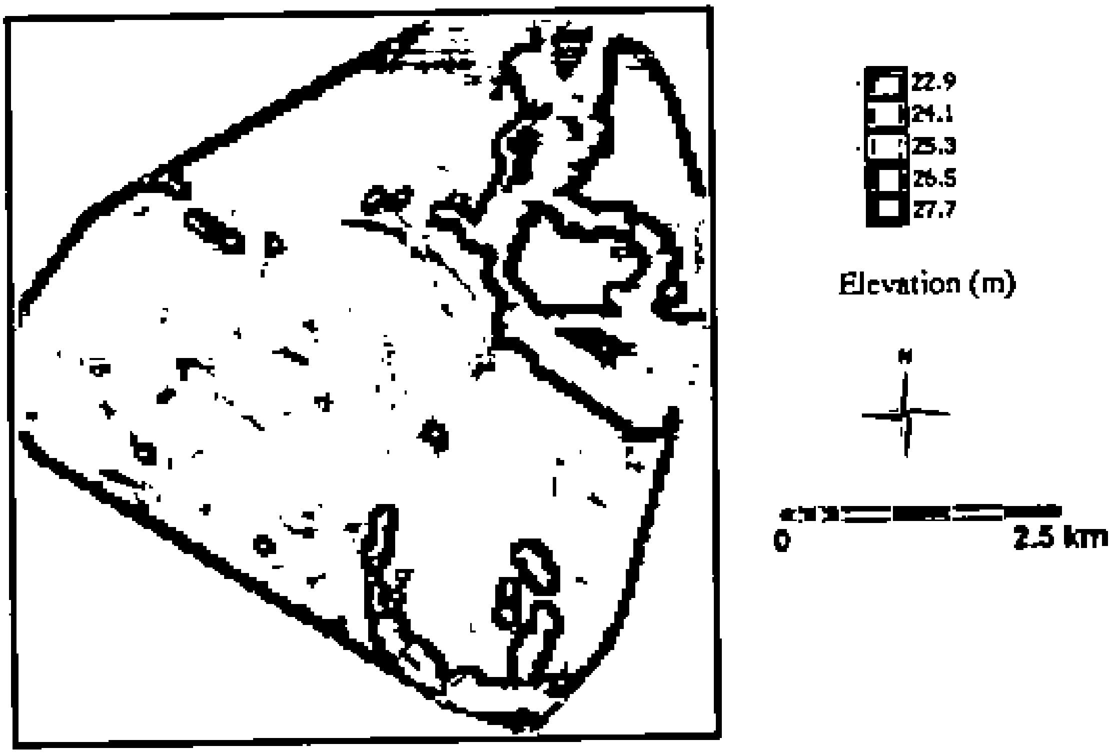


Figure 6.21: Map containing agricultural land homestead and infrastructure

As the agricultural land, homestead and infrastructure of the study area found >22.91 meter land area, the land area of Tarapur union>22.91 meter gives an indication of unspecified landuse map of the study area based on DEM. Such types of landuse maps have similarity with the land use map prepared based on multispectral classification of Landsat image on the date 24th February, 2005 of the study area Tarapur union.

From field survey and existing data analysis, it is found that homestead area of Tarapur union is located on an elevation considering flood depths corresponding to 10-to 20-year return periods. The homestead area of Tarapur union is found to be greater than 25.91 meter (PWD). Figure 6.22 shows homestead area and infrastructure only. Maps containing homestead area and infrastructure have been prepared using map calculation command from operation list.

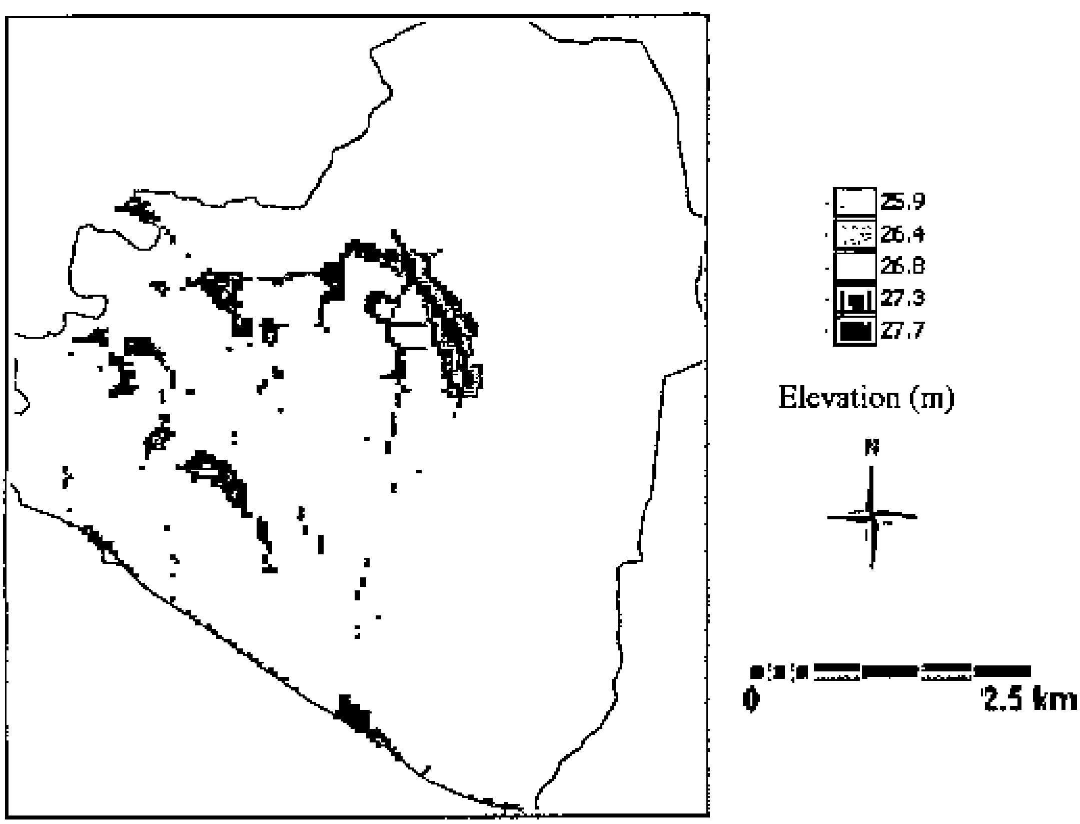


Figure 6.22: Homestead area and infrastructure only

From the above data analysis, only the agricultural land of the study area is found in between the elevation 22.9 to 25.91 meter. As this study intends to determine the vulnerability for agriculture, the flood depth below or equal to 25.91 meter or below or equal to 10-year return period will only determine the vulnerability for agriculture. Flood depth greater than 25.91 meter will determine the vulnerability for agriculture and other sector like homestead and infrastructure. Figure 6.23 shows the map containing agricultural land only. Map containing agricultural land only have been prepared using map calculation command from operation list.

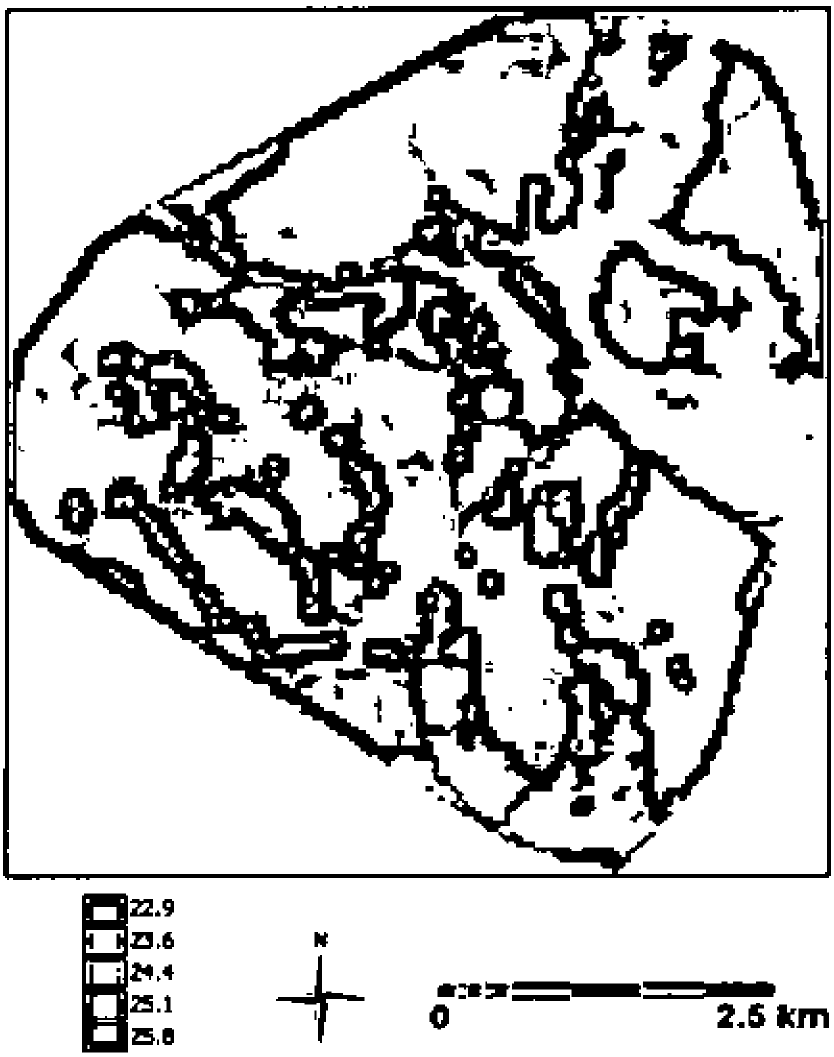


Figure 6.23: Map containing agricultural land only

6.10 Identification of Vulnerable Agricultural Land Regarding Different Return Periods

In order to develop flood vulnerability maps for different return period vulnerable agricultural land regarding different flood depths for different return periods will have to be identified Vulnerability function will then act upon these identified vulnerable lands. Maps containing vulnerable agricultural land regarding different return periods have been prepared using map calculation command from operation list.

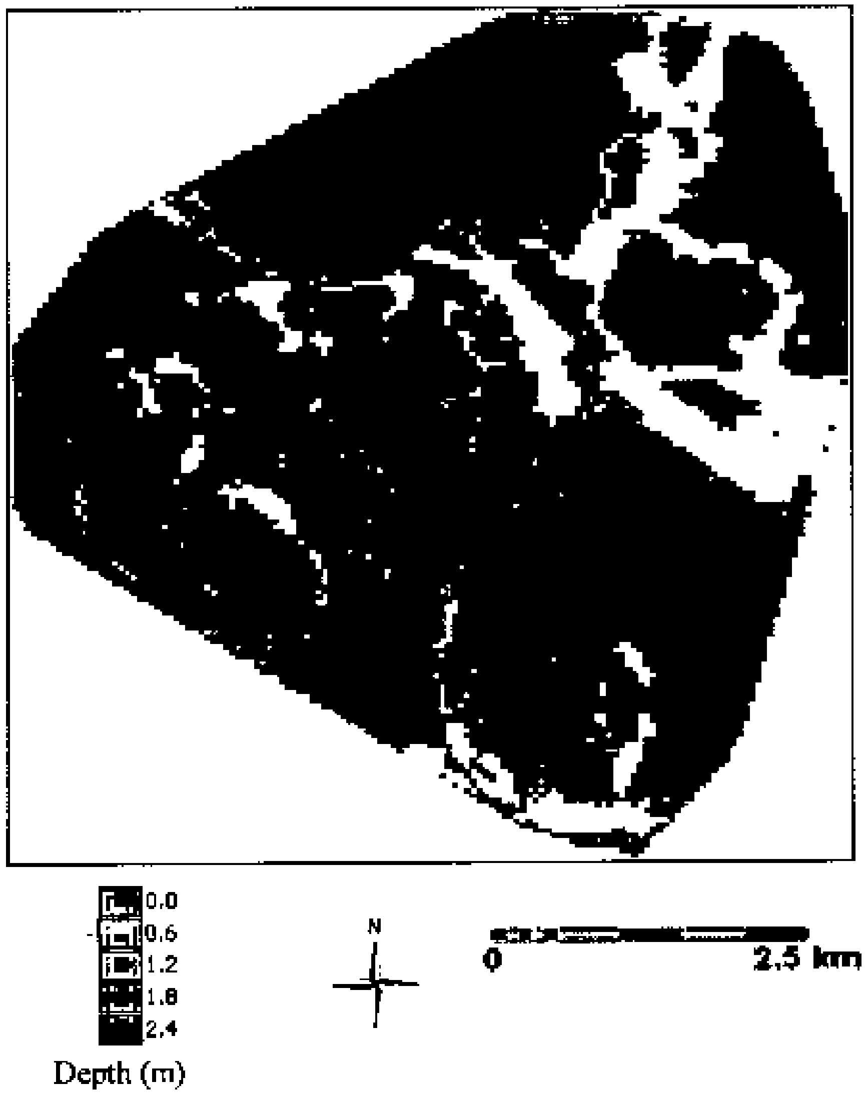


Figure 6.24: Map containing agricultural land for 2-year return period

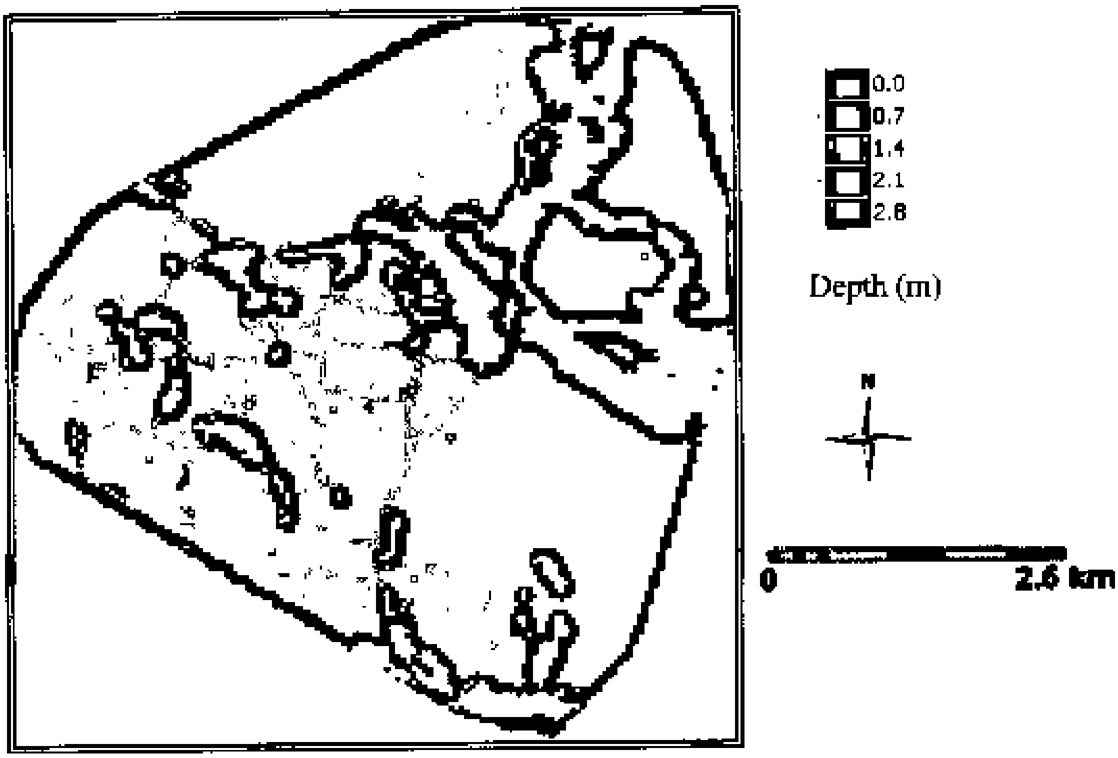


Figure 6.25: Map containing agricultural land for 5-year return period

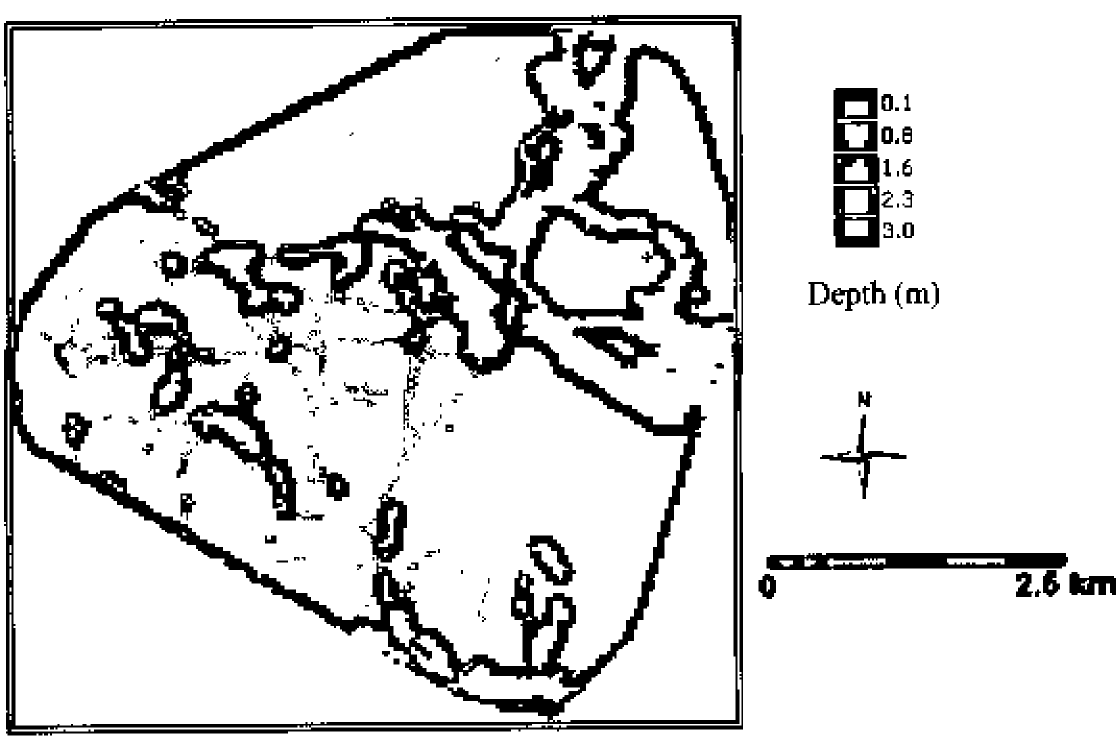


Figure 6.26: Map containing agricultural land for 10-year return period

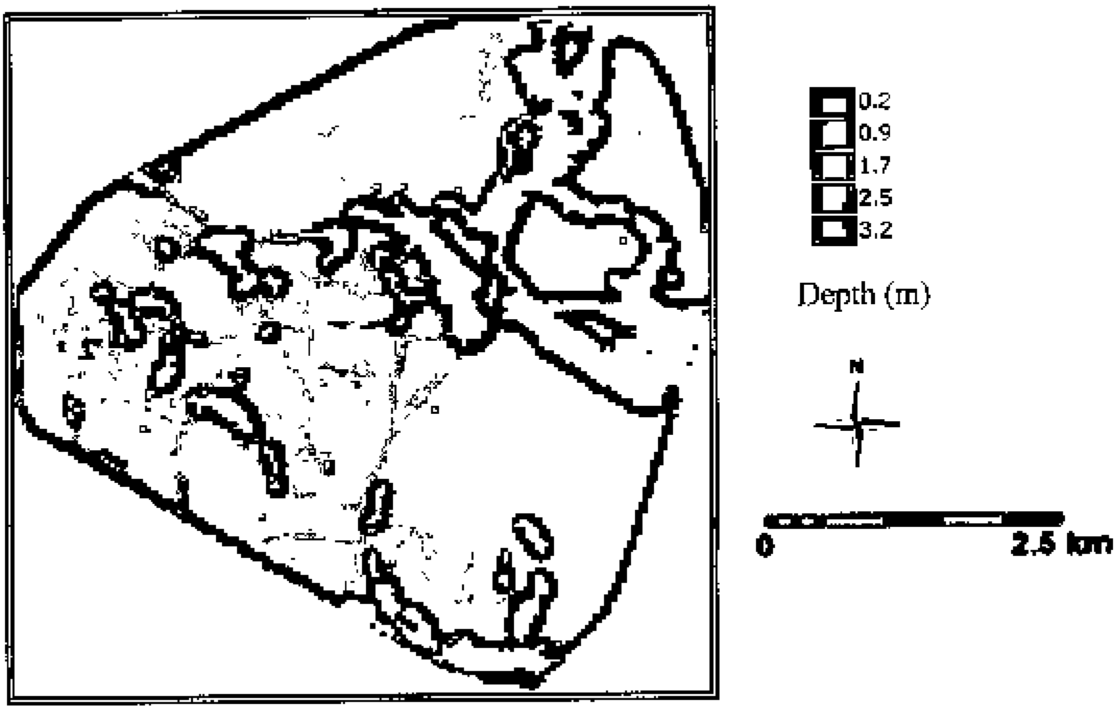


Figure 6.27: Map containing agricultural land for 20-year return period

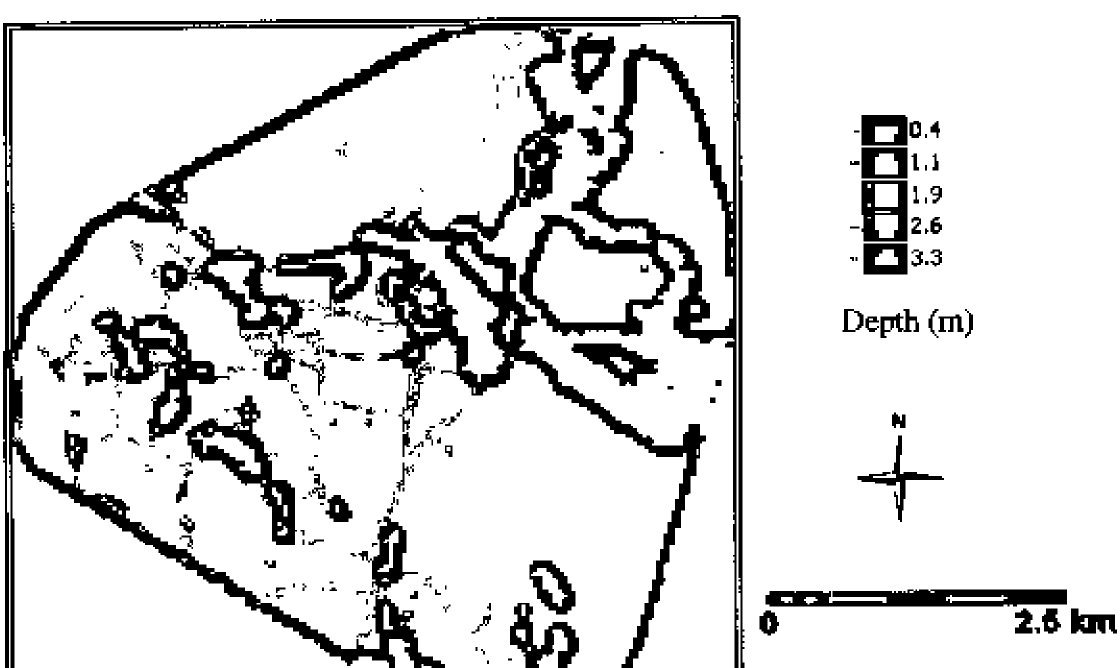


Figure 6.28: Map containing agricultural land for 50-year return period

6.11 Development of Vulnerability Map for Agriculture using Vulnerability Function

Vulnerability maps represent the response or susceptibility of an area to natural hazards or disaster like flood regarding 0 for no damage or 1 for complete damage. Vulnerability maps indicate the status of an area so that priority list for mitigation measures can be taken. Vulnerability maps are also important for taking the decision of what types of mitigation measures in what area will be taken or will be suitable. Vulnerability maps are essential for determination of specific risk, elements at risk, total risk and for estimation of total damages of an area due to flood or any types of natural disaster. In short vulnerability map gives an overall overview of an area regarding a natural disaster like flood. Flood vulnerability maps for agriculture of the study area regarding different flood return periods are given below:

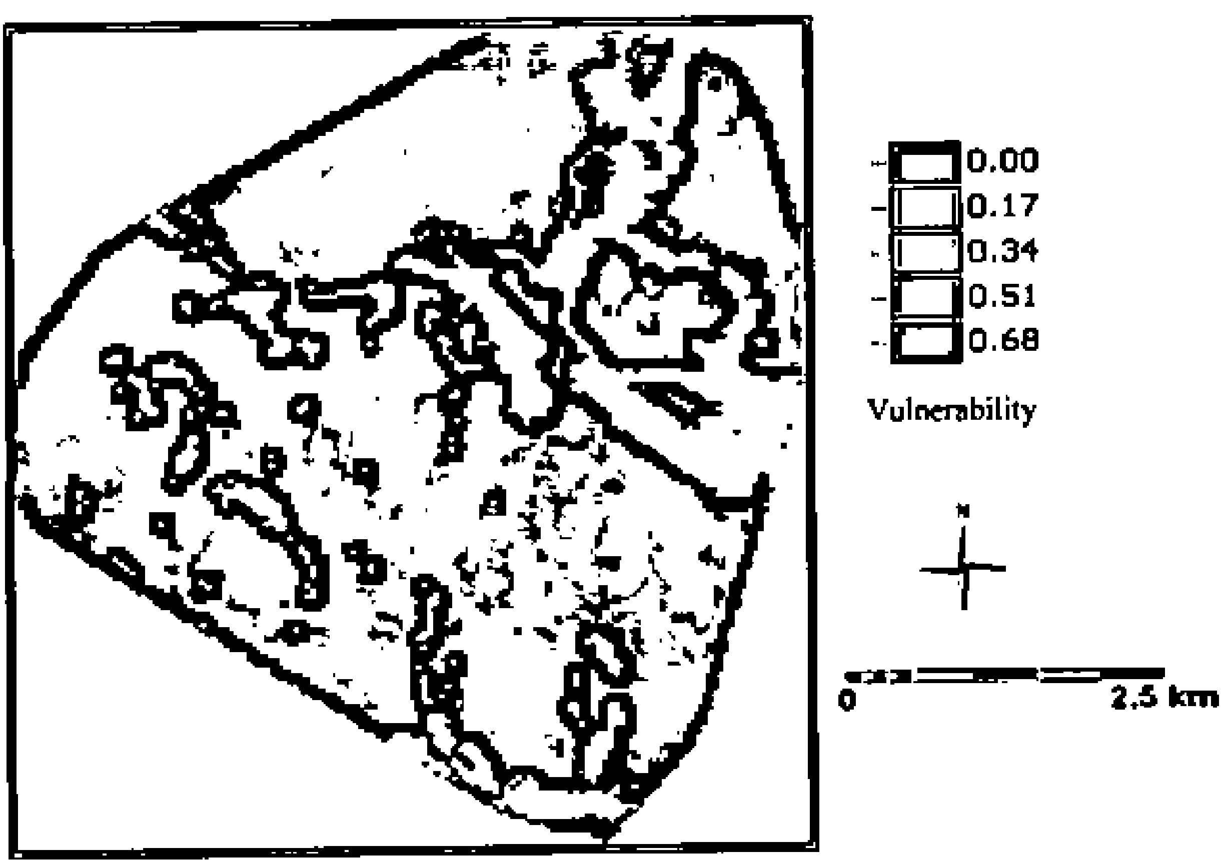


Figure 6.29: Vulnerability map of agricultural land for 2-year return period

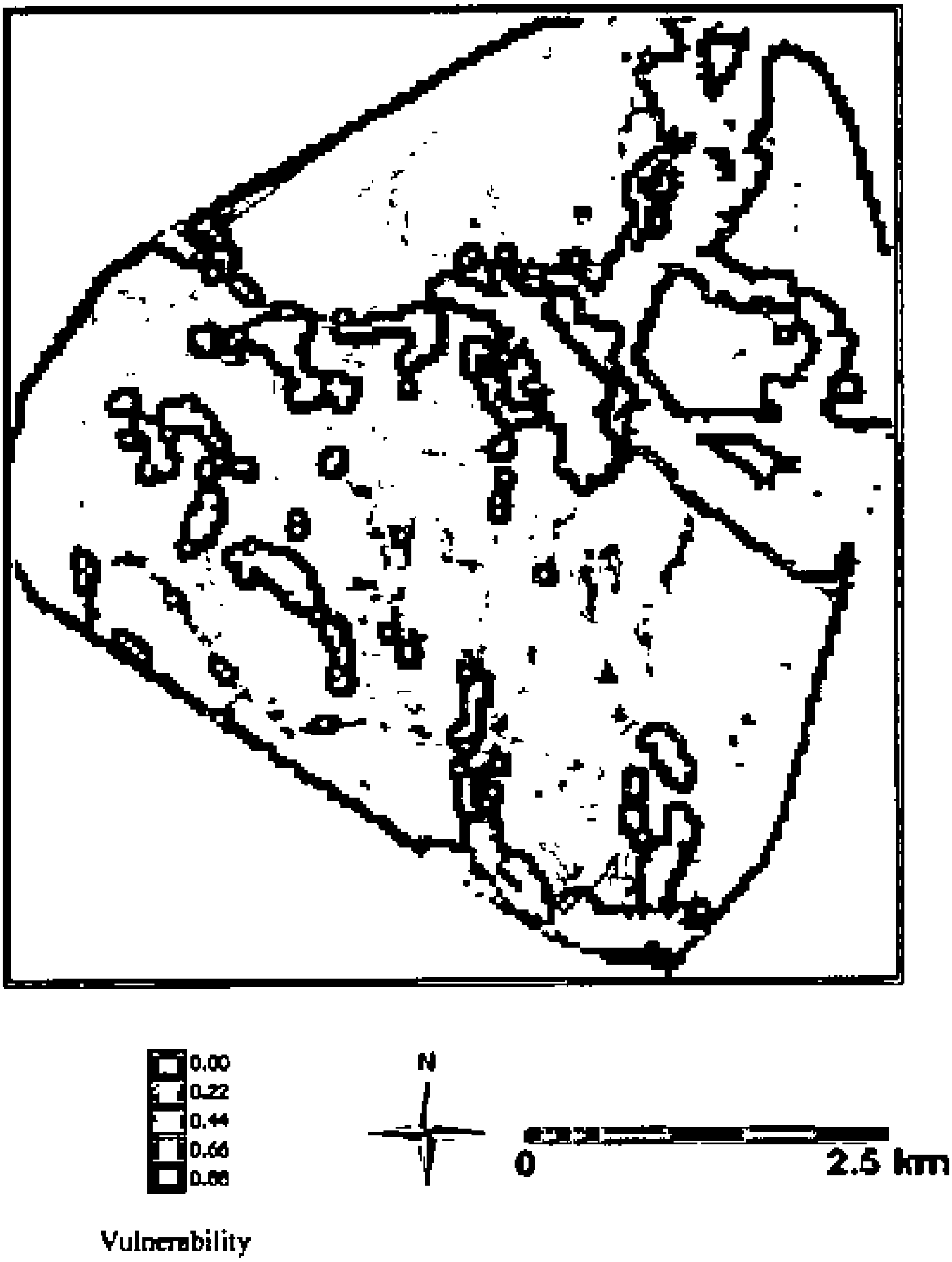


Figure 6.30: Vulnerability map of agricultural land for 5-year return period

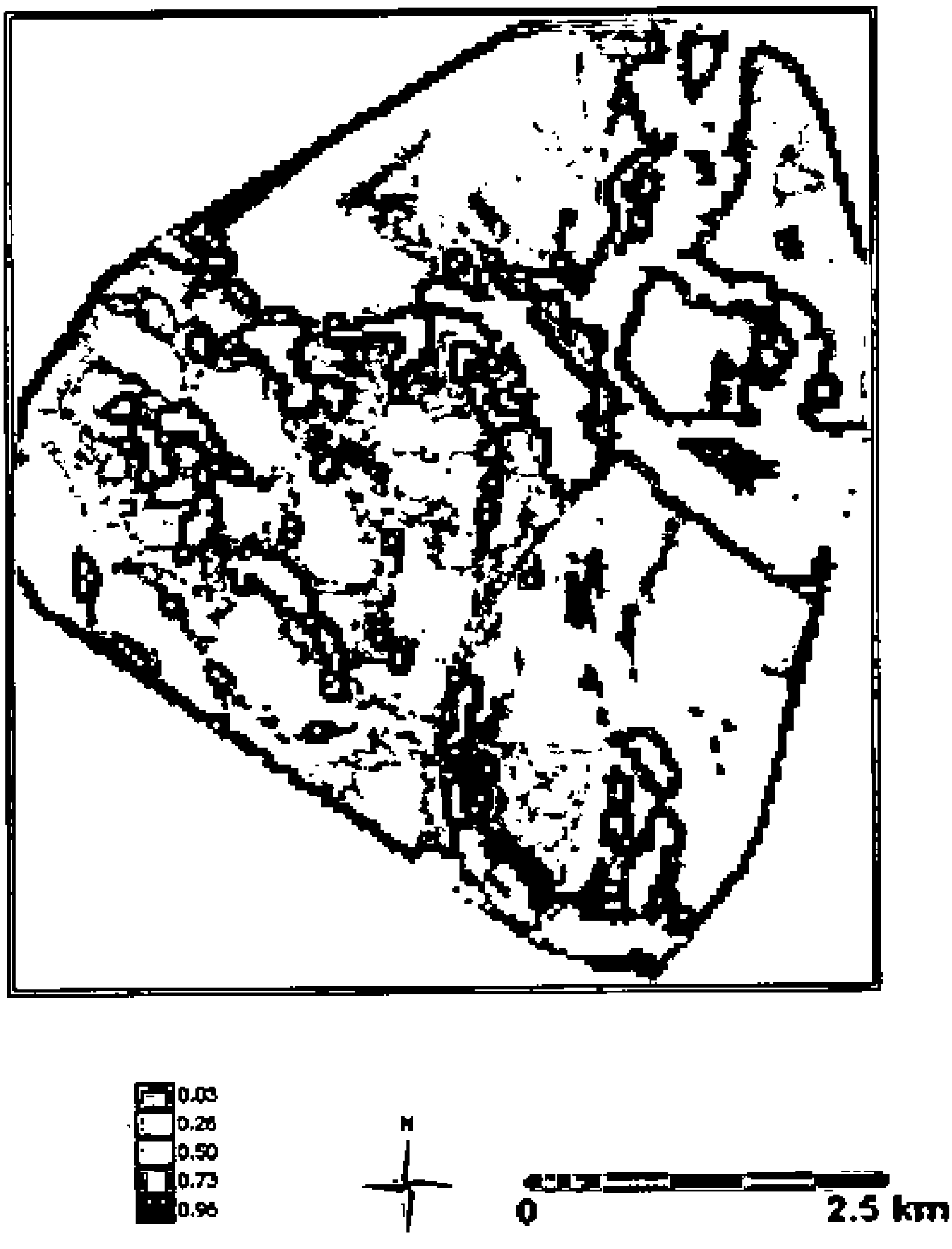


Figure 6.31: Vulnerability map of agricultural land for 10-year return period

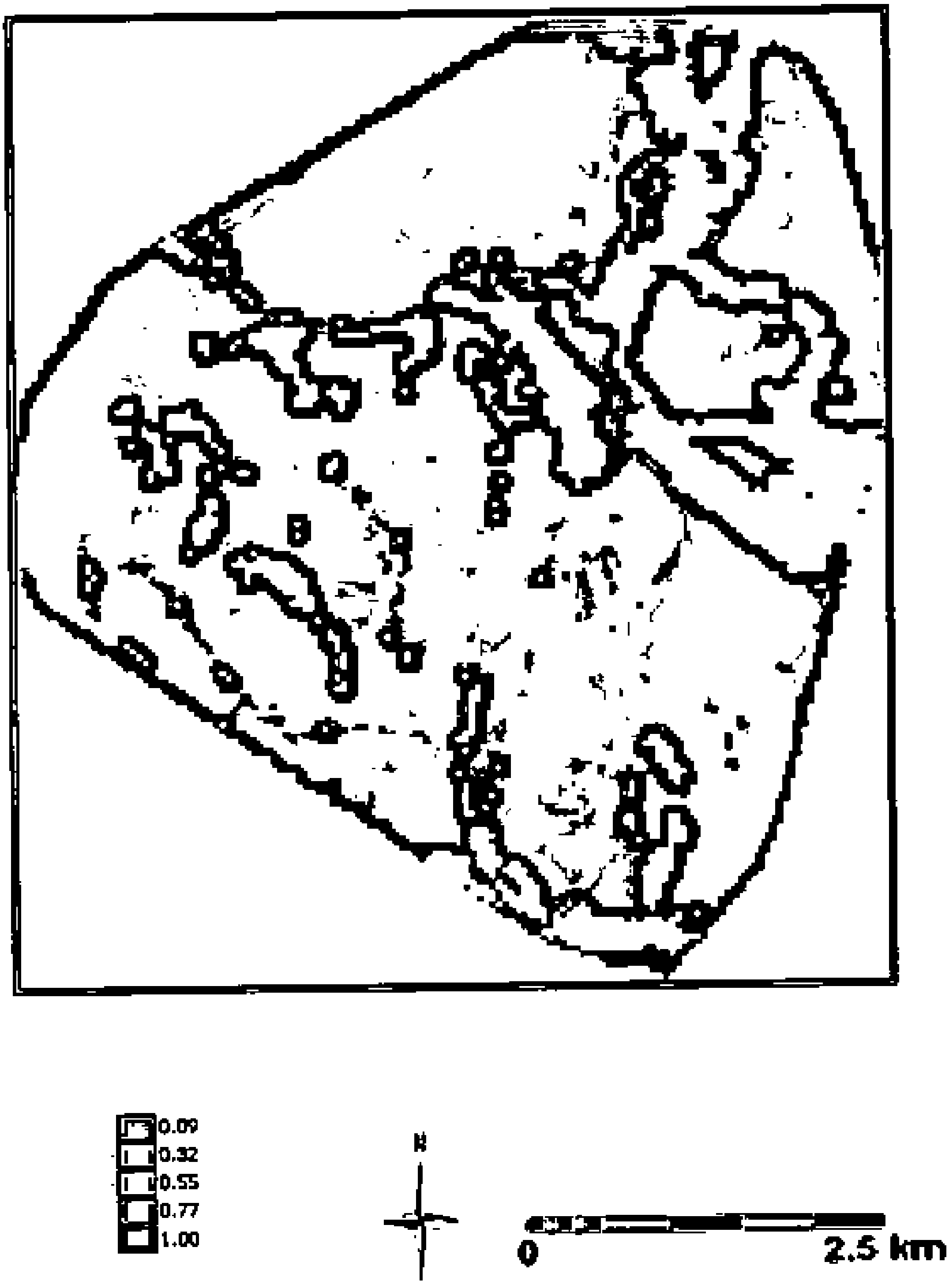


Figure 6.32: Vulnerability map of agricultural land for 20-year return period

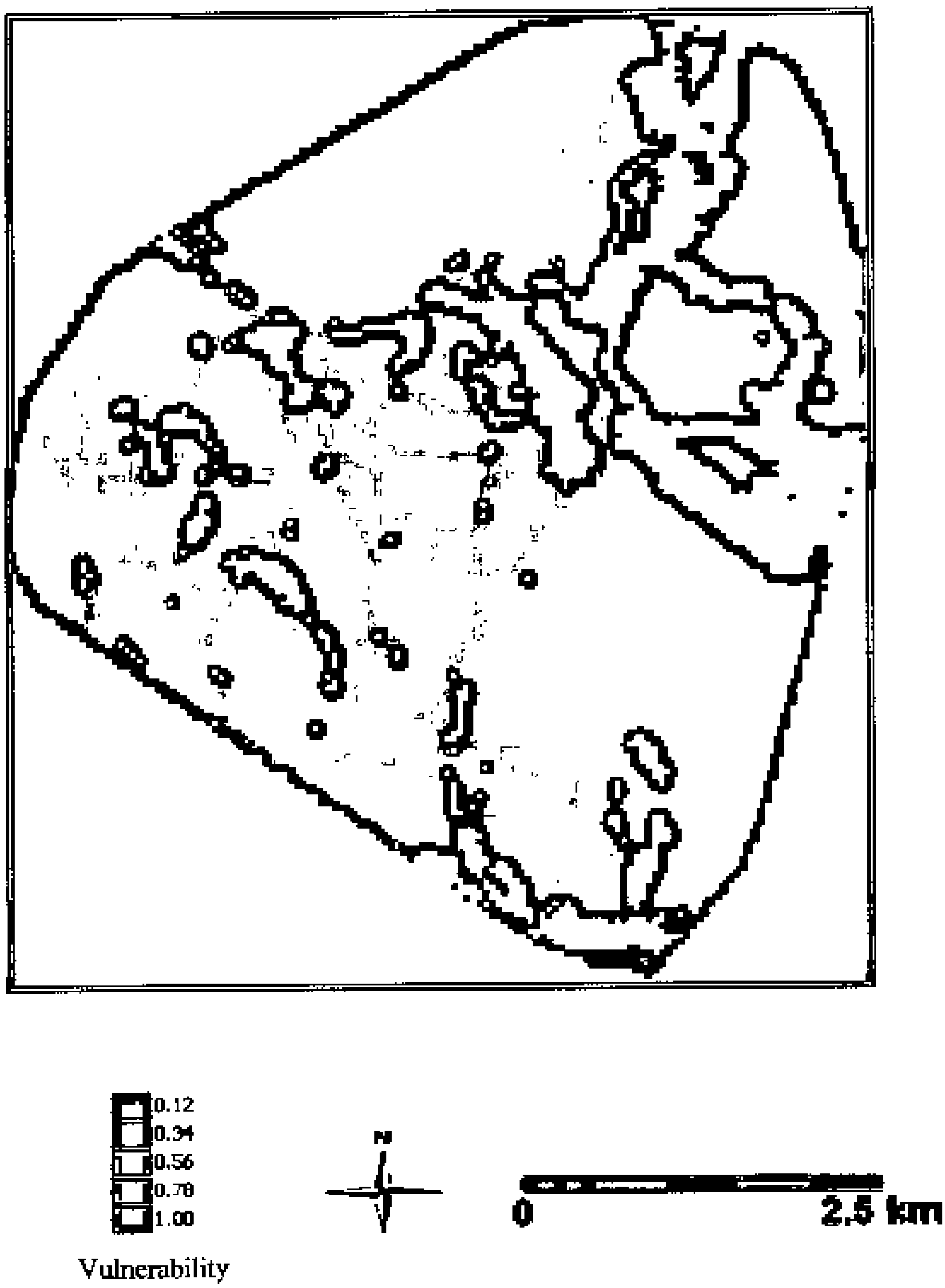


Figure 6.33: Vulnerability map of agricultural land for 50-year return period

From the flood vulnerability map it is found that the magnitude of vulnerability increases corresponding to different (higher) return period and about three (3) meter rise of water level brings complete damages to crops of the study area. Due to uneven distribution of topography equal rise of water level does not lead to equal damages to all the area.

Complete or 100% damages observe in both flood vulnerability maps of 20-and 50-year return periods. The extent of higher magnitude of vulnerability is high in flood vulnerability map of 50-year return period compare to 20-year return period. And in all the maps higher vulnerability was observed in the area close to river where as low vulnerability was observed in the high land far away from the river.

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Bangladesh is a high flood prone country. The study area Tarapur is a union of Sundarganj thana under Gaibandha district. It is located in the northern part of the country bounded by two major rivers–Brahmaputra (Jamuna) in the eastern side and Teesta in the northern part. Geoinformatics provides a broad range of tools for determining areas affected by floods or for forecasting areas likely to be flooded due to high river water levels. This study attempts to apply geoinformatics for flood study in Tarapur with a view to develop flood inundation maps, to assess flooding for different flood magnitudes, to develop flood hazard vulnerability function of agriculture and to assess flood hazard vulnerability of agriculture for different flood magnitudes.

Flood inundation maps identify flooded and non-flooded areas for each particular flood level. To assess flooding for different flood magnitudes flood inundation maps have been prepared based on DEM and satellite image. A gradual increase of flood inundation has been observed in flood inundation maps with higher return periods. For 2-,5-,10-,20-and 50-year return period about 87%, 93%, 94%, 95% and 96% of the area were found to be inundated, respectively. The same trends were also observed in flood depth maps. For 2-,5-,10-,20-and 50-year return periods the maximum depths of flood water were observed 4.7m, 5.1m, 5.3m, 5.5m and 5.6m, respectively.

In flood inundation map based on DEM and water level on 23rd July'04 about 88% area was found to be inundated while the inundated area was found to 78% on flood inundation map based on screen digitizing of Radar image on 23rd July'04.

Vulnerability functions relate hazard intensity to vulnerability. In order to develop a vulnerability function for agriculture of the study area a relationship between flood depth and damage to agriculture was established. This was achieved through an extensive field survey together with secondary data analysis. The magnitude of vulnerability for agriculture of Tarapur union is found to increases more or less linearly up to three meter depth of water and then it becomes horizontal.

Vulnerability maps represent the response or susceptibility of an area to natural hazards or disaster like flood regarding 0 for no damage or 1 for complete damage. The vulnerability of Tarapur has been assessed with five floods viz. 2-, 5-, 10-, 20- and 50-year return periods. It is found that Tarapur union is vulnerable for all the five return periods as most of the area are low lying flat lands. Vulnerability due to 10-, 20- and 50-year return periods are very high compared to 2-or 5-year return period. Area close to river bank is relatively high vulnerable compared to the area far away from the river bank. Flood levels due to 20- and 50-year return periods brings almost 100 % damages to crops. The magnitude of vulnerability of agriculture due to floods varies in different locality of the study area due to uneven distribution of topography. During the monsoon period homestead area is also found to be affected by flooding of 10-, 20- and 50- year return periods.

This study is basically an integration of DEM and Remote Sensing .The basic element of this study is Digital Elevation Model (DEM). This study shows that integration of DEM and Remote Sensing can be an efficient technique to analyze flood inundation and related damage of an area.

7.2 Recommendations

The analyses of this study have been done with the interpolated water level based on distance but this procedure actually does not represent the original water level of the locality. This is why the two flood inundation maps based on Satellite image and DEM show some discrepancy.

This study is conducted considering only the monsoon flood, but sometimes significant damages occur due to flash flood that occurs early in the year. Due to flash flood vegetables and few rice crops are damaged which also affect economy of the locality. So it is recommended that further study be conducted considering the whole time period of flooding.

Only the agriculture has been considered for vulnerability mapping in the study area. Further studies can include other damages including damages to household and infrastructure.

It is clear that proper damage assessment is the key to prepare vulnerability function. Damage assessment in Bangladesh is still not systematic and consistent. For example not much data were available on damage to agriculture, infrastructure and other sectors for the 2004 flood.

The flood vulnerability maps developed in this study can also be used for developing a flood zoning map. This zoning map can also be used for selecting the types of crops and area for cultivation during the monsoon period on the basis of magnitudes of vulnerability of different zones.

Operational applications of remotely sensed information are growing. Opportunities are even more with the introduction of higher resolution satellite images. However, high costs of image data and technology restrict their use in a developing country like Bangladesh. Improvements in this context will certainly enhance an even wider scale application of the spatial information sciences for sustainable integrated development.

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APPENDIX-A

QUESTIONNAIRE FOR LOCAL RESPONDENTS

Title of the Thesis Work: Application of Geo-informatics for Flood Study at Tarapur Union of Gaibandha

A. General information of the respondent

Serial No. . . . . . .

1. Identification of the respondent: Date:

Name of the respondent. . . . .

Father's name . . . .

Age: . . . .

2. Location:
   Village: . . . .

3. Education:
   - ❖ Don't know how to read and write
   - ❖ Passed ------ class
   - ❖ Passed S.S.C./H.S.C./Bachelor degree/Master degree/More
   - ❖ Madrasha

4. Occupation:
   ☐ Business/Trader, ☐ Agriculture, ☐ General Labour, ☐ Service,
   ☐ Transport operator, ☐ Unemployed, ☐ Old/Handicapped, ☐ Artesian,

☐ Other ....

5. Period of living in the village/locality:
☐ Less than10 years,☐ 10 to 15 years, ☐15 to 20 years. ☐ 20 to 25 years, ☐ More than 25 years

B. Agricultural information of Tarapur union

6. Types of crops cultivate in Tarapur union:

☐ Aus ☐ Aman ☐ IRRI ☐ Boro ☐ Others (vegetables, wheat etc.)

7. Crop cultivation period:

☐ January-February ☐ March-April ☐ May-June ☐ July-August ☐ September-October ☐ November-December

8. Crop harvesting period:

☐ January-February ☐ March-April ☐ May-June ☐ July-August ☐ September-October ☐ November-December

9. Normal agricultural production (Per Acre) for Rabi crop-----------------

10. Normal agricultural production (Per Acre) for Kharif crop ---------------

C. General flood information of Tarapur union

11. Types of floods occur in Tarapur union:

☐ Only early flash flood ☐ Only monsoon flood ☐ Both types of flooding

12. Normally early flash flood occurs in the month--

13. Normally monsoon flood occur in the month--

14. Flood become more devastating if occur in the month-----------------------------------

15. Frequency of early flash flood in Tarapur union:

☐ Flood occurs every year ☐ Flood occurs every alternative year ☐ Flood occurs every three to five years or more

16. Frequency of monsoon flood in Tarapur union:

☐ Flood occurs every year ☐ Flood occurs every alternative year ☐ Flood occurs every three to five years or more

17. Causes of early flash flood:

☐ Due to early rainfall in the locality ☐ Run-off due to early excessive rainfall in upstream boundary ☐ Due to over flow from Teesta River ☐ Due to over flow from Brahmaputra

18. Causes of monsoon flood:

☐ Due to monsoon rainfall in the locality ☐ Run-off due to excessive rainfall in upstream boundary ☐ Due to over flow from Teesta River ☐ Due to over flow from Brahmaputra

19. Intensity of early flash flood in the locality:

☐ Occurs once in a year ☐ Occurs twice or more in a year ☐ Occurs every alternative year ☐ Occurs every three to five years or more

20. Intensity of monsoon flood in the locality:

☐ Occurs once in a year ☐ Occurs twice or more in a year ☐ Occurs every alternative year ☐ Occurs every three to five years or more

21. Maximum depth of water due to early flash flood in Tarapur union:

☐ One feet ☐ Two feet ☐ Three feet ☐ Four feet ☐ Four and half feet ☐ More than five feet

22. Maximum depth of water due to monsoon flood in Tarapur union:

☐ One feet ☐ Two feet ☐ Three feet ☐ Four feet ☐ Four and half feet ☐ More than five feet

D. Agricultural damage due to early flash flood

23. Relation between duration of standing flash flood water and damage of crops:

☐ No damage if duration become not more than------------- days

☐ One-fourth of total crops damage if duration----------- days ☐ One-third of total crops damage if duration--------- days ☐ Half of total crops damage if duration----------- days ☐ Two-third of total crops damage if duration--------- days ☐ Total crops damage if duration----------- days

24. Damage due to one feet depth of water due to early flash flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

25. Damage due to two feet depth of water due to early flash flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

26. Damage due to three feet depth of water due to early flash flood:
☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

27. Damage due to four feet depth of water due to early flash flood:
☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

28. Damage due to four and half feet depth of water due to early flash flood:
☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

29. Damage due to more than five feet depth of water due to early flash flood :
☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

E. Agricultural damage due to monsoon flood

30. Relation between duration of standing flash flood water and damage of crops:
☐ No damage if duration become not more than------------- days
☐ One-fourth of total crops damage if duration----------- days ☐ One-third of total crops damage if duration-------- days ☐ Half of total crops damage if duration----------- days ☐ Two-third of total crops damage if duration----------- days ☐ Total crops damage if duration----------- days

31. Damage due to one feet depth of water due to monsoon flood:
☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

32. Damage due to two feet depth of water due to monsoon flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

33. Damage due to three feet depth of water due to monsoon flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

34. Damage due to four feet depth of water due to monsoon flood

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

35. Damage due to four and half feet depth of water due to monsoon flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

36. Damage due to more than five feet depth of water due to monsoon flood:

☐ No damage of crops ☐ One-fourth of total crops damage ☐ One-third of total crops damage ☐ Half of total crops damage ☐ Two-third of total crops damage ☐ Total crops damage

Signature of the Enumerator

APPENDIX B-I

Maximum water levels data of different stations (July to September):

Year	Dalia WL	Noonkhaoa WL	Tarapur WL	Chilmari WL	Bahadurabad WL
1988	52.89	27.5	24.7744847	23.58	19.39
1989	52.69	26.2	24.8718512	23.69	20.08
1990	51.83	25.91	24.1653306	22.99	19.2
1991	52.8	26.9	25.3847347	24.22	19.9
1992	52.31	26.39	24.961882	23.8	18.75
1993	51.91	27.03	24.6769915	23.52	20.36
1994	52.6	25.42	25.5300634	24.38	19.99
1995	52.08	27.33	25.0484333	23.9	19.94
1996	52.3	26.88	25.2684333	24.12	20.37
1997	52.03	26.82	25.0655806	23.92	19.82
1998	52.6	27.35	25.6547655	24.51	20.17
1999	52.28	26.52	25.5074299	24.37	19.32
2000	52.02	26.6	25.2762073	24.14	20.09
2001	52.42	25.91	25.752947	24.62	19.89
2002	52.74	27.19	26.1688716	25.04	20.18
2003	52.16	26.65	25.8286833	24.71	20.62
2004	52.2	27.07	25.8878682	24.77	19.58

Source: BWDB

APPENDIX B-II

Different Methods of Flood Frequency Analysis

Log Normal Distribution

If a random variable x has a log normal distribution (LN2) distribution then the log transformed variable has a normal distribution. The transformed variable is denoted by

$y = \ln[x]$

Where $x \rangle 0$.

The maximum likelihood method is generally best for fitting the LN2 distribution. The maximum likelihood method gives:

$$\bar{y} = 1/n\sum_{i=1}^{n}\ln(x_i)$$

$$s_y^2 = 1/n\sum_{i=1}^{n}[\ln(x_i) - \bar{y}]^2$$

Estimate of flood flow corresponding to T-year return period can be obtained from

$$X_T = e^{(\bar{y}+Z_T*S_y)}$$

Where for flood flow $Z_t = ((1-1/T)^{0.135} - (1/T)^{0.135})/0.1975$

And for low flow $Z_t = ((1/T)^{0.135} - (1-1/T)^{0.135})/0.1975$

Where Z_T is the standard normal variate, $\bar{y}$ is mean and S_y standard deviation of the log transformed data.

Detail calculation for estimating of flood flow using Log Normal Distri' corresponding to T-year return period is given in Table-A

Log Normal Distribution for Water Level at Tarapur Union of Teesta River

Table-A

Order, m	Sorting in Descending (xi)	y=ln(xi)	pi	T =1/pi	Z_T	y	Sy	y+zt*sy	X_T= e^ y+zt*sy
1	26.16887	3 26457	0 0333	30	1.8411	3.230	0.0203	3.2673	26.241
2	25.88787	3 25377	0.0889	11.25	1.3481			3 2300	25.279
3	25.82868	3.25149	0.1444	6 923077	1.0584			3.2300	25.279
4	25.75295	3 24855	0.2000	5	0.8386			3.2300	25.279
5	25.65477	3 24473	0.2556	3.913043	0.6540			3.2300	25 279
6	25.53006	3 23986	0.3111	3.214286	0.4899			3.2300	25.279
7	25.50743	3.23897	0.3667	2.727273	0.3386			3.2300	25.279
8	25.38473	3.23415	0.4222	2.368421	0 1949			3.2300	25 279
9	25.27621	3.22986	0.4778	2.093023	0 0554			3.2300	25 279
10	25 26843	3.22956	0.5333	1.875	-0.0831			3.2300	25.279
11	25 06558	3.2215	0.5889	1.698113	-0.2232			3.2300	25 279
12	25.04843	3.22081	0 6444	1.551724	-0 3681			3.2300	25 279
13	24 96188	3.21735	0.7000	1.428571	-0.5215			3.2300	25.279
14	24.87185	3.21374	0 7556	1.323529	-0 6889			3.2300	25 279
15	24 77448	3.20981	0.8111	1 232877	-0.8790			3.2300	25.279
16	24.67699	3.20587	0 8667	1.153846	-1 1090			3 2300	25.279
17	24 16533	3.18492	0.9222	1 084337	-1.4215			3 2300	25.279

Correlation between xi and X_T= 0.446283580840047

3-Parameter Log Normal Distribution

The three-parameter log-normal (LN3) distribution has one more parameter than the LN2 distribution has. When a lower bound parameter ξ is subtracted from data and then logarithms are taken. the transformed variable has a normal distribution. The transformed variable is denoted by

$y = \ln(x - \xi)$

A simple and defined estimator of ξ is the quantile-lower-bound estimator

$$\xi = (x_1 * x_n - x^2_{median})/(x_1 + x_n - 2x_{median})$$

When $x_1 + x_n - 2x_{median}$>0, where x_1 and x_n are the largest and smallest observed values respectively; is the sample medium equal to x_{k+1} for odd sample sizes $n = 2k+1$ and $½(x_k + x_{k+1})$ for n=2k.When $x_1 + x_n + 2x_{median} < 0$ the formula provides an upper bound so that $y = \ln(\xi - x)$ would be normally distributed.

Median is the middle most value of a given sample.

Again ξ , $\bar{y}$ and S_y (standard deviation) can be obtained from the transformed data. Estimate of flood flow corresponding to T-year return period based on $y = \ln(\xi - x)$ can be obtained from

$x_T = \xi - e^{(\bar{y} + z_T * S_y)}$

And the calculated flood flow using 3-Parameter Log Normal Distribution is given in Table-B

3-Parameter Log Normal Distribution for Water Level at Tarapur Union of Teesta River

Table-B

Order, m	Sorting in descending (xi)	Median	£	y=ln(£-xi)	y	Sy	pi	T =1/pi	ZT	y +zt*sy	e^(y +zt*sy)	X_T=£-e^(y+zt*sy)
1	26.169	25.27621	29.82059	1.2952	1.50629	0 112175	0.033333	30	1.8411	1.7128	5.545	24 276
2	25 888			1.3693			0 1	10	1.3481	1.6575	5.246	24.574
3	25.829			1.3843			0 1625	6.153846	1.0584	1.6250	5 079	24.742
4	25.753			1 4031			0.225	4 444444	0.8386	1 6004	4.955	24 866
5	25.655			1.4269			0.2875	3.478261	0.6540	1.5796	4.853	24.967
6	25.530			1 4564			0 35	2.857143	0.4899	1.5612	4.765	25.056
7	25.507			1 4617			0.4125	2.424242	0.3386	1.5443	4.685	25.136
8	25.385			1 4897			0.475	2.105263	0.1949	1.5282	4.610	25.211
9	25.276			1.5139			0.5375	1.860465	0 0554	1.5125	4.538	25.283
10	25.268			1.5156			0 6	1.666667	-0 0831	1.4970	4.468	25.352
11	25 066			1.5592			0.6625	1.509434	-0.2232	1.4812	4.398	25 422
12	25 048			1.5628			0.725	1.37931	-0 3661	1.4650	4 328	25.493
13	24.962			1.5808			0.7875	1 269841	-0.5215	1.4478	4 254	25 567
14	24 872			1.5991			0.85	1.176471	-0 6889	1.4290	4 175	25.646
15	24.774			1.6186			0.9125	1.09589	-0.8790	1 4077	4.086	25 734
16	24.677			1.6378			0.975	1.025641	-1.1090	1.3819	3.982	25.838
17	24 165			1.7326			1.0375	0.963855	-1.4215	1 3468	3.845222	25.975

Correlation between xi and X_T= -0.9888491

Pearson Type III Distribution

The Pearson Type III Distribution (P3) has three parameters. A P3 distribution can be fitted to a sample of data by using the product moment of the data.

Estimate of flood flow corresponding to T-year return period can be obtained from

$x_T = \bar{x} + K_t S_x$

Where K_T is a frequency factor. The frequency factor for T<100 years and absolute value of skewness<2 are well approximate by the Wilson-Hilferty transformation.

$K_t = 2/g_x(1+(Z_T * g_x/6) - g_x^2/36)^3 - 2/g_x$

Where Z_T is the standard normal variate and S_x, g_x are standard deviation and coefficient of skewness of normal data (not transformed) respectively.

The calculated flood flow using Pearson Type III Distribution is given in Table-C.

Pearson Type- III Distribution for Water Level at Tarapur Union of Teesta River

Table-C

Order, m	Sorting in descending (xi)	pi	T =1/pi	Z_T	X=average xi	g_x	S_x	K_T	X_T=X +K_T* S_x
1	26 16887163	0.03333	30	1.8411	25.284	-0.33136	0.511	1.7047	26 1550
2	25.88786819	0.08889	11.25	1 3481				1.2974	25.9468
3	25.82868326	0.14444	6.923076923	1.0584				1 0466	25.8187
4	25.75294698	0.20000	5	0.8386				0.8504	25.7184
5	25.65476549	0 25556	3.913043478	0.6540				0.6818	25.6322
6	25 53006344	0 31111	3.214285714	0.4899				0.5289	25 5541
7	25.50742986	0.36667	2.727272727	0 3386				0.3853	25.4807
8	25.3847347	0.42222	2 368421053	0 1949				0.2467	25.4099
9	25.27620726	0.47778	2.093023256	0.0554				0.1099	25.3400
10	25.2684333	0 53333	1.875	-0.0831				-0.0279	25 2695
11	25.06558056	0.58889	1.698113208	-0 2232				-0.1696	25.1971
12	25.0484333	0 64444	1 551724138	-0 3681				-0.3183	25.1211
13	24 96188195	0.70000	1.428571429	-0.5215				-0 4784	25.0393
14	24.87185116	0.75556	1 323529412	-0.6889				-0.6561	24.9485
15	24.77448474	0.81111	1.232876712	-0.8790				-0.8619	24 8433
16	24.67699153	0 86667	1.153846154	-1 1090				-1.1163	24.7133
17	24.1653306	0 92222	1.084337349	-1.4215				-1 4720	24.5315

Correlation between xi and X_T = 0.990461074

Log Pearson Type III Distribution

Log Pearson Type III Distribution (LP3) distribution describes a random variable whose logarithms are P3 distributed. Thus

$y = \ln x$

the method of estimating the parameters of the LP3 distribution is similar to that for the P3 distribution except that logarithms of the data are to be taken before estimating moments. Thus for a set of observations $(x_1, x_2, \ldots\ldots x_n)$ the transformed data are given by $y_1 = \ln x_1, y_2 = \ln x_2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots, y_n = \ln x_n$

Estimate of flood flow corresponding to T-year return period can be obtained from

$x_T = e^{(\bar{y} + K_T * S_y)}$

$K_T = 2/g_y(1 + (Z_T * g_y/6) - g_y^2/36)^3 - 2/g_y$

Where g_y is the coefficient of skewness of log transformed data.

The calculated flood flow using Log Pearson Type III Distribution is given in Table-D

Log Pearson Type- III Distribution for Water Level at Tarapur Union of Teesta River

Table-D

Order, m	Sorting in descending (xi)	pi	T =1/pi	Z_T	y=ln(xi)	y (average y)	G_x	S_y	G_y	K_T	$y+K_T*S_Y$	X_T=e^ $(y+K_T*S_y)$
1	26.169	0.0333	30	1.8411	3.2646	3.229971	-0.331	0.02028	-0.38232	1.6830	3.2641	26.157
2	25.888	0.0889	11.25	1.3481	3.2538					1.2886	3.2561	25.948
3	25.829	0.1444	6.923077	1.0584	3.2515					1.0438	3.2511	25.820
4	25.753	0.2000	5	0.8386	3.2485					0.8514	3.2472	25.719
5	25.655	0.2556	3.913043	0.6540	3.2447					0.6854	3.2439	25.633
6	25.530	0.3111	3.214286	0.4899	3.2399					0.5344	3.2408	25.554
7	25.507	0.3667	2.727273	0.3386	3.2390					0.3921	3.2379	25.481
8	25.385	0.4222	2.368421	0.1949	3.2341					0.2544	3.2351	25.410
9	25.276	0.4778	2.093023	0.0554	3.2299					0.1182	3.2324	25.340
10	25.268	0.5333	1.875	-0.0831	3.2296					-0.0194	3.2296	25.269
11	25.066	0.5889	1.698113	-0.2232	3.2215					-0.1611	3.2267	25.196
12	25.048	0.6444	1.551724	-0.3681	3.2208					-0.3103	3.2237	25.120
13	24.962	0.7000	1.428571	-0.5215	3.2173					-0.4713	3.2204	25.038
14	24.872	0.7556	1.323529	-0.6889	3.2137					-0.6504	3.2168	24.948
15	24.774	0.8111	1.232877	-0.8790	3.2098					-0.8584	3.2126	24.843
16	24.677	0.8667	1.153846	-1.1090	3.2059					-1.1164	3.2073	24.713
17	24.165	0.9222	1.084337	-1.4215	3.1849					-1.4787	3.2000	24.532

Correlation between xi and X_T = 0.990355

Gumble Distribution

The Gumble distribution is the most widely used distribution in flood frequency analysis. The Gumble distribution is also known as the Extreme value Type-1 (EV1) distribution. The probability weighted moment (PWM) method is employed in this study to estimate parameters of Gumble distribution. Parameter estimation by the PWM method is a recent method which is widely used for those distributions that CDF can be explicitly inverted. Estimate of flood flow corresponding to T-year return period can be obtained from

$x_T = u + \alpha * y_T$

Where $u = \bar{x} - 0.5772\alpha$

$\alpha = S_x \sqrt{6/\pi}$

$y_t = -\ln(-\ln(1 - 1/T))$

The calculated flood flow using Gumble Distribution is given in Table-E.

Gumble Distribution for Water Level at Tarapur Union of Teesta River

Table-E

Order, m	Sorting in descending (xi)	pi	T =1/pi	Z_T	[-ln(1-1/T)]	y_T=-ln[-ln(1-1/T)]	S_x	X	α	u	X_T
1	26.169	0 033	30	1.841	0.034	3.384	0 5111	25.284	0.399	25.054	26 403
2	25.888	0.089	11.25	1.348	0.093	2.374					26 000
3	25.829	0 144	6.923077	1.058	0 156	1.858					25.794
4	25.753	0.200	5	0.839	0 223	1.500					25.652
5	25.655	0.256	3 913043	0 654	0.295	1.220					25.540
6	25 530	0.311	3.214286	0 490	0.373	0.987					25.447
7	25 507	0.367	2.727273	0 339	0.457	0.784					25.366
8	25.385	0.422	2.368421	0.195	0.549	0 600					25.293
9	25.276	0.478	2.093023	0.055	0.650	0.431					25 226
10	25.268	0 533	1.875	-0.083	0 762	0.272					25.162
11	25.066	0 589	1.698113	-0.223	0.889	0.118					25 101
12	25.048	0 644	1.551724	-0 368	1 034	-0.034					25.040
13	24.962	0 700	1 428571	-0.522	1.204	-0 186					24 980
14	24 872	0.756	1.323529	-0 689	1 409	-0.343					24.917
15	24.774	0.811	1.232877	-0.879	1.667	-0 511					24.850
16	24 677	0.867	1.153846	-1.109	2.015	-0.701					24.775
17	24 165	0.922	1.084337	-1.422	2.554	-0.938					24.680

Correlation between xi and X_T = 0.950228

APPENDIX B-III

Goodness-of-fit analysis for selecting the most appropriate distribution

SL NO.	Types of Analysis	Value	Rank
1	Correlation between Xi& X_T (Log Normal Distribution)	0.4462835	4
2	Correlation between Xi and X_T (3-Parameter Log Normal Distribution)	-0.9888491	5
3	**Correlation between Xi and X_T (Pearson Type III Distribution)**	**0.9904610**	1
4	Correlation between Xi and X_T (Log Pearson Type III Distribution)	0.990355	2
5	Correlation between Xi and X_T (Gumble Distribution)	0 950228	3

APPENDIX B-IV
Pearson Type III Distribution

Water levels regarding different return period based on Pearson Type III Distribution

Return Period (Year)	Z_T	X	S_T	G_X	K_T	$X_T=X+K_T*S_T$
2	0	25.284	0.5111	-0.331	0.0550589	25.31193569
5	0.8386	25.284	0.5111	-0.331	0.8503944	25.71840[illegible]17
10	1.2813	25.284	0.5111	-0.331	1.24028342	25.9176589
20	1.6493	25.284	0.5111	-0.331	1.5491136	26.07548876
50	2.0636	25.284	0.5111	-0.331	1.8805788	26.24488964

APPENDIX C-I

Items	Bangladesh	Gaibandha	% of Bangladesh
Gross cropped area	28616451	608419	2.13
Intensity of cropping (%)	174	190	-
Aman-Local	6036661	84064	1.39
HYV and Pajam	4510985	153947	3.41
Aua-Local	3156748	6231	0.20
HYV and Pajam	991867	15189	1.53
Boro- Local	1129701	13965	1.24
HYV and Pajam	5007116	175620	3.51
% of HYV Rice to gross cropped area	36.7	56.66	-
Wheat-Local	508042	8780	1.73
HYV	1013947	34222	3.38
Jute	1297433	34311	2.64
Sugarcane	329016	329016	2.50

Basic Information of Cropped Area (Area in acres) of Farm Holdings:

Source: BBS, Census of Agriculture-1996

Cropping pattern of Tarapur union

Rabi	- Kharif I	- Kharif II
• Boro(rice)	– Fallow	– Transplanted Aman (Rice)
• Wheat	– Jute	- Transplanted Aman
• Potato	– Boro	– Transplanted Aman
• Mustard	– Boro	– Transplanted Aman
• Vegetable	– Jute	– Transplanted Aman
• Boro	– Vegetable	– Transplanted Aman

Source: BBS. Census of Agriculture-1996

APPENDIX C-II

Comparison of land use practices of Sundarganj thana of 1996 with 1983-1984 Census:

(Area in acres)

Items	1983-1984			1996		
	All Holdings	Non-farm Holdings	Total	All Holdings	Non-farm Holdings	Total
Homestead Area	4042	517	3525	5258	1112	4146
Percentage	100	12.79	87.21	100	21.15	78.85
Net Cultivated Area	67882	41	67841	58258	88	58170
Percentage	100	0.06	99.94	100	0.15	99.85
Gross Cropped Area	-	-	140820	-	-	113669
Percentage	-	-	100	-	-	100
Crop Area						
HYV Aus and Pajam	-	-	2876		-	3774
HYVAman and Pajam	-	-	6053	-	-	30902
HYV Boro and Pajam	-	-	2430	-	-	27863
Wheat	-	-	10516	-	-	9603
Pulses	-	-	3855	-	-	765
Oil Seeds	-	-	1038	-	-	2902
Crash Crops	-	-	13759	-	-	11711

Source: BBS. Census of Agriculture-1996