A PROJECT PAPER

ON

A STUDY ON FLOOD PATTERN OF BANGLADESH USING FLOOD INUNDATION MAPS GENERATED FROM MODIS IMAGES

By

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Submitted in Partial Fulfillment of the Requirements for the

Master of Engineering Degree

Department of Water Resources Engineering

Bangladesh University of Engineering and Technology (BUET)

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CANDIDATE'S DECLARATION

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

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The project paper titled "A STUDY ON FLOOD PATTERN OF BANGLADESH USING FLOOD INUNDATION MAPS GENERATED FROM MODIS IMAGES" submitted by Shahriar Hussain, Student ID: 1009162024, Session: October 2009, has been accepted as satisfactory in partial fulfillment of requirement for the degree of MASTER OF ENGINEERING IN WATER RESOURCES ENGINEERING on 16th September, 2015.

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Abstract

Remote sensing technologies can allow a quick mapping of large regions and may provide valuable support in flood crisis management. In Bangladesh, Flood Forecasting and Warning Center (FFWC) generates flood inundation map from hydrodynamic model output. In this study, a comparison has been conducted between flood inundation maps generated from MODIS images and inundation maps generated from model output by FFWC from the year 2004 to 2014. From this comparison it has been found that, among the five BWDB zones, inundation maps generated by FFWC in Northwest zone (NW) (R^2=0.915), North central zone (NC) (R^2=0.896), Northeast zone (NE) (R^2=0.929) and Southeast zone (SE) (R^2=0.959) have a strong correlation with the inundation maps generated from MODIS images of that zones. MODIS inundation maps have a very poor correlation in Southwest zone (SW) (R^2=0.058) which is because of fewer water level measuring stations in that zone and the model which has been used to prepare flood maps, does not consider tidal effect of this zone.. It has also been found that, correlation between MODIS inundation maps and FFWC inundation maps of a zone depends on the number of water level observing station presents in the that zone. However the overall correlation between these two types of inundation maps has been found as R^2=0.701. Studying flood pattern of Bangladesh was also an objective of this study. It has been seen that, flood pattern found from MODIS inundation maps has a good consistency with observed data found in annual flood reports of FFWC. Besides, the method that developed in this study has been found very effective in the area where ground observation data are not available. It can also be very useful for regular monitoring of flood situation in daily basis because of the freely available MODIS images in website. From this study, it can be concluded that, this method of flood inundation mapping from MODIS image has a huge potential of observing and monitoring flood pattern and flood extent in Bangladesh.

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Acronyms and Abbreviations

BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information System
DEM	Digital Elevation Model
FAP	Flood Action Plan
FFWC	Flood Forecasting and Warning Center
GBM	Ganges, Brahmaputra, Meghna Basin
IPCC	Intergovernmental Panel on Climate Change
MODIS	Moderate Resolution Imaging Sperctroradiometer
NC	North central zone
NE	Northeast zone
NW	Northwest zone
SE	Southeast zone
SW	Southwest zone
WL	Water Level

Chapter 1

Introduction

1.1 Background and research motivation:

Bangladesh is a low-laying flat country situated in the lower part of the great Ganges Brahmaputra Meghna (GBM) basin (Figure 1.1). The total drainage area of Ganges Brammaputra Meghna basin is 1.75 million sq.km (Figure 1.1) and the average annual water flow is 1350 billion cubic meters, which is drained through Bangladesh but the GBM basin area within Bangladesh is only about 7-10% of the total area (FFWC, 2007). That is why; flooding is an annual recurring event in Bangladesh during monsoon and very often it experiences devastating flood that causes damage to crops and properties.

Figure1.1: The Ganges, The Brahmaputra, The Meghna river basin[1]

In the past two decades, extensive flooding has occurred in Bangladesh (in 1987, 1988, 1998, 2004) leading to colossal damages to private and public assets, infrastructures and the

[1] http://www.jrcb.gov.bd/basin_map.html

destruction of crop yields. Figure1.2 provides an historical account of flooded area in Bangladesh.

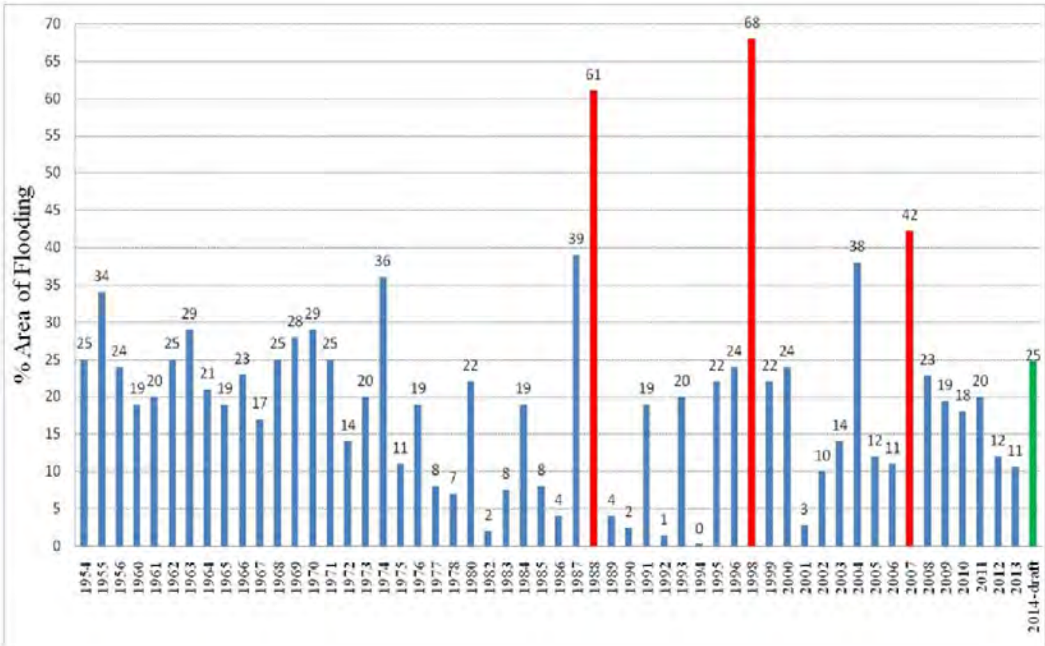

Figure1.2 Historical flood affected area of Bangladesh[2]

A view generally held by climatologists is that, due to global climate change, catastrophic floods in Bangladesh will appear more frequently and with increasing severity (IPCC, 2001). The recent history of flooding in Bangladesh indicates that the interval between catastrophic floods is decreasing and the intensity and duration of such floods are both increasing (Ahmad and Ahmed 2003). Table 1.1 shows the damage due to some major floods occurred in Bangladesh during last 30 years.

Table 1.1 Some notable floods and its damages.

Event	Impact
1987 flood	Inundated over 57,000 sq-km area, estimated damage US$ 1.0 billion and human death 2055 (The World Bank, 2002)
1988 flood	Inundated 61% of the country, persons affected 45 million, 2300 deaths, damage worth about US$ 1.2 billion (The World Bank, 2002)

[2] http://wreforum.org/bapon/blog/7289

1998 flood	Inundated 100,250 sq-km (68%) of the country, 1100 deaths, persons affected31 million, damaged 500,000 homes, 23,500 km roads and 4500 embankment, destroyed crops of 500,000 ha of land, damage worth about US$2.8 billion (The World Bank, 2002)
2004 flood	Inundated 38% of the country, 750 deaths, persons affected 36 million, damaged 58,000 km roads and 3,100 km embankment, crop damage 1.3million ha, damage worth about US$ 2.2 billion (ADB-World Bank, 2004)

For these reasons, flood is considered as one of the major disasters in Bangladesh.

After the devastating flood that took place in 1987 and 1988, the Bangladesh Government took an initiative to create an action plan known as Flood Action Plan (FAP) with the help of World Bank. But because of its emphasis on structural mitigation (e.g., building embankments or cross dams etc), this plan had been criticized by many. Especially the proposal of containing all major rivers by embankments was very ambitious and might not be feasible considering its technical and socioeconomic limitations (Jahir, 1991). “Total” flood control is inappropriate in this country because of the dependence of crop yield on normal flooding (Jahir, 1991). For this reason, non-structural measures like flood zoning, flood forecasting for early evacuation etc along with structural measures like embankments, dam are important for effective and sustainable mitigation projects.

Preparing Flood Inundation maps is the first step of non-structural mitigation measure. As high resolution remote sensing image is very costly, images from free sources have been used for this study. In this study, a method has been developed to create relatively accurate flood inundation map than the inundation map generated by the Flood Forecasting and Warning Center (FFWC), a government agency that has the mandate to disseminate flood information to the people of Bangladesh. This study also shows that free satellite image can be a useful tool to understand the behavior of flood pattern and thus very helpful to prepare proper and sustainable planning against this disaster.

1.2 Objectives

The main goal of this study is to use free satellite image as a tool to understand flood pattern of Bangladesh. The specific objectives are

- To generate flood inundation maps using open source remote sensing images.

- To compare flood inundation maps generated from Remote sensing images with the inundation maps prepared by observed data.
- To study flood inundation behavior/pattern from the generated flood inundation maps.

1.3 Organization of thesis

This report contains six chapters. The first chapter provides an introduction that contains Background and research motivation for this study. It also contains the Objectives of this study. The second chapter reviews the development of using satellite data in flood inundation mapping over the years. It also describes briefly about MODIS and advantage of using this over other freely available data. Current method of preparing flood inundation Map in Bangladesh has also been described in this chapter. The third chapter is Study Area and Data Acquisition which includes a brief description of the study area. It also describes the sources of data and the process of data acquisitions. The fourth chapter explains detail Methodology used in this study. Results and Discussions are described in chapter five and finally in chapter six, the conclusions and recommendations are provided.

Chapter 2

Literature Review

2.1 Introduction:

Status of flood inundation in time and space is important in evaluating the relationships between variations in the water regime, local agricultural activity, and ecosystem behavior from a global viewpoint. Remote sensing images can be effective and efficient tools to determine flood inundation areas (Islam et al., 2009). These technologies allow a quick mapping of large regions and may provide valuable support in flood crisis management and effective early warning for disasters. It is used for flood mapping (Jain et al., 2005; Sakamoto et al., 2007; Xiao et al., 2005), flood monitoring (Sakamoto et al., 2007; Jain et al., 2006), flood damage assessment (Dewan et al., 2006), flood forecasting (Patro et al., 2009; Van Der Knijff et al., 2010), validating numerical inundation models and rainfall run-off analyses (Machado and Ahmed, 2007; Patro et al., 2009).

2.2 Flood Inundation mapping using satellite data:

Since the year 2000 there have been a number of spaceborne satellites and sensors that have changed the approach to managing the natural disasters. The increase in the satellite data acquisition rates, sensor resolution, improvement of change detection algorithms and integration of remote sensing systems has significantly improved the real-time assessment and management of natural hazards (Harun, 2009). Currently there has been an increase in the ability to predict certain natural hazards using satellite imagery that can be incorporated into early warning systems (Harun, 2009). The sensors that are used are of two kinds: passive and active sensors. The passive sensors are that sensors that depend on external light source whereas; the active sensors have their own source of light (Sun. et al, 2011). Both types of sensors can be utilized by the specific community for the remote sensing of natural disasters. Since the year 2000, a number of new high resolution passive sensors that provide panchromatic, visible, near infrared and thermal imagery have become operational. Some of the satellites that have the passive sensors are IKONOS 2, Terra (ASTER), Terra (MODIS), Spot 5, Aqua (MODIS), FORMOSAT 2, ALOS, KOMPSAT, Orb View 3 and others. The satellites with active sensors are ERS 32, Radarsat 1, SRTM, Envisat (ASAR) and ALOS (Palsar). Recent satellite missions have provided high resolution topography imagery using interferometric synthetic aperture radar (SAR) techniques. SAR sends out a microwave pulse and records the reflected pulse at two points separated by baseline distance. The resulting parallax can be used to measure elevation with higher accuracy. But the drawback of this system is that, it has a long repeat time (Metternicht et al. 2005). It is impossible to identify particular satellite suitable for any specific type of purpose for a given type of natural disaster. It depends on the objective, the characteristics of the satellite and also cost factor.

2.3 What is MODIS?

MODIS (or Moderate Resolution Imaging Sperctroradiometer) is the key instrument abroad the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths.

Table 2.1 Sensor specification of MODIS (MODIS, 2015)

Item	Specification
Orbit:	705 km, 10.30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular.
Scan Rate:	20.3 rpm, cross track.
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diameter off –axis, afocal (collimated), with intermediate field stop.
Size:	1.0 x 1.6 x 1.0 m.
Weight:	228.7 kg.
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbit average)
Quantization:	12 bits

Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years

MODIS's moderate-resolution optical sensor of 250–500m becomes useful tools for scientific studies and research. Many studies were conducted to determine surface water content such as estimating the extent of paddy fields by Xiao et al. (2006; 2005), detecting inundation areas through vegetation cover conversion by Zhan et al. (2002) etc. The Dartmouth Flood Observatory (2006) monitors flood disasters all over the world using MODIS data. Sakamoto et al. (2007) were developed a methodology to detect the spatio-temporal flood distribution in the Cambodia and Vietnam using MODIS data. The main advantages of using MODIS data are: (1) time series data is available during flood period, (2) data is available for the globe, (3) data can be downloaded free of cost through internet and (4) the accuracy of flood inundation map lies within the acceptable range [R^2 lies between 0.77 and 0.97] (Islam et al., 2009).

2.4 Current method of preparing Flood Inundation Map in Bangladesh:

Bangladesh is situated in the world's most dynamic hydrological and in the biggest deltaic system. Flood causes serious damage to its economy and lives in almost every year. As a non-structural mitigation measure, Bangladesh Government has established Flood Forecasting and Warning center (FFWC), an institution of Bangladesh Water Development Board (BWDB) that has the authority and mandate to disseminate flood warnings to the people. BWDB divides Bangladesh into 6 zones namely Northeast Zone (NE), Northwest Zone (NW), North center Zone (NC), Southwest Zone (SW), Southeast Zone (SE) and Hilly Areas (HA) (Figure 2.1). This Center also disseminate flood inundation map as a routine work during the flood season. The flood inundation map they prepared is an output based on the result file/data of the Flood Forecasting Model and Digital Elevation Map (DEM). This is done by using MIKE 11 FF module and GIS, where the results are found from MIKE 11 Rainfall-Runoff and Hydrodynamic modeling simulation. Flood inundation for whole country is a macro level product of FFWC, that shows a general overview of flood situation of the whole country (FFWC, 2007). The problem of these inundation maps is that the DEM used to generate the inundation maps, is very course (300 m resolution). Also, it does not cover the southern part that is coastal region of Bangladesh. Beside this, the model generates inundation data where there is no river station data available, by interpolation. That is why; actual scenario cannot be generated properly by this method. A detail and authentic DEM may improve significantly the inundation status of the map they produce.

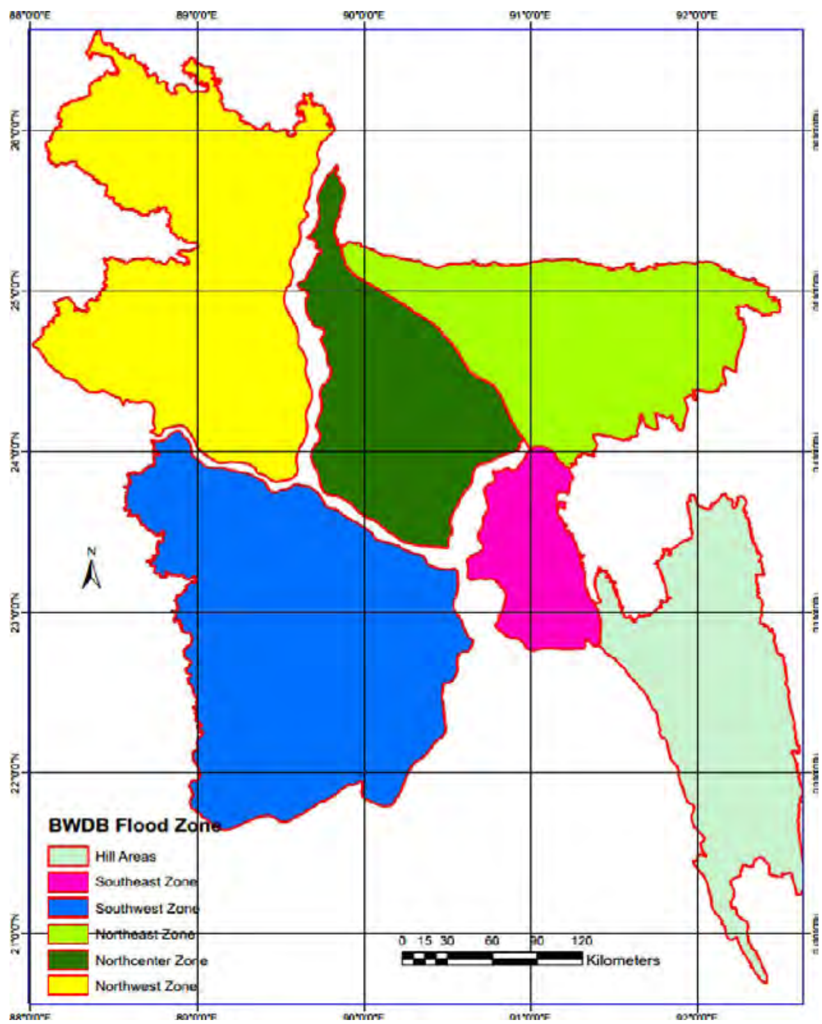

Figure 2.1 BWDB Flood Zones of Bangladesh

Chapter 3

Study Area and Data Acquisition

3.1 Geography:

Bangladesh is a riverine country located in South Asia with a largely marshy jungle coastline of 710 km (441mi) on the northern littoral of the Bay of Bengal. Formed by a delta plain at the confluence of the Ganges (Padma), Brahmaputra (Jamuna), and Meghna Rivers and their tributaries, Bangladesh's alluvial soil is highly fertile, but vulnerable to flood and drought. Hills rise above the plain only in the Chittagong Hill Tracts in the far southeast and the Sylhet division in the northeast. Straddling the Tropic of Cancer, Bangladesh has a tropical monsoon climate characterized by heavy seasonal rainfall, high temperatures, and high humidity (Wikipedia, 2015).

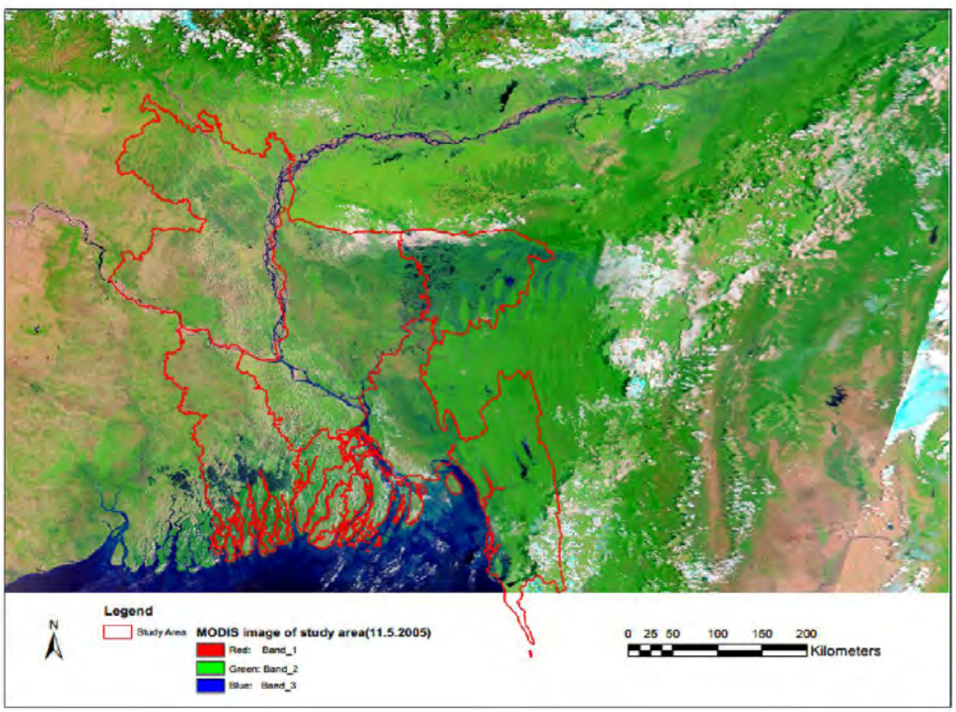

Figure3.1 Map showing the study area

3.2 Climate:

Heavy rainfall is a characteristic of Bangladesh causing it to flood every year. With the exception of the relatively dry western region of Rajshahi, where the annual rainfall is about

1,600 mm (63.0 in), most parts of the country receive at least 2,300 mm (90.6 in) of rainfall per year (Wikipedia, 2015). Because of its location just south of the foothills of the Himalayas, where monsoon winds turn west and northwest, the region of Sylhet in northeastern Bangladesh receives the greatest average precipitation.

About 80% of Bangladesh's rain falls during the monsoon season. The monsoons result from the contrasts between low and high air pressure areas that result from differential heating of land and water. During the hot months of April and May hot air raises over the Indian subcontinent, creating low-pressure areas into which rush cooler, moisture-bearing winds from the Indian Ocean. This is the southwest monsoon, commencing in June and usually lasting through September. Dividing against the Indian landmass, the monsoon flows in two branches, one of which strikes western India. The other travels up the Bay of Bengal and over eastern India and Bangladesh, crossing the plain to the north and northeast before being turned to the west and northwest by the foothills of the Himalayas (Wikipedia, 2015).

3.3 Types of Flood:

In Bangladesh, there are four types of floods that are normally encountered (DDM, 2014).

1. **Flash Flood from Hilly Areas**:

Flash flood prone areas of Bangladesh are at the foothills. Intense local and short-lived rainfall often associated with mesoscale convective clusters is the primary cause of flash floods. These are characterized by a sharp rise followed by a relatively rapid recession. Often with high velocities of on-rush flood damages crops, properties and fish stocks of the wetland. Flash flood can occur within a few hours. In the months of April and May flash floods affect the winter rice crop at the harvesting stage, and are common in the districts of Northeast and Southeast regions of the country.

2. **Monsoon Floods or Normal flood from major rivers:**

The word flood is generally synonymous with river flood. River flood is a common phenomenon in this country caused by bank overflow. Of the total flow, around 80% occurs in the 5 months of monsoon from June to October (WARPO, 2004). A similar pattern is observed in case of rainfall also. As a consequence to these skewed temporal distribution of river flow and rainfall, Bangladesh suffers from abundance of water in monsoon, frequently resulting into floods and water scarcity in other parts of the year, developing drought conditions (IEB, 1998). Climatologically, the discharge into Bangladesh, from upper catchments, occurs at different time of the monsoon. In the Brahmaputra maximum discharge occurs in early monsoon in June and July whereas in the Ganga maximum discharge occurs in August and September. Synchronization of the peaks of these rivers results in devastating floods. Such incidents are not uncommon in Bangladesh. The rivers of Bangladesh drain about 1.72 million sq km area of which 93% lies outside its territory in India, Nepal, Bhutan and China (WARPO, 2004). The annual average runoff of the cross boundary rivers is around 1200 cubic kilometers (WARPO, 2004).

3. **Rain-fed Flood**:

This kind of flood generally occurs in many parts of the country but is mainly prevalent in the south-western part of the country. This kind of flood also occurs in the flood plains where natural drainage systems have been disturbed either due to human interferences e.g. construction of unplanned rural roads and encroachment of river courses etc. or due to gradual decay of the natural drainage system. When intense rainfall takes place in those areas, the natural drainage system cannot carry the run-off generated by the storm and causes temporary inundation in many localities. This kind of rain-fed flood is increasing in the urban areas.

4. **Floods Due To Storm Surges:**

This kind of flood mostly occurs along the coastal areas of Bangladesh over a coastline of about 800 km along the southern part. Continental shelves in this part of the Bay of Bengal are shallow and extend to about 20-50 km. Moreover, the coastline in the eastern portion is conical and funnel like in shape. Because of these two factors, storm surges generated due to any cyclonic storm is comparatively high compared to the same kind of storm in several other parts of the world. In case of super-cyclones, maximum heights of the surges were found to be 10-15 m, which causes flooding in the entire coastal belt. The worst kind of such flooding was on 12 Nov 1970 and 29 April 1991 which caused loss of 300,000 and 138,000 human lives respectively (FFWC, 2005). Coastal areas are also subjected to tidal flooding during the months from June to September when the sea is in spate due to the southwest monsoon wind.
In this study, first three types of flood have been considered because of their recurring phenomena.

3.4 Data Acquisition:

Primary data that have been used in this study are MODIS data. MODIS data are freely distributed through various public URL sources. List of Data sources is given bellow:

1. USGS Earth Explorer (EE)

   All LP DAC MODIS and selected ASTER products are available for search, browse and direct download at http:// earthexplorer.usgs.gov/

2. USGS Global Visualization Viewer (GloVis)

   All LP DAAC ASTER and selected MODIS data holdings are available. Landsat 7 ETM+, Landsat 4/5 TM, Landsat 1-5 MSS, EO-1 Hyperion, MRLC, and Tri-Decadal data sets are also available at http:// glovis.usgs.gov/

3. LP DAAC Data Pool

   Selected LP DAAC ASTER and MODIS data are available. All data are at no charge. http:// lpaac.usgs.gov/get_data/ data_pool

4. MODIS Near-real time Data:

   On a near real-time basis NASA's MODIS Terra and Aqua satellite images are available at free of charge and can be downloaded from below link: http://lance-modis.eosdis.nasa.gov/imagery/subsets/?project=fas&subset/ .

Chapter 4

Methodology

4.1 Introduction:

Methodology of generating flood map using MODIS image was originally developed by Sakamoto et al. (2007). In this study, a modified method has been developed. Steps of the analysis are shown in the figure 4.1.

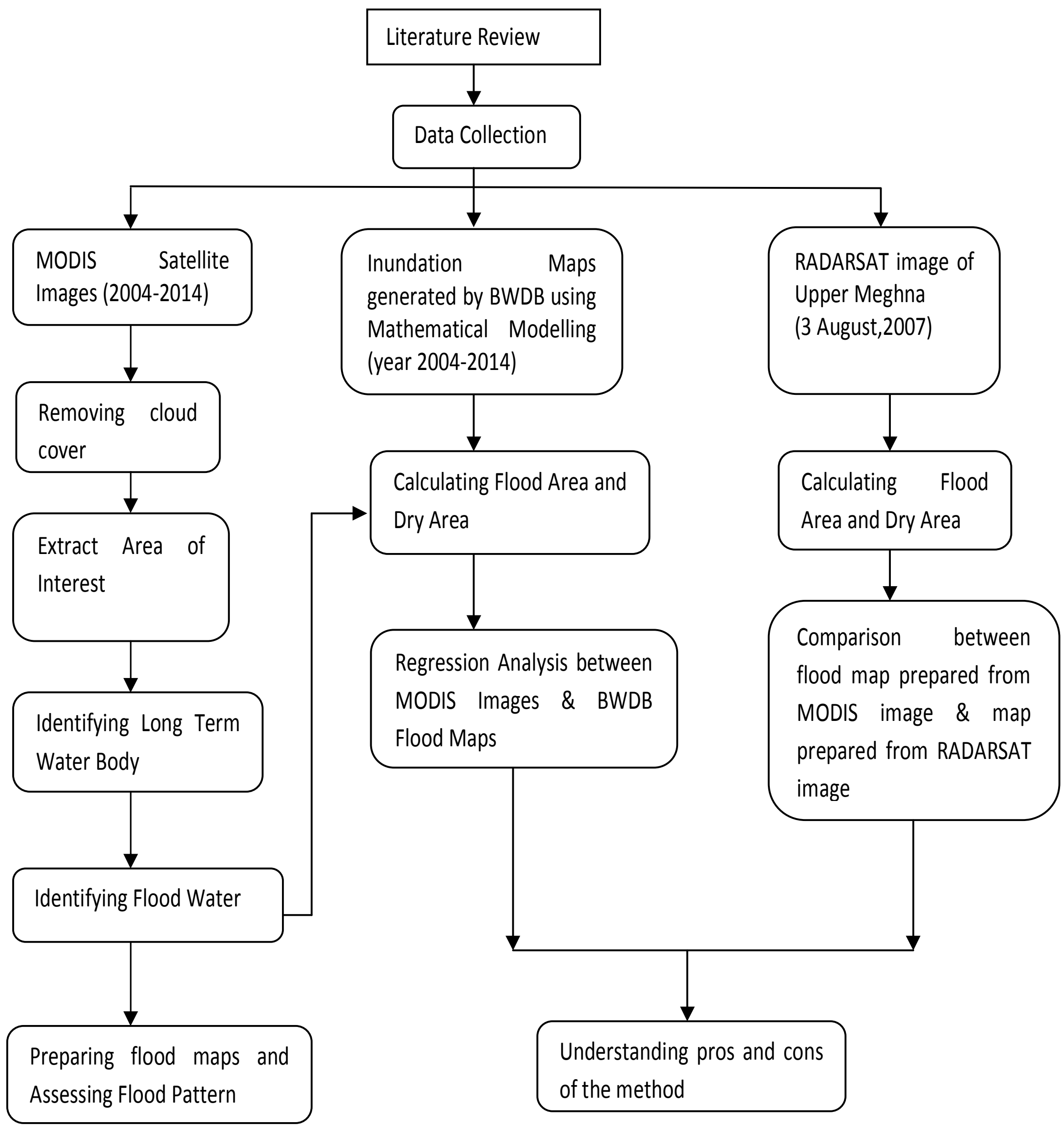

Figure 4.1 Steps of analysis

4.2 Data Collection:

In this study three types of data have been used. MODIS satellite images from the year 2004 to 2014, which have been downloaded from website, inundation maps generated by BWDB from the year 2004 to 2014, which have been collected from FFWC, BWDB and the RADARSAT image of upper Meghna, which has been collected from CEGIS.

4.3 Removing Cloud Cover:

The satellite sensors acquired MODIS image are passive sensors and cannot penetrate cloud cover. That is why; it is not possible to get flood image in the monsoon season as the sky is frequently covered by thick cloud in Bangladesh. To overcome this problem, Myanmar Information Management Unit (MIMU) has developed a tool called MODIS Flood Mapping Tool (The beta version of the tool can be downloaded from the website: http://themimu.info/GIS/index.php). The core program of this tool is written in C language and the Graphic User Interface (GUI) is written in MS Visual C#. The core program is developed as an individual standalone executable program and it supports the batch processing. The programs uses the GDAL (Geospatial Data Abstraction Library), JPEG library, GeoTiff library and Dr. Honda image processing library which are distributed as General Public License version > 2.0. In this tool, Terra and Aqua images are inserted as an input data. It creates cloud free image for Natural Color Composite and Band 7-2-1 Combination False Color Composite images by removing cloud from Terra & Aqua images using image fusion method. The output file carries the same geo-information as the first input file inserted in the tool. The tool only accepts and does the processing when the two input images have the same dimensions (rows, columns and band). Figure 4.2 to Figure 4.4 show the output of images after removing cloud cover with the help of MODIS Flood Mapping Tool.

4.4 Extract Area of interest:

After removing cloud cover from MODIS satellite images, area of interest for the study has been extracted with help of ArcGIS 10.2 software (Figure 4.6). Here the extent of the Area of interest is up to the political boundary of Bangladesh.

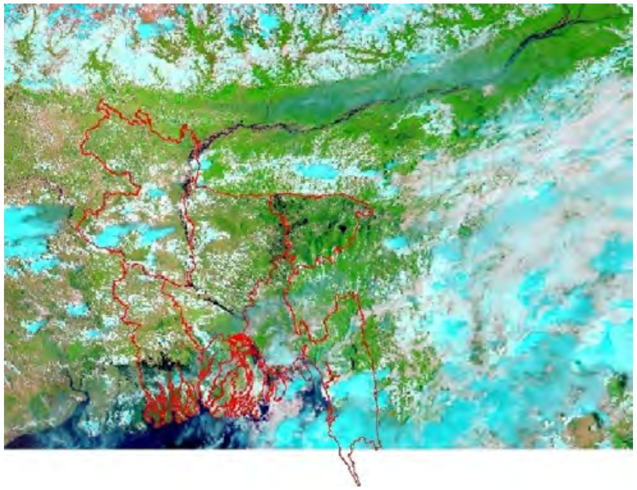

Figure 4.2 MODIS aqua image of 17th May, 2007.

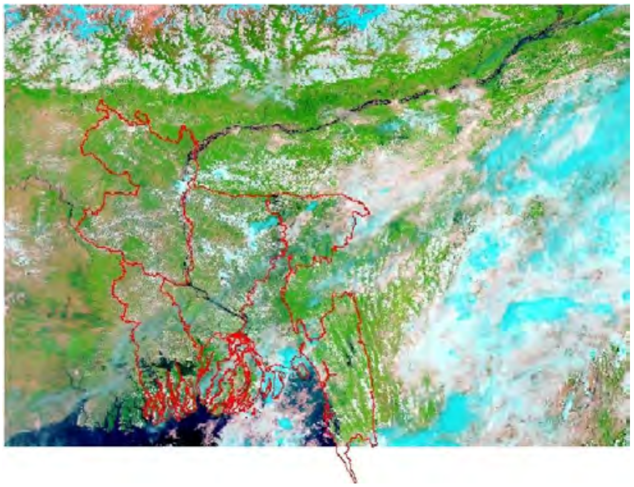

Figure 4.3 MODIS terra image of 17th May, 2007.

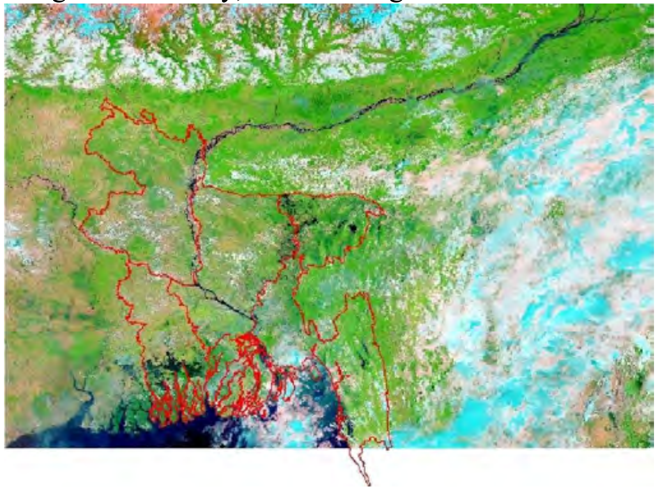

Figure 4.4 MODIS terra image of 17th May, 2007. (After cloud removed)

4.5 Detecting Surface Water Extent and Identifying Long Term Water Bodies Using MODIS Data:

After extracting area of interest, surface water extent has to be detected and long term water bodies need to be identified. In the past, Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) were used to identify water related surface (Rogers and Kearney, 2004). To date, more than 40 multi-spectral remote sensing based indices have been developed and used to monitor water and vegetation properties. Among these, NDVI is the most widely used VI; however, it is sensitive to atmospheric aerosols and soil background. The main reason of using Short-wave infrared (SWIR) is, it is highly sensitive to moisture content in the soil and the vegetation canopy. Various approaches have been reported that make use of the spectroscopic characterization of SWIR against water content. Studies showed that NDWI in paddy fields exceeds NDVI derived from SPOT data for the same period of flooding and rice-planting in eastern Jiangsu Province, China (Xiao et al. (2002b)). In recent years, many studies use anomalies between the Land Surface Water Index (LSWI) and Vegetation Indexes (NDVI or EVI) in an algorithm to estimate the distribution of paddy fields in South China and Southeast Asia (Xiao et al. (2006; 2005)). In Table 4.1, detail description of the indices derived from MODIS data along with the band number and solar spectrum has been presented.

Table 4.1 Detail description of the indices derived from MODIS data along with the band number and solar spectrum.

Indices	Equation
Normalized Difference vegetation Index (NDVI)	NDVI= $\frac{\rho NIR-\rho RED}{\rho NIR+\rho RED}$
Enhanced Vegetation Index (EVI)	EVI= $2.5\ x\ \frac{\rho NIR-\rho RED}{\rho NIR+6\ x\rho RED-7.5x\rho BLUE}+1$
Land Surface Water Index (LSWI)	LSWI = $\frac{\rho NIR-\rho SWIR}{\rho NIR+\rho SWIR}$
Normalized Difference Snow Index (NSDI)	`NSDI= $\frac{\rho NIR-\rho SWIR}{\rho NIR+\rho SWIR}$

Where, ρRED is the reflectance of red (620-670 nm, MODIS Band 1), ρNIR is the reflectance of near infrared (841-876 nm, MODIS Band 2), $\rho BLUE$ is the reflectance of blue (459-479 nm, MODIS Band 3), $\rho SWIR$ is the reflectance of short-wave infrared (1628-1652 nm, MODIS Band 6) of the solar spectrum.

However, in this study, MODIS Rapid Mapper Tool has been used for detecting flood water in the MODIS images. This program delineates the water body and classifies the water body into different classes depending on the reflectance properties of water and underlying land cover type. The Grid Code varies from 10 to 255 (Figure 4.6-4.7). Grid code 10-30 are for deep/still water like lake and ocean, grid code 35 are for sandy-water, grid code 50-80 are for shallow water mixed with vegetation or land. The output classes are as in the following tables.

Table 4.2 Grid Code for Classified Water Mask (MODIS flood Mapping tool User's manual, 2012).

GRIDCODE	Class Names	Remark
10	Deep/still/permanent water/ lake/Ocean	May contain mountain shadow or cloud shadow
20	Water/Ocean	-ditto-
30	Water/Ocean	-ditto-
35	Water/Sandy water	-ditto-
40	Water mixed with vegetation	-ditto-
50	Water mixed with vegetation	-ditto-
60	Water mixed with vegetation	-ditto-
70	Water mixed with vegetation	-ditto-
80	Water mixed with vegetation	-ditto-
255	Other non water area	

After identifying water-related pixels it is essential to classify whether it is flood pixel or a long term water bodies. It is difficult to identify vegetation mixed with water and vegetation completely flooded by water. In this study GRIDCODE 10 to 80 have been considered as flood water and designated as 10 and non water areas have been designated as 255. However, in Bangladesh there have been many water bodies in flood plain such as permanent fresh water, lakes or shallow lakes where water can be found more than 6 months. In this study, water-related pixel which has an inundation period more than 120 days has been classified as long term water bodies (Figure 4.8) and thus did not consider as a flood water pixel.

The logical steps of identifying flood water cell as shown in the following figure:

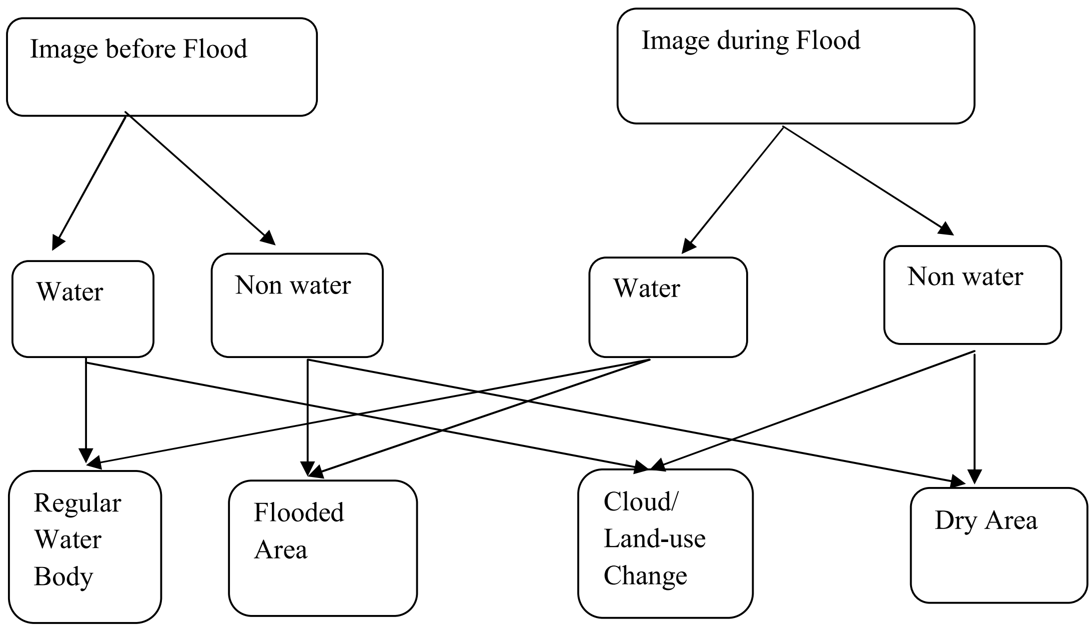

Figure 4.5: Logical steps determining flooded and non flooded area

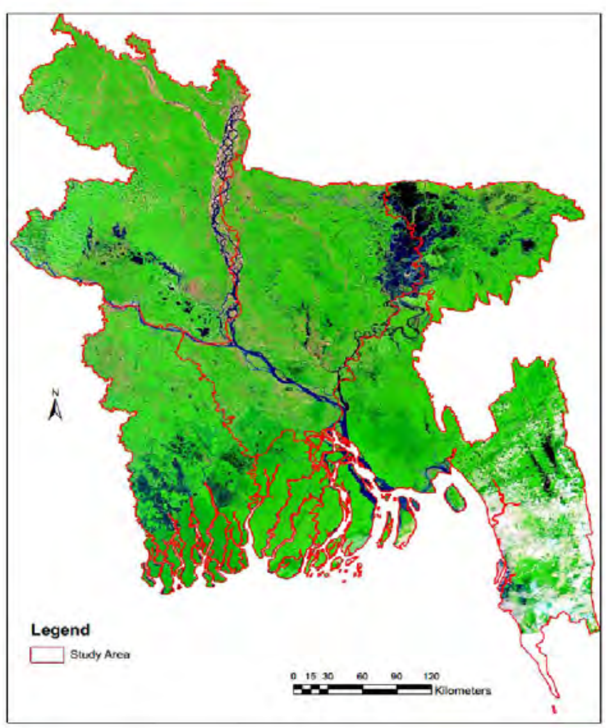

Figure 4.6 Extracted area of interest (31.10.2014).

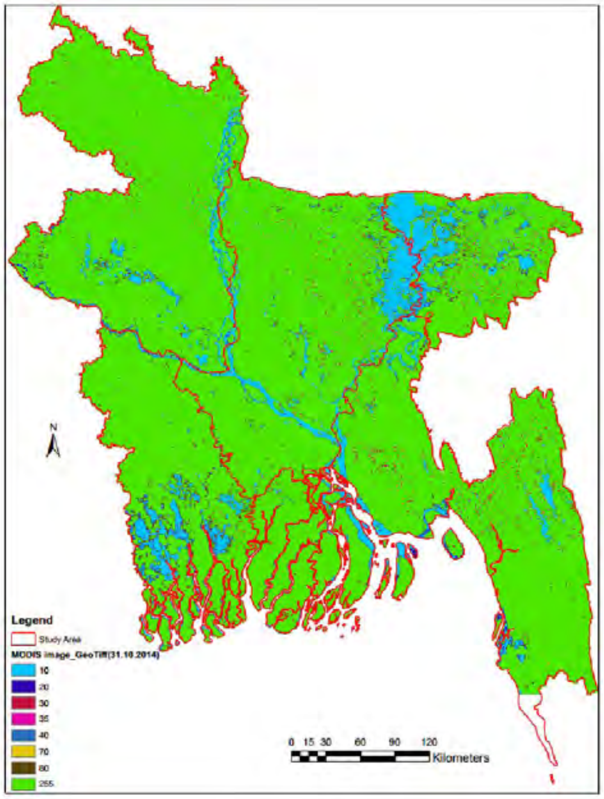

Figure 4.7 MODIS image showing Gridcode in GeoTiff format (31.10.2014).

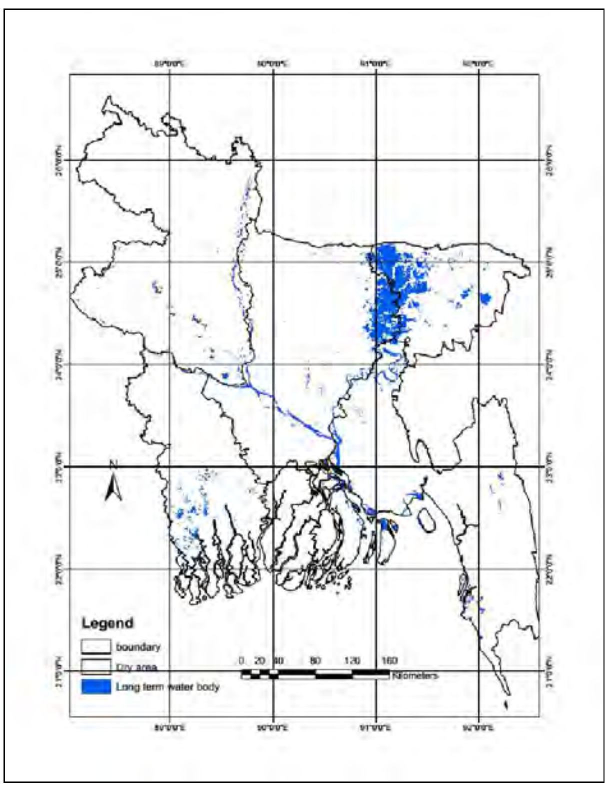

Figure 4.8 Long Term Water Bodies.

4.6 Preparing Flood Inundation Maps and Assessing Flood Pattern:

After identifying Flood water, Inundation Maps from the year 2004 to 2014 have been prepared. In this study, from three available images of each month of a flood season (May to October), three maps have been prepared, one map in the beginning, one in the middle and one at the end of a month. Total inundated area then calculated by multiplying the number of cell count, to the area of each cell (Resolution of the image). All these processing and flood inundation maps preparations have been conducted by ArcGIS 10.2 software. By plotting the graphs between inundated area Vs time of these years, flood pattern of different regions and whole Bangladesh has been prepared. Later, these inundation maps prepared from MODIS images have been compared with the inundation maps generated by FFWC and RADARSAT image. This comparison has been done by regression analysis.

Chapter 5

Results and Discussions

In this study an analysis has been conducted for the year of 2004 to 2014 except the year from 2011 to 2013 because the data was not available. Analysis has been conducted both in zone wise format and in general format. BWDB flood zones (Figure 2.1) have been considered during zone wise analysis for this study. Two types of outcomes have been generated by this analysis.

- Flood Inundation Maps from the year 2004 to 2014.
- Analysis of flooding pattern of Bangladesh.

5.1 Flood Inundation Maps from the year 2004 to 2014

5.1.1 Inundation Maps generated from MODIS images:

Inundation maps of different years have been shown in Figure from A1.1 to A1.89. In this study normally a month has been divided into three quarters and single image of each quarter has been generated for analysis, unless it could not be collected due to cloud cover.

5.1.2 Comparison with BWDB inundation maps:

i) **In general format**: Flood inundation maps prepared from MODIS images were in generally compared with the flood maps prepared by BWDB. The area of inundation in both maps has been calculated. Figure A2.1 to Figure A2.25 showed the comparison between the two types of images. The correlation between these two maps has been found as $R^2 = 0.701$. (Figure 5.1.1)

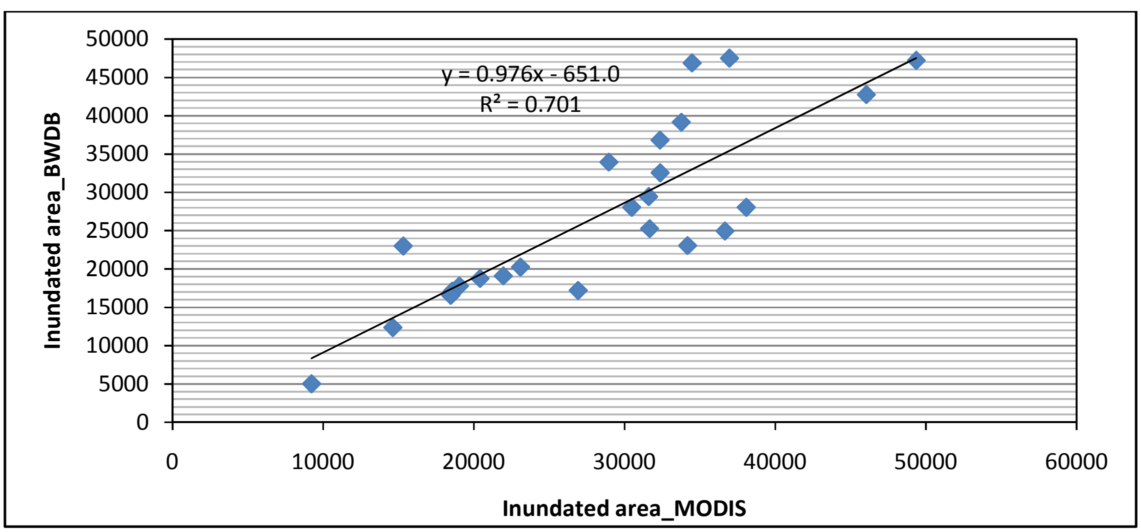

Figure 5.1.1: Comparison between MODIS flood images and BWDB flood maps

ii) **Zone wise format:** In this format, the whole Bangladesh has been divided into 6 zones described in chapter 2. Details are given below

a) **Northwest Zone:** Comparison of Northwest Zone between MODIS images and BWDB flood maps has been shown in figure 5.1.2. The correlation between two data in this zone has been found as r^2 = 0.915 which indicates a strong correlation.

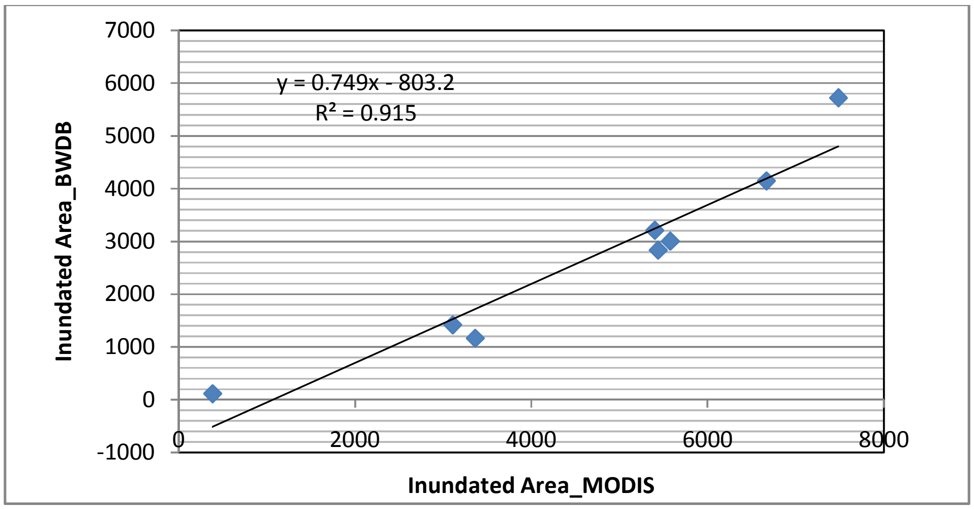

Figure 5.1.2: Correlation between MODIS images and BWDB inundation maps in Northwest Zone

b) **North central Zone**: Comparison of North central Zone between MODIS images and BWDB flood maps has been shown in figure 5.1.3. The correlation between two data in this zone has been found as r^2 = 0.896 which also indicates a strong correlation.

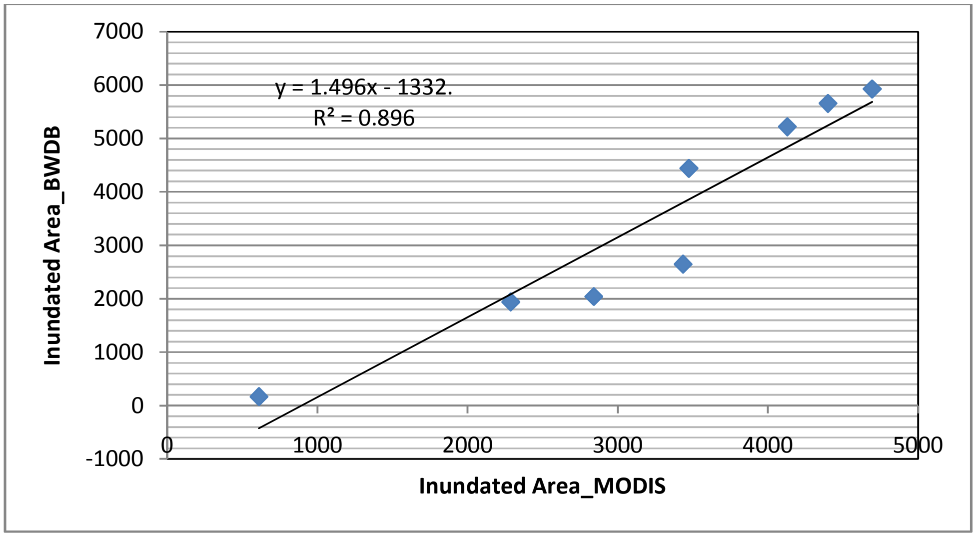

Figure 5.1.3: Correlation between MODIS images and BWDB inundation maps in North central Zone.

c) **Northeast Zone**: Comparison of Northeast Zone between MODIS images and BWDB flood maps has been shown in figure 5.1.4. The correlation between two data in this zone has been found as $r^2 = 0.929$ which indicates good correlation.

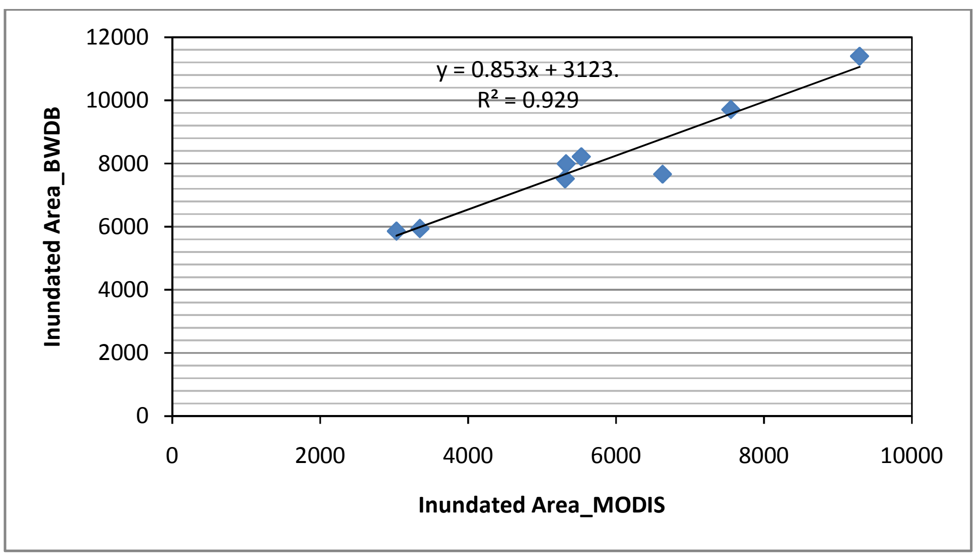

Figure 5.1.4: Correlation between MODIS images and BWDB inundation maps in Northeast Zone.

d) **Southwest Zone**: Comparison of Southwest Zone between MODIS images and BWDB flood maps has been shown in figure 5.1.5. The correlation between two data in this zone has been found as $r^2 = 0.058$ which indicates very low correlation.

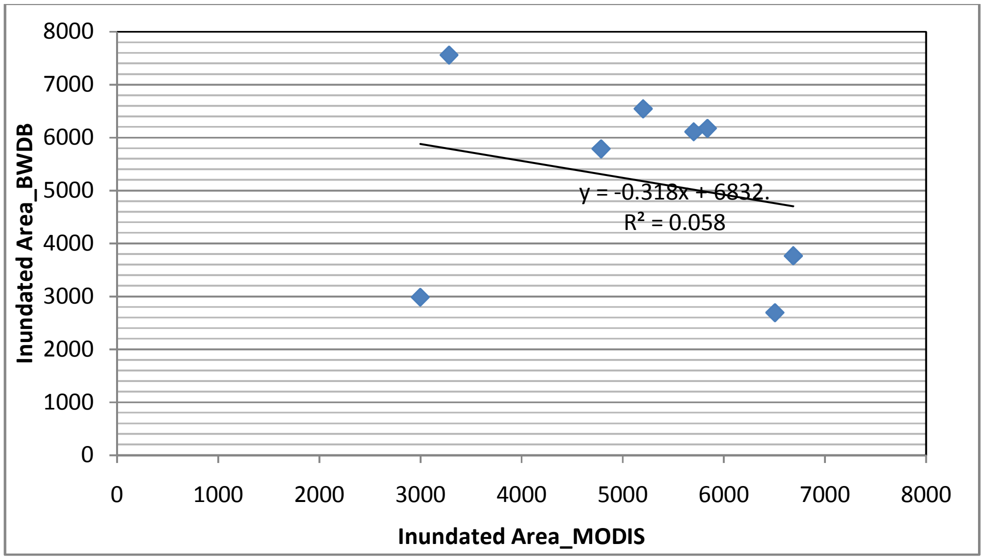

Figure 5.1.5: Correlation between MODIS images and BWDB inundation maps in Southwest Zone.

e) **Southeast Zone:** Comparison of Southeast Zone between MODIS images and BWDB flood maps has been shown in figure 5.1.6. The correlation between two data in this zone has been found as r^2 = 0.959 which indicates very high correlation.

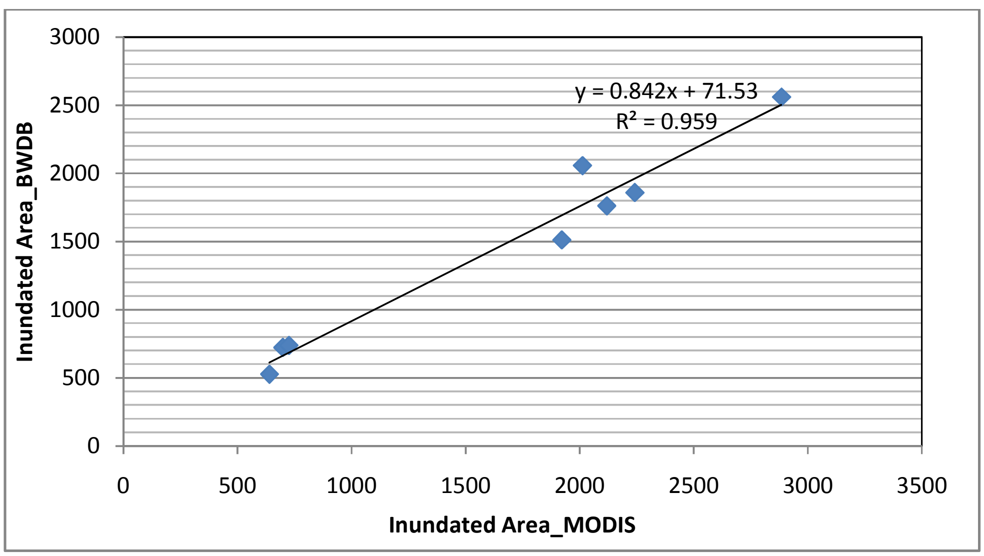

Figure 5.1.6: Correlation between MODIS images and BWDB inundation maps in Southeast Zone.

5.2 Flood Pattern Analysis

5.2.1 Flood pattern of the year 2004:

i) **In general pattern**: Bangladesh experienced a very unusual flooding in the year 2004. Flash flood occurred in the northern region of it. During the month of April, a series of 8 days intense storms brought early flooding in Sylhet region (Annexure A1.1). This flooding prolonged to the month of late May. Figure 5.2.1 shows heavy rainfall occurred in the month of April which is very unusual as monsoon comes in June to September in this country.

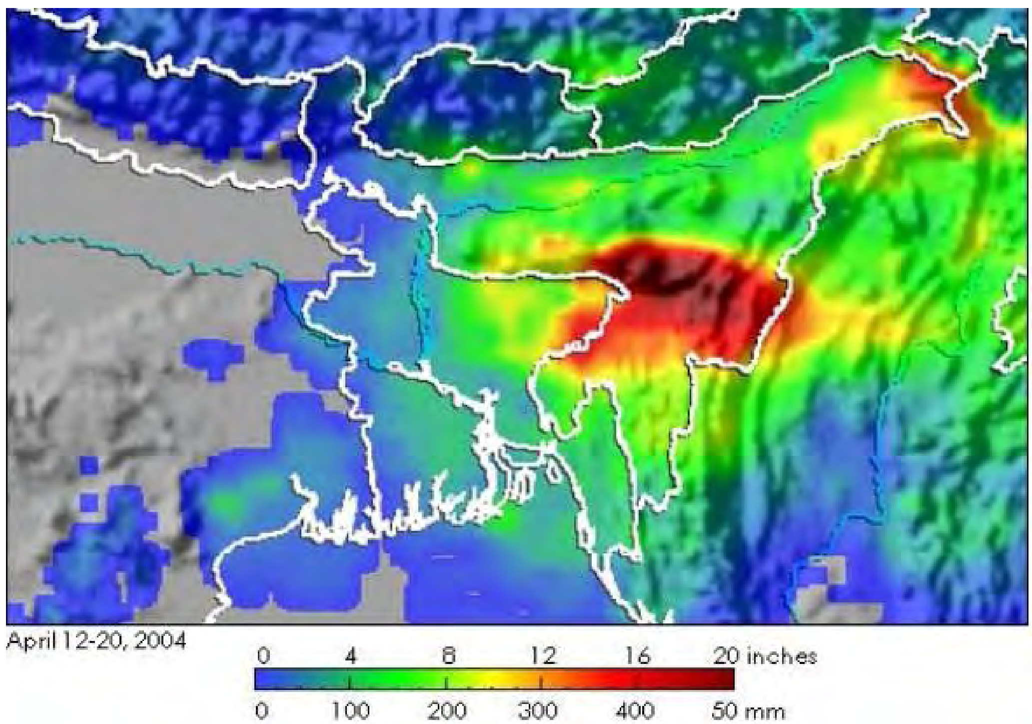

Figure 5.2.1 : Extensive rainfall in Meghna basin in the month of April 2004. (source: Rahman et al., 2005)

In this year after the unusual flash flood in April-May, a more intense pick had come in the late of July (Figure 5.2.2). About 24% area of Bangladesh were inundated at this peak (Figure 5.4.1). Another peak had come in the month of Mid October (Figure 5.2.2). Around 31% areas were inundated at this peak (Figure 5.4.1).

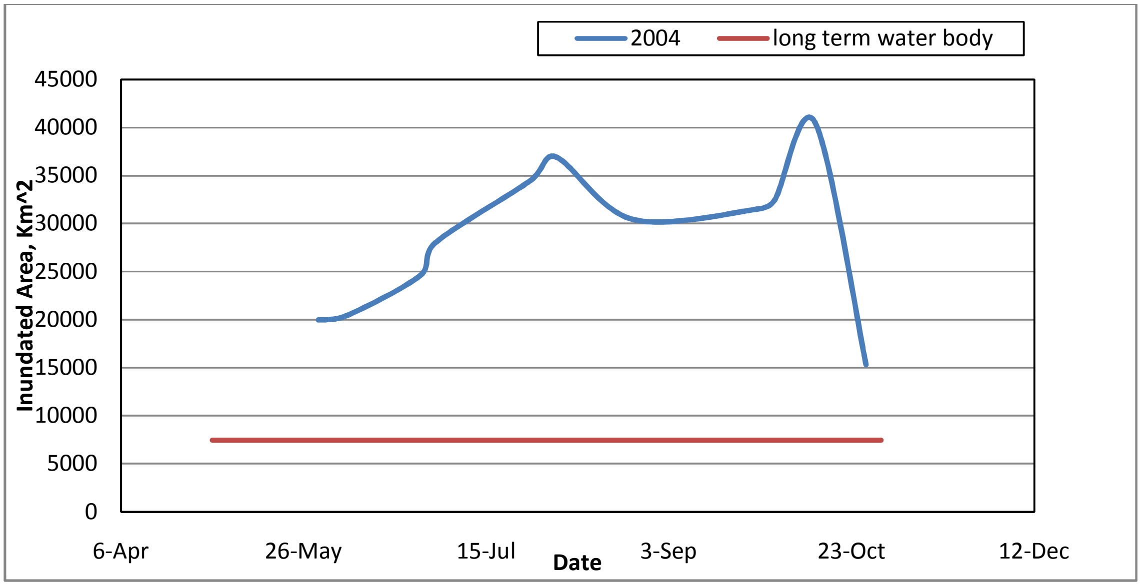

Figure 5.2.2: Inundation pattern of Bangladesh in the year 2004.

ii) **Zone wise Flood Pattern**:

a) **Northwest Zone**: The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. First peak had come in the last week of June. Second peak had also come in the last week of July (Figure 5.2.3) which is unusually early for this region.

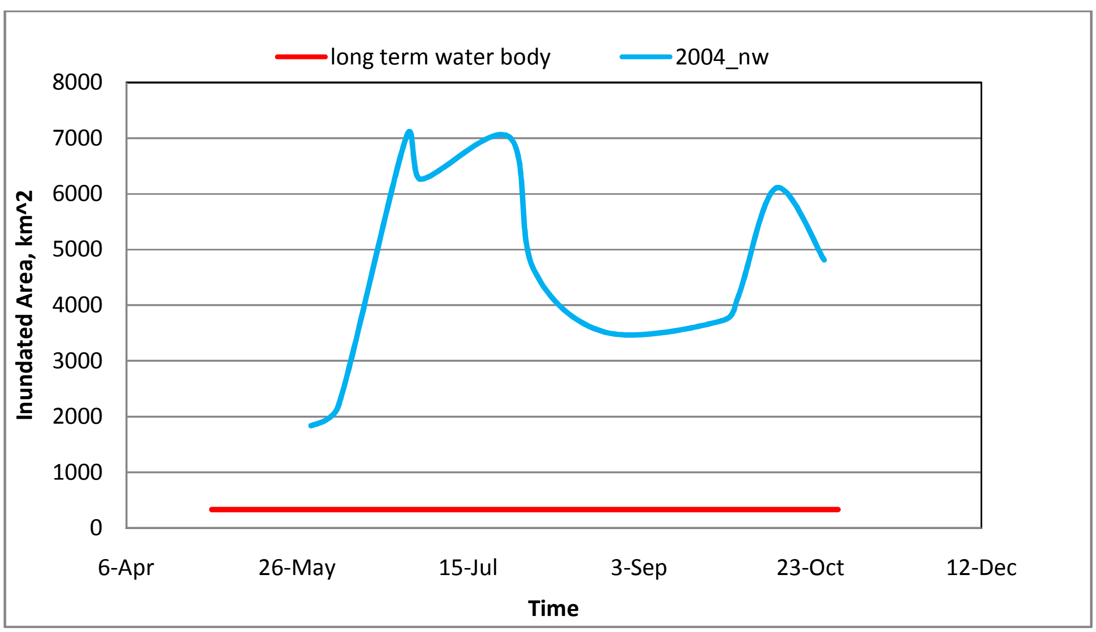

Figure 5.2.3 : Inundation pattern of Northwest region in the year 2004.

3rd peak had come in the mid of October. The most affected districts during 2004 flood of this region are Gaibandha, Naogaon, Bogra and Sirajganj. (Figure 5.2.4)

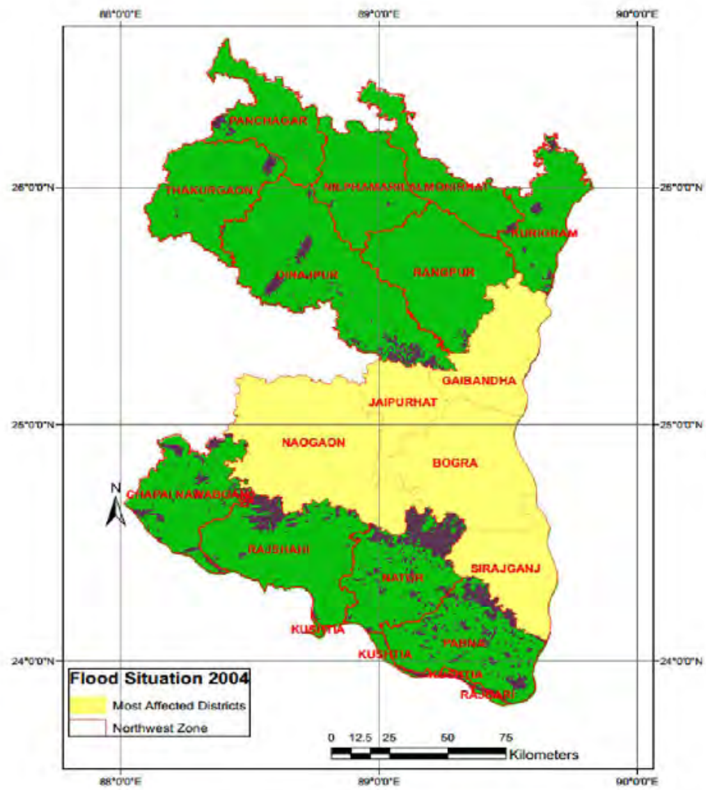

Figure 5.2.4: Most affected area of Northwest zone in the year 2004.

b) **North central Zone:** The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. This zone of Bangladesh had experienced a peak in the last week of July. Another peak had come in the mid October of this year (Figure 5.2.5).

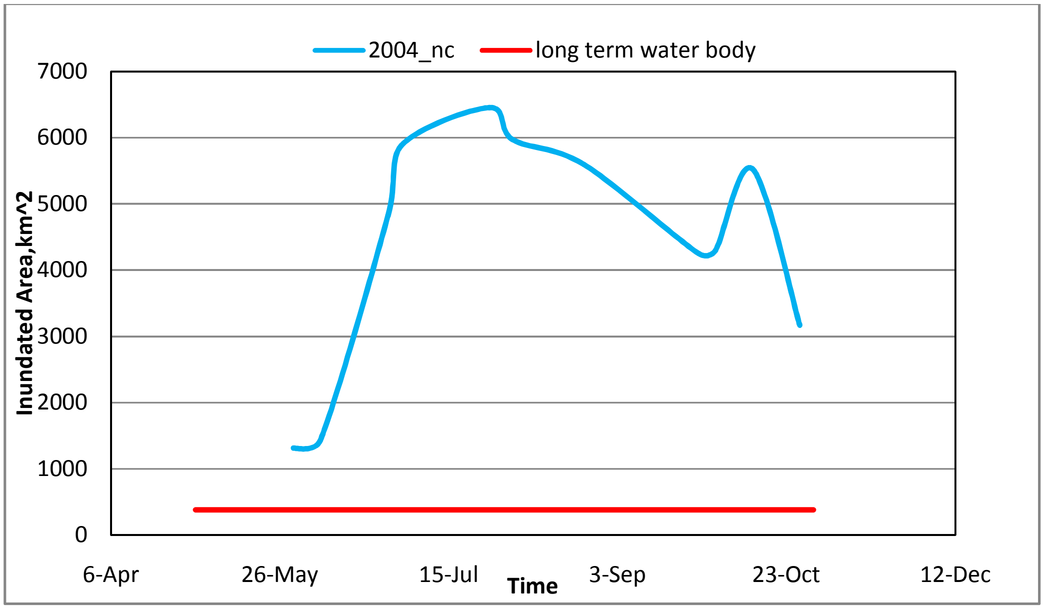

Figure 5.2.5: Inundation pattern of North central zone in the year 2004.

The most affected districts by this flood are Dhaka, Manikganj, Tangail and Jamalpur. (Figure 5.2.6)

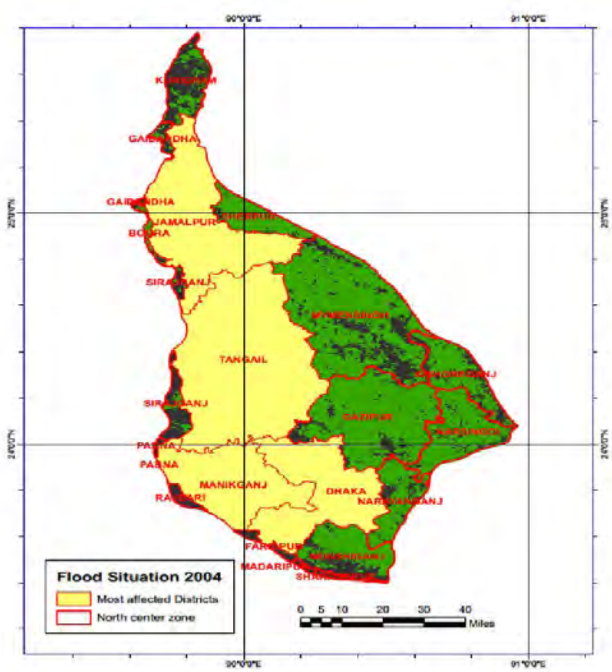

Figure 5.2.6: Most affected area of North central zone in flood 2004

c) **Northeast Zone**: The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. This zone experienced flash flood in the month of April and May

(Annexure A1.13). The peak had also come in the 1 week of July, 4th week of August and in the mid of October (Figure 5.2.7).

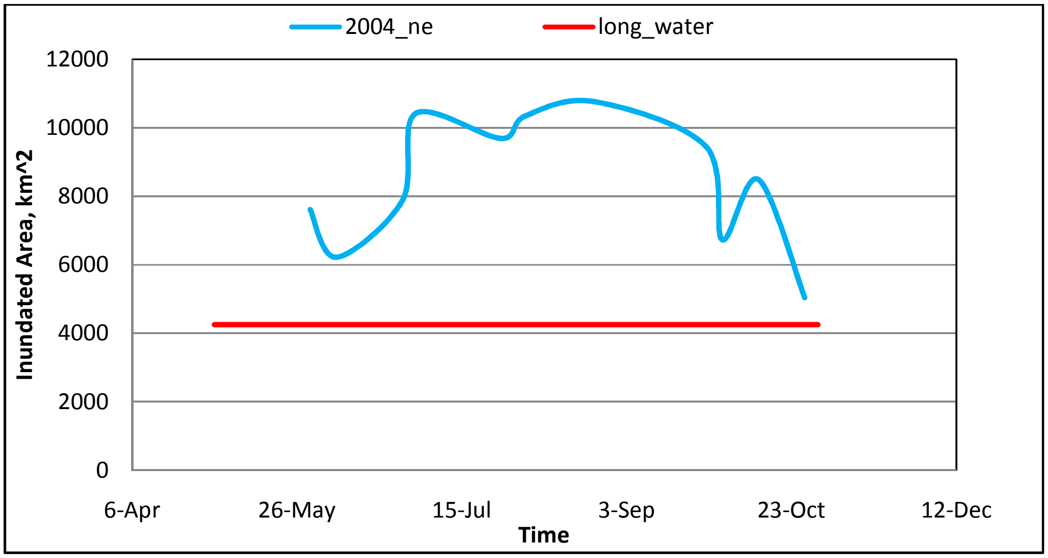

Figure 5.2.7: Inundation pattern of Northeast zone in the year 2004.

In this area, monsoon flood does not cause much damage because of
Sylhet depression called locally as "Haor". It stores a huge amount of flood water and thus creates fewer problems to the people. However the most affected areas of this region has been shown in Figure 5.2.8.

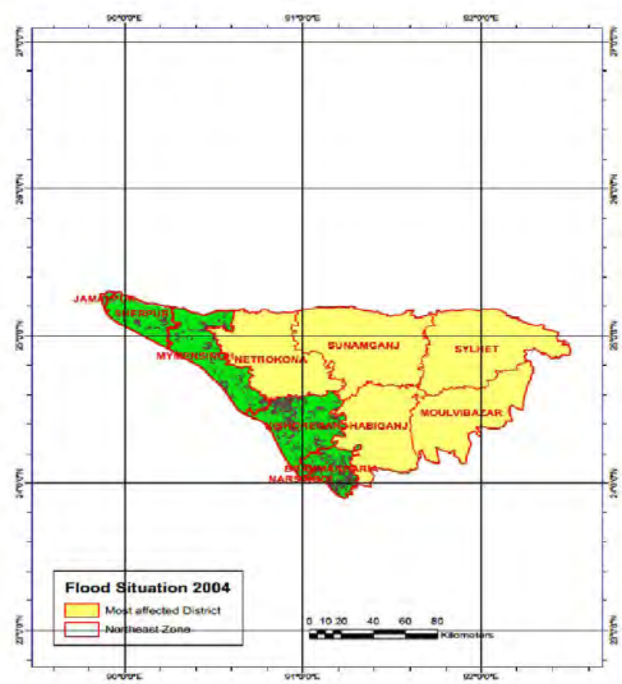

Figure 5.2.8: Most affected areas of Northeast zone in flood 2004

d) **Southwest Zone:** In the Southwest zone, there are some areas in Jessore, Satkhira and Khulna district where water is logged for most of the period of a year (Annexure A1.6). In this area flood peak had come in the last week of September (Figure 5.2.9). The Ichamoti, the Kodla, the Kobadak and the Lower Meghna are the major rivers of this region. The most affected areas of this region are Jessore, Satkhira, Khulna, Bagerhat, Faridpur, Madaripur, Shariyatpur (Figure 5.2.10).

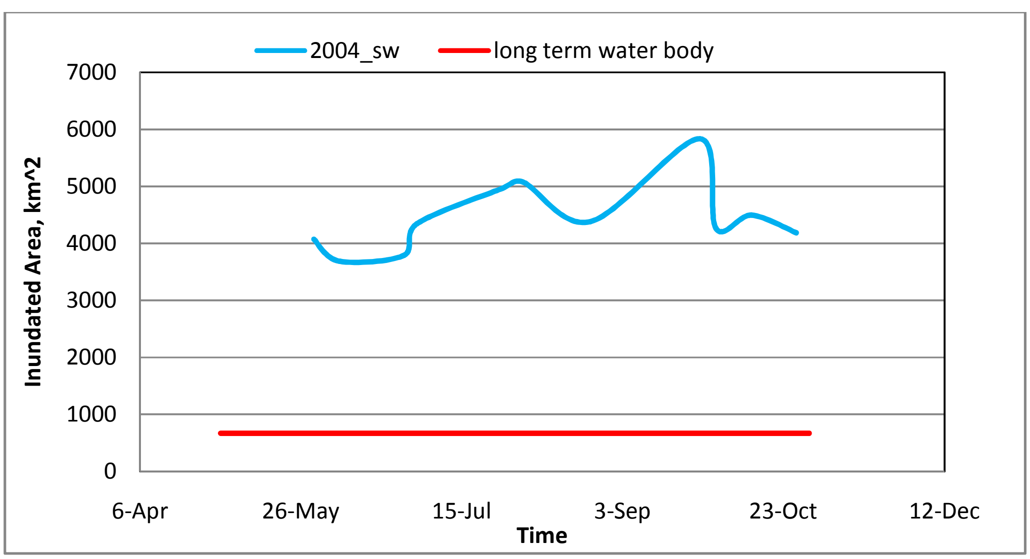

Figure 5.2.9: Inundation pattern of Southwest zone in the year 2004.

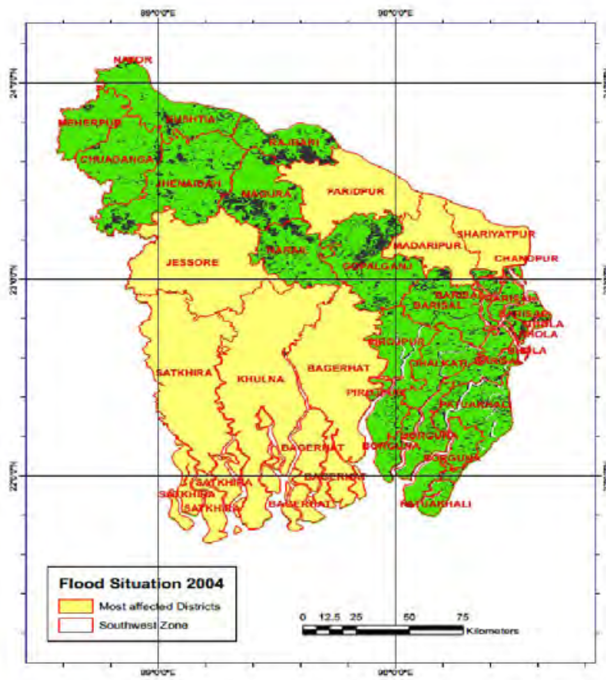

Figure 5.2.10: Most affected areas of Southwest zone in Flood 2004.

e) **Southeast Zone:** In this zone, flood peak had come in the last week of July. Highest inundation occurred in the last week of September (Figure 5.2.11). The Gumti and the Upper Meghna are the major rivers of this region.

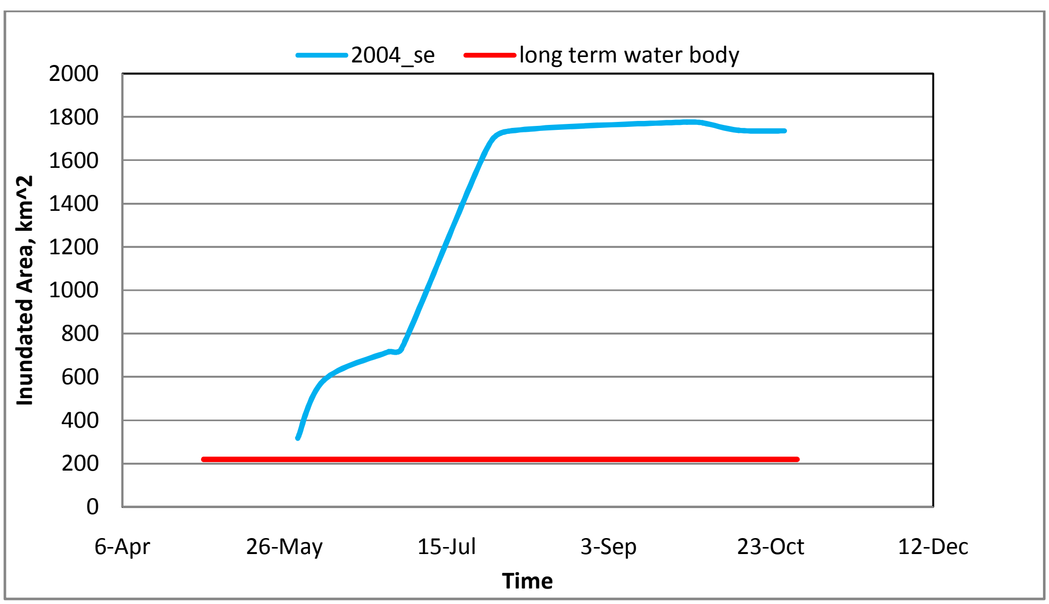

Figure 5.2. 11: Inundation pattern of Southeast zone in the year 2004.

The most affected areas of this region are Comilla and Brahmanbaria Districts. (Figure 5.2.12).

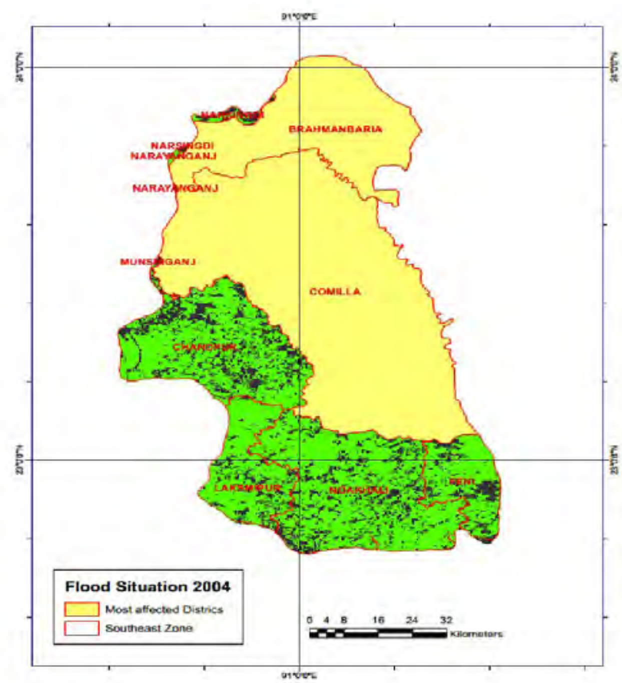

Figure 5.2.12: Most affected areas of Southeast zone in the year 2004

5.2.2 Flood Pattern of the year 2005:

i) **In general pattern:** In 2005 Bangladesh experienced normal flood. But in northeast part it experienced huge flash flood due to intense rainfall in the month of May (Annexure A1.13). Around 23% areas had been inundated at the peak of the flood in 2005 (Figure 5.4.1). The overall flooding pattern of this year has been shown in Figure 5.2.13. From this figure it is seen that, two peak had come in this year. One was in Mid May and another one was in the last week of August.

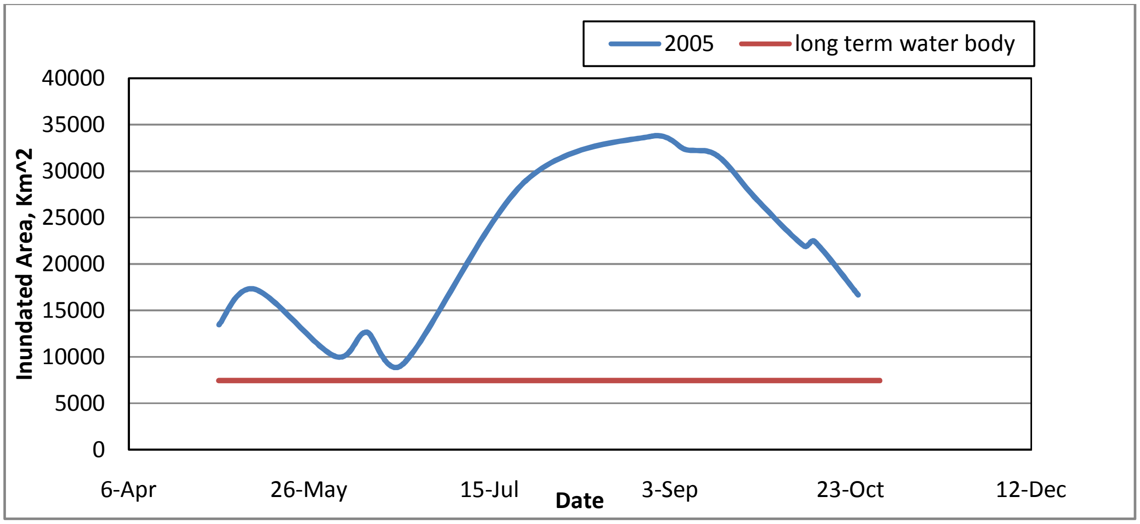

Figure 5.2.13: Inundation pattern of Bangladesh in the Year 2005.

ii) Zone wise Flood pattern:

a) **Northwest Zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. First peak had come in the last week of August. Second peak had also come in the mid of October (Figure 5.2.14) which is normal for this region.

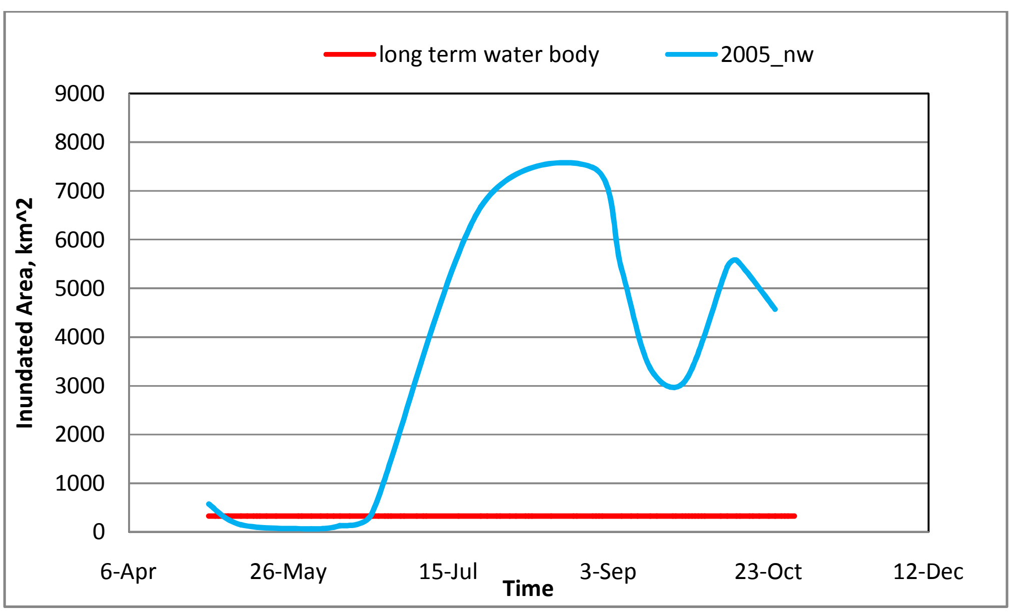

Figure 5.2. 14: Inundation pattern in Northwest zone in the year 2005.

The most affected areas of this zone were Sirjganj, Bogra, Gaibandha and Kurigram (Figure 5.2.15).

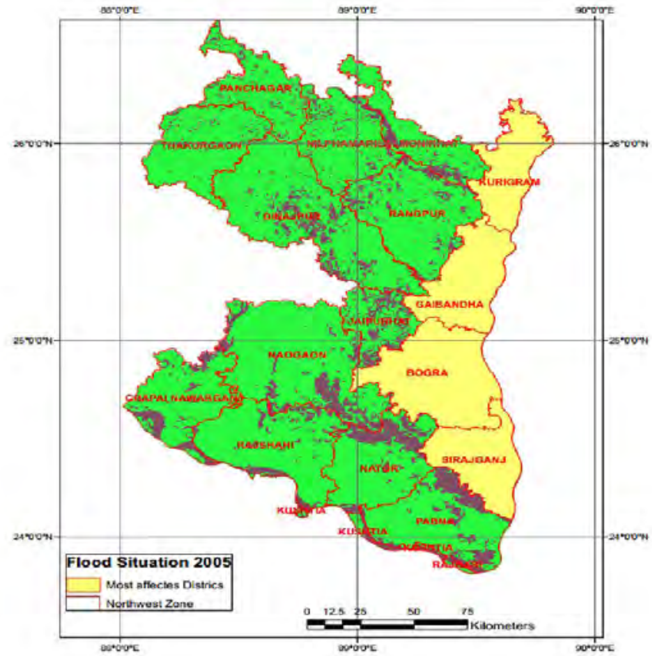

Figure 5.2.15: Most affected areas of Northwest zone in flood 2005.

b) **North central zone**: The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. Because of heavy rainfall in Brahmaputra and Meghna basin in August (FFWC, 2005), this zone of Bangladesh experienced a peak in the first week of September (Figure 5.2.16).

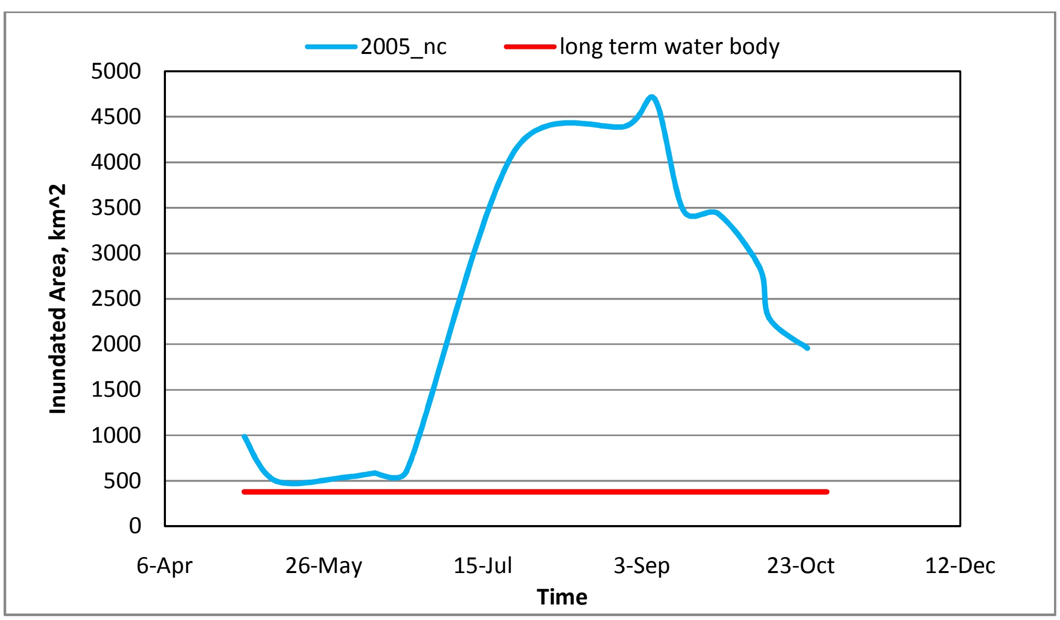

Figure 5.2.16: Inundation pattern in North center zone in the year 2005

The most affected areas of this zone were Manikgang, Tangail, and Jamalpur (Figure5.2.17).

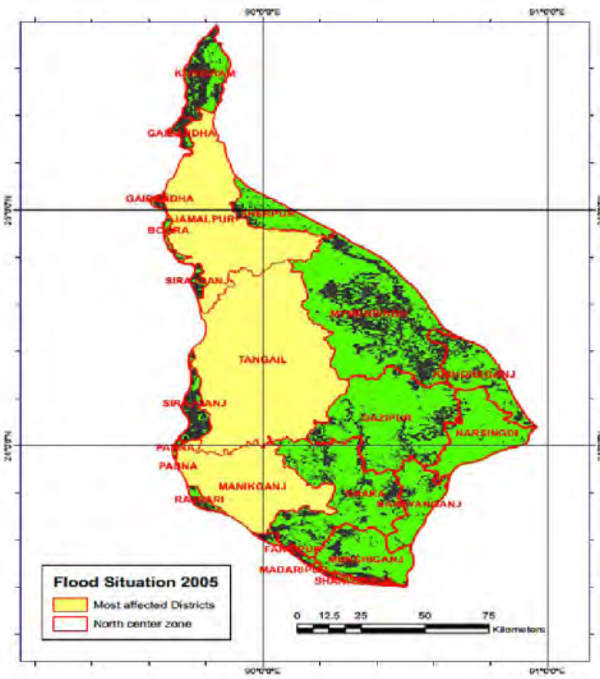

Figure 5.2.17: Most affected areas of North central zone in the year 2005

c) **Northwest Zone:** In 2005, northwest zone of Bangladesh experienced severe flash flood in the second week of May. This flood occurred due to heavy rainfall in this region. (FFWC, 2005). Two peaks had come in this month. One was in second week of May and another one was in the last week of July (Figure 5.2.18).

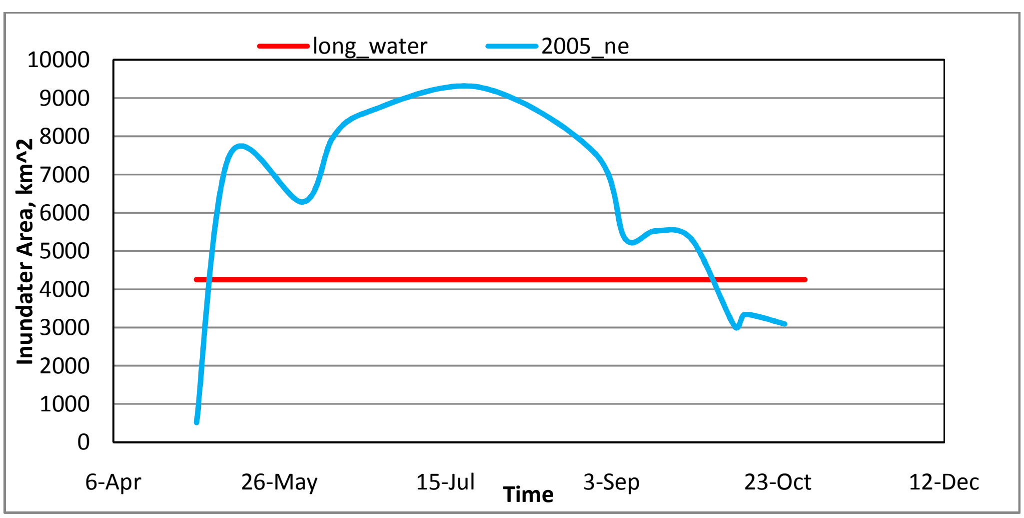

Figure 5.2.18: Inundation pattern of Northeast zone in the year 2005.

The most affected areas of this region were Sylhet, Sunamganj, Netrokona and Habiganj (Figure 5.2.19).

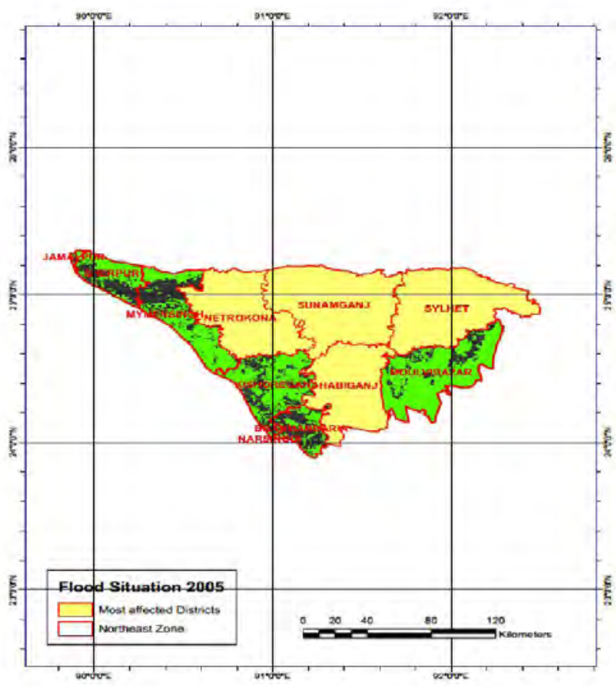

Figure 5.2.19: Most affected areas of Northeast zone in the year 2005.

d) **Southwest Zone:** In this area flood peak had come in the 2nd week of May and in the last week of September (Figure 5.2.20). The Ichamoti, the Kodla, the Kobadak and the Lower Meghna are the major rivers of this region. The most affected areas of this region are Satkhira, Khulna (Figure 5.2.21).

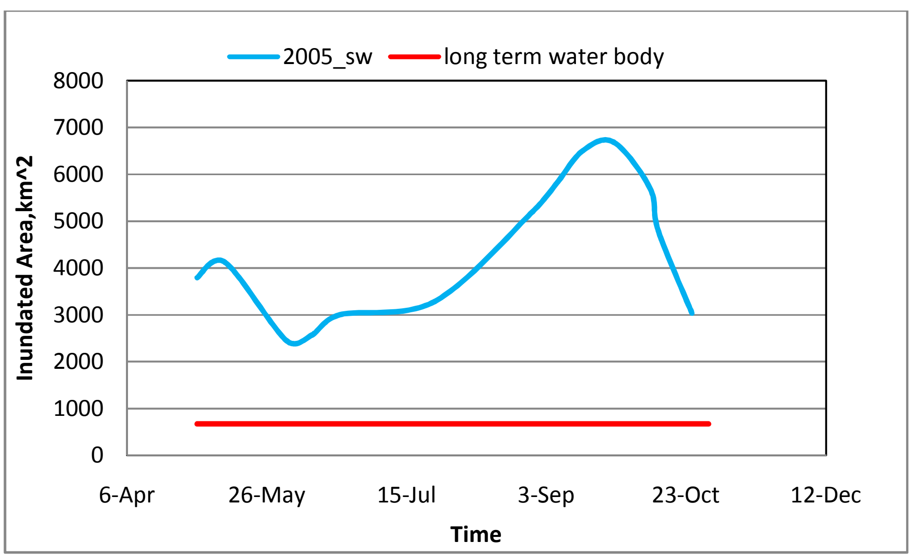

Figure 5.2.20: Inundation pattern of Southwest zone in the year 2005.

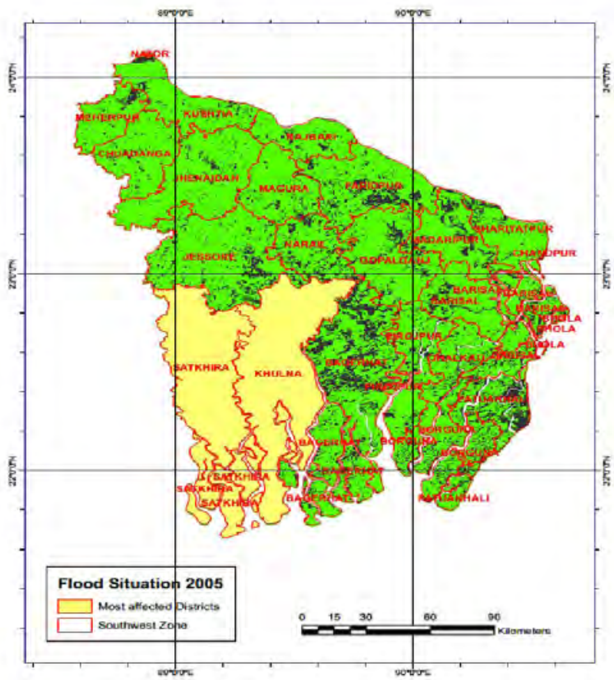

Figure 5.2.21: Most affected areas of Southwest zone in the year 2005.

e) **Southeast Zone:** In this zone, flood peak had come in the 2nd week of May and in the last week of September (Figure 5.2.22). The Gumti and the Upper Meghna are the major rivers of this region.

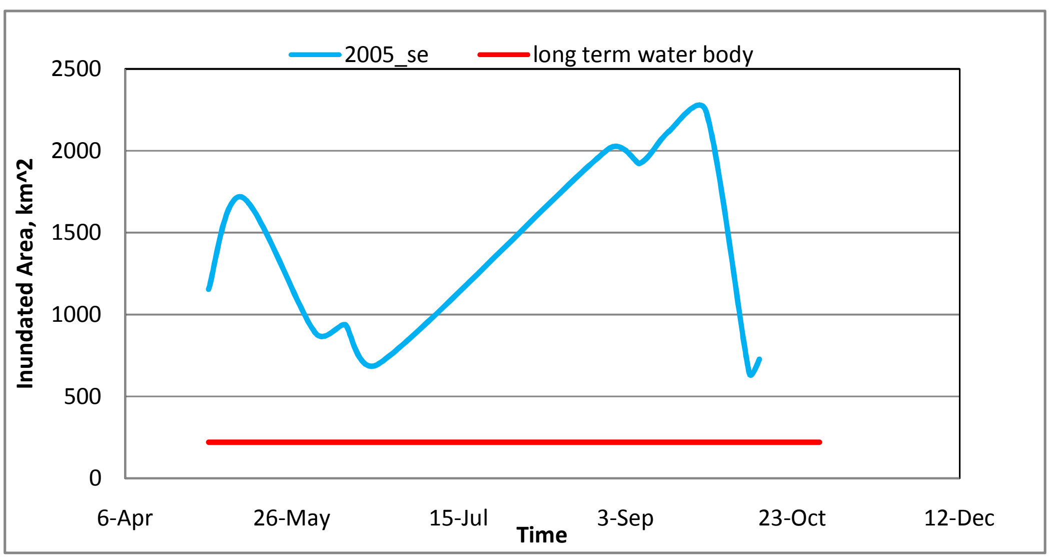

Figure 5.2.22: Inundation pattern of Southeast zone in the year 2005.

The most affected areas of this zone were Chadpur, Comilla and Brahmanbaria (Figure 5.2.23).

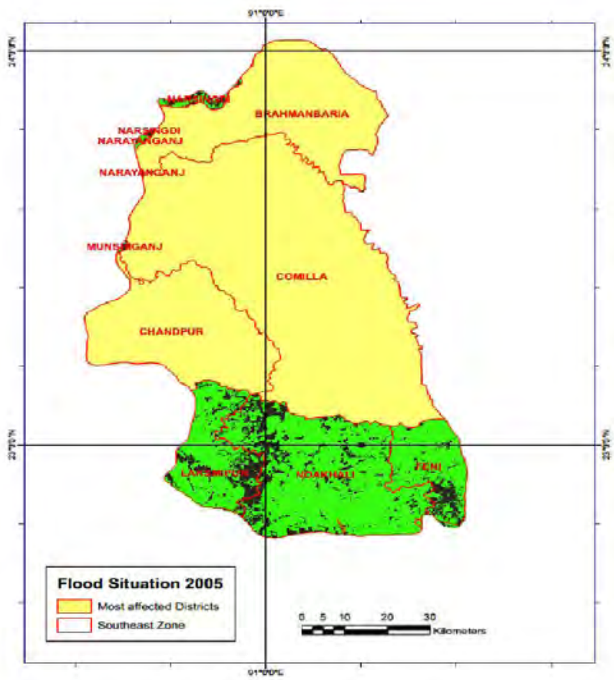

Figure 5.2.23: Most affected areas of Southeast zone in the year 2005.

5.2.3 Flood Pattern of the year 2006:

i) **In general Pattern**: In 2006, Bangladesh experienced a normal flood. Peaks had come in the 2nd week of August and in the last week of September (Figure 5.2.24). Around 14% of total country had been inundated in this year (Figure 5.4.1).

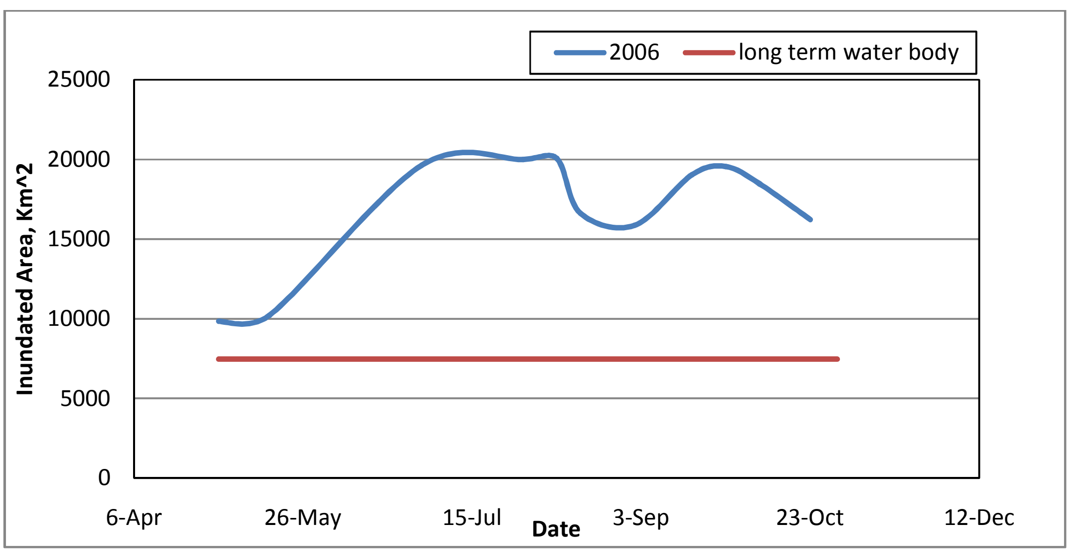

Figure 5.2.24: Inundation pattern of Bangladesh in the year 2006.

ii) **Zone wise Pattern**:

a) **Northwest Zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. First peak had come in the 2nd week of August and second in the 2nd week of October (Figure 5.2.25). The most affected areas of this zone were Bogra and Gaibandha (Figure 5.2.26).

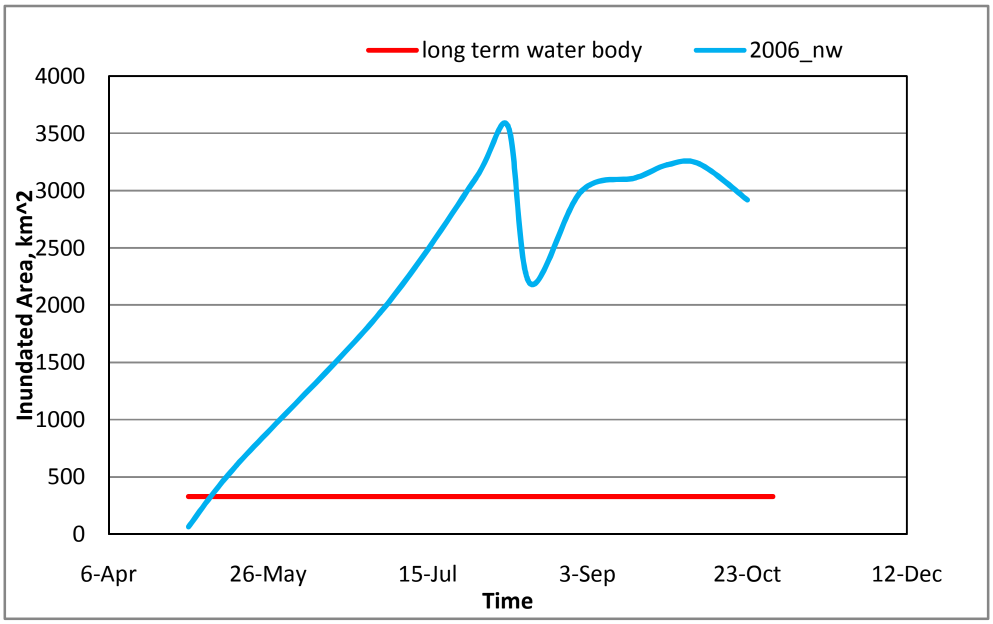

Figure 5.2.25: Inundation pattern in Northwest zone in the year 2006.

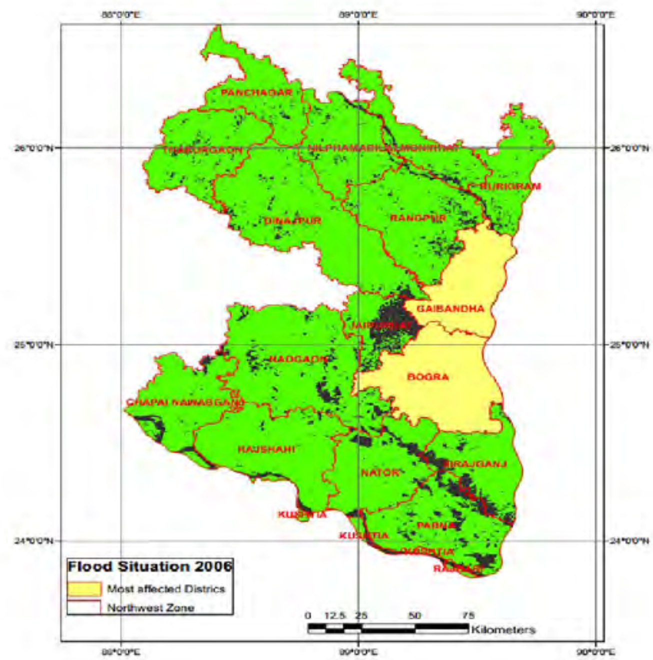

Figure 5.2.26: Most affected areas of Northwest zone in the year 2006.

b) **North central Zone**: The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. This zone of Bangladesh experienced a peak in the 3rd week of September (Figure 5.2.27). The most affected areas of this zone were Manikganj, Dhaka and Mymenshingh (Figure 5.2.28).

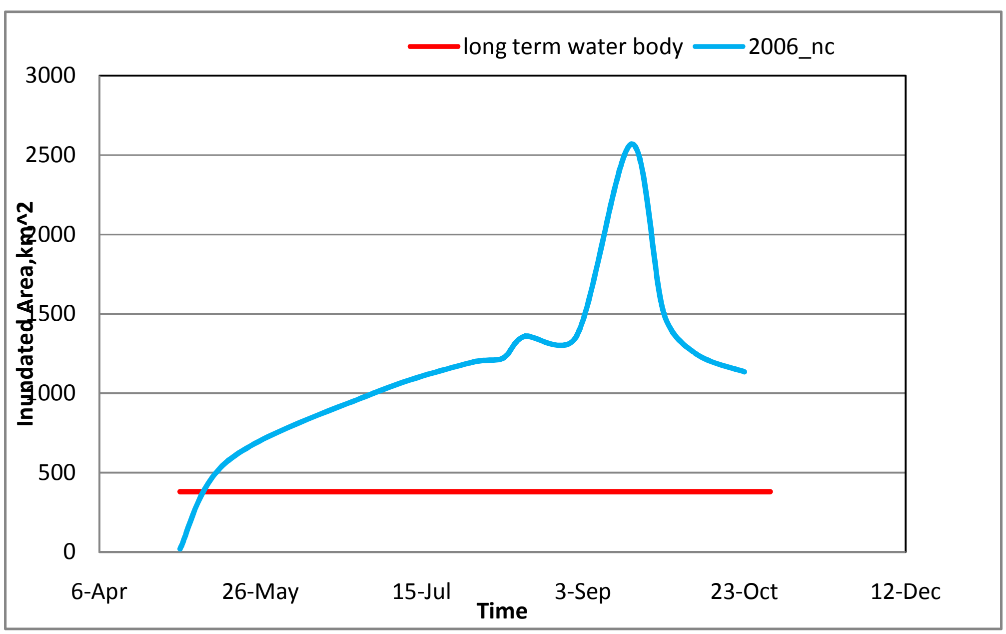

Figure 5.2.27: Inundation pattern of North center zone in the year 2006.

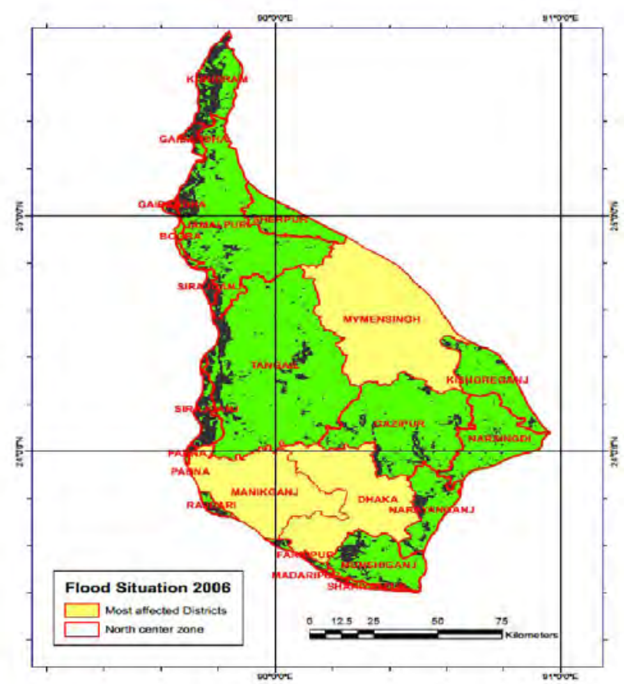

Figure 5.2.28: Most affected areas of North central zone in the year 2006.

c) **Northeast zone:** The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. This zone is a flash flood zone. Due to hilly areas, flood water rush to this zone and causes this types of flood. But in 2006, there was no flash flooding incidence occurred in this area. The peak had come in the last week of June (Figure 5.2.29). The most affected areas of this zone were Sunamganj, Habiganj and Sylhet (Figure 5.2.30).

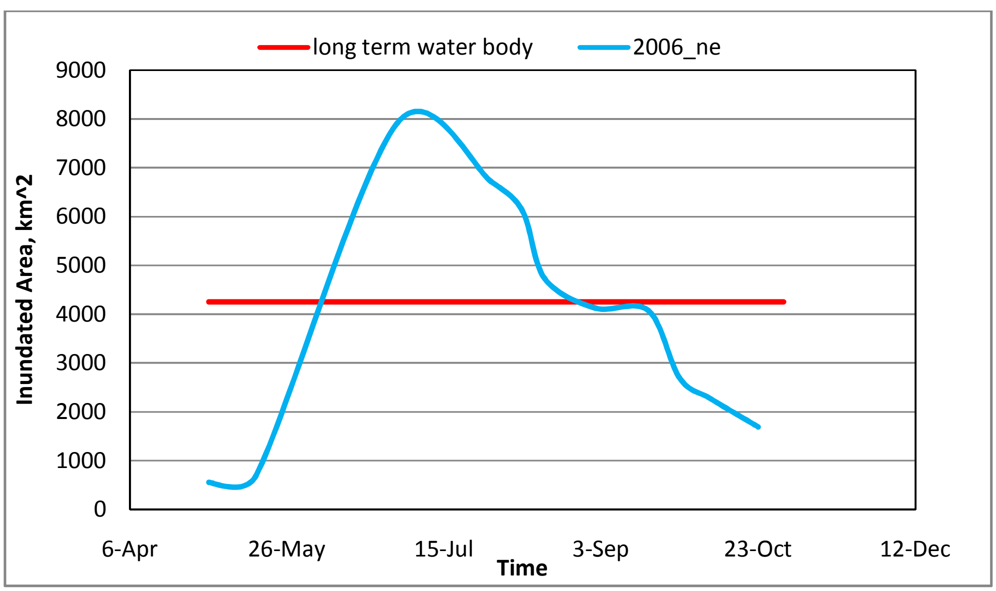

Figure 5.2.29: Inundation pattern of Northeast zone in the year 2006.

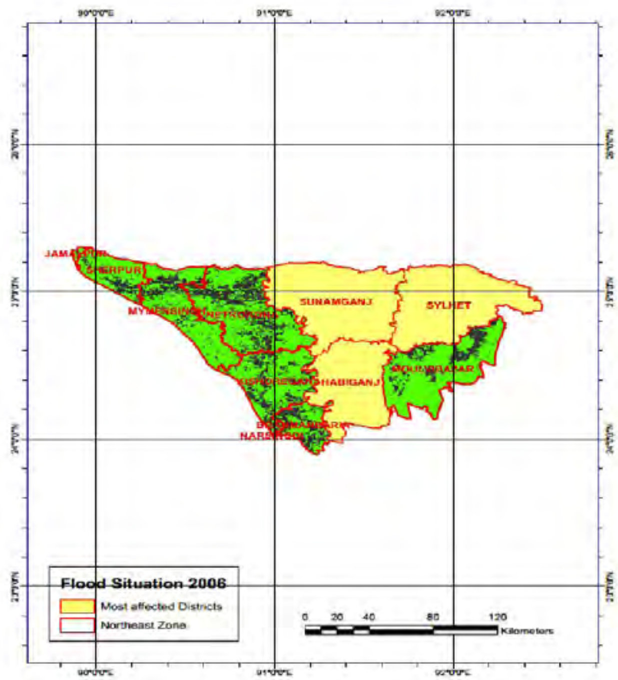

Figure 5.2.30: Most affected areas of Northeast zone in the year 2006.

d) **Southwest Zone:** In this area flood peak had come in the 3rd week of May, August and September (Figure 5.2.31). The Ichamoti, the Kodla, the Kobadak and the Lower Meghna are the major rivers of this region. The most affected areas of this region were Satkhira and Khulna (Figure 5.2.32).

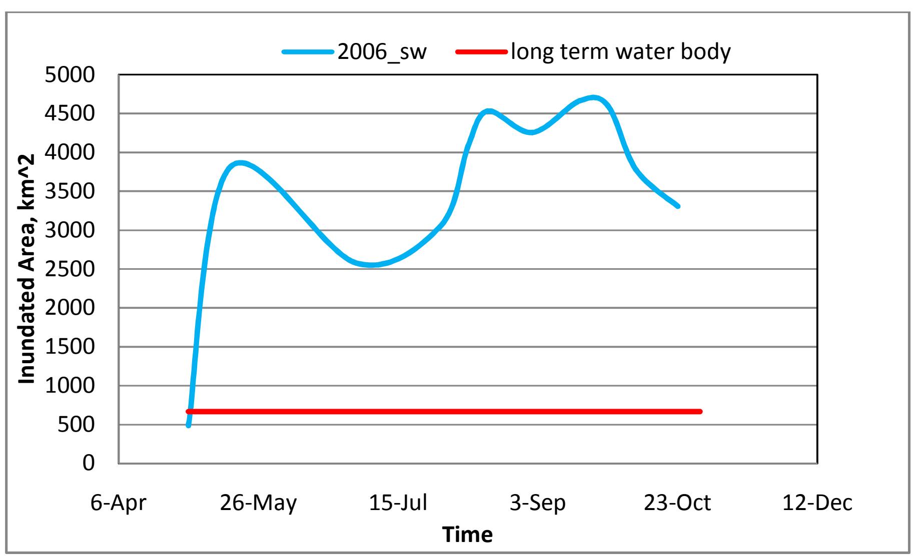

Figure 5.2.31: Inundation pattern of Southwest zone in the year 2006.

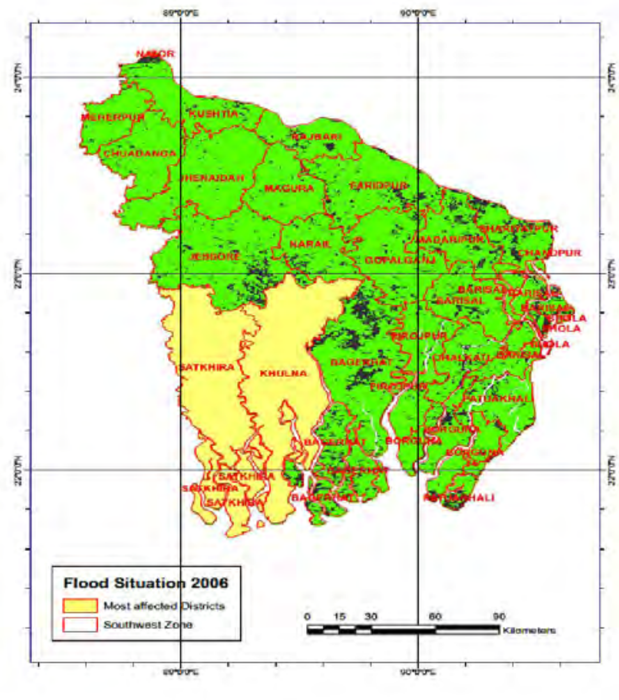

Figure 5.2.32: Most affected areas of Southwest zone in the year 2006.

e) **Southeast Zone:** In this zone, flood peak had come in the last week of June and in the 2nd week of October (Figure 5.2.33). The Gumti and the Upper Meghna are the major rivers of this region. The most affected areas of this zone were Comilla and Brahmanbaria (Figure 5.2.34).

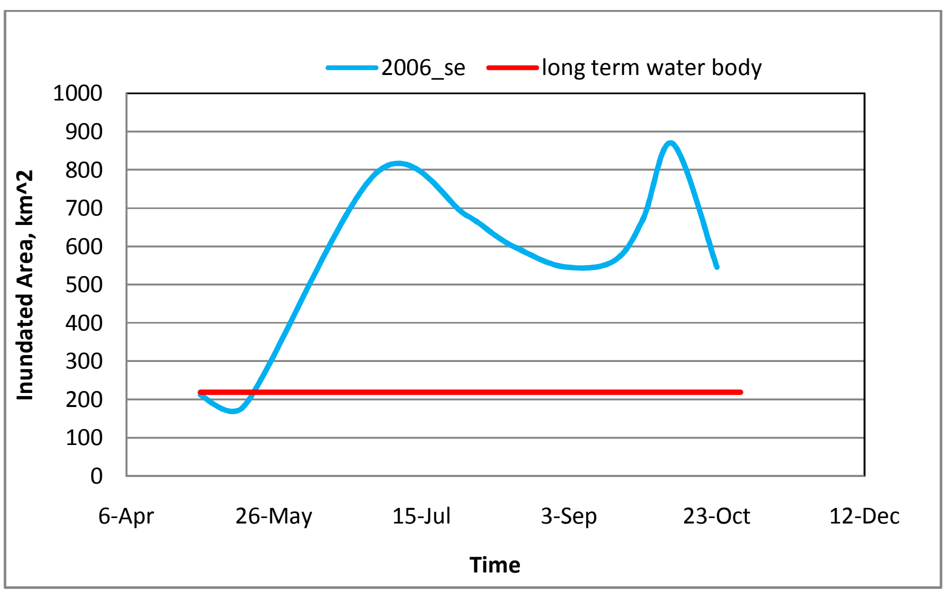

Figure 5.2.33: Inundation pattern of Southeast Zone in the year 2006.

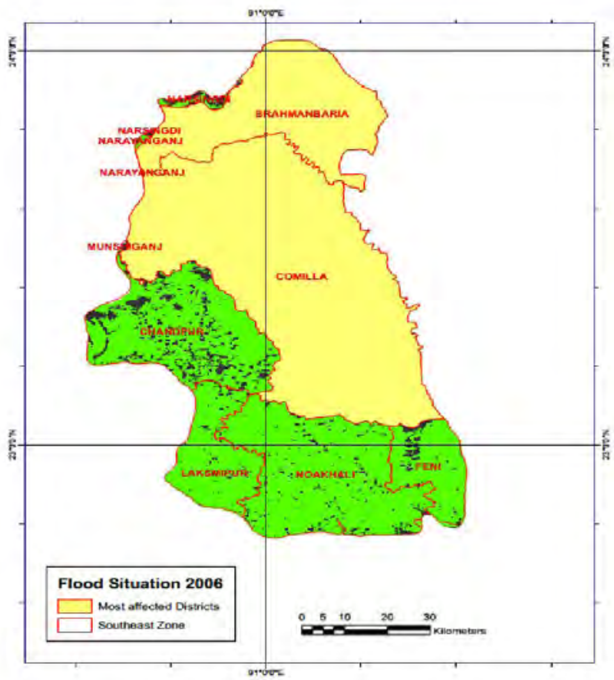

Figure 5.2.34: Most affected areas of Southeast zone in the year 2006.

5.2.4 Flood Pattern of the year 2008:

i) **In general pattern**: Flood in 2008 have been considered as a normal flood in Bangladesh. Water level with area of inundation began to increase from June and reached at peak in the 1st week of August. Then situation improved for a while but again it increased and reached at another peak in the 1st week of September (Figure 5.2.35). From the mid September water level went down as well as flood situation improved. The accumulated flooded area in 2008 was 27.80% (Figure 5.4.1).

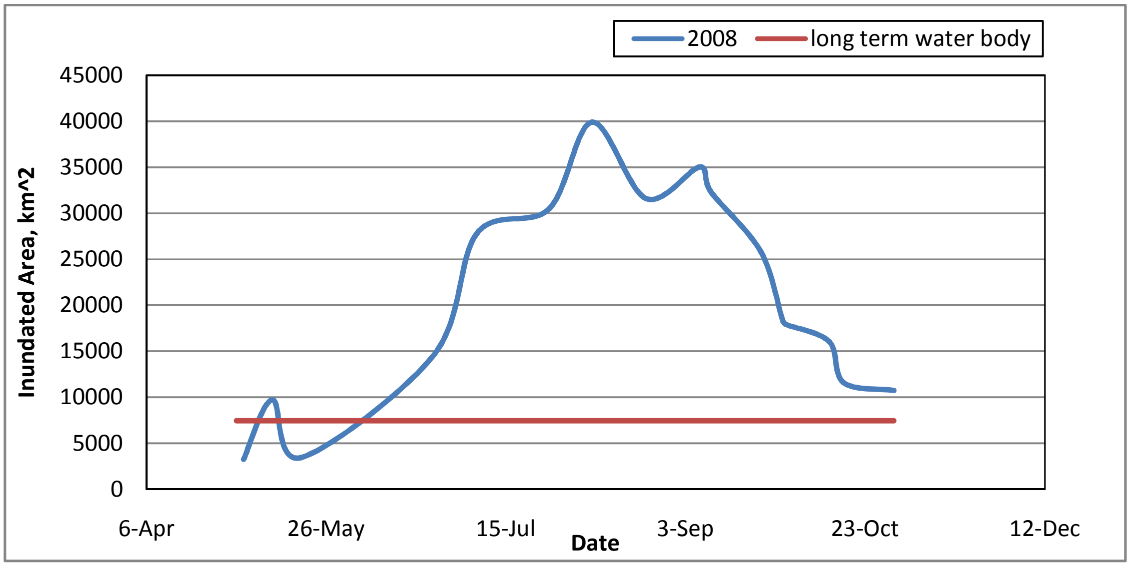

Figure 5.2.35: Inundation Pattern of Bangladesh in the year 2008.

ii) Zone wise Pattern:

a) **Northwest zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. First peak had come in the 2nd week of August and Second peak had come in the 2nd week of September (Figure 5.2.36). The most affected areas of this zone were Bogra, Jaipurhat and Gaibandha (Figure 5.2.37).

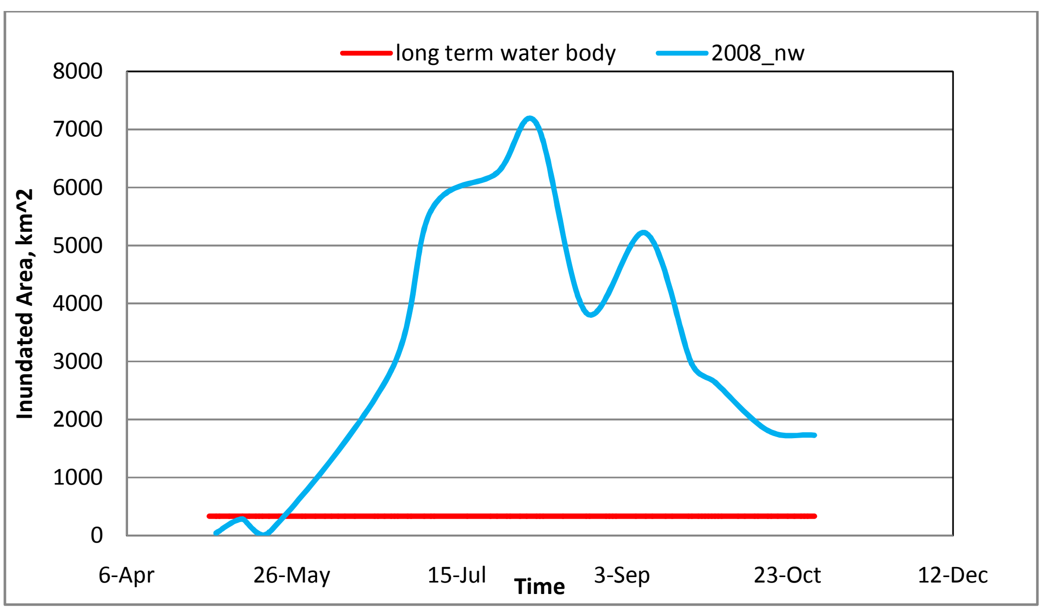

Figure 5.2.36: Inundation pattern of Northwest zone in the year 2008.

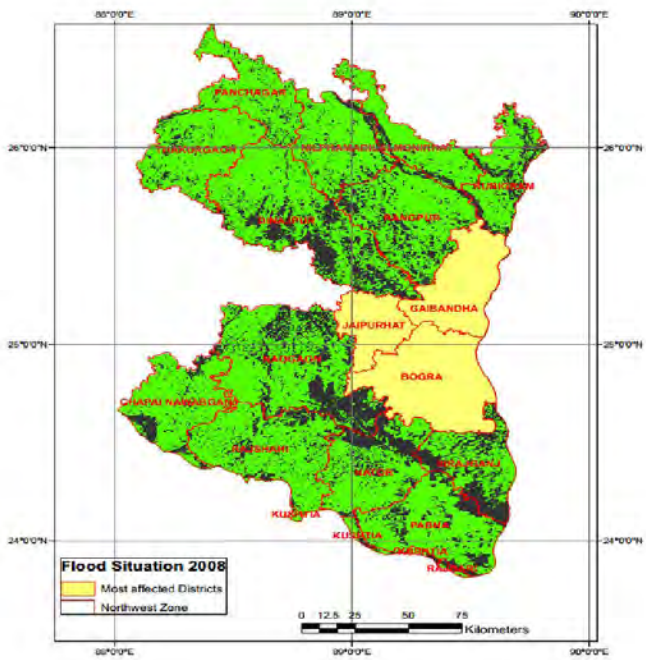

Figure 5.2.37: Most affected areas of Northwest zone in the year 2008.

b) **North central Zone:** The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. This zone of Bangladesh experienced a peak in the 2nd week of August and in the 1st week of September (Figure 5.2.38). The most affected areas of this zone were Manikganj, Tanglail and Jamalpur (Figure 5.2.39).

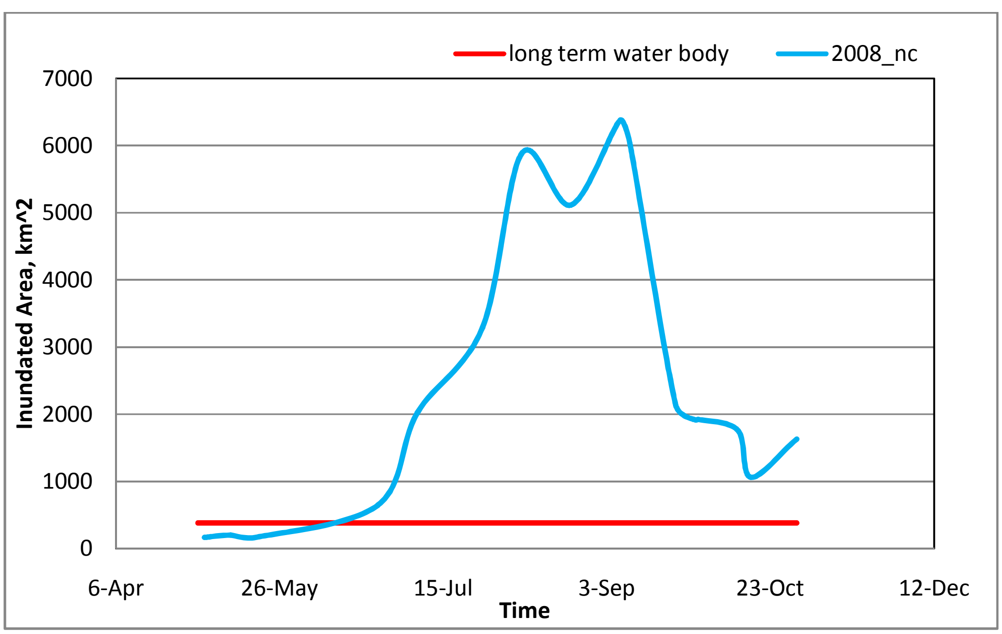

Figure 5.2.38: Inundation pattern of North central zone in the year 2008.

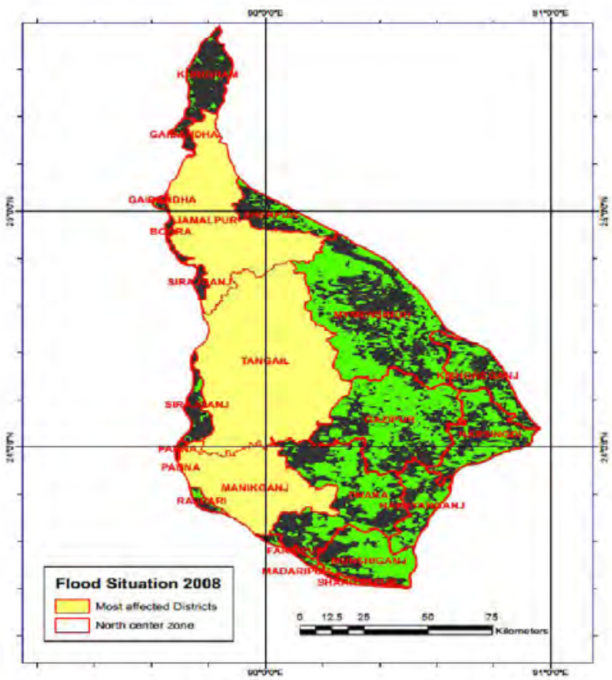

Figure 5.2.39: Most affected areas of North central zone in the year 2008.

c) **Northeast Zone:** The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. This zone is a flash flood zone. Due to hilly areas, flood water rush to this zone and causes this types of flood. In 2008, flash flood of moderate magnitude occurred in this region. The peak had come in the last week of August (Figure 5.2.40). The most affected areas of this zone were Sunamganj, Netrokona and Sylhet (Figure 5.2.41).

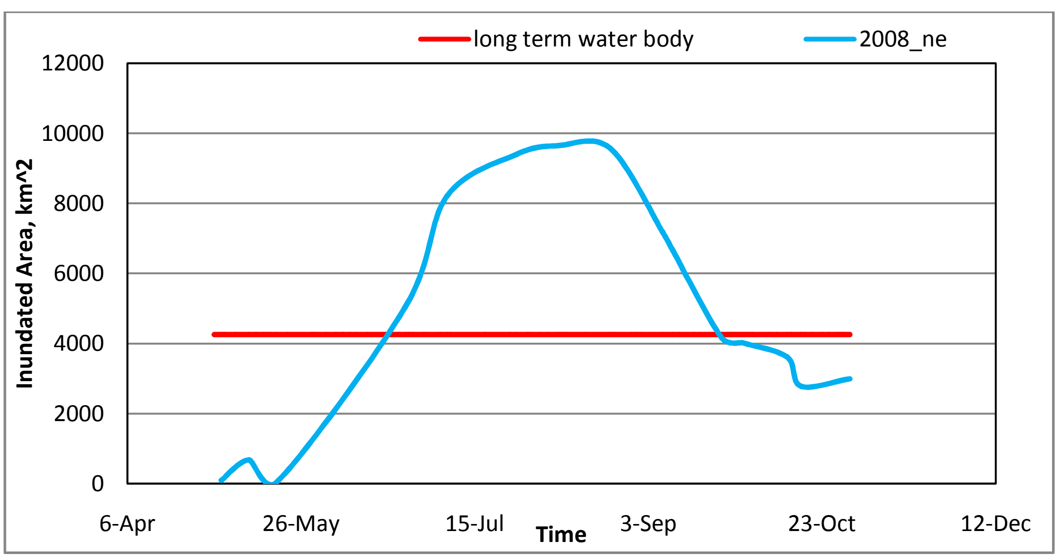

Figure 5.2.40: Inundation pattern of Northeast zone in the year 2008.

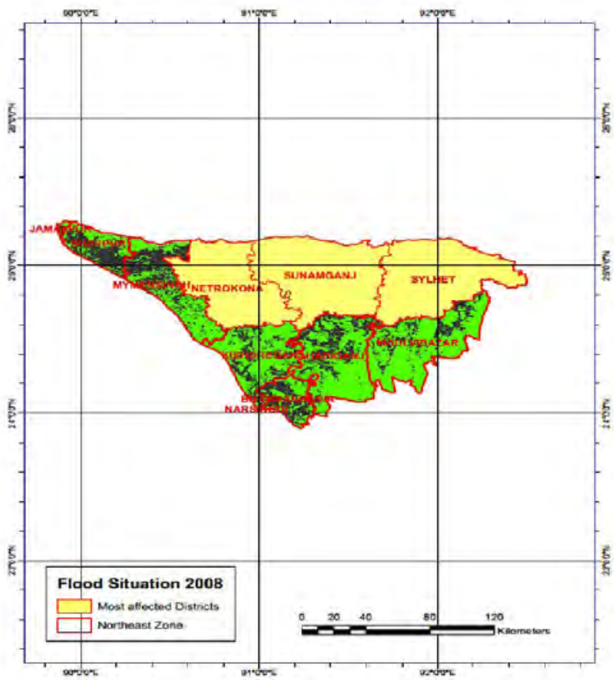

Figure 5.2.41: Most affected areas of Northeast zone in the year 2008.

d) **Southwest Zone:** In this area flood peak had come in the 4th week of July and 1st week of September (Figure 5.2.42). The Ichamoti, the Kodla, the Kobadak, and the Lower Meghna are the major rivers of this region. The most affected areas of this region were Satkhira, Khulna, Bagerhat and Jessor (Figure 5.2.43).

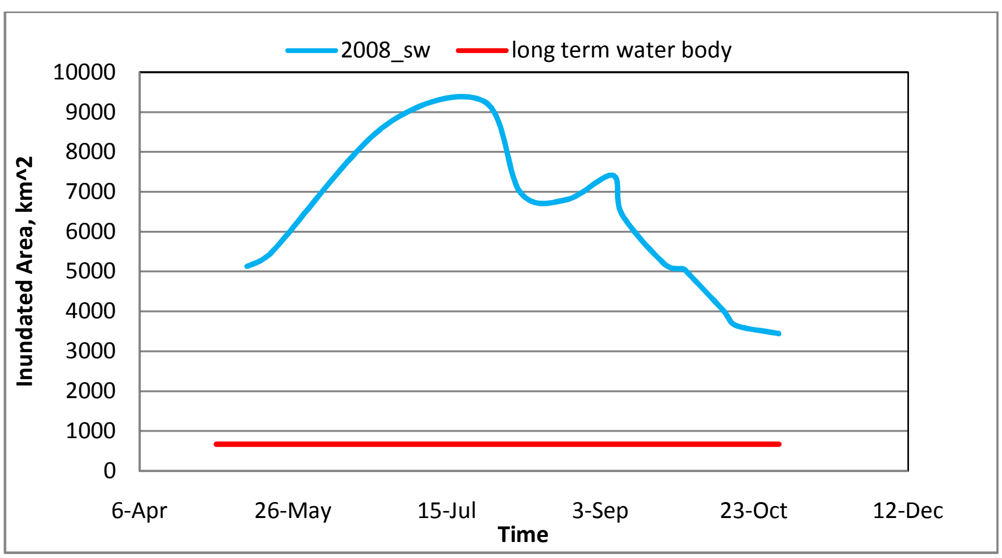

Figure 5.2.42: Inundation pattern of Southwest zone in the year 2008.

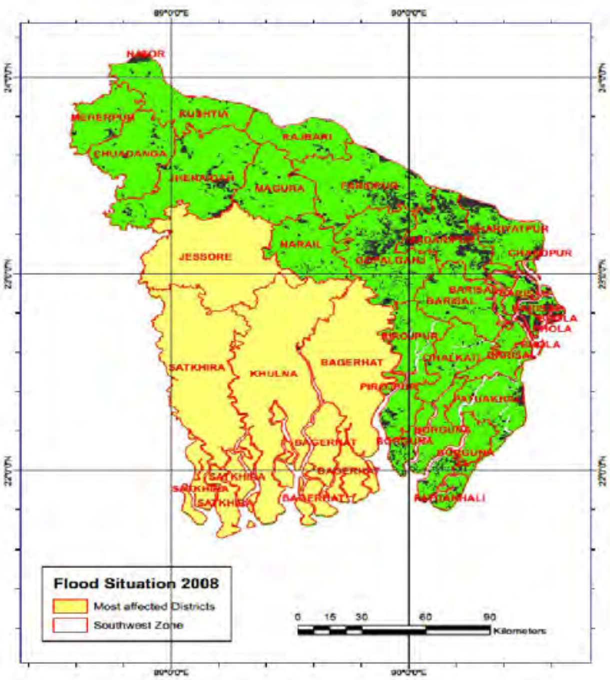

Figure 5.2.43: Most affected areas of Southwest zone in the year 2008.

e) **Southeast Zone:** In this zone, flood peak had come in the 1st week of July, September and in the 2nd week of October (Figure 5.2.44). The Gumti and the Upper Meghna are the major rivers of this region. The most affected district of this zone was Brahmanbaria (Figure 4.2.45).

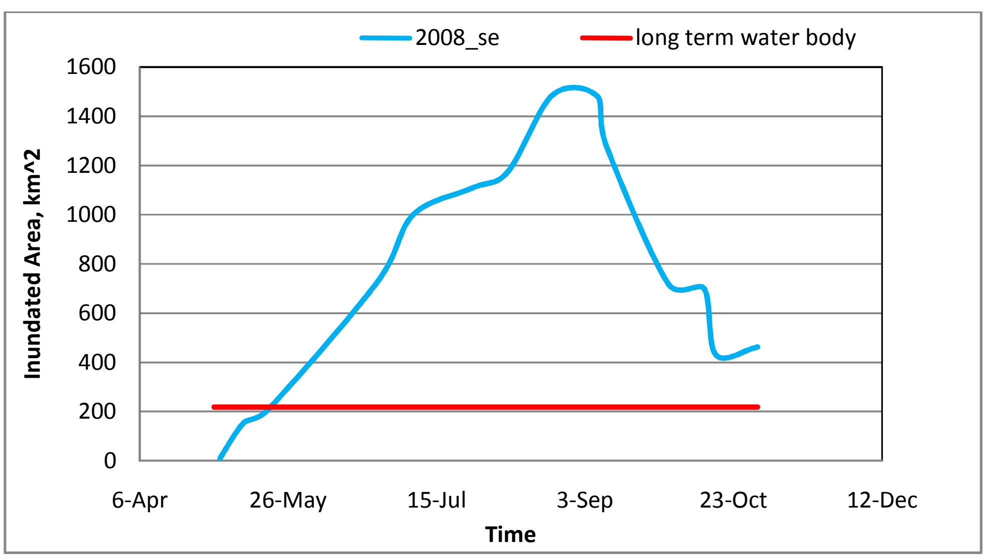

Figure 5.2.44: Inundation pattern of Southeast zone in the year 2008

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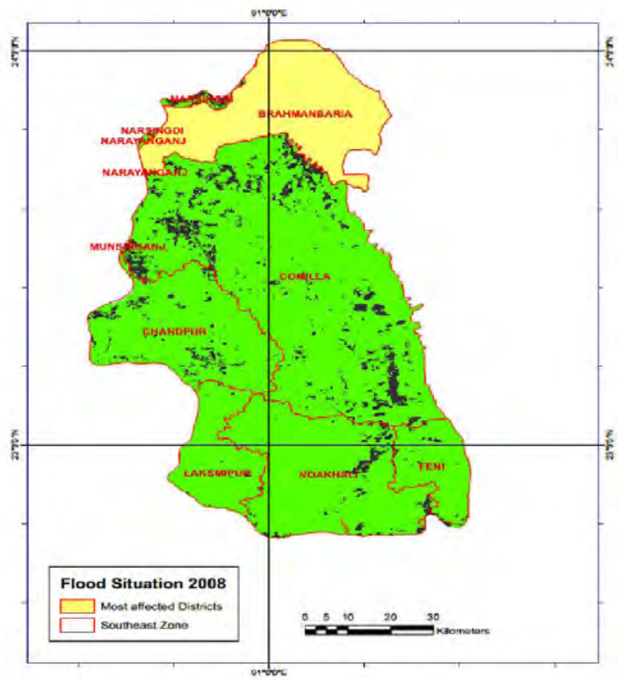


Figure 5.2.45: Most affected area of Southeast zone in the year 2008.

5.2.5 Flood Pattern of the year 2009:

i) **In general pattern:** 2009 was also a normal flooding year for the country. Though some areas of northeastern part were affected by flash flood in early May. Water began to rise like normal flooding years in June and reached at maximum peak in the last week of August (Figure 5.2.46). From September the situation was getting better. The accumulated flooded area in 2009 was around 21% of total area of the country which indicates normal flood (Figure 5.4.1).

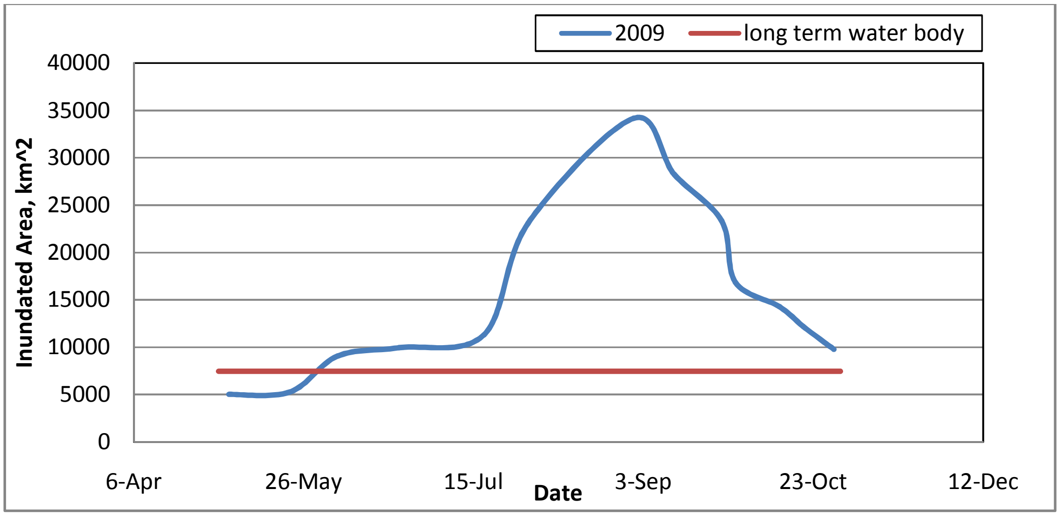


Figure 5.2.46: Inundation pattern of Bangladesh in the year 2009.

ii) **Zone wise Pattern**:

a) **Northwest Zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. Areas of long term water body of this zone are 328 square kilometer. First peak of this zone had come in the last week of August and second peak had come in the 2nd week of October (Figure 5.2.47). The most affected areas of this zone were Bogra, Sirajganj and Gaibandha (Figure 5.2.48).

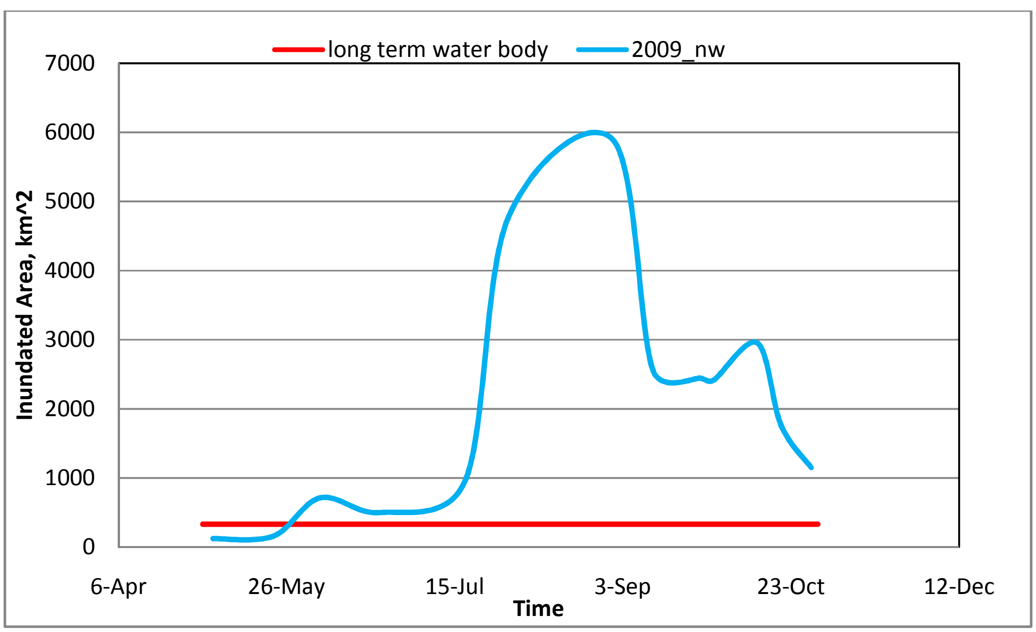


Figure 5.2.47: Inundation pattern of Northwest zone in the year 2009.

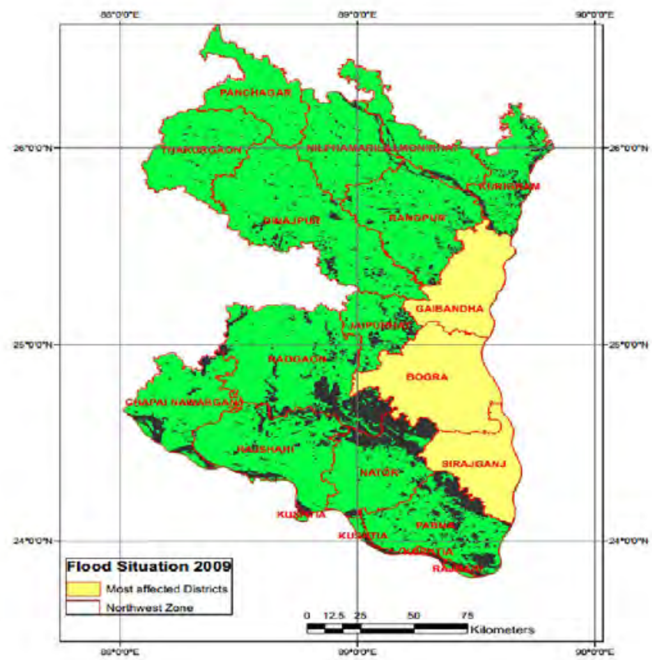


Figure 5.2.48: Most affected areas of Northwest zone in the year 2009.

b) **North central Zone:** The Brahmaputra, the Upper Meghnaand and the Padma are the major rivers of this zone. Areas of long term water body of this zone are 380 square kilometer. This zone of Bangladesh experienced a peak in the 1st week of June and another one in the last week of August (Figure 5.2.49). The most affected areas of this zone were Tanglail and Jamalpur (Figure 5.2.50).

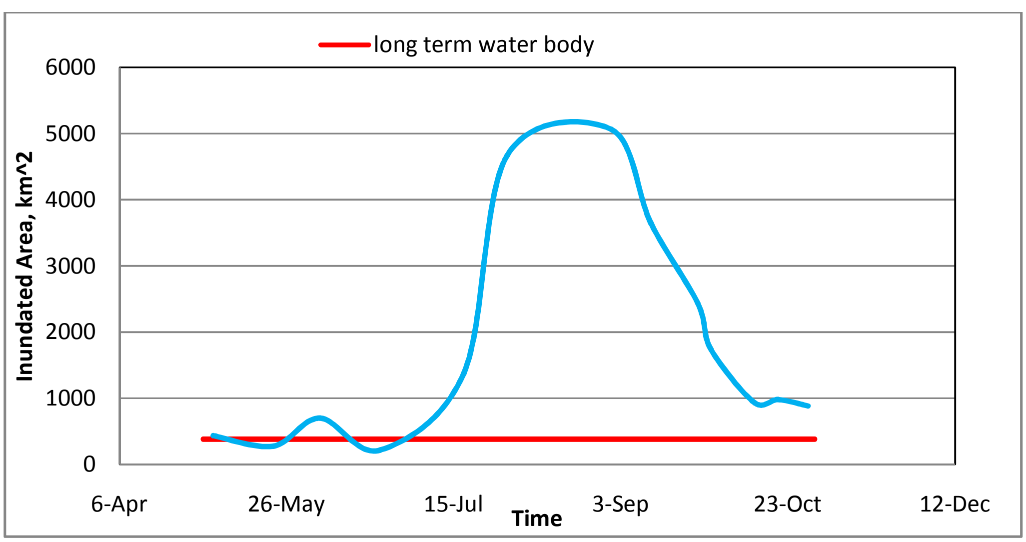


Figure 5.2.49: Inundation pattern of North central zone in the year 2009.

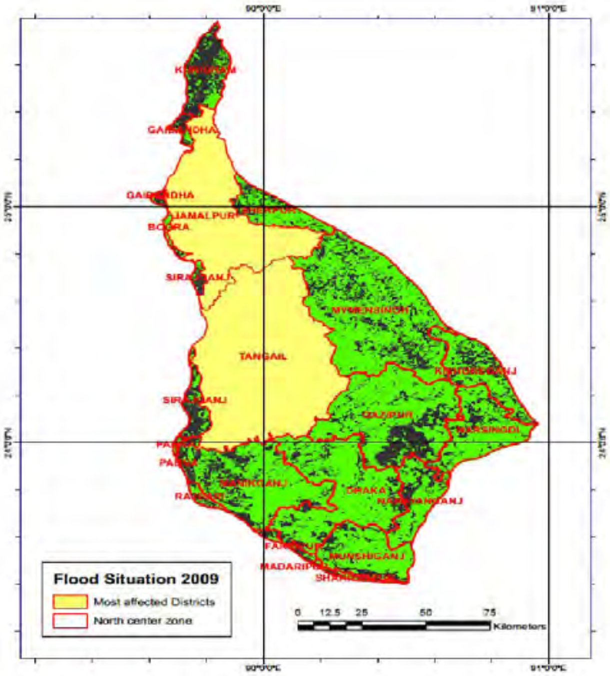


Figure 5.2.50: Most affected areas of North central zone in the year 2009.

c) **Northeast Zone:** The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. Areas of long term water body of this zone are 4254 square kilometer. This zone is a flash flood prone zone. Due to hilly areas, flood water rush to this zone and causes this types of flood. In 2009, some areas of this region were affected by flash flood. The peak had come in the last week of August (Figure 5.2.51). The most affected areas of this zone were Sunamganj, Netrokona and Habiganj (Figure 5.2.52).

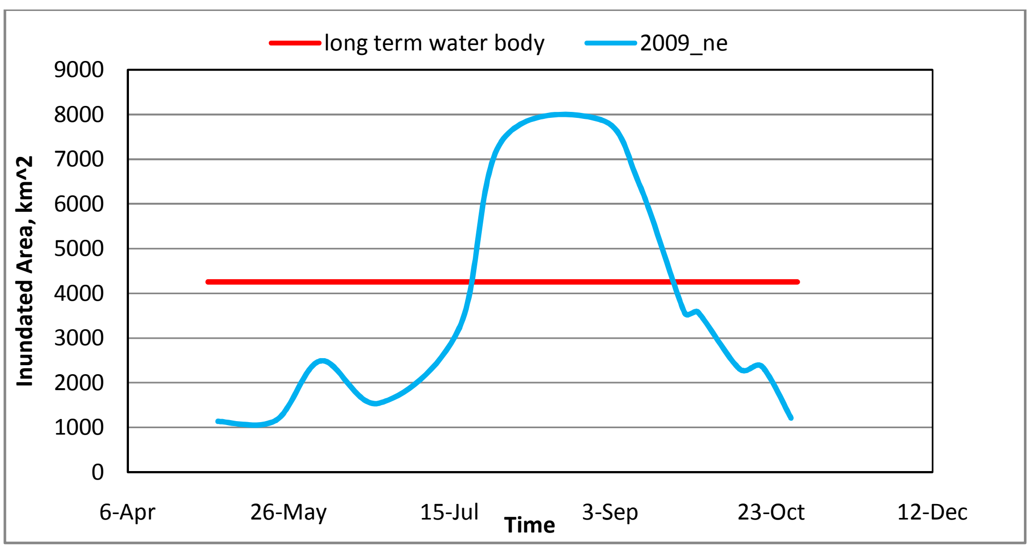


Figure 5.2.51: Inundation pattern of Northeast zone in the year 2009.

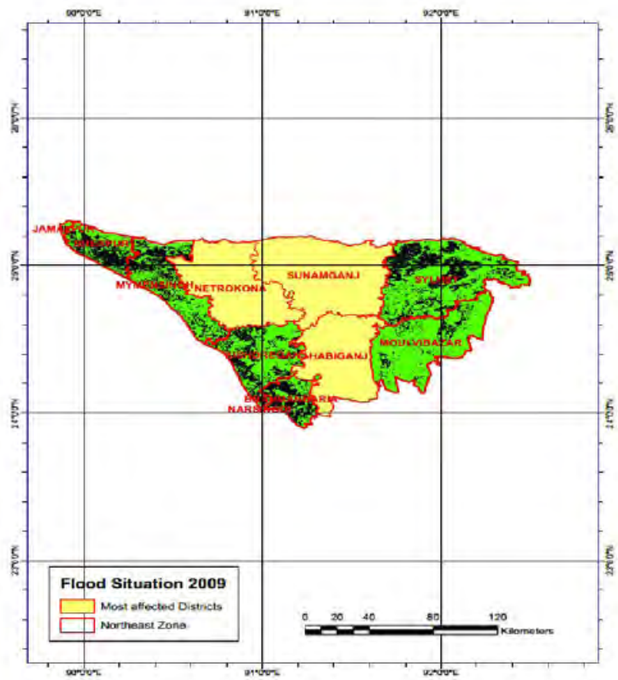


Figure 5.2.52: Most affected areas of Northeast zone in the year 2009.

d) **Southwest Zone:** In this area flood peak had come in the 4th week of September (Figure 5.2.53). Some areas of this zone are encountered severe water logging problem. Area of long term water body of this zone is 667.13 square kilometer. The Ichamoti, the Kodla, the Kobadak and the Lower Meghna are the major rivers of this region. The most affected areas of this region were Satkhira, Khulna, Bagerhat. (Figure 5.2.54).

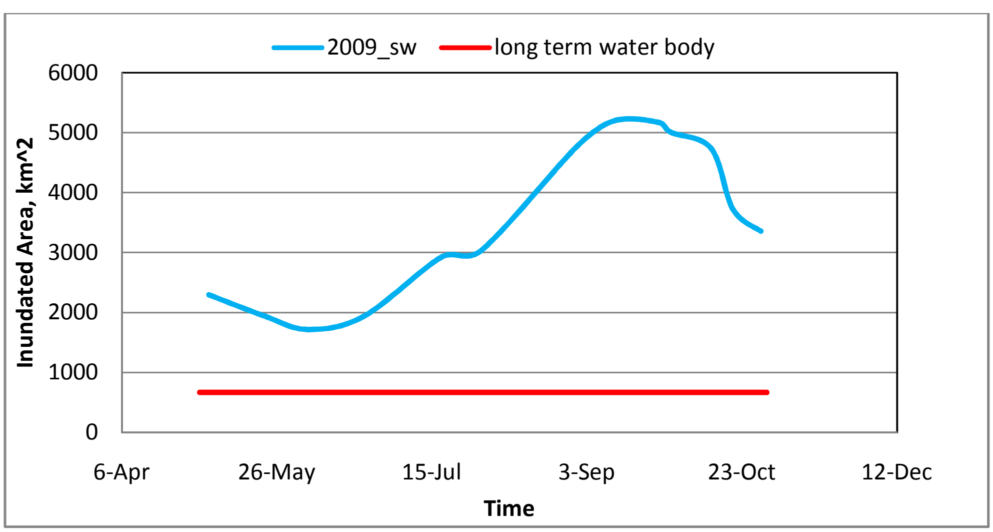


Figure 5.2.53: Inundation pattern of Southwest zone in the year 2009.

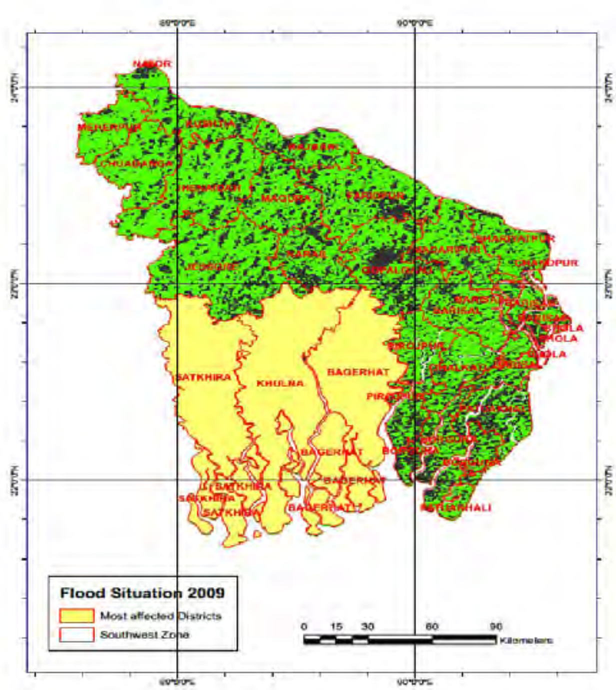


Figure 5.2.54: Most affected areas of Southwest zone in the year 2009.

e) **Southeast Zone:** In this zone, flood peak had come in the last week of August and in the 3rd week of October (Figure 5.2.55). Areas of long term water body of this zone are 219 square kilometer. The Gumti and the Upper Meghna are the major rivers of this region. The most affected areas of this zone were Comilla and Brahmanbaria (Figure 5.2.56).

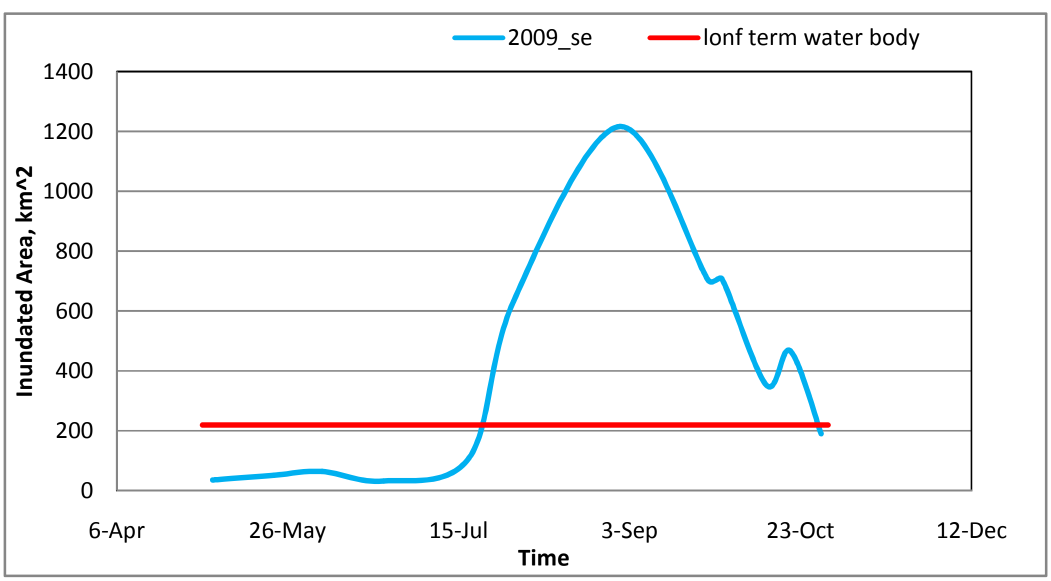


Figure 5.2.55: Inundation pattern of Southeast zone in the year 2009.

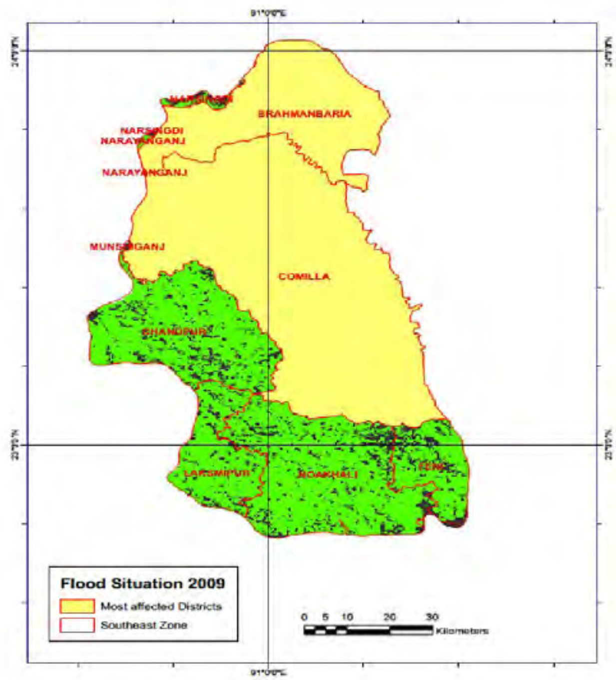


Figure 5.2.56: Most affected areas of Southeast zone in the year 2009.

5.2.6 Flood Pattern of the year 2010:

i) **In general pattern:** The overall flood situation in 2010 was normal for the country. But the northeast part of Bangladesh was devastated by flash flood in this year (Figure A1.67 to A1.68). Water began to rise in mid of June and reached at maximum peak in the last week of July (Figure 5.2.57). Situation remained stable until August and it was getting better from the last week of August. The accumulated flooded area in 2010 was around 22% of total areas, indicates normal flood (Figure 5.4.1).

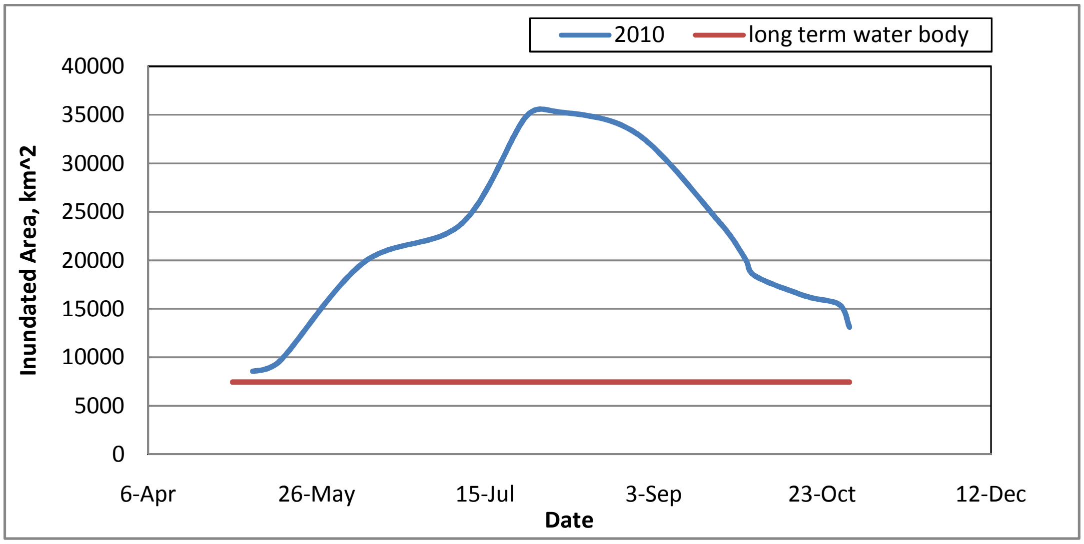


Figure 5.2.57: Inundation pattern of Bangladesh in the year 2010.

ii) **Zone wise Pattern:**

a) **Northwest zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. Areas of long term water body of this zone are 328 square kilometer. In this zone flood peak had come in the 1st week of August (Figure 5.2.58). The most affected areas of this zone were Bogra and Sirajganj (Figure 5.2.59).

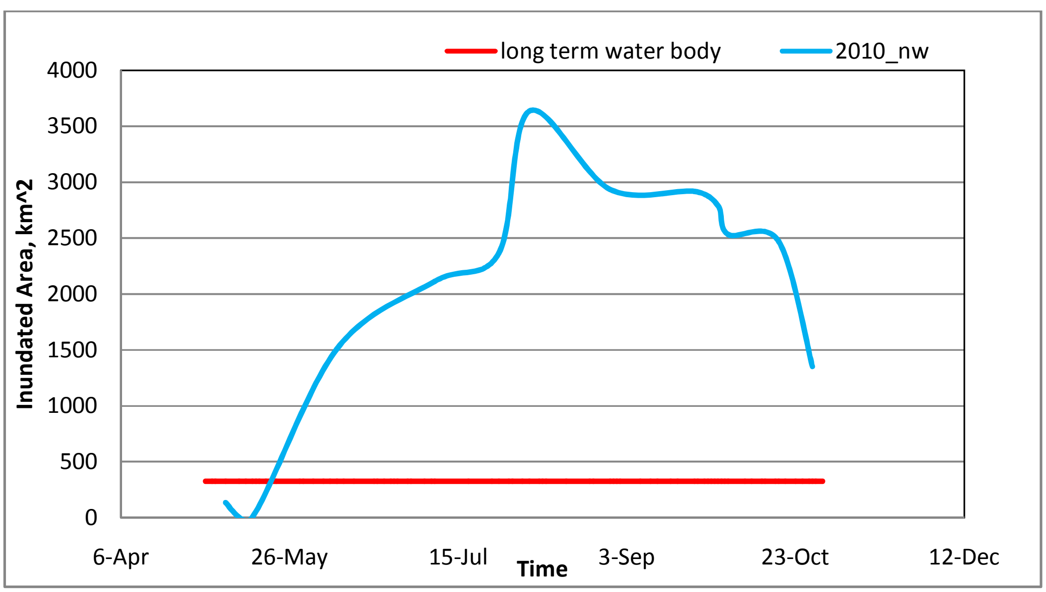


Figure 5.2.58: Inundation pattern of Northwest zone in the year 2010.

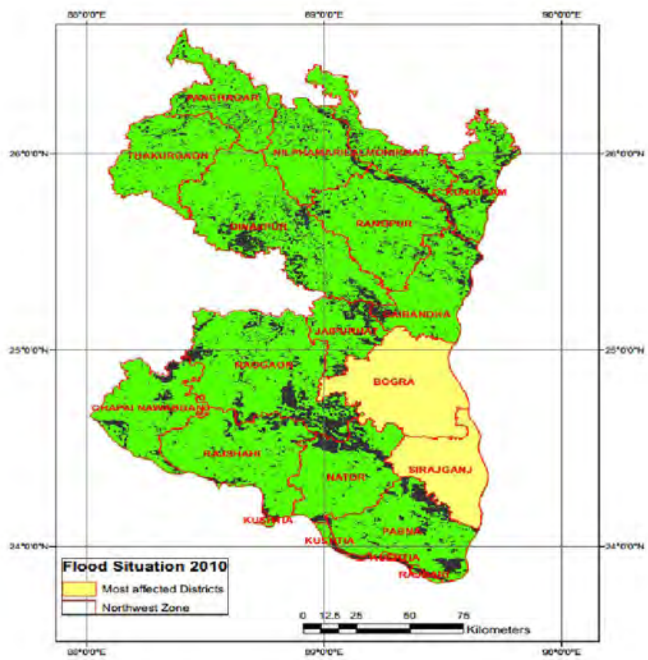


Figure 5.2.59: Most affected areas of Northwest zone in the year 2010.

b) **North central zone:** The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. Areas of long term water body of this zone are 380 square kilometer. In 2010, this zone of Bangladesh experienced a peak in the 2nd week of June, in the last week of July and in the last week of September (Figure 5.2.60). The most affected areas of this zone were Tanglail and Jamalpur (Figure 5.2.61).

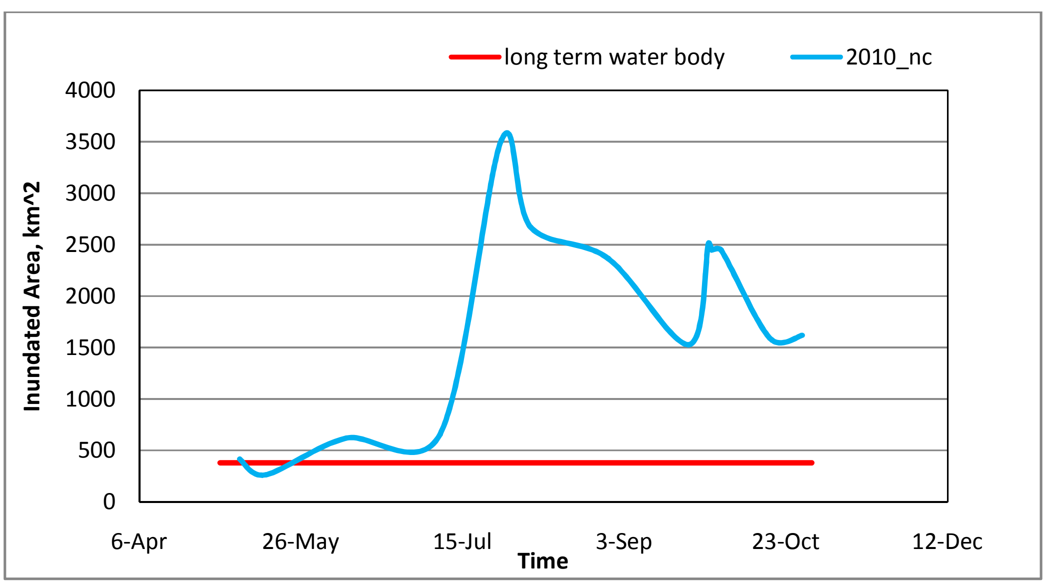


Figure 5.2.60: Inundation pattern of North central zone in the year 2010.

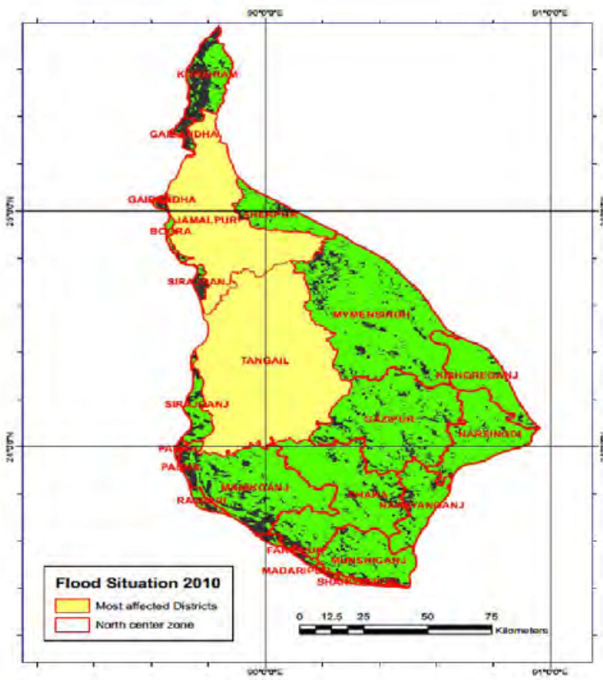


Figure 5.2.61: Most affected areas of North central zone in the year 2010.

c) **Northeast zone:** The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. Areas of long term water body of this zone are 4254 square kilometer. This zone is a flash flood prone zone. Due to hilly areas, flood water rush to this zone and causes this type of flood. In 2010, this area was devastated by flash flood which occurred in early May. Many areas had been inundated from mid of May and reached at the highest peak in the 1st week of July. Another peak had come in the 1st week of August. The last peak had come in the last week of September (Figure 5.2.62). The most affected areas of this zone were Sunamganj and Habiganj (Figure 5.2.63).

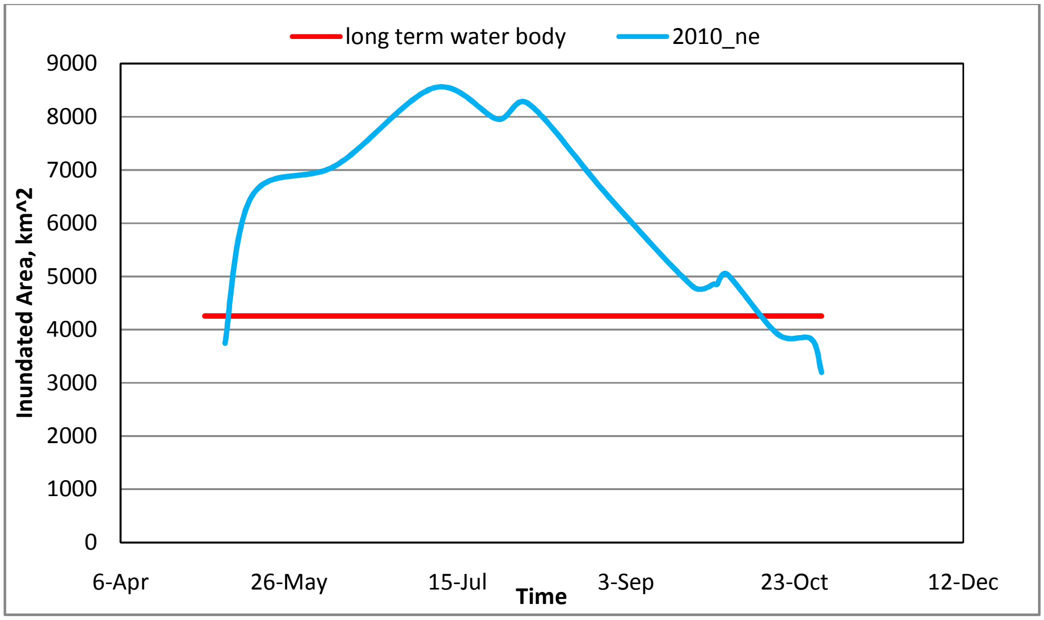


Figure 5.2.62: Inundation pattern of Northeast zone in the year 2010.

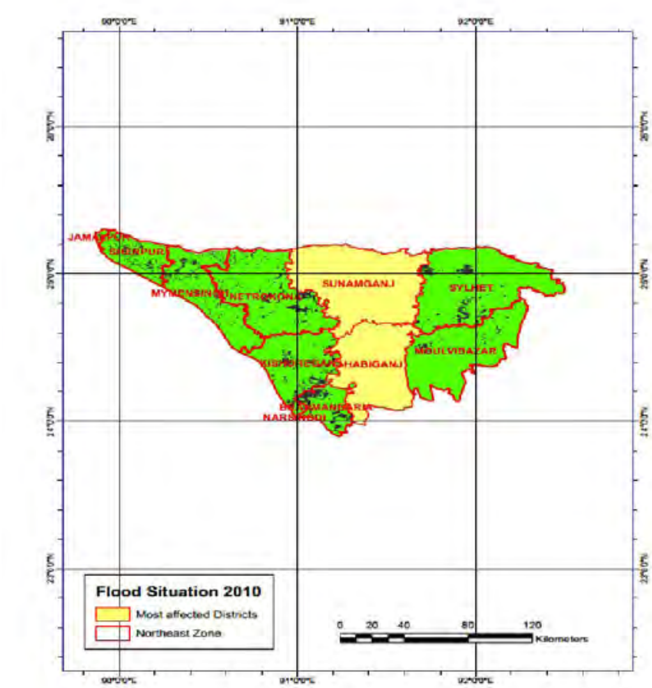


Figure 5.2.63: Most affected areas of Northeast zone in the year 2010.

d) **Southwest zone**: In this area flood peak had come in the 2nd week of June. Other peaks had come in the 1st week of August and in the last week of September (Figure 5.2.64). Some areas of this zone are encountered severe water logging problem. Areas of long term water body of this zone are 667.13 square kilometer.

The Ichamoti, the Kodla, the Kobadak and the Lower Meghna are the major rivers of this region. The most affected areas of this region were Satkhira and Khulna (Figure 5.2.64).

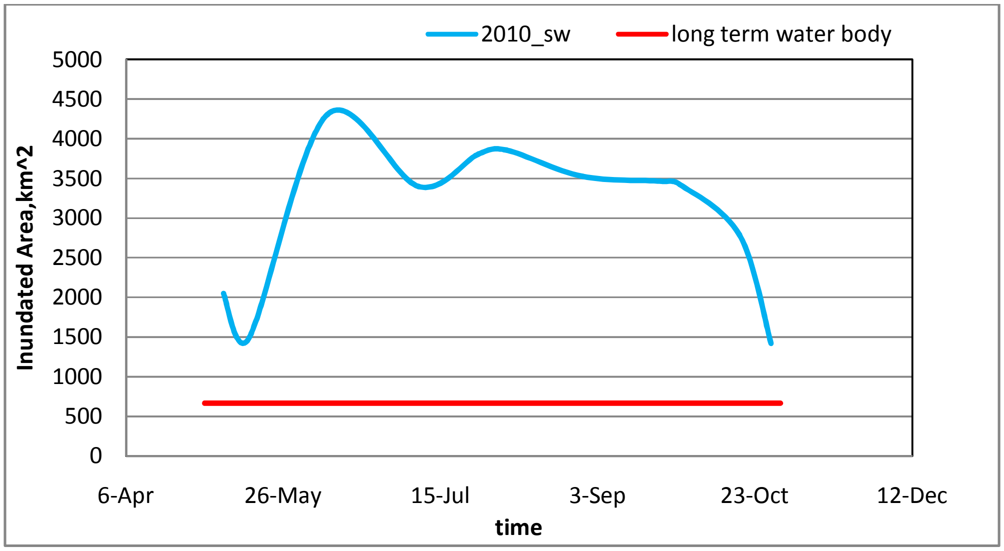


Figure 5.2.64: Inundation pattern of Southwest zone in the year 2010.

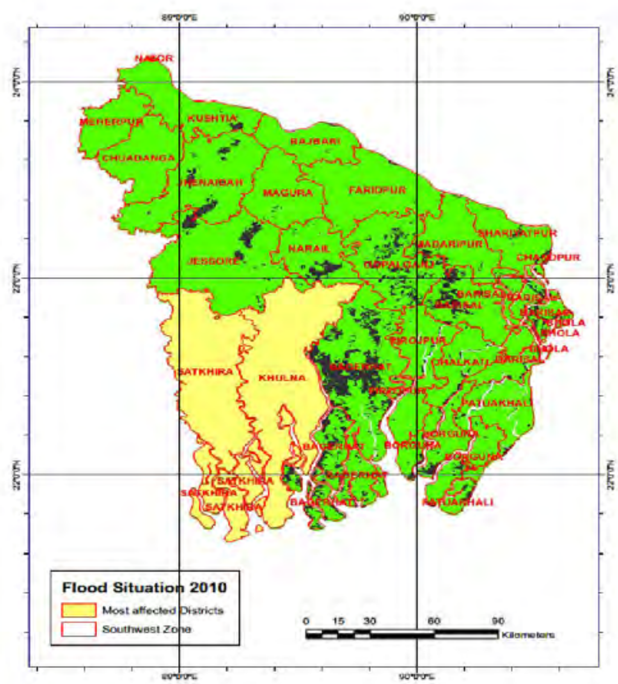


Figure 5.2. 65: Most affected areas of Southwest zone in the year 2010.

e) **Southeast zone:** In this zone, flood peak had come in the 1st week of August (Figure 5.2.67). Areas of long term water body of this zone are 219 square kilometer. The Gumti and the Upper Meghna are the major rivers of this region.

The most affected areas of this zone were Comilla and Brahmanbaria (Figure 5.2.68).

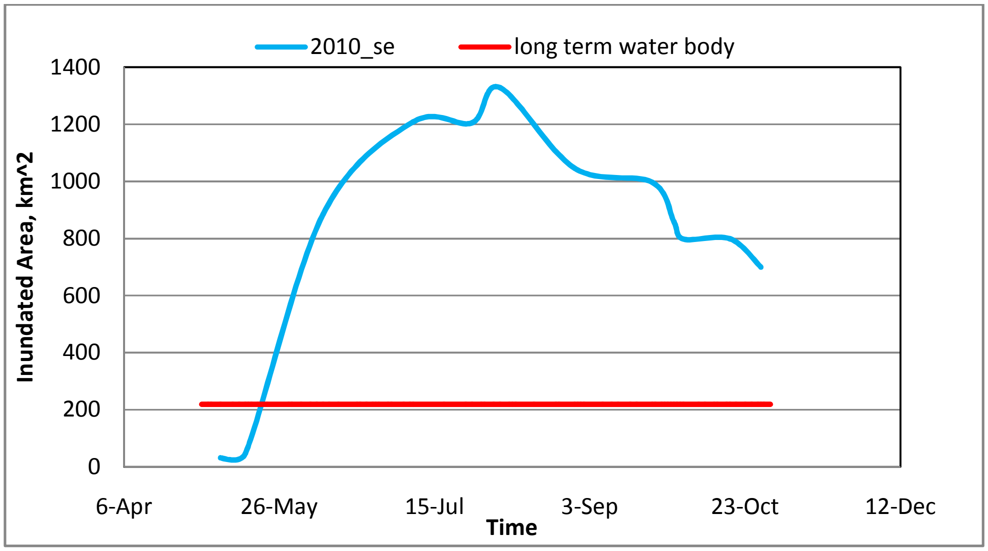


Figure 5.2.66: Inundation pattern of Southeast zone in the year 2010.

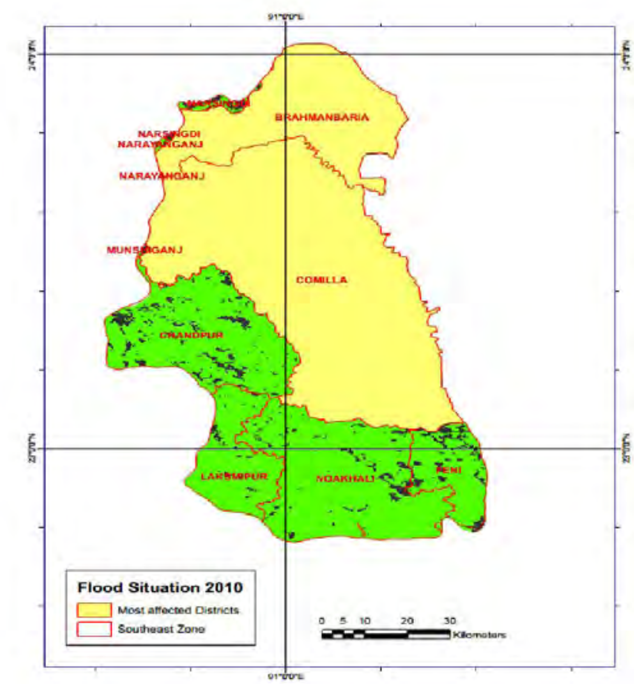


Figure 5.2.67: Most affected areas of Southeast zone in the year 2010.

5.2.7 Flood Pattern of the year 2014:

i) **In general pattern:** 2014 was a normal flooding year for the country. Water level of the rivers as well as inundation areas increased into the peak in the last week of August and in the last week of September (Figure 5.2.68). The accumulated flooded area in 2014 was around 20% of the total area which indicates as normal flood (Figure 5.4.1).

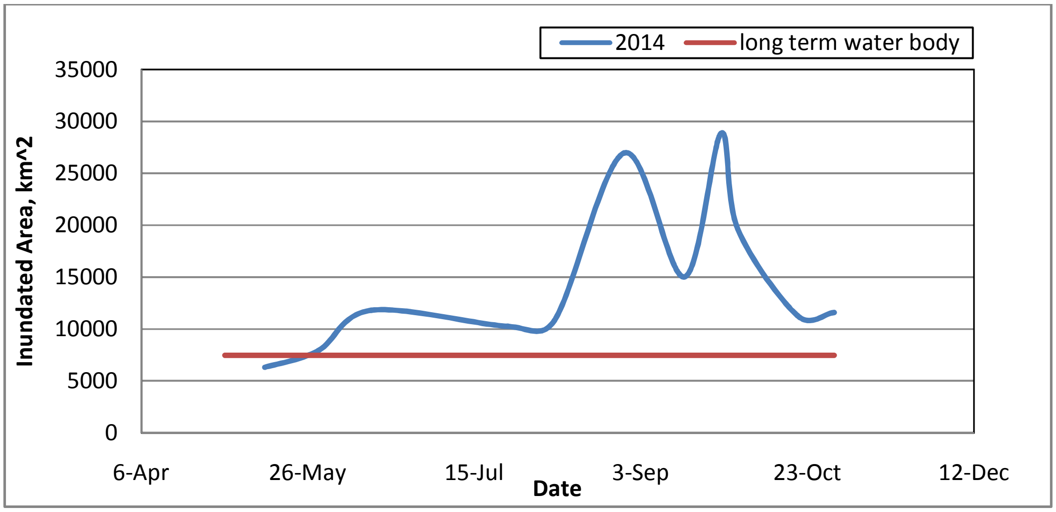


Figure 5.2.68: Inundation pattern of Bangladesh in the year 2014.

ii) **Zone wise pattern:**

a) **Northwest zone:** The Ganges, the Brahmaputra and the Teesta are the major rivers in this zone. Areas of long term water body of this zone are 328 square kilometer. In this zone flood peak had come in the last week of July, August and September (Figure 5.2.69). The most affected areas of this zone were Bogra and Jaipurhat (Figure 5.2.70).

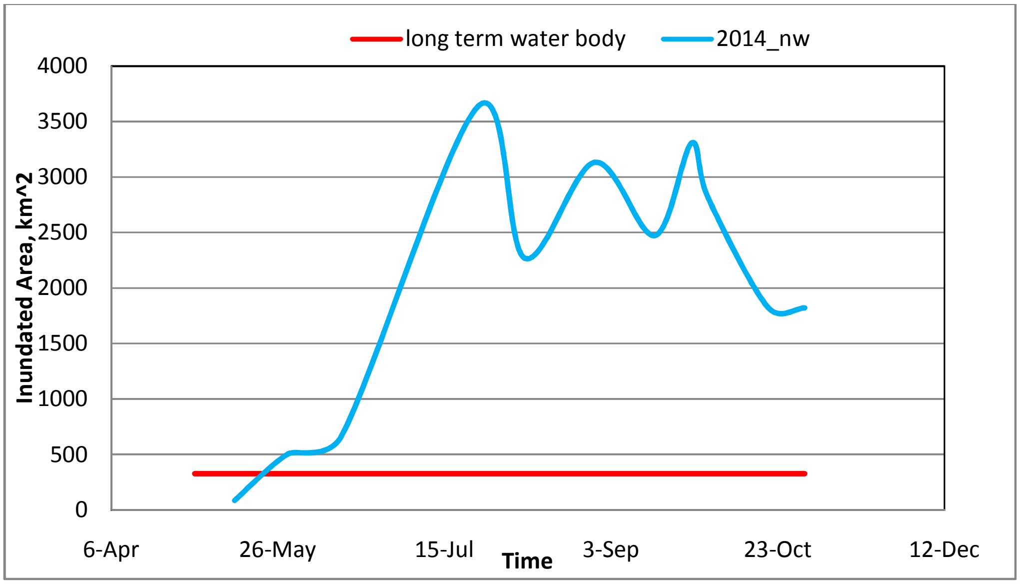


Figure 5.2.69: Inundation pattern of Northwest zone in the year 2014.

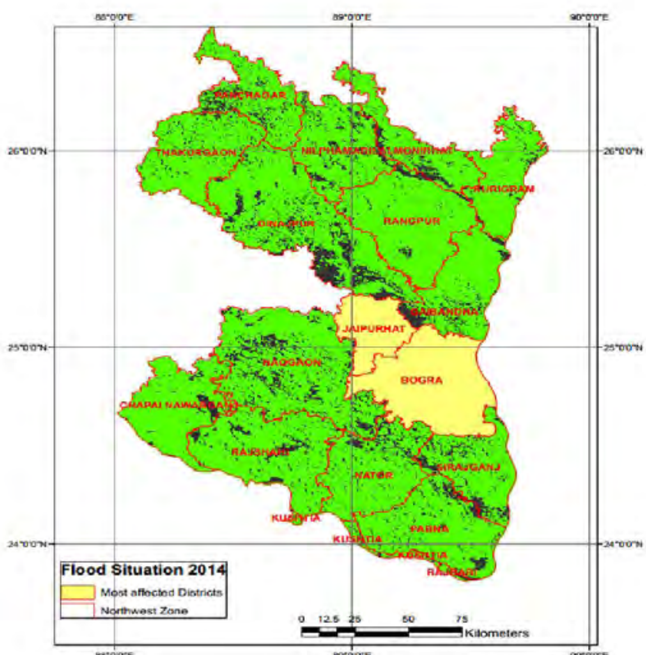


Figure 5.2.70: Most affected areas of Northwest zone in the year of 2014.

b) **North central zone:** The Brahmaputra, the Upper Meghna and the Padma are the major rivers of this zone. Areas of long term water body of this zone are 380 square kilometer. In 2014, this zone of Bangladesh experienced peaks in the last week of August and September (Figure 5.2.71). The most affected areas of this zone were Tangail and Jamalpur (Figure 5.2.72).

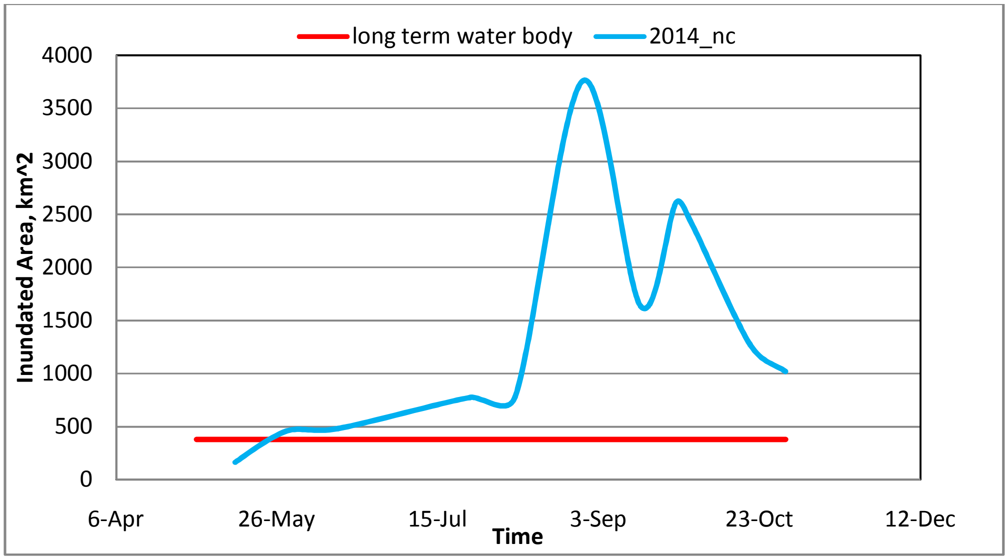


Figure 5.2.71: Most affected areas of North central zone in the year of 2014.

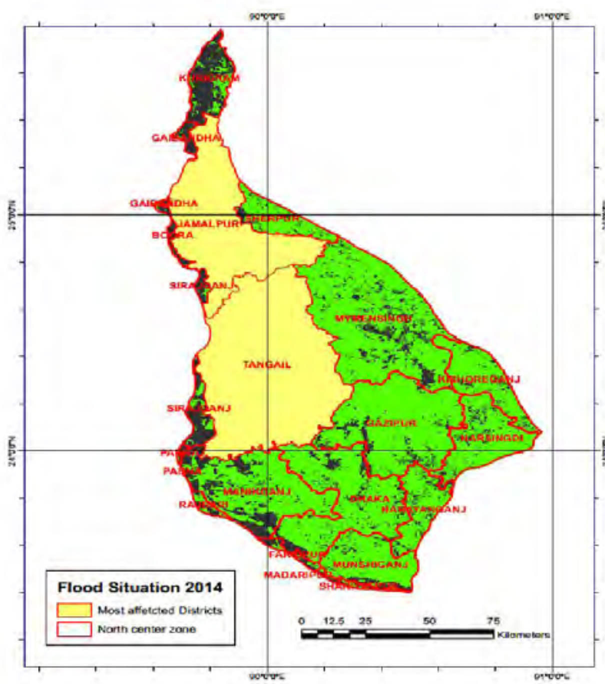


Figure 5.2.72: Most affected areas of North central zone in the year 2014.

c) **Northeast zone:** The Surma, the Kushiara and the Upper Meghna are the major rivers in this zone. Areas of long term water body of this zone are 4254 square kilometer. This zone is a flash flood zone. Due to hilly areas, flood water rush to this zone and causes this types of flood. In 2014, no severe flash flood was occurred in this region. The peaks had come in the last week of August and 1st week of October (Figure 5.2.73). The most affected areas of this zone were Sunamganj, Netrokona and Sylhet (Figure 5.2.74).

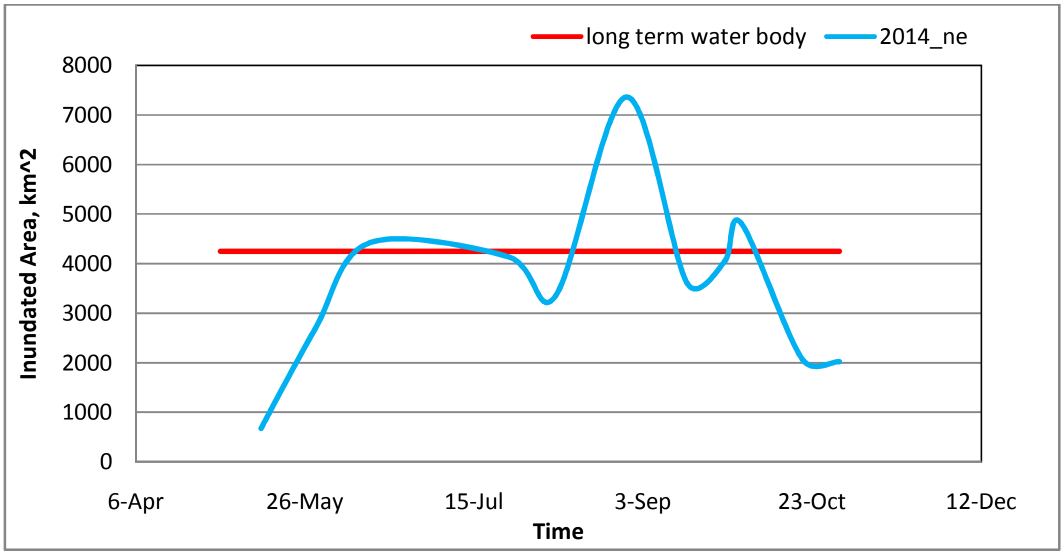


Figure 5.2.73: Inundation pattern of Northeast zone in the year 2014.

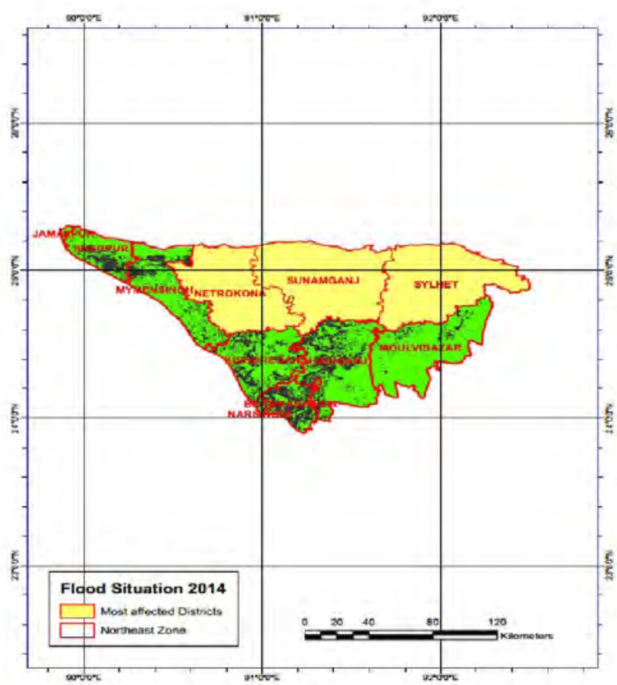


Figure 5.2.74: Most affected areas of Northeast zone in the year 2014.

d) **Southwest zone:** In this area flood peak had come in the last week of August and in the 1st week of October (Figure 5.2.75). Some areas of this zone are encountered severe water logging problem. Area of long term water body of this zone is 667.13 square kilometer. The Ichamoti, the Kodla, the Kobadak and the

Lower Meghna are the major rivers of this region. The most affected areas of this region were Satkhira Khulna and Bagerhat (Figure 5.2.76).

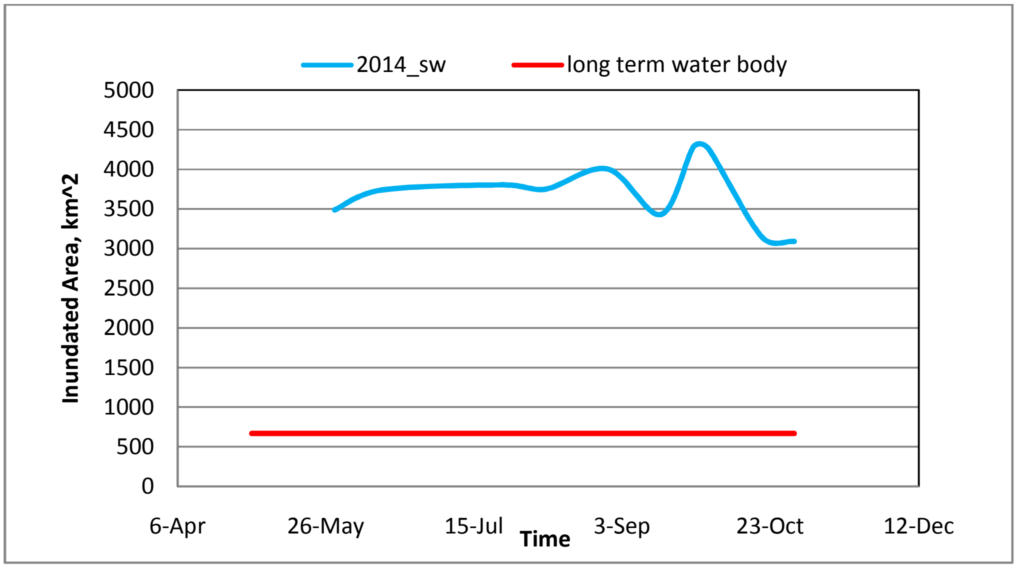


Figure 5.2.75: Inundation pattern of Southwest zone in the year 2014.

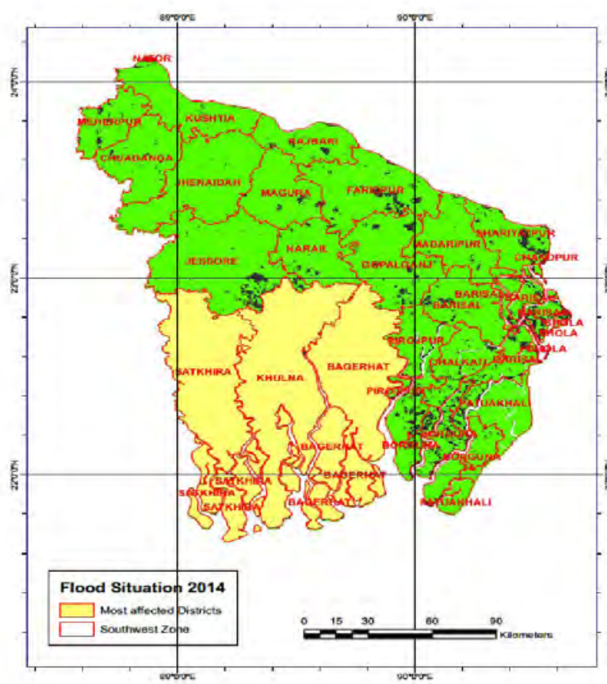


Figure 5.2.76: Most affected areas of Southwest zone in the year 2014.

e) **Southeast zone:** In this zone, flood peak had come in the last week of August and in the 1st week of October (Figure 5.2.77). Areas of long term water body of this zone are 219 square kilometer. The Gumti and the Upper Meghna are the major rivers of this region. The most affected areas of this zone were Comilla and Brahmanbaria (Figure 5.2.78).

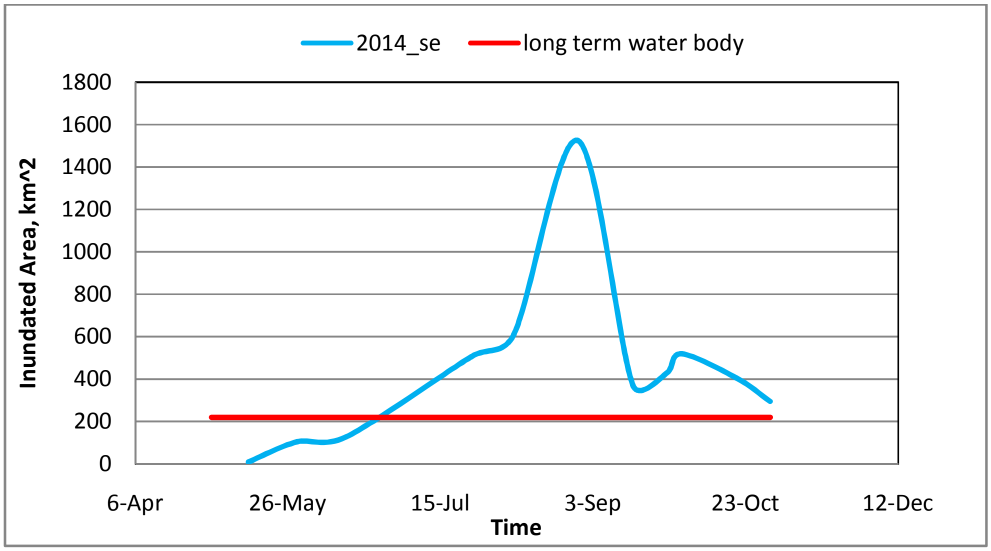


Figure 5.2.77: Inundation pattern of Southeast zone in the year 2014.

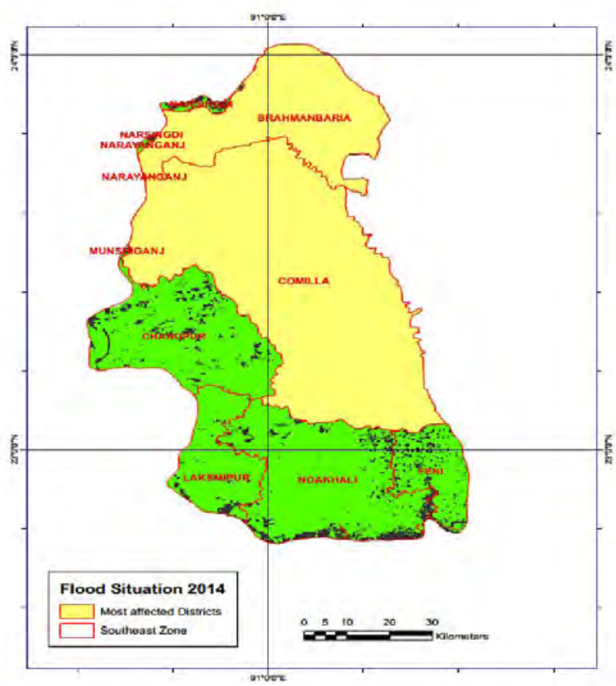


Figure 5.2.78: Most affected areas of Southeast zone in the year 2014.

5.3 Comparison of MODIS image with RADARSAT image:

In this study flood map prepared by MODIS image has also been compared with more accurate RADARSAT (50 meter resolution) image. As RADARSAT image is expensive that is why a single image of upper Meghna has been collected (Figure 5.3.1, 5.3.2, 5.3.3). As it is not possible to conduct regression analysis for a single image, two image of same area has been compared by raster subtraction process. In this process, in both images, pixels consisting flood water have been denoted by 10 and pixels without flood water have been denoted as 255. Then the RADARSAT image has been subtracted from the MODIS image using ArcGIS software. Thus Pixel with same value will be found as 0 and has been considered as perfect matched. Pixel with different value will be found as +245 or -245. In both cases the pixel has been considered as mismatched (Figure 5.3.4). Later percentage of total matched pixel to the mismatched pixel will be determined. In this process, flood inundation map prepared from MODIS image, has been found as 76% matched with the flood inundation map prepared by RADARSAT image.

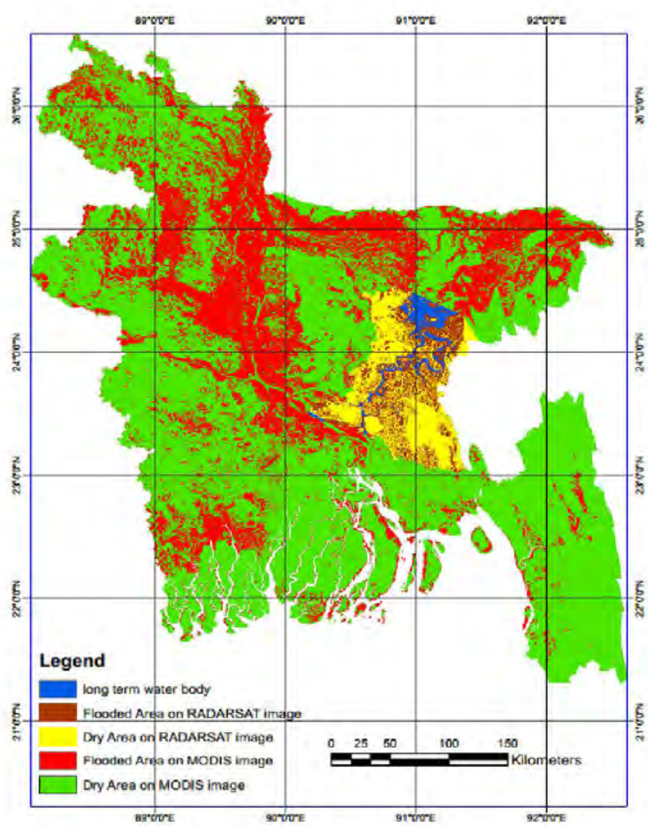


Figure 5.3.1: MODIS and RADARSAT inundation map (03.08.2007).

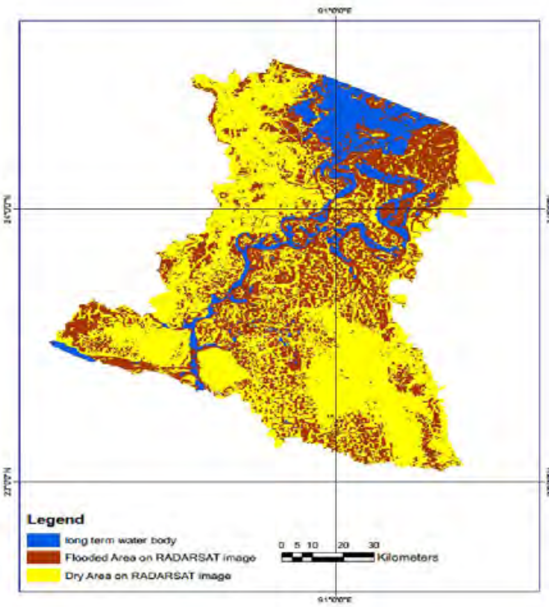


Figure 5.3. 2: RADARSAT flood inundation map of Upper Meghna (03.08.07).

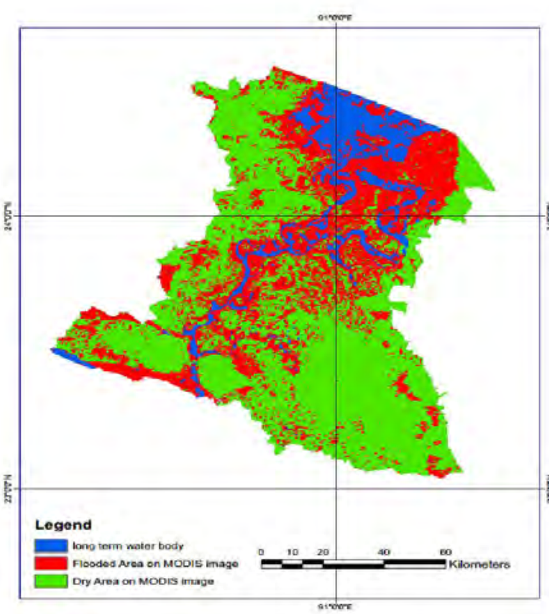


Figure 5.3.3: MODIS inundation map of Upper Meghna (03.08.07).

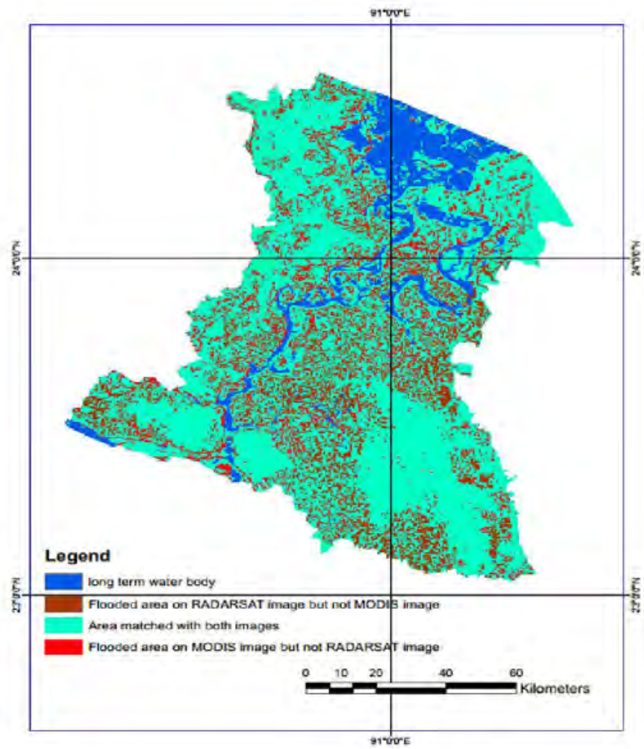


Figure 5.3.4: Comparison between RADARSAT inundation map and MODIS inundation map.

5.4 Discussions

- This study has covered the flood season of Bangladesh from the year 2004 to 2014. Data from 2011 to 2013 was not available thus could not possible to analyze.
- In this study, it has been found that, overall correlation between flood inundation maps prepared from MODIS images and inundation map prepared from BWDB inundation data is 0.701. Flood inundation maps prepared from MODIS images have better correlation with BWDB flood images in the Northwest, North central, Northeast and Southeast zones. In Southwest zone, it has a poor correlation. This may be because this zone is a tidal zone and the model used by FFWC (BWDB) is a hydrodynamic model and does not consider tidal effect. On the other hand there are a few number of WL observing stations currently functioning (Table 5.1). So the actual flood situation cannot be reflected by the model output in this zone.

Table 5.1 Relation between the amount of areas covered by a single Water Level measuring station and the correlation value between MODIS image and BWDB flood image.

Sl No	Zone_Name	Area (km^2)	Number of WL measuring station	Area covered per station (km^2)	Correlation between MODIS image and BWDB flood image (r^2)
1	NC	16297.9	14	1164.14	0.896
2	NE	20853.5	15	1390.23	0.929
3	NW	31302.3	21	1490.59	0.915
4	SE	7103.96	6	1183.99	0.959
5	SW	35130.1	7	5018.59	0.058

- In this research, overall and zone wise flood pattern of Bangladesh have been studied. From figure 5.4.1 it has been observed that maximum inundation occurred in Bangladesh in August, 2007. In 2004, another severe flood hit in this country. Around 31% area was flooded by this flood. Regarding zone wise pattern, in Northwest zone, maximum area was inundated in 2007 (Figure 5.4.2). Around 35% areas were inundated in that year. In 2005 around 25 % areas were inundated in that year. In North central zone, around 40% areas were inundated in 2004 (Figure 5.4.3). This area was also severely affected in 2007 and 2008. In Northeast zone, maximum area was inundated in 2007 (Figure 5.4.4). Around 54% areas were inundated at that time. In 2004, around 51% areas were inundated. This is a flash flood zone. In 2005 and 2010, this area was severely affected by flash flood. In Southeast zone, maximum inundation occurred in 2005 (Figure 5.4.5). Around 32% areas were inundated in this year. In 2005, this area was also affected by pre-monsoon flood which was occurred in early May of 2005. In Southwest zone, maximum area was inundated in 2008 (Figure 5.4.6). Around 26% areas were inundated in this year.

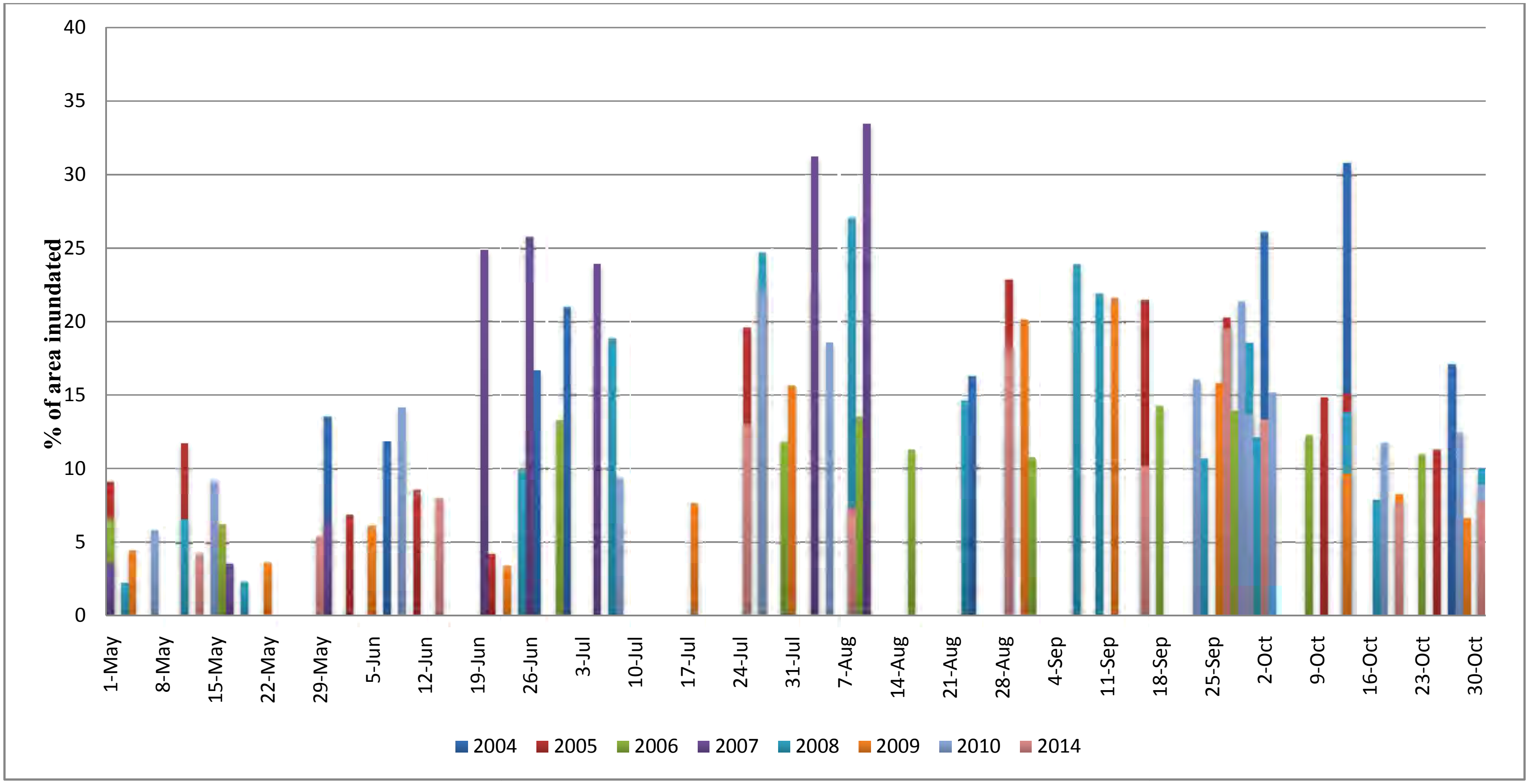


Figure 5.4.1 Percentage of area of inundation for different years calculated from MODIS images.

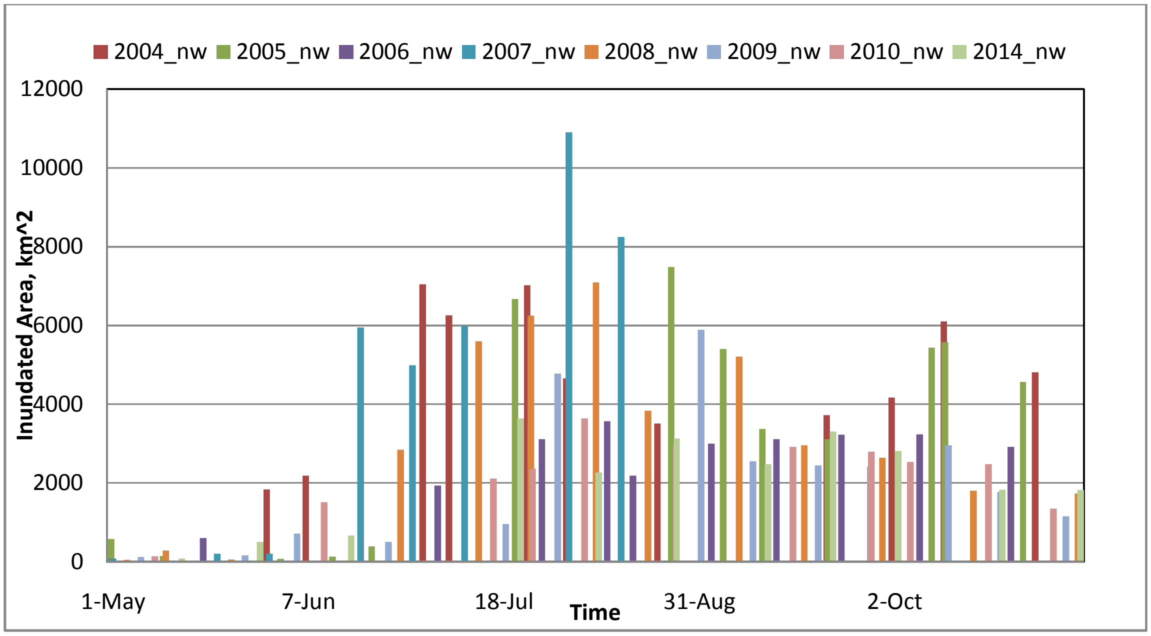


Figure 5.4.2 Area inundated in the Northwest zone calculated from MODIS images.

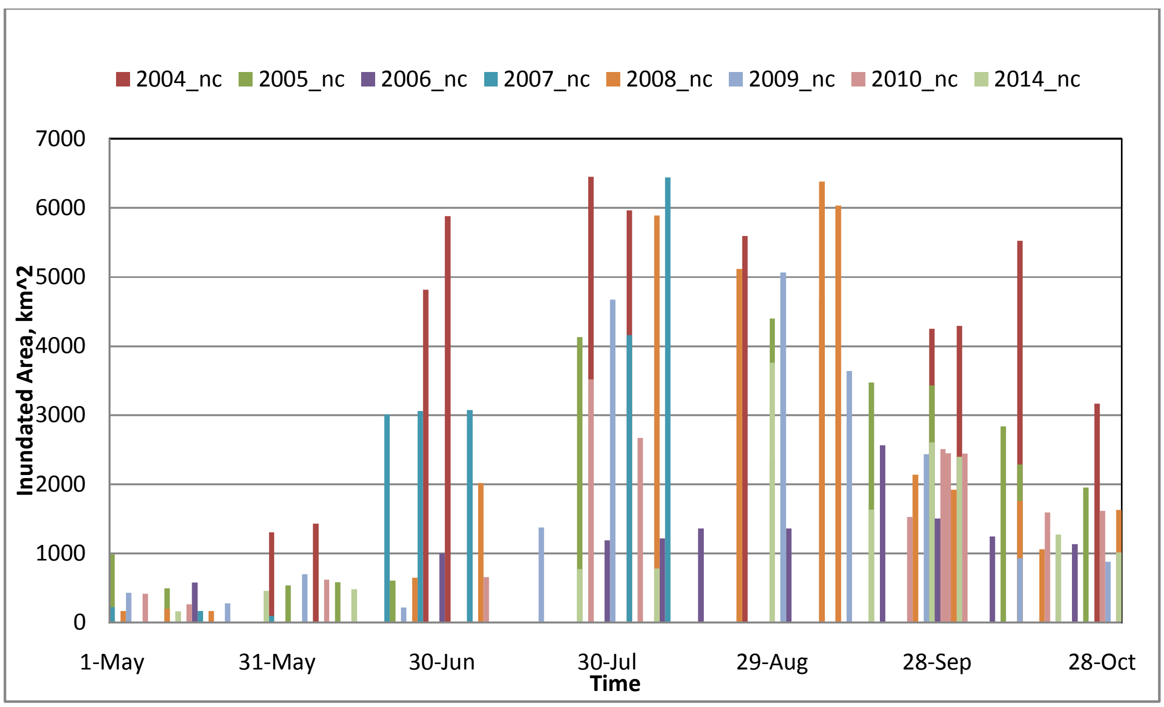


Figure 5.4.3 Area inundated in the North central zone calculated from MODIS images.

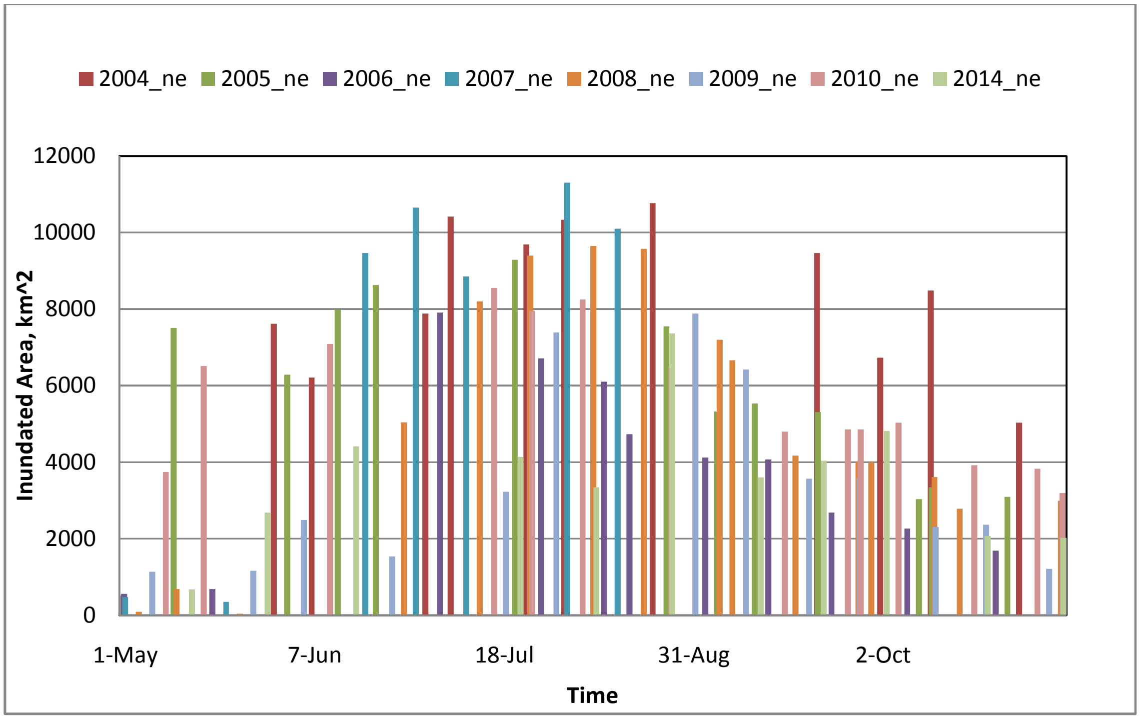


Figure 5.4.4 Area inundated in the Northeast zone calculated from MODIS images.

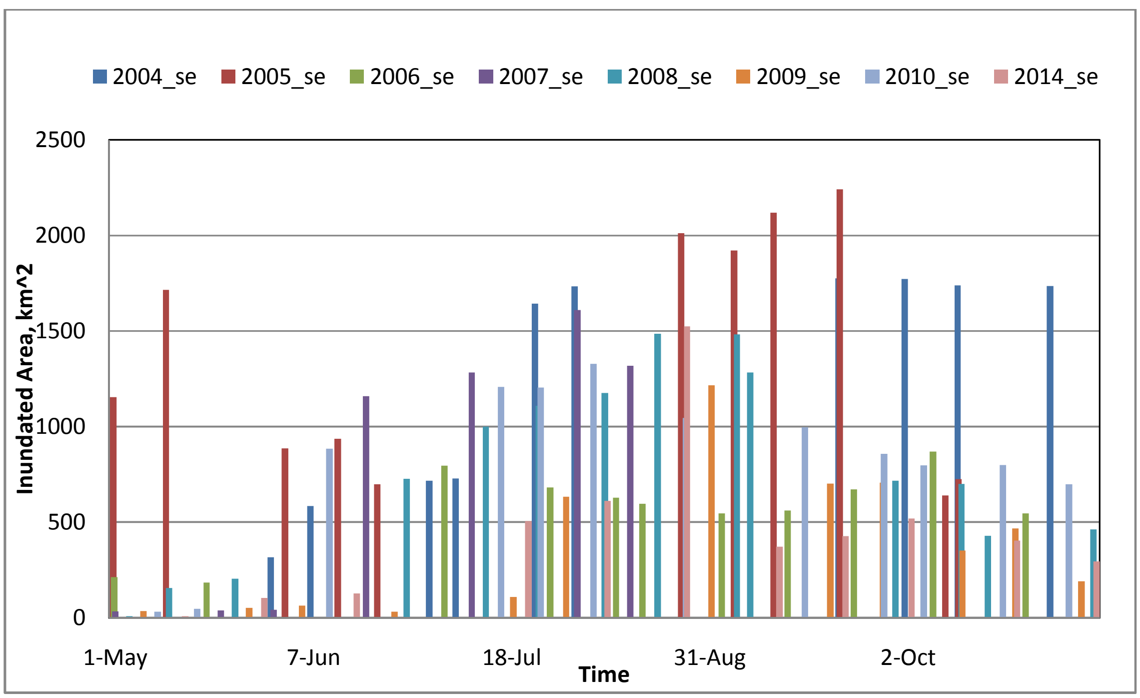


Figure 5.4.5 Area inundated in the Southeast zone calculated from MODIS images.

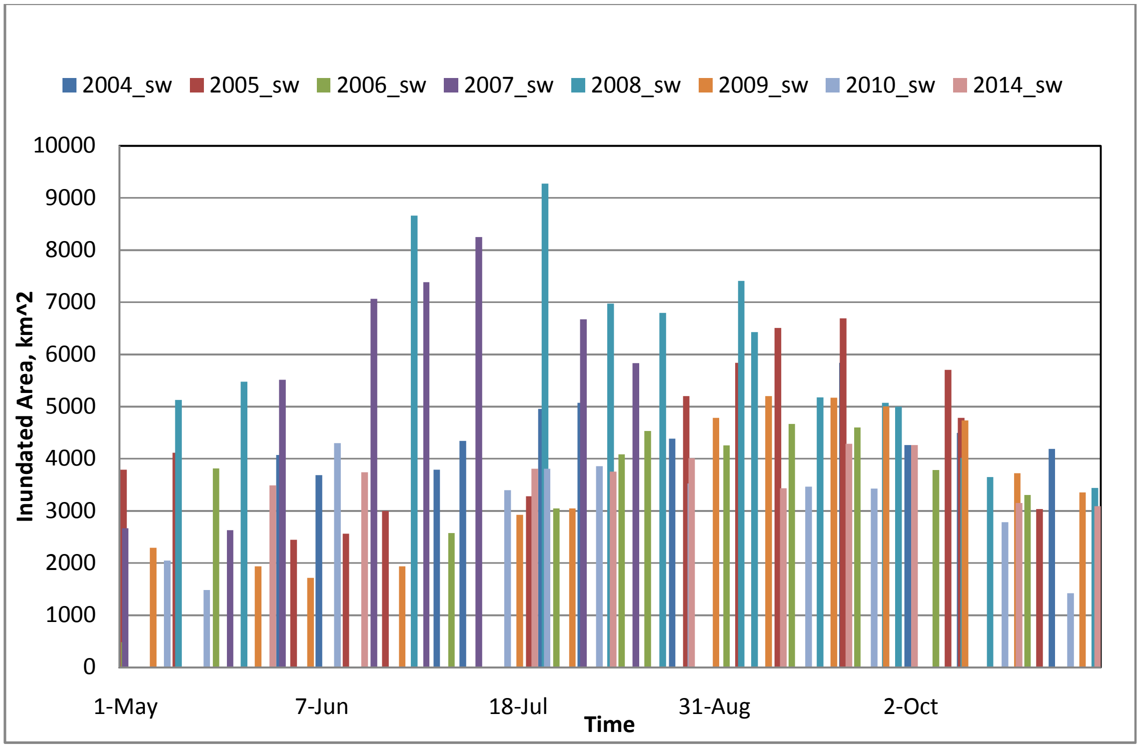


Figure 5.4.6 Area inundated in the Southwest zone calculated from MODIS images.

- From this study it is evident that generally there are two flood-picks in Bangladesh (Annexure A3.1). First peak comes in the later part of July and the second one comes in late September. There are three flood-prone zones in Bangladesh, The Brahmaputra basin, the Padma basin and the Meghna basin. In early monsoon (March to May) the north-eastern part of Bangladesh generally affected by Flash flood.
- In this study, priority has been given to monsoon flood and flash flood. But as MODIS data is available in daily basis, this process could be very useful to study coastal flooding pattern also (Figure 5.4.7).

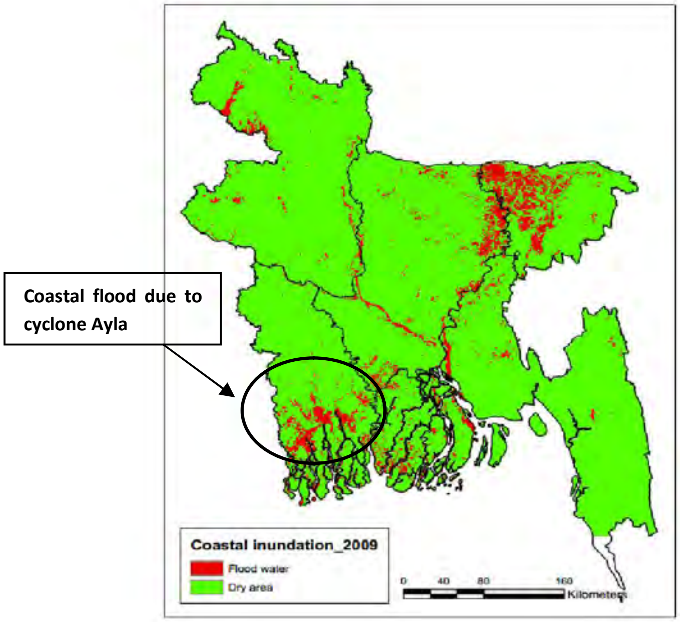


Figure 2.4.7 Coastal flood due to cyclone "Ayla" obtained from MODIS image

- Flood is a wave phenomenon and all satellites have their repeating intervals. So most of the time, time of acquisition of satellite data does not coincide with the time of flood peak which is related to the maximum inundation area. On the other hand, MODIS Terra/Aqua is a passive satellite; its sensor cannot receive radiance from a cloud covered ground. If both Terra and Aqua images are covered by cloud than it cannot be possible to remove cloud from MODIS images.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

In this study, MODIS images of 250 m resolution have been used. It is a moderate resolution imagery which is freely available in website. The website is being updated every day. In this study images from the year 2004 to 2014 have been collected. Images from 2011 to 2013 could not be collected as it was not available in the website.

There were three objectives in this study. First objective was to generate flood inundation maps using MODIS images. To fulfill this objective a method has been developed in this study to prepare flood inundation map. This method is quick and convenient. Both in general and zone wise flood maps have been prepared in this study. Generally three Maps (depends on availability and cloud removing possibility) have been prepared for each month of the studied years. Regarding second objective which was to compare flood inundation maps with the inundation maps prepared by BWDB, a regression analysis has been conducted between these two types of maps. From the analysis, the overall value of the coefficient of determination or R^2 has been found as 0.701. In zone wise analysis, it showed greater correlation to the BWDB inundation maps in Northwest zone (R^2= 0.915), in North central zone (R^2= 0.896), in Northeast zone (R^2= 0.929) and in Southeast zone (R^2= 0.959). In Southwest zone, the correlation has been found very poor as R^2=0.058. The reason for this could be due to lack of WL measuring stations available in this zone and the model which has been used to prepare flood maps does not consider tidal effect of this zone. To fulfill the third objective which was to study flood inundation pattern/behavior of Bangladesh using MODIS images, Area of inundation Vs Time graphs have been plotted to study the inundation pattern with respect to time for the study area both in general and zone wise format. From these graphs it has been observed that, generally there are two flood peaks occurred in this country. One comes in June-July period and another comes in September-October period. Flood water generally begins to decrease after the mid of October. Flash flood pattern has been observed through these graphs. Percent of area inundated during the flood season has also been found from percentage of area inundated Vs Time graphs. Zone wise most affected districts have been found from these graphs as well.

Preparing flood inundation map from MODIS images is easier and more accurate way to do this. Its products are free and have a great advantage in the high frequency observation. That is why; this method is very useful to understand the pattern of temporal flood in Bangladesh and thus can be useful to prepare effective planning against it.

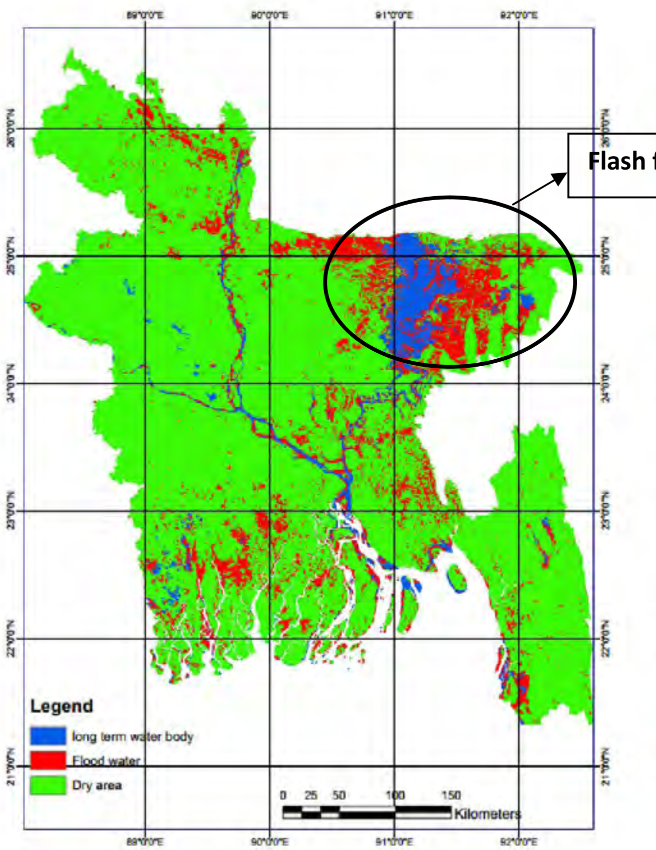
6.2 Recommendations

Based on the findings of the study, the following recommendations are being proposed for further studies.

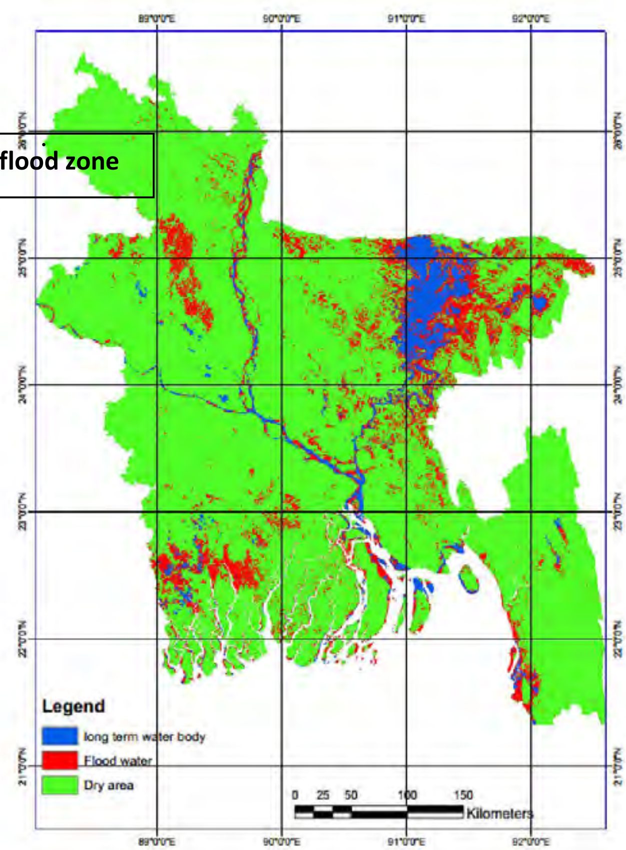
- In this study, single image of high resolution RADARSAT data has been compared with Inundation map prepared from MODIS image due to unavailability. Comparison with more high resolution images would be better.
- Automation of the process of preparing inundation map developed in this study can be done.
- If high resolution image could have been collected then district wise inundation map could have also been prepared by this process.
- As MODIS images are moderate resolution data, this process might be very effective to delineate large water bodies like "Haors" or river banks etc.

Annexure

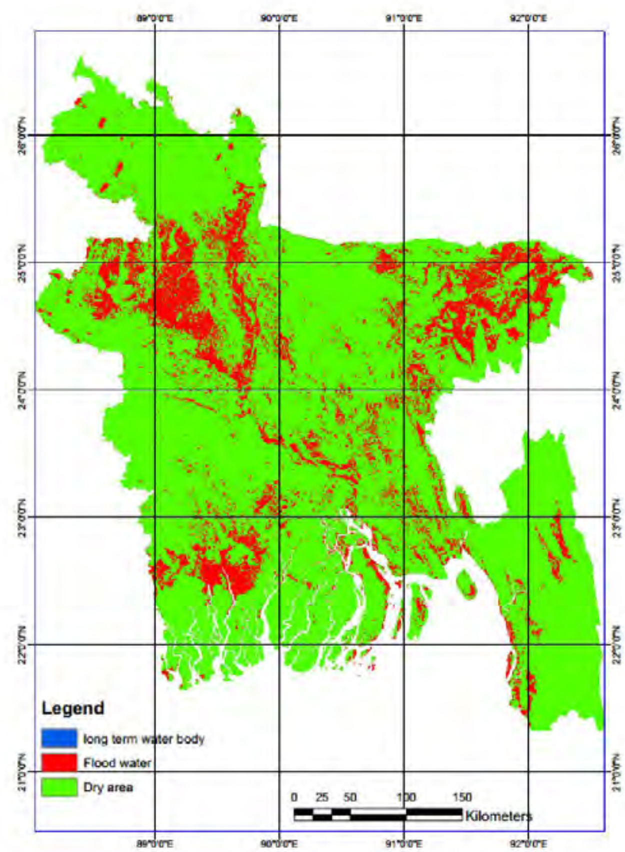
A1 **<u>Flood maps for different years generated from MODIS images.</u>**

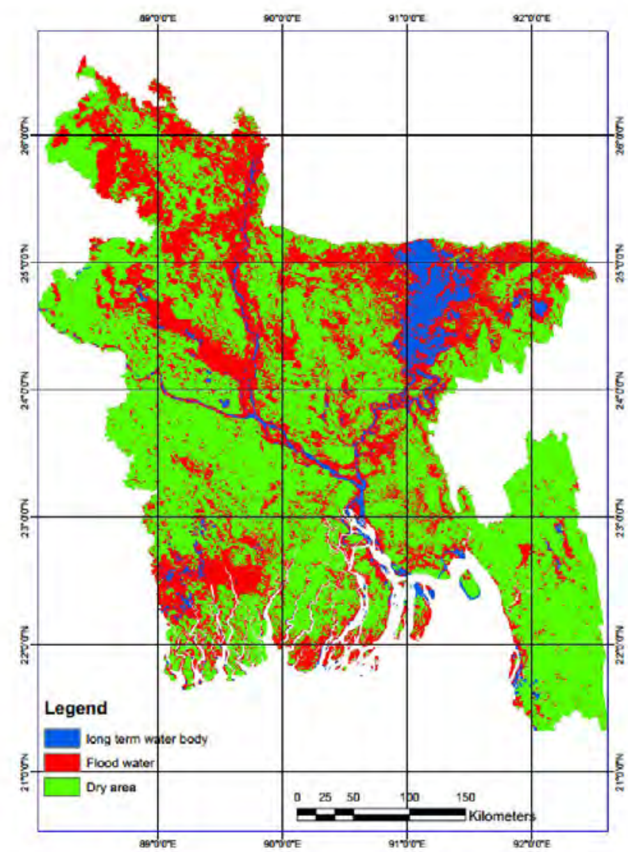


FigA1.1: Flood map of May 30, 2004



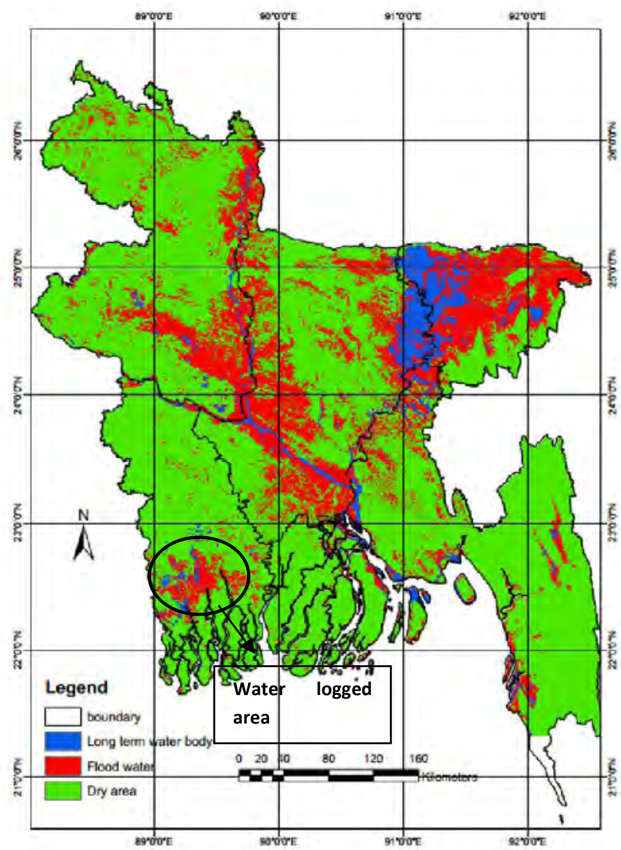
FigA1.2: Flood map of June 7, 2004



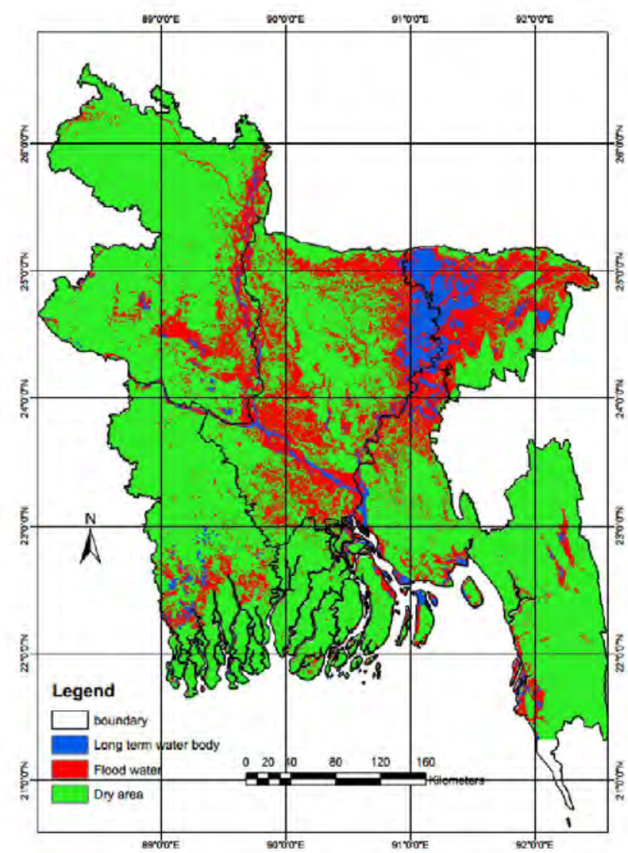


FigA1.3: Flood map of June 27, 2004

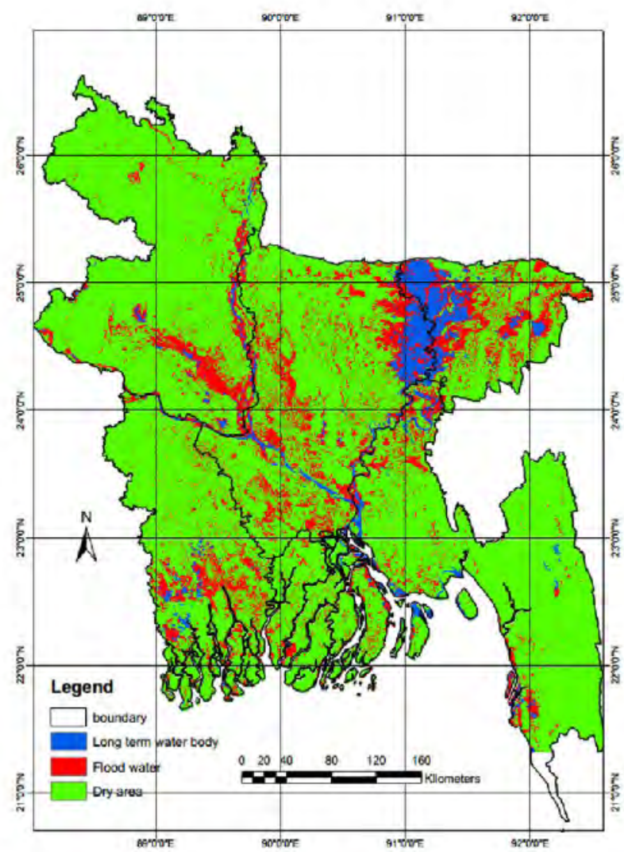
FigA1.4: Flood map of July 01, 2004



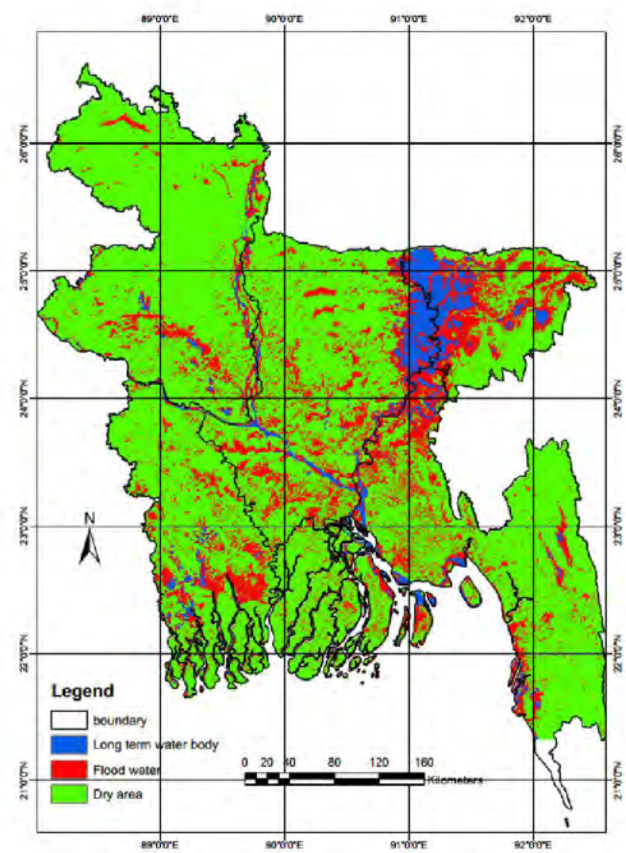
FigA1.5: Flood map of Jul 27, 2004.



FigA1.6: Flood map of Aug 03, 2004.



FigA1.7: Flood map of Aug 24, 2004



FigA1.8: Flood map of Sep 27, 2004

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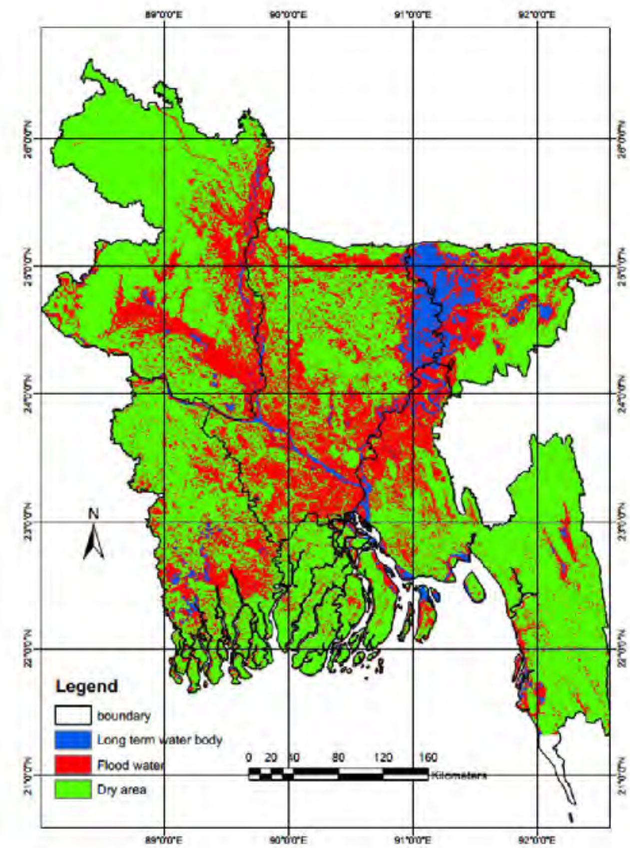
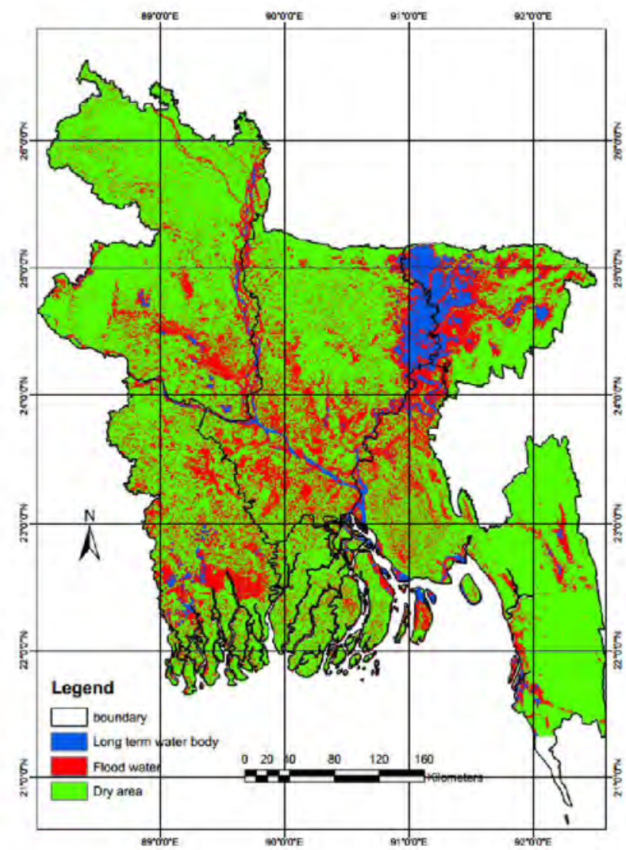
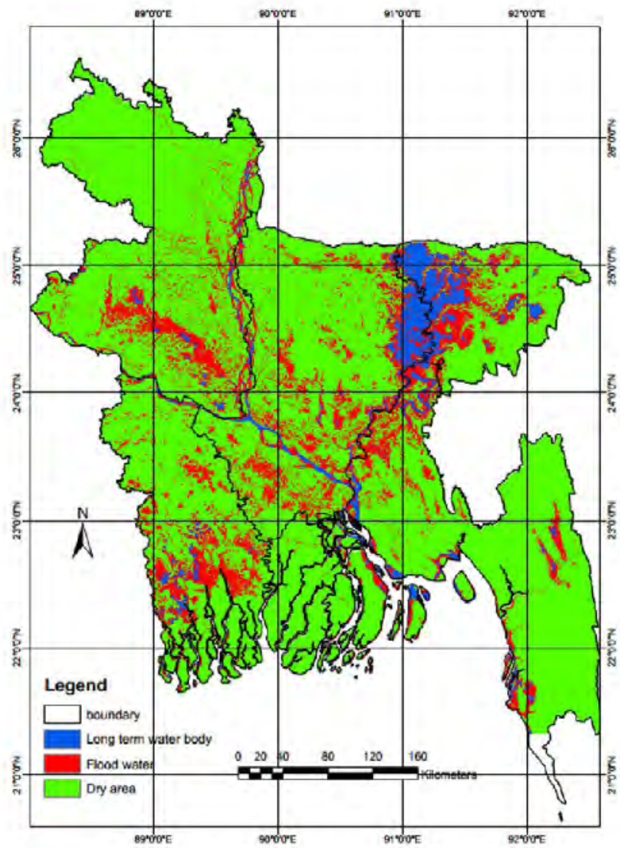


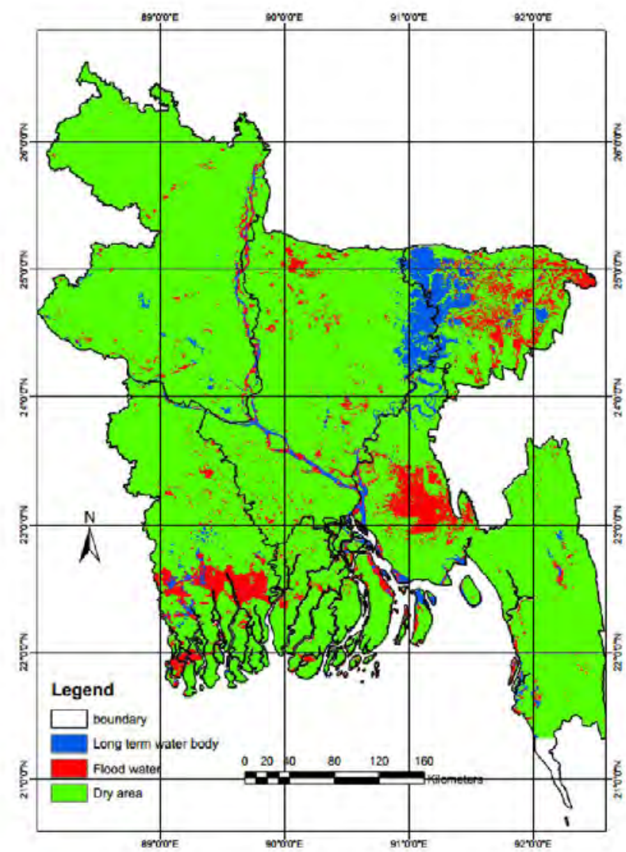
FigA1.9: Flood map of Oct 2, 2004



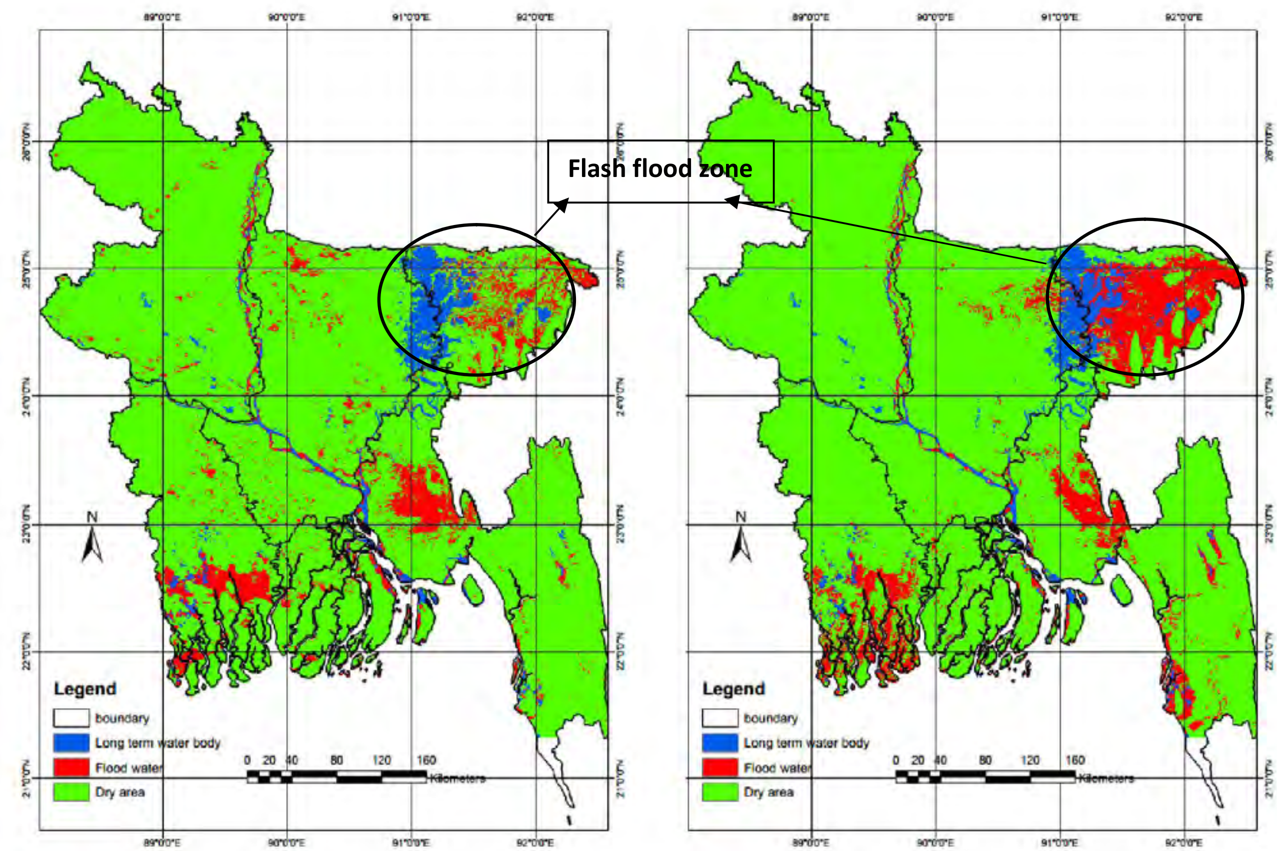
FigA1.10: Flood map of Oct 13, 2004



FigA1.11: Flood map of Oct 27, 2004.

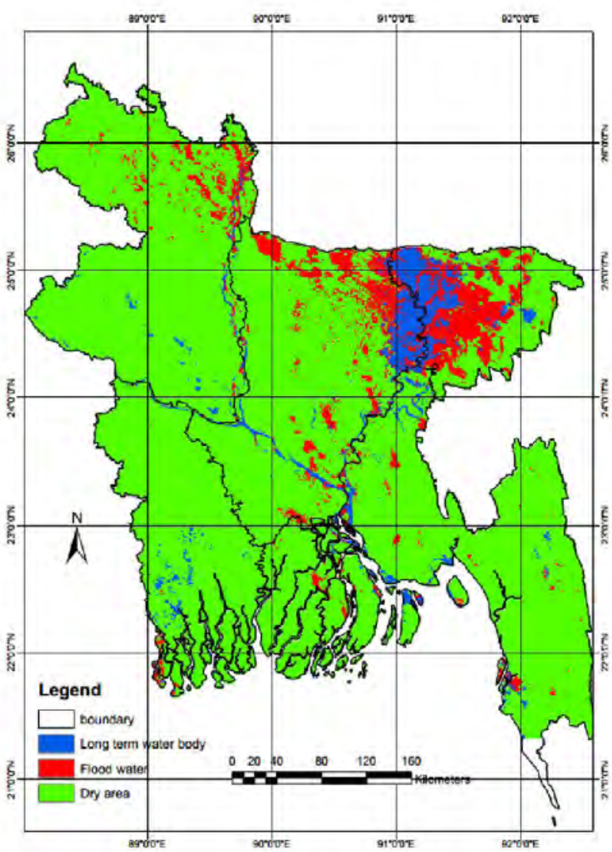


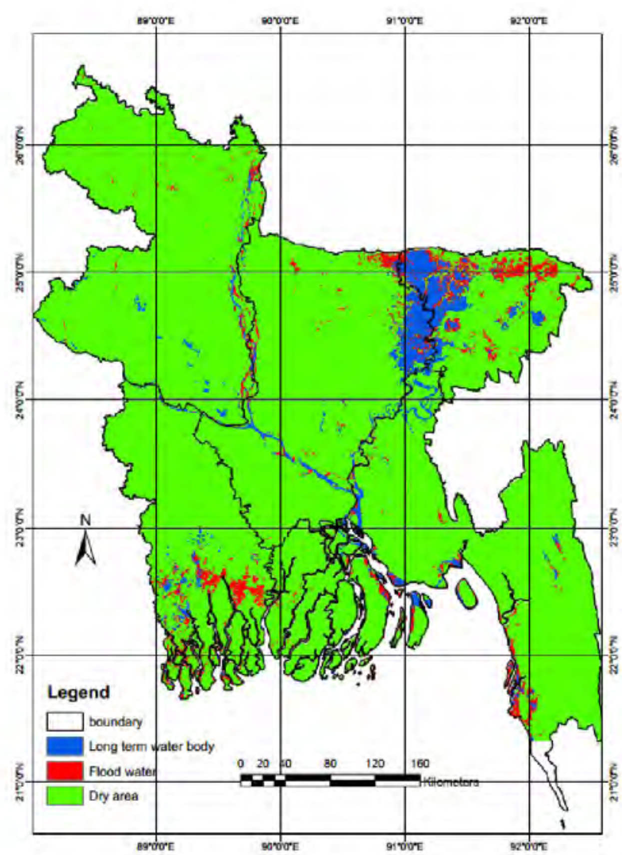
FigA1.12 Flood map of May 01, 2005.



FigA1.13: Flood map of May 11, 2005

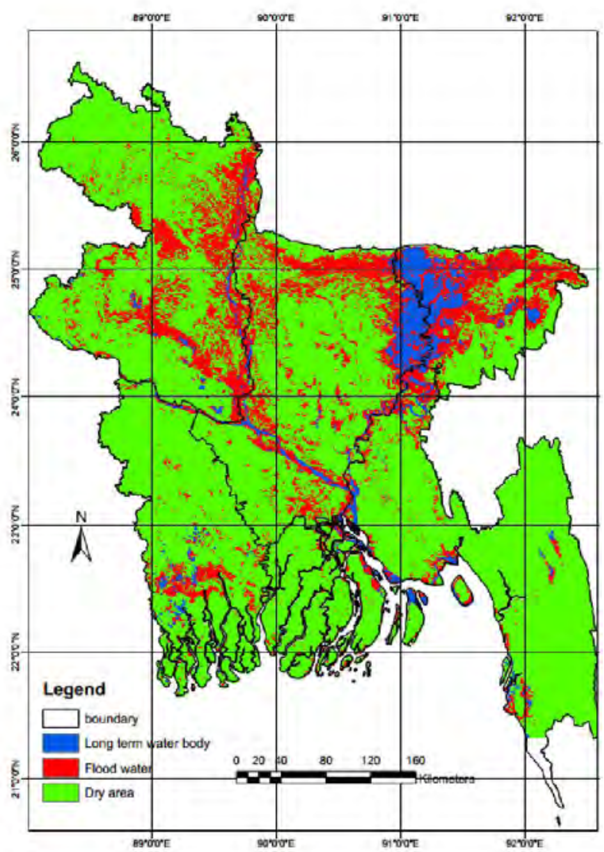
FigA1.14: Flood map of Jun 02, 2005





FigA1.15: Flood map of Jun 11, 2005

FigA1.16: Flood map of Jun 21, 2005



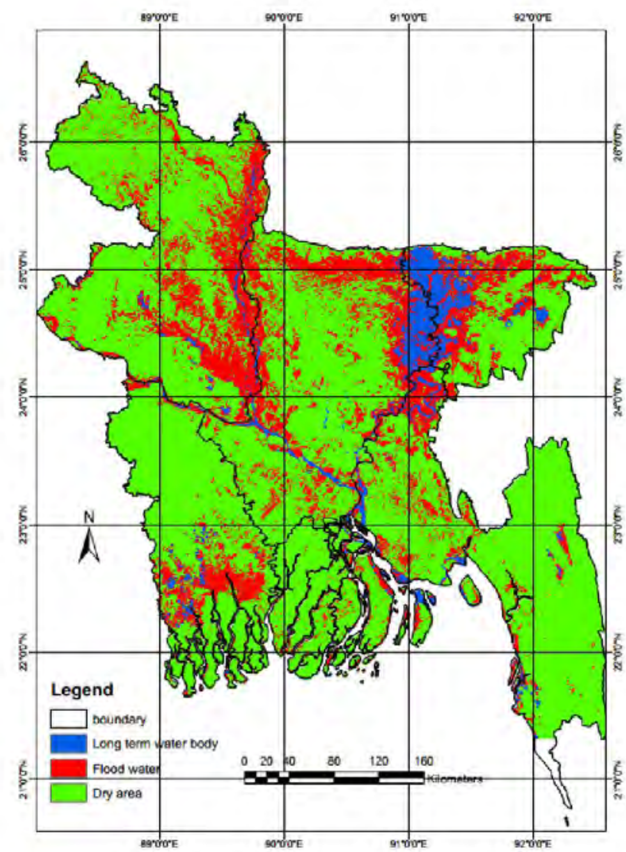


Fig A1.17: Flood map of Jul 25, 2005.

Fig A1.18: Flood map of Aug 29, 2005

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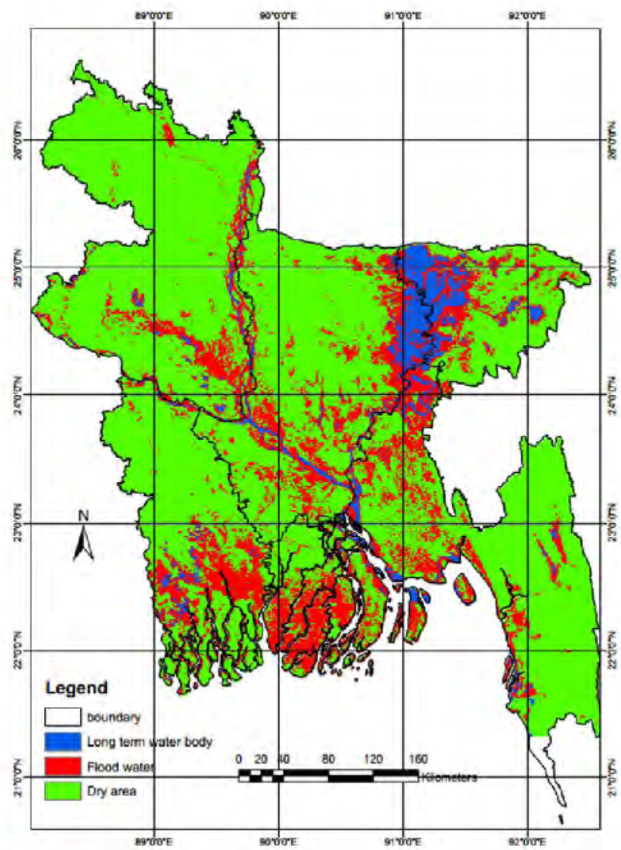
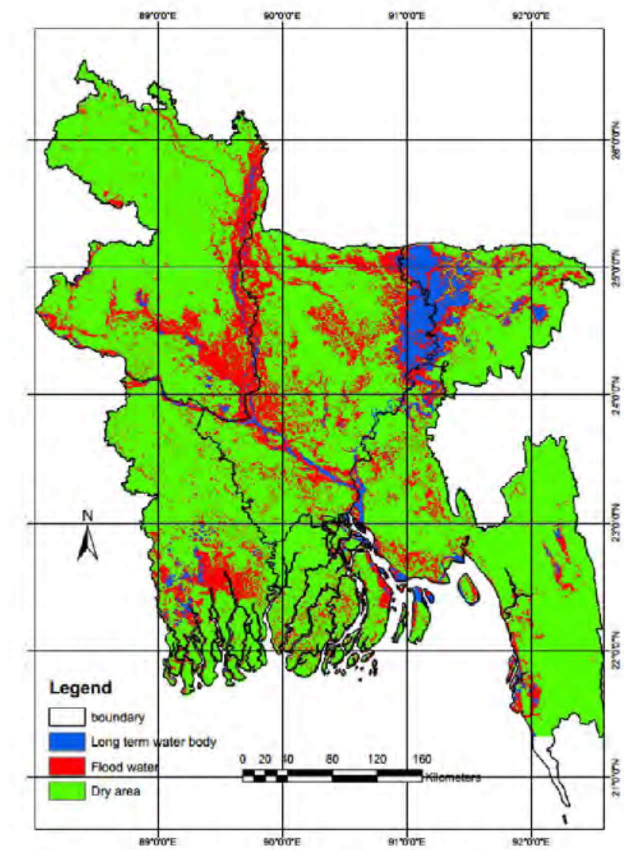
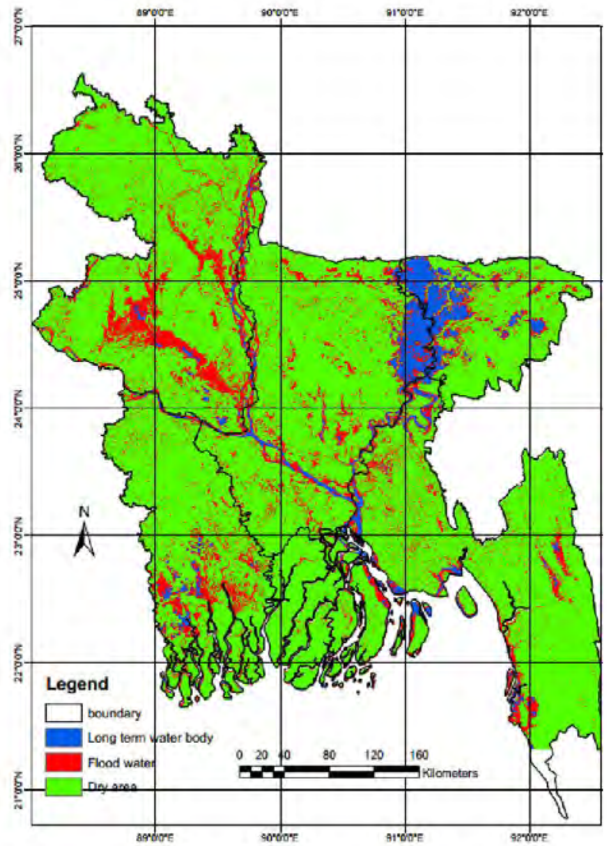


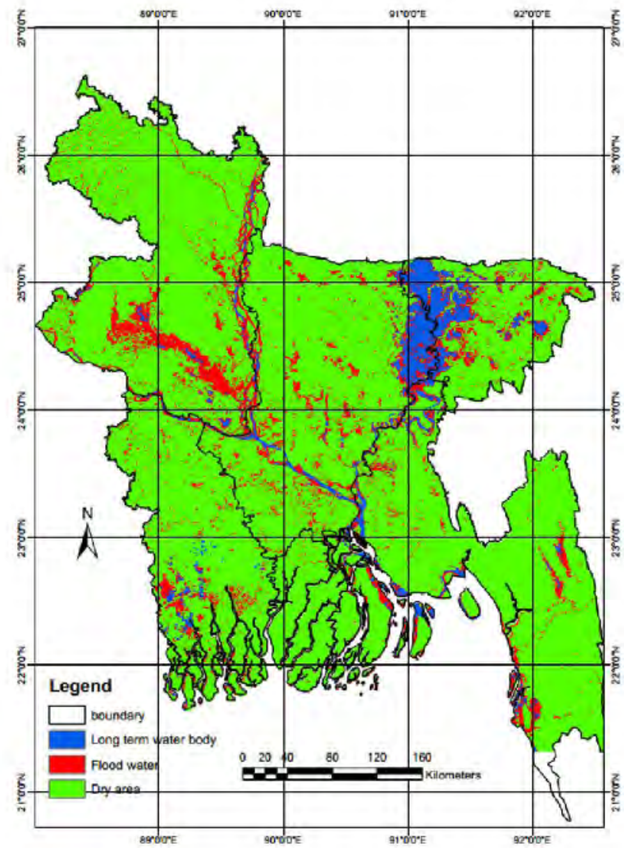
FigA1.19: Flood map of Sep 16, 2005



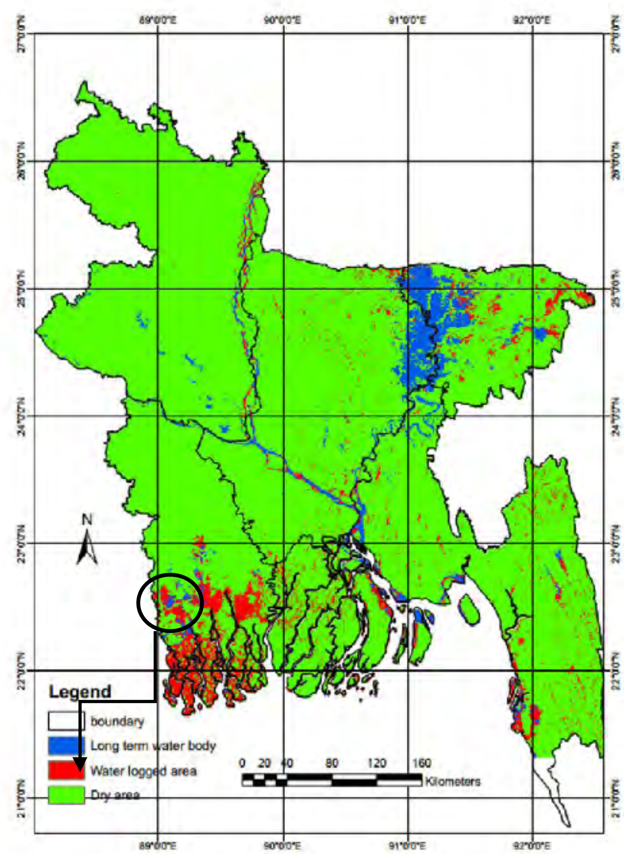
FigA1.20: Flood map of Sep 27, 2005

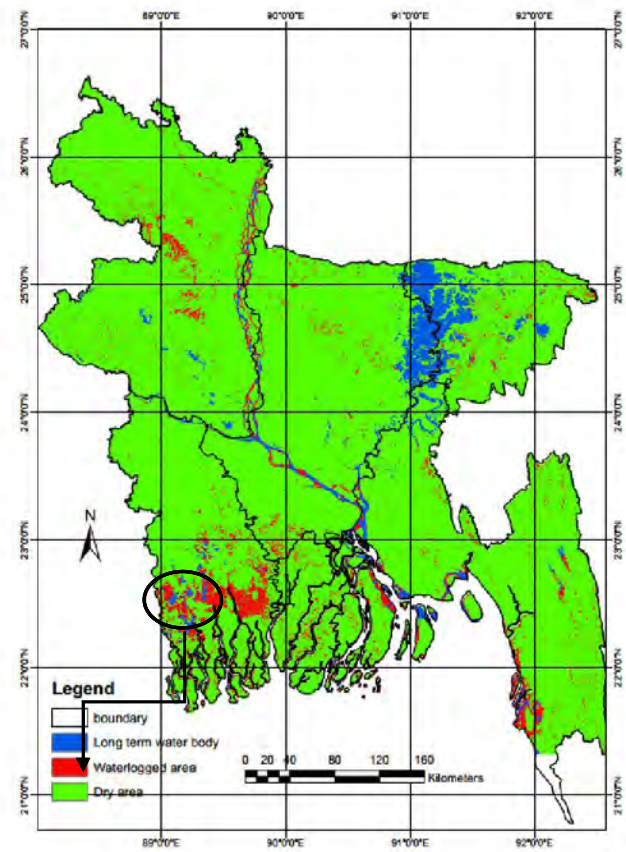


FigA1.21: Flood map of Oct 13, 2005



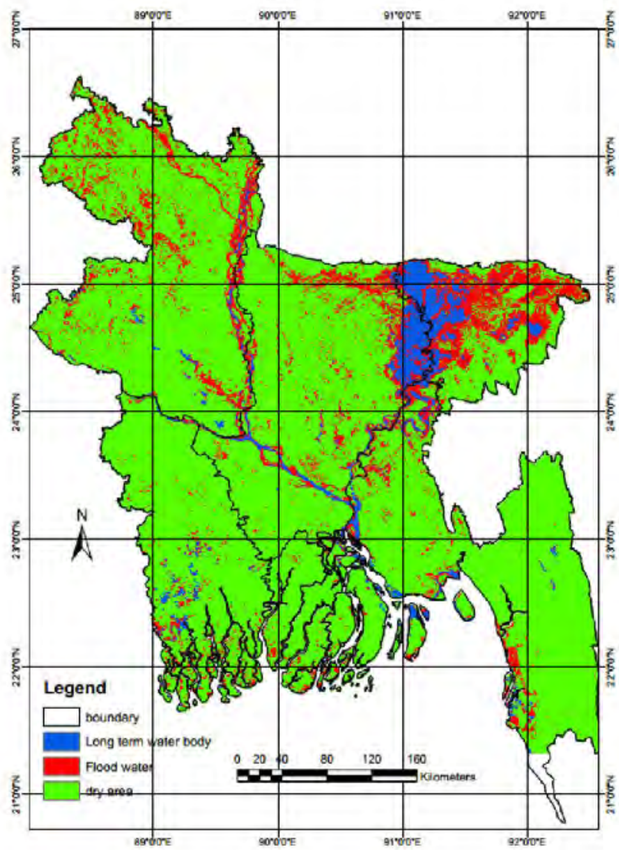
FigA1.22: Flood map of Oct 25, 2005



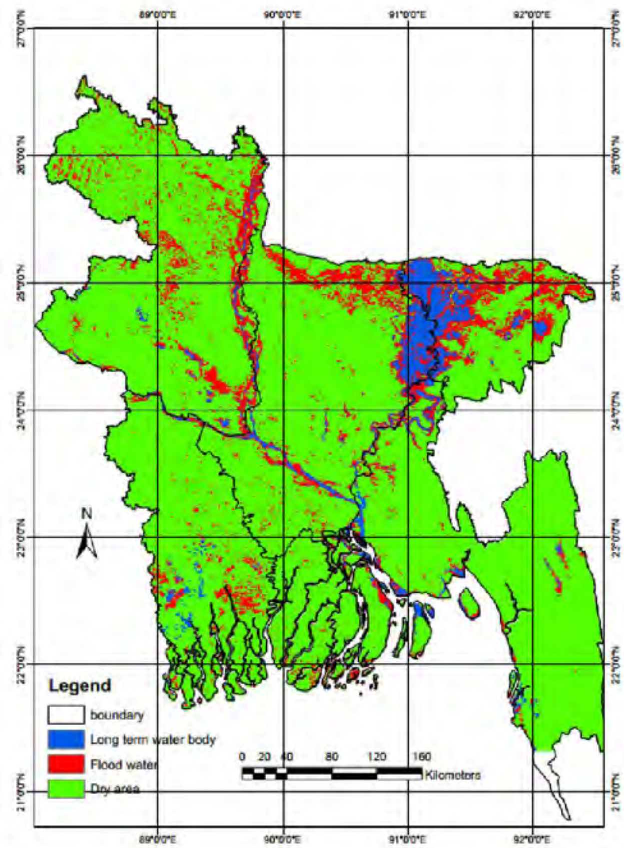


FigA1.23: Flood map of May 01, 2006

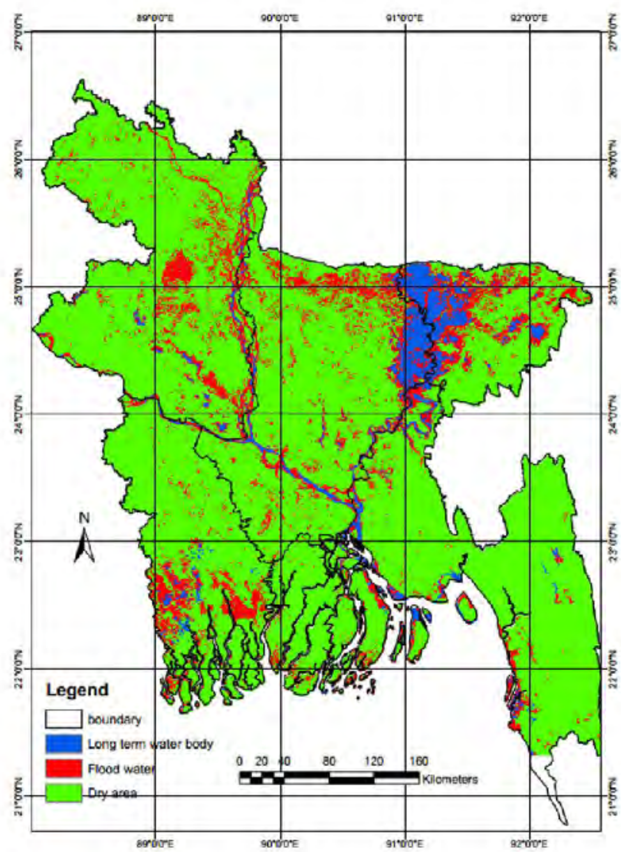
FigA1.24: Flood map of May 16, 2006

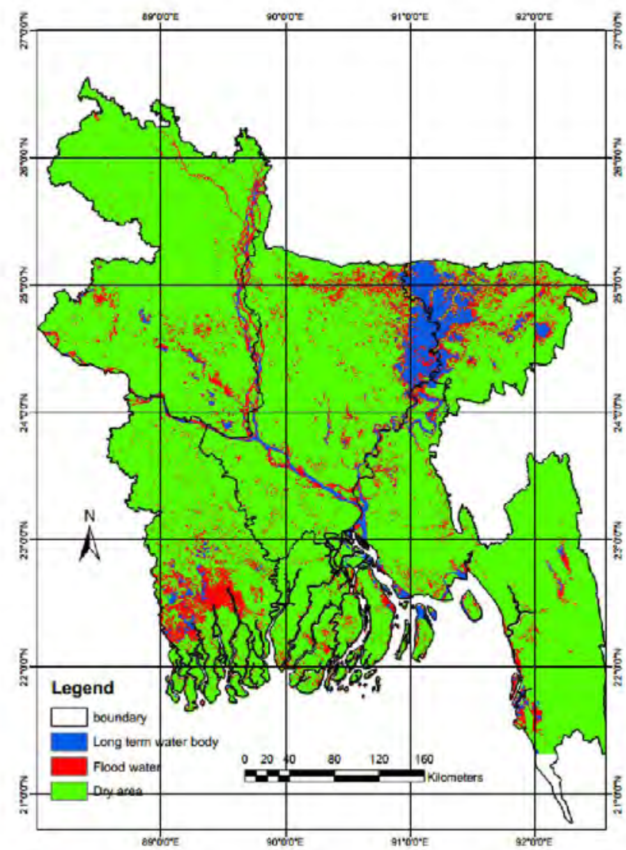


FigA1.25: Flood map of Jun 30, 2006



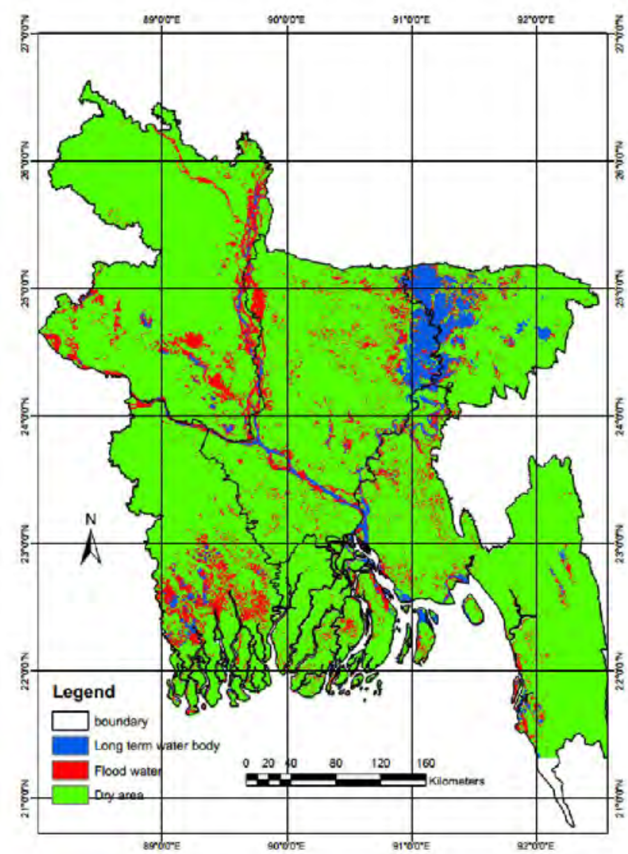
FigA1.26: Flood map of Jul 30, 2006



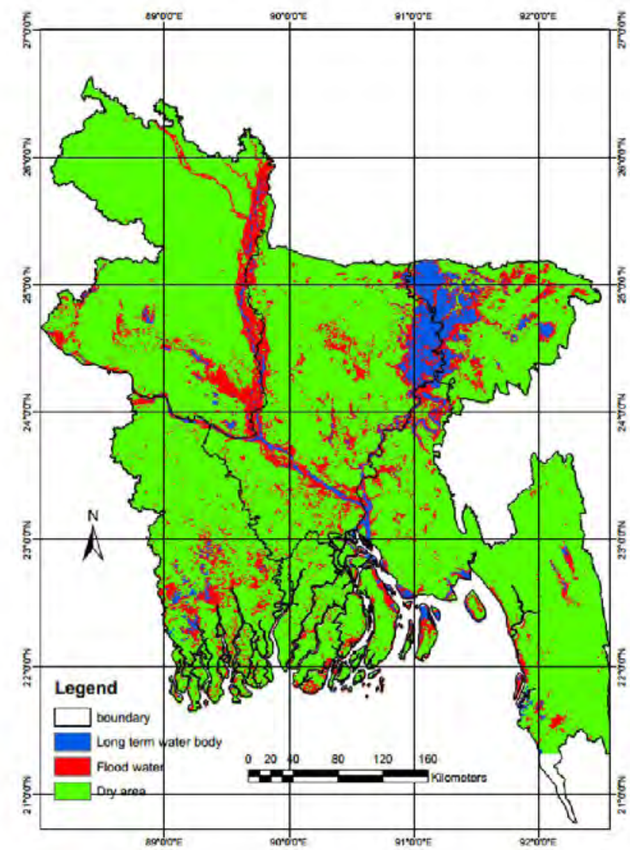


FigA1.27: Flood map of Aug 09, 2006

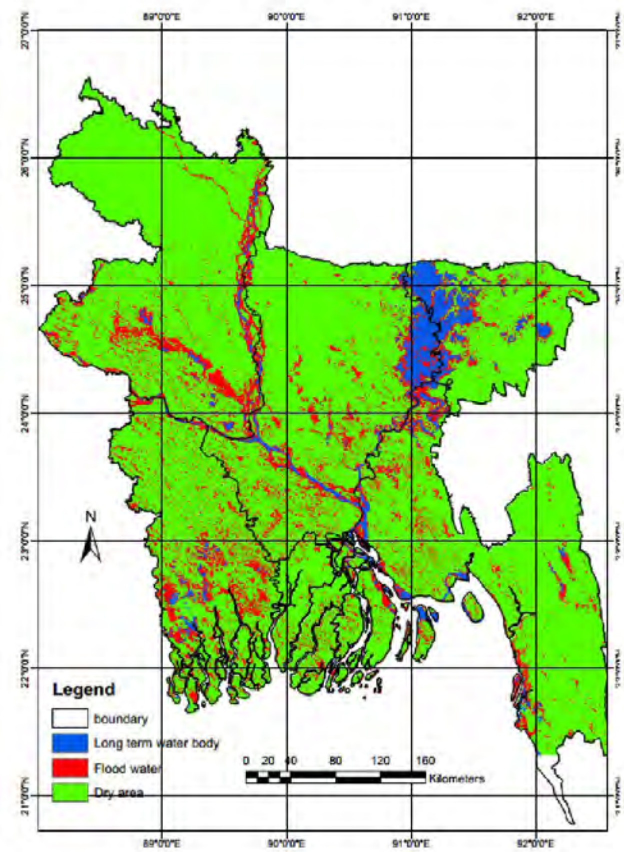
FigA1.28: Flood map of Aug 16, 2006



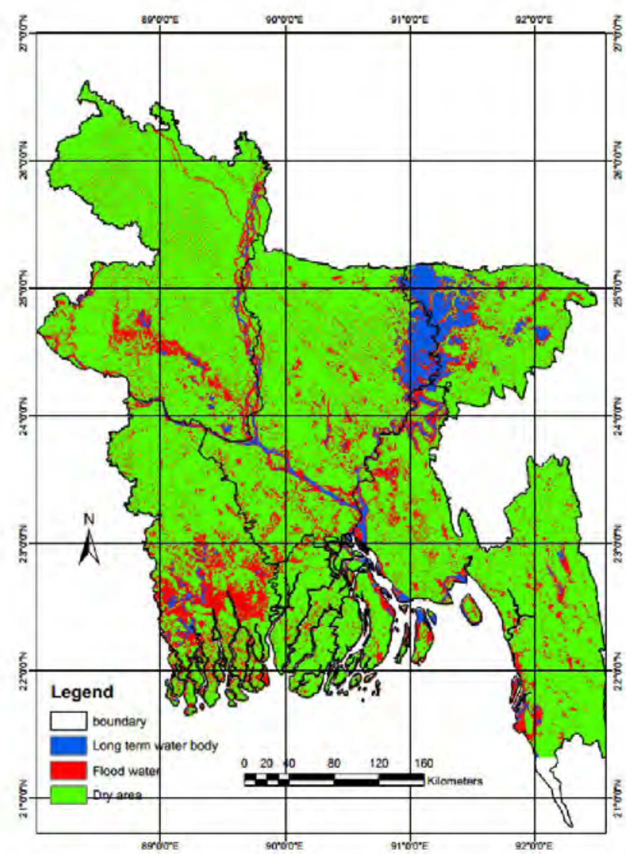
FigA1.29: Flood map of Sep 01, 2006



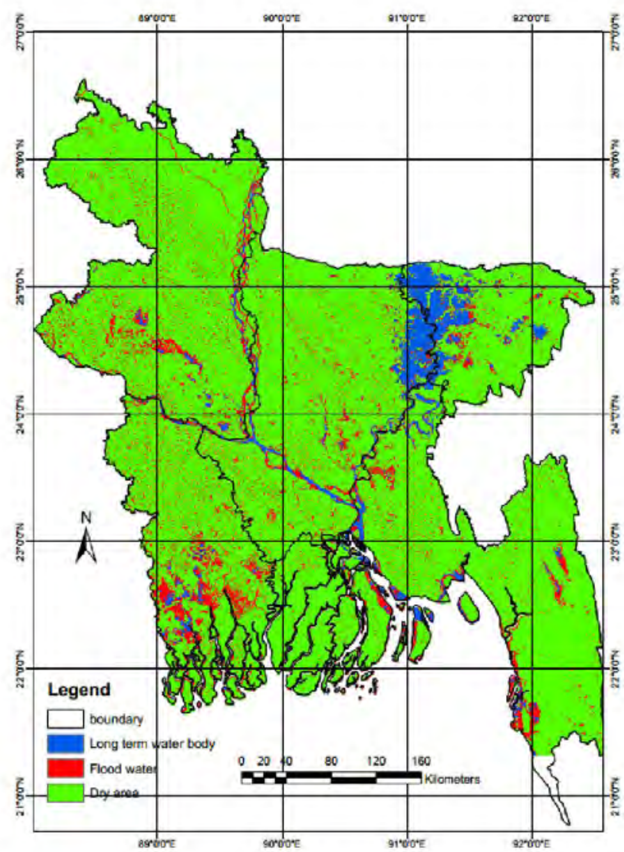
FigA1.30: Flood map of Sep 18, 2006



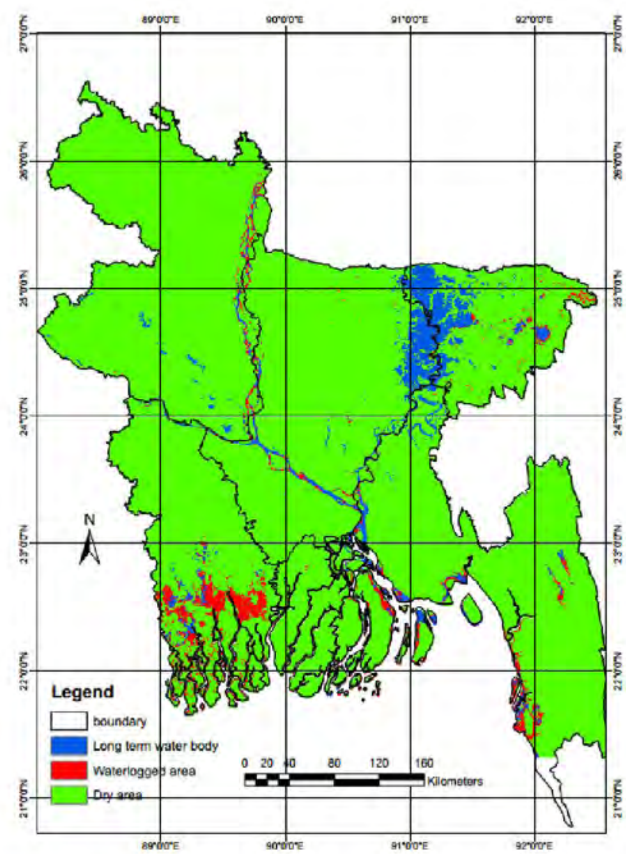
FigA1.31: Flood map of Sep 28, 2006



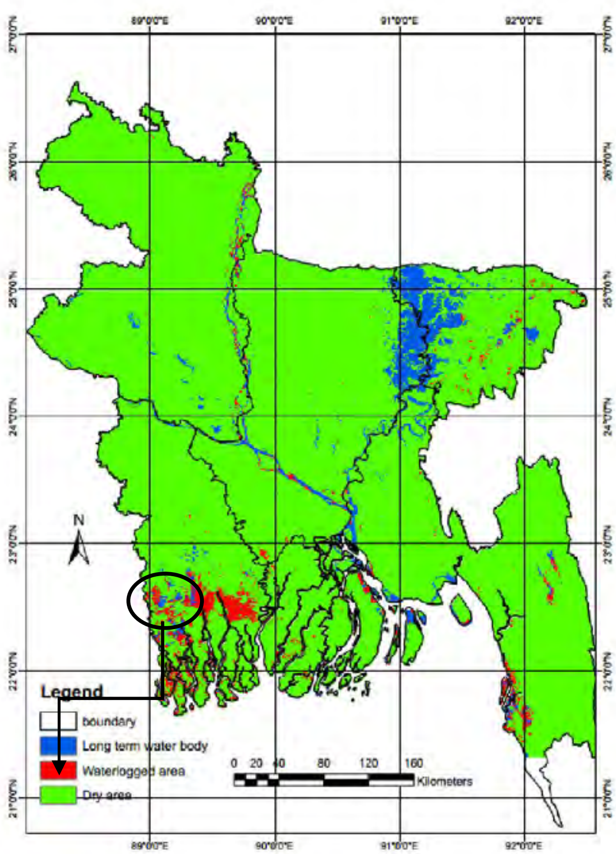
FigA1.32: Flood map of Oct 08, 2006



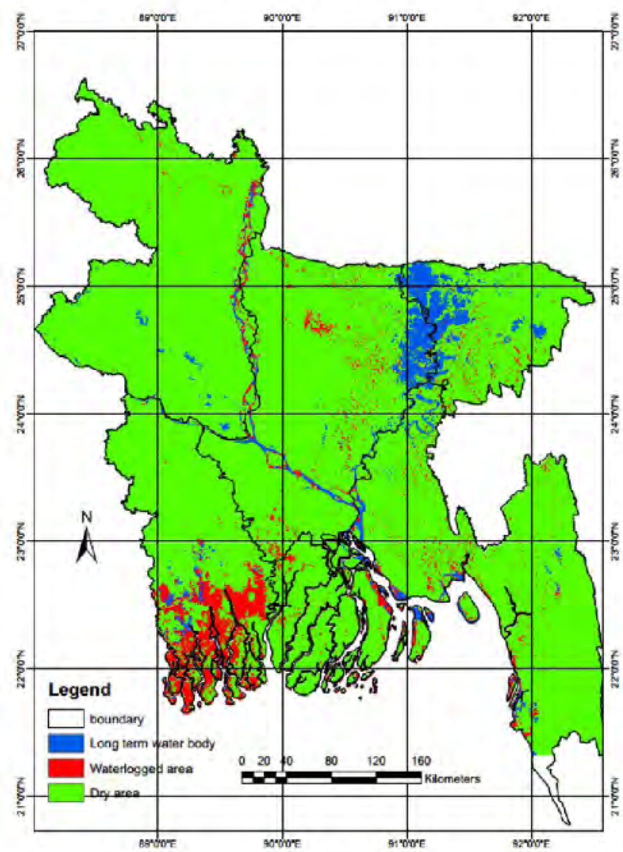
FigA1.33: Flood map of Oct 23, 2006



FigA1.34: Flood map of May 01, 2007



FigA1.35: Flood map of May 17, 2007.



FigA1.36: Flood map of May 30, 2007

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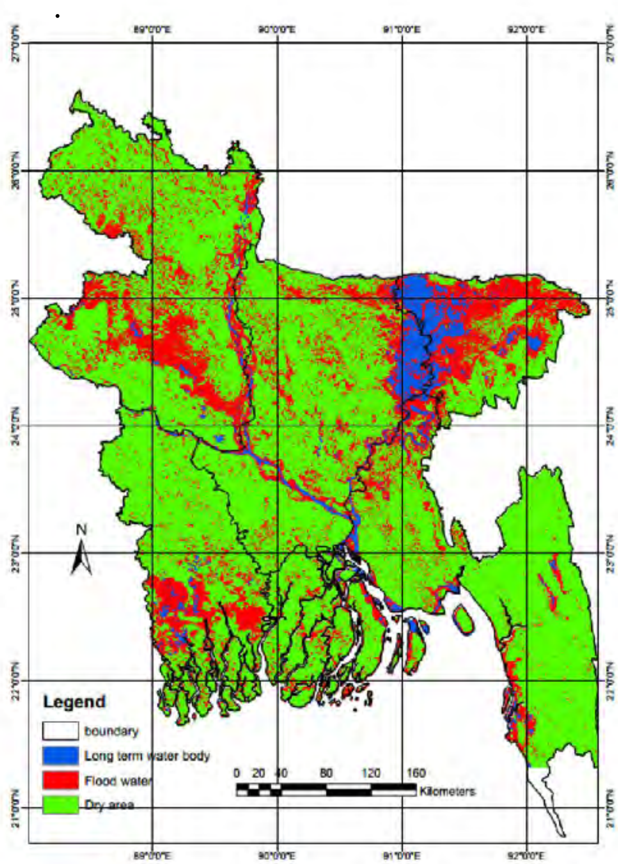
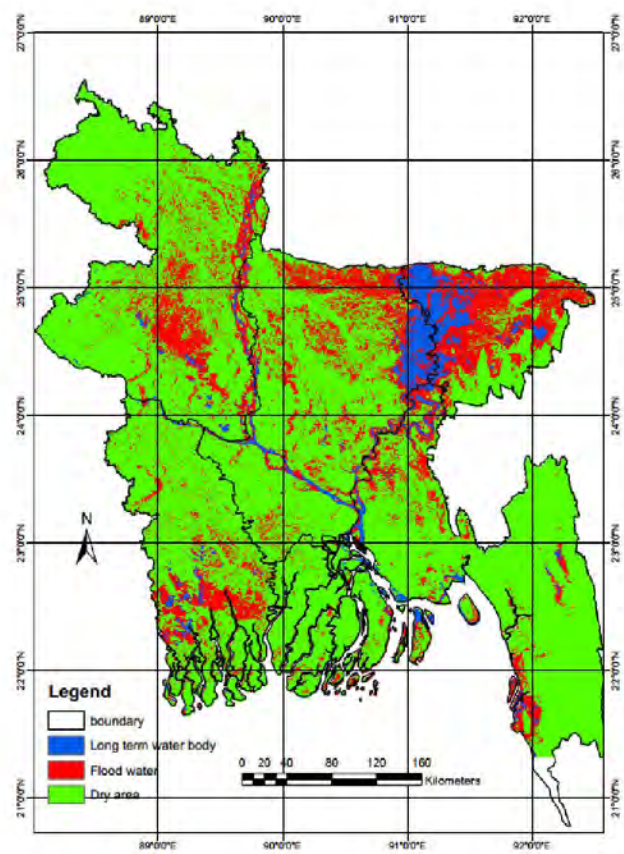


FigA1.37: Flood map of Jun 20, 2007.



FigA1.38: Flood map of Jun 26, 2007

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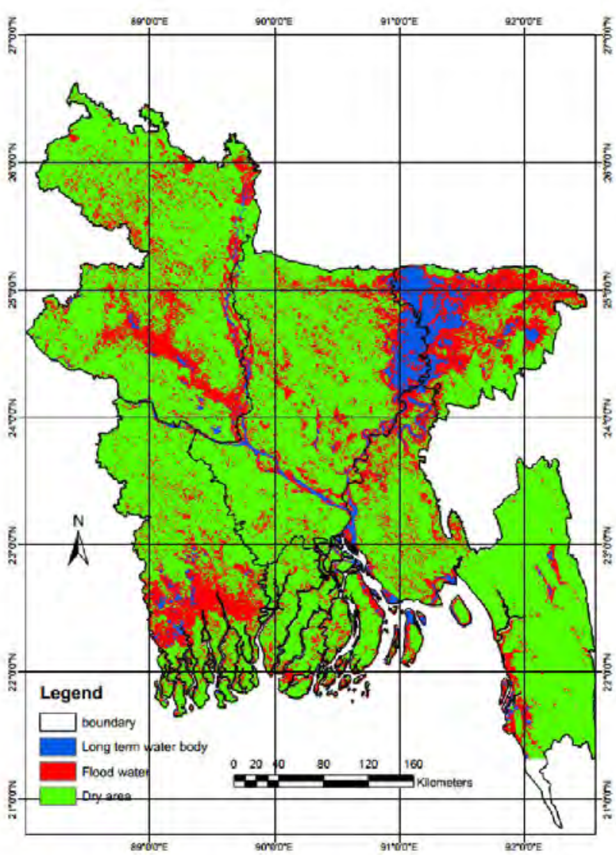
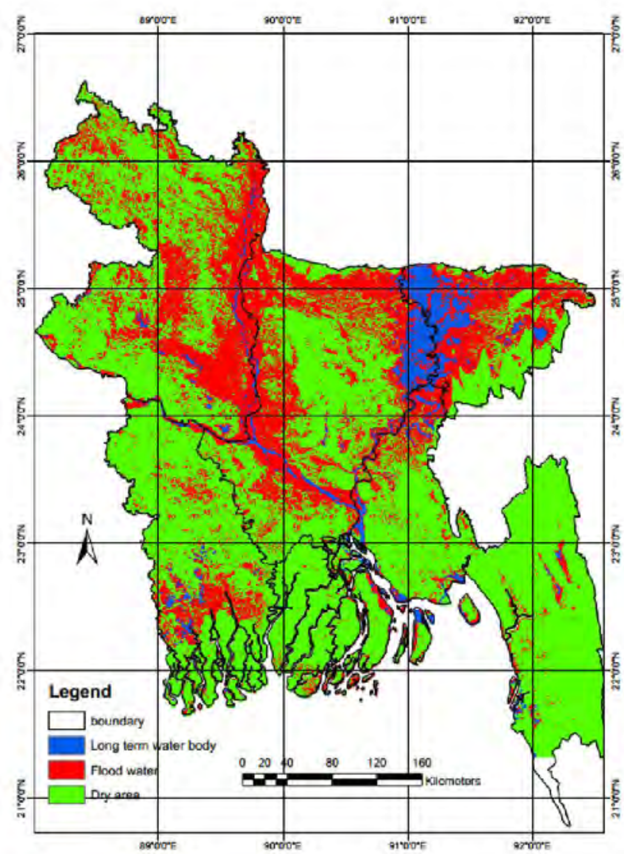
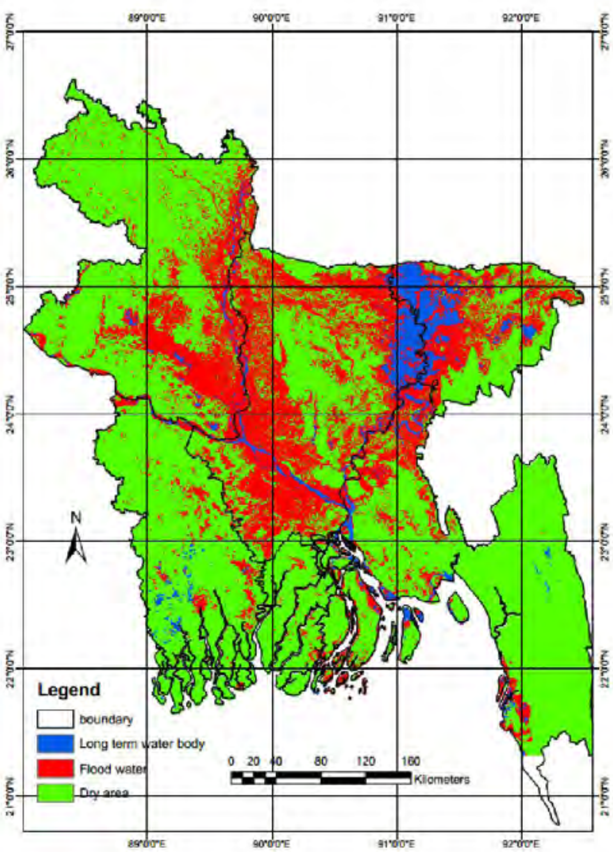


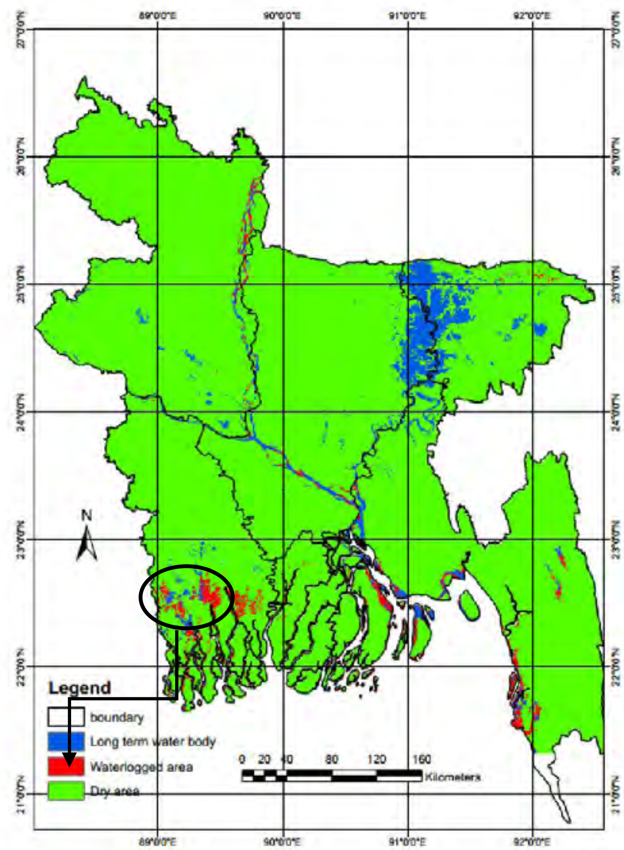
FigA1.39: Flood map of Jul 05, 2007.



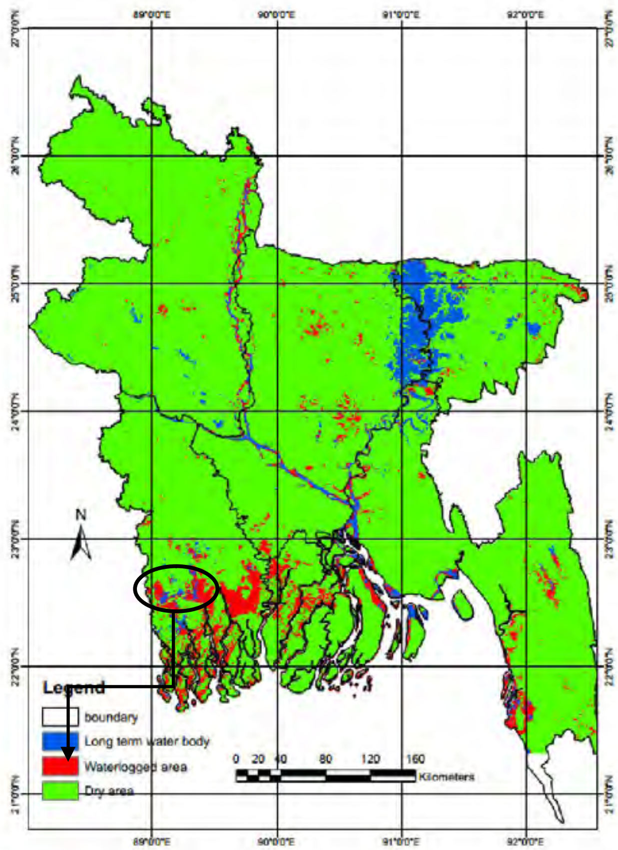
FigA1.40: Flood map of Aug 03, 2007

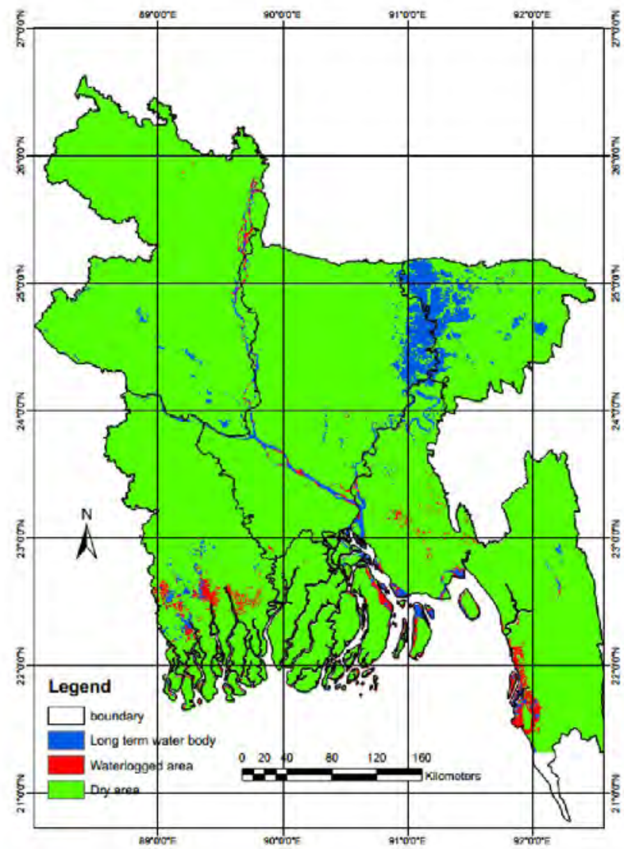


FigA1.41: Flood map of Aug 10, 2007



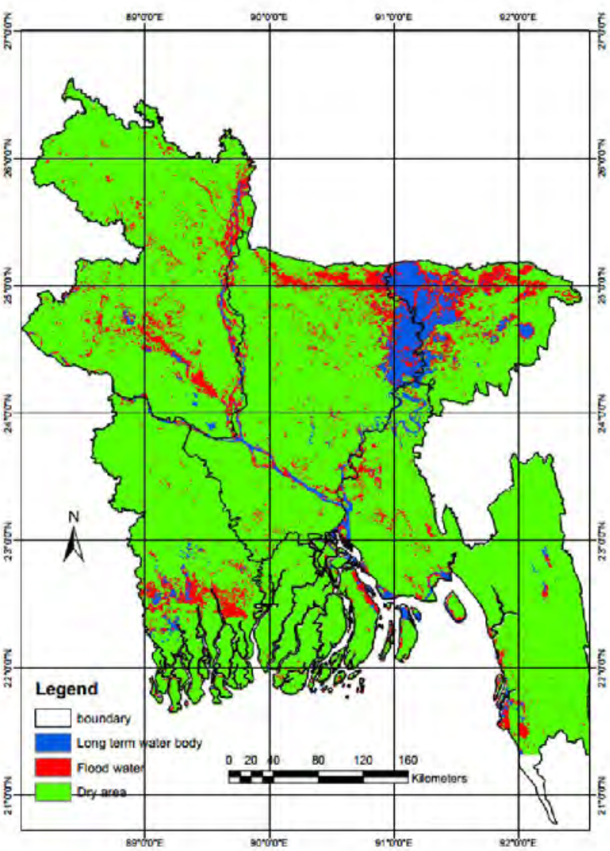
FigA1.42: Flood map of May03, 2008



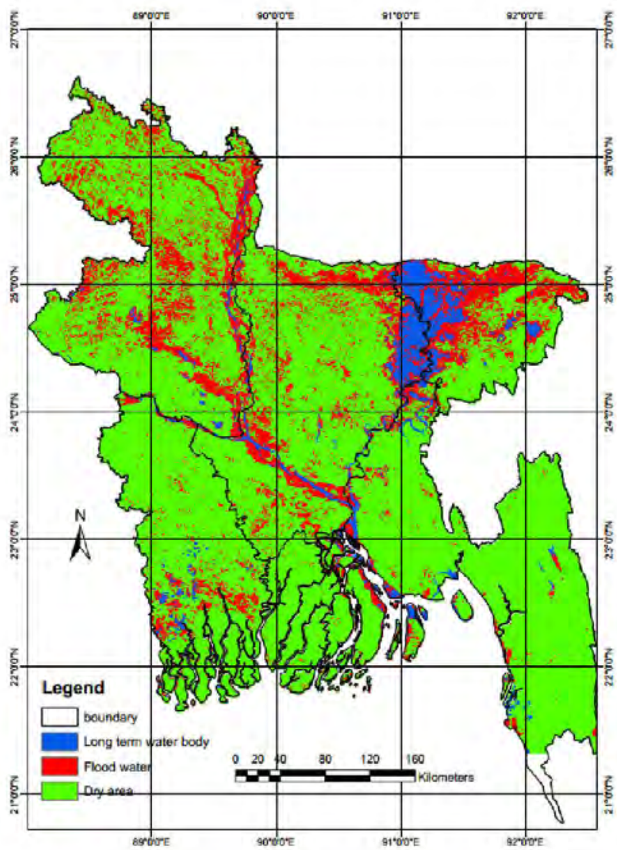


FigA1.43: Flood map of May 11, 2008

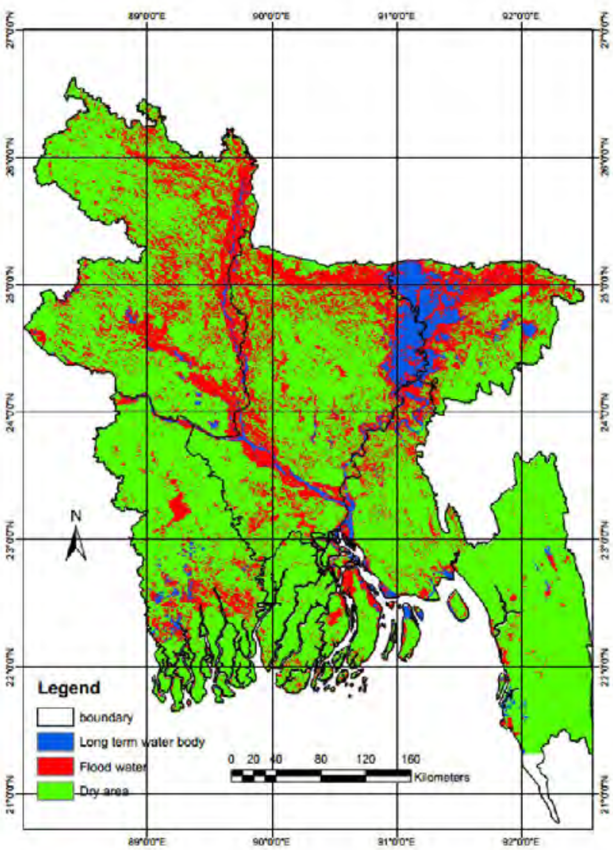
FigA1.44: Flood map of May 19, 2008

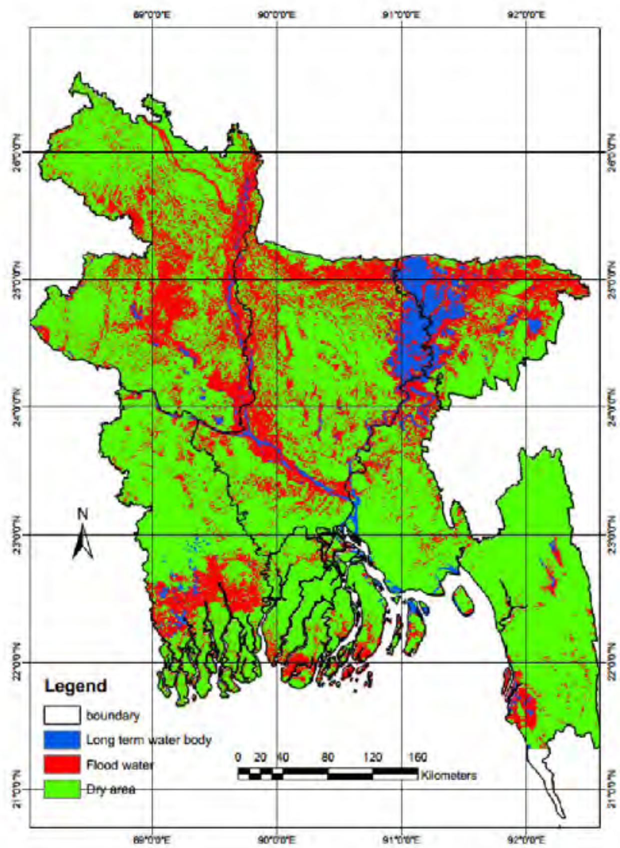


FigA1.45: Flood map of Jun 25, 2008



FigA1.46: Flood map of Jul 07, 2008





FigA1.47: Flood map of Jul 27, 2008.

FigA1.48: Flood map of Aug 08, 2008

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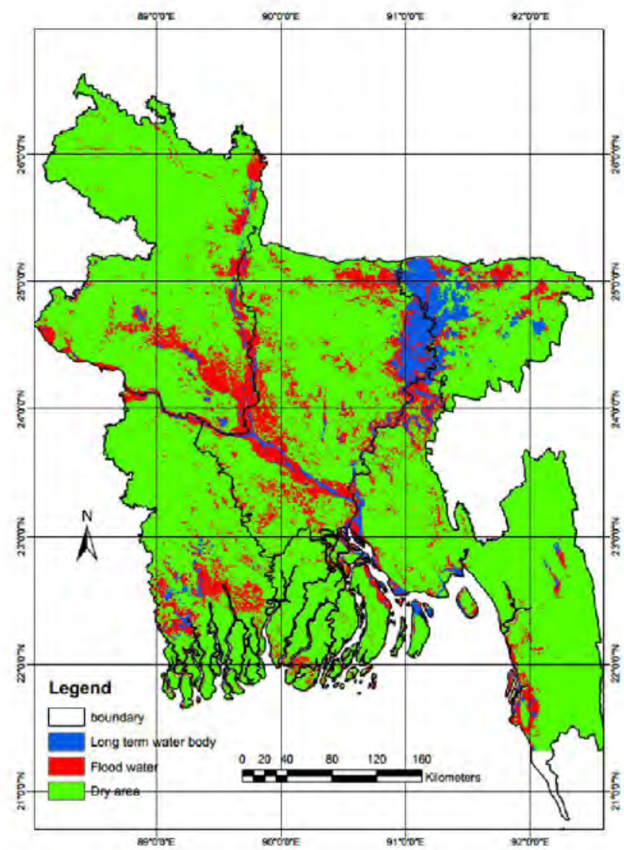
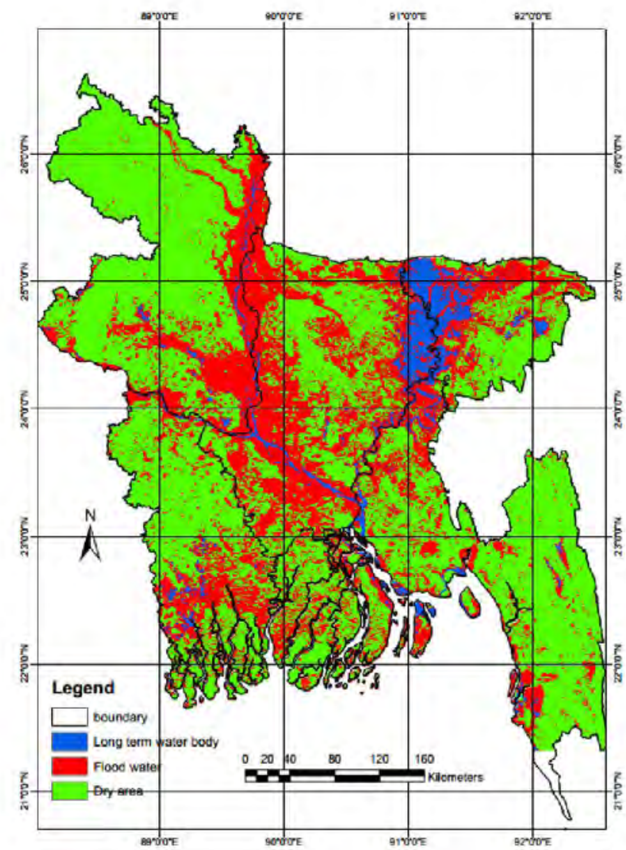
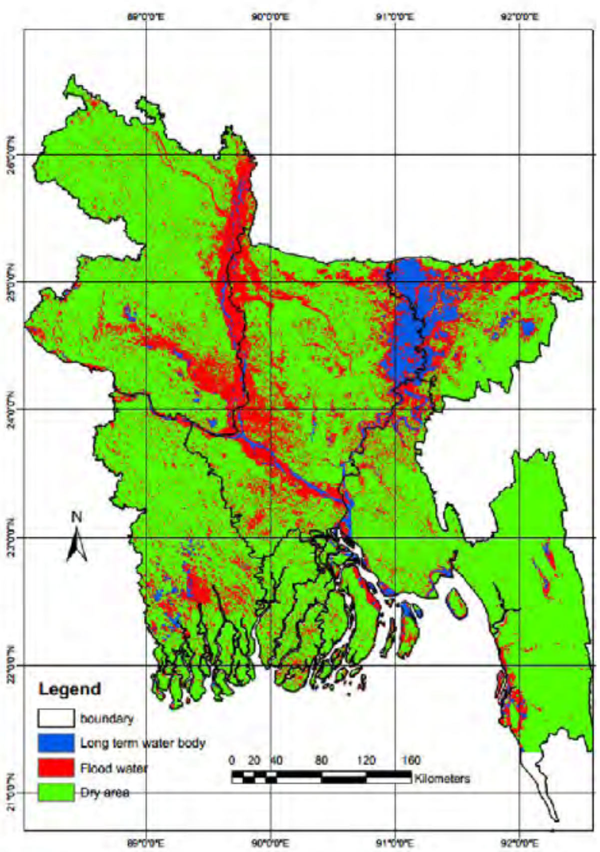
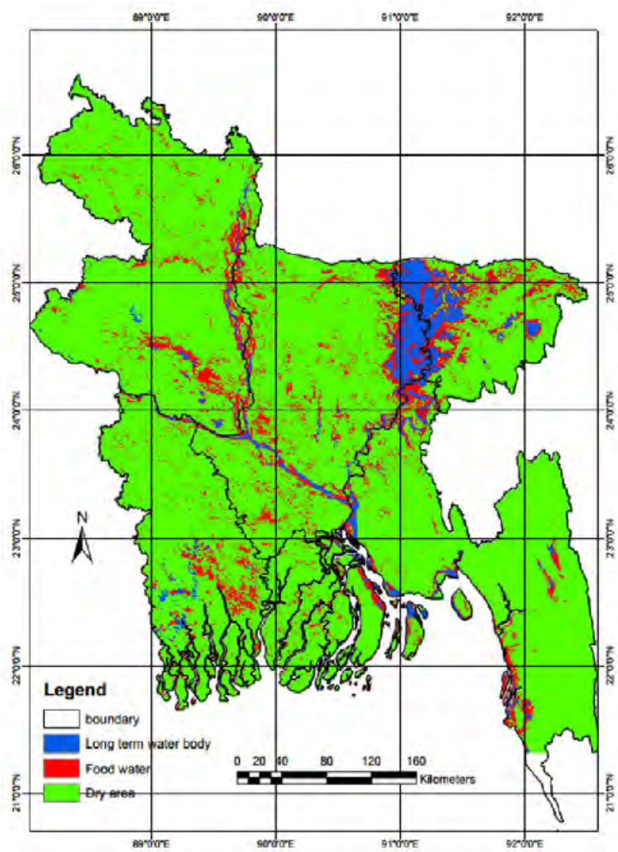


FigA1.49: Flood map of Aug 23, 2008.



FigA1.50: Flood map of Sep 07, 2008





FigA1.51: Flood map of Sep 10, 2008

FigA1.52: Flood map of Sep 24, 2008

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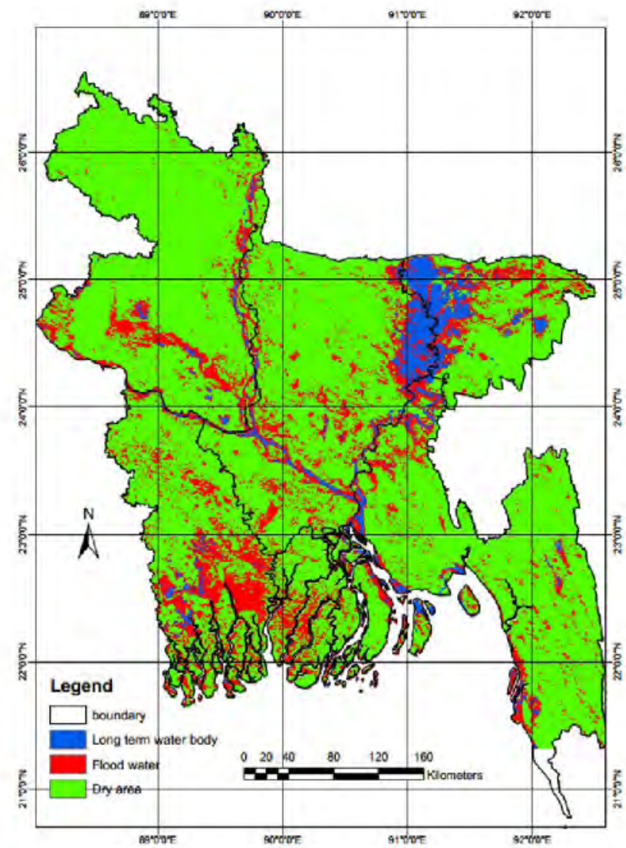
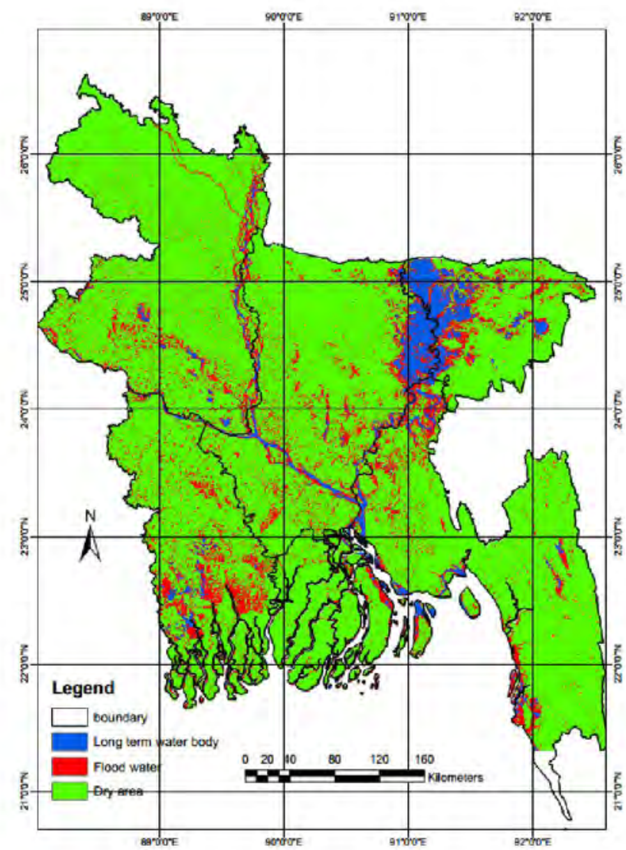
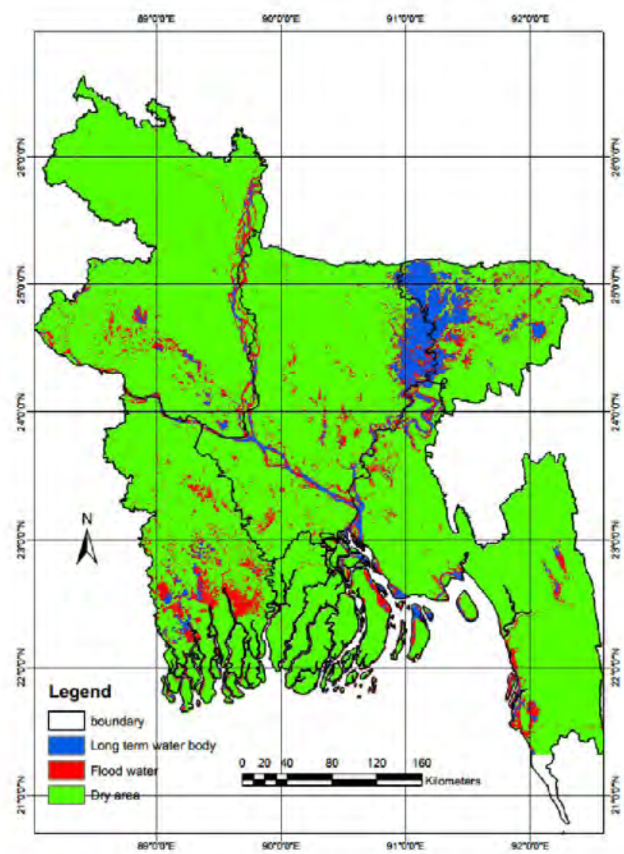


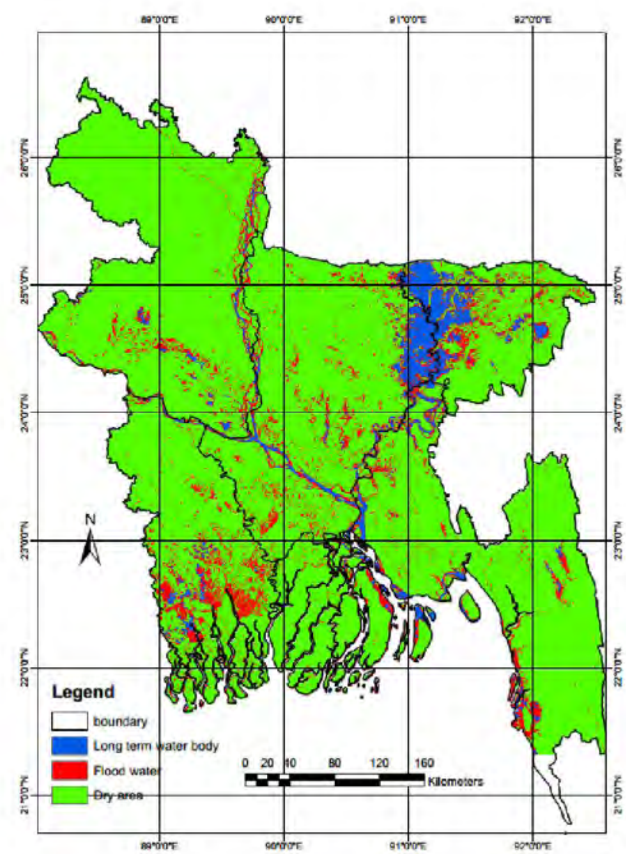


FigA1.53: Flood map of Sep 30, 2008.

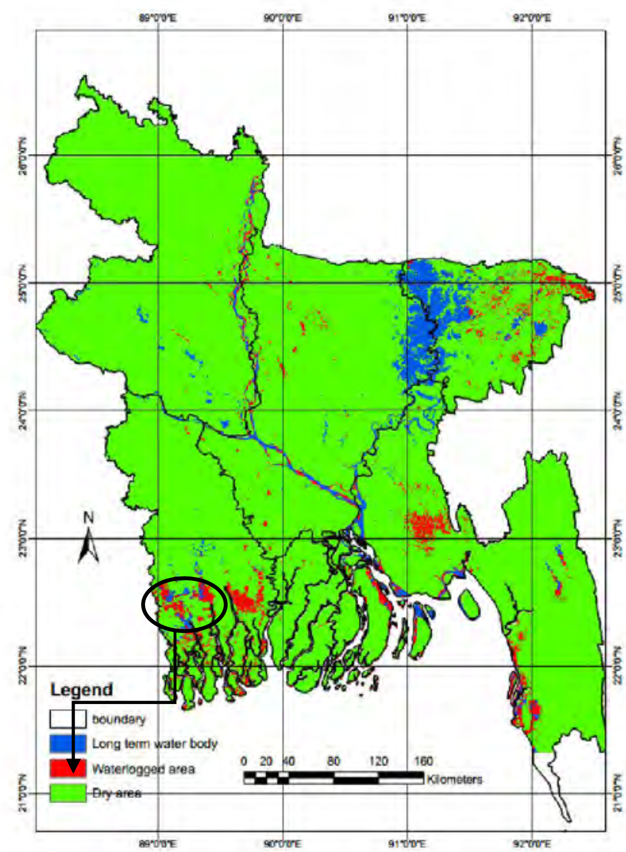
FigA1.54: Flood map of Oct 13, 2008



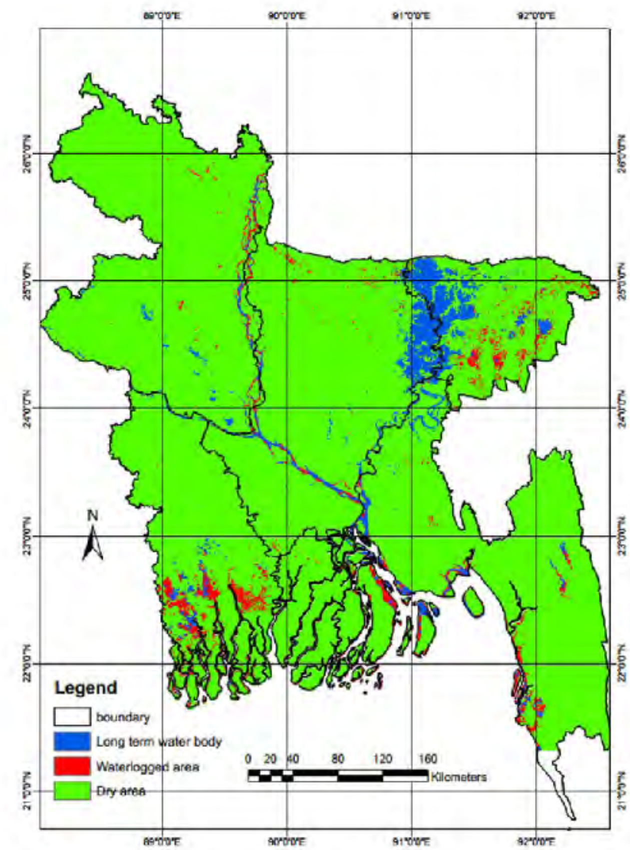
FigA1.55: Flood map of Oct 17, 2008.



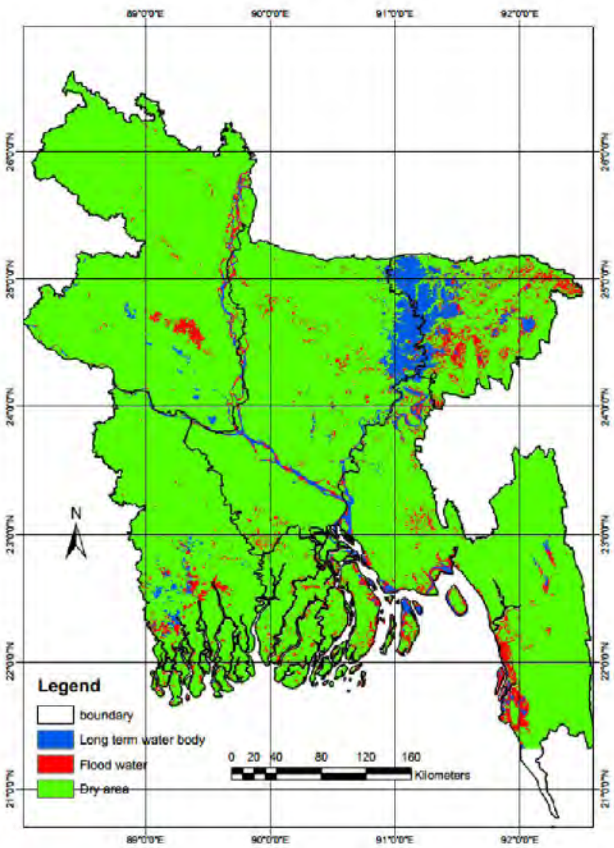
FigA1.56: Flood map of Oct 31, 2008

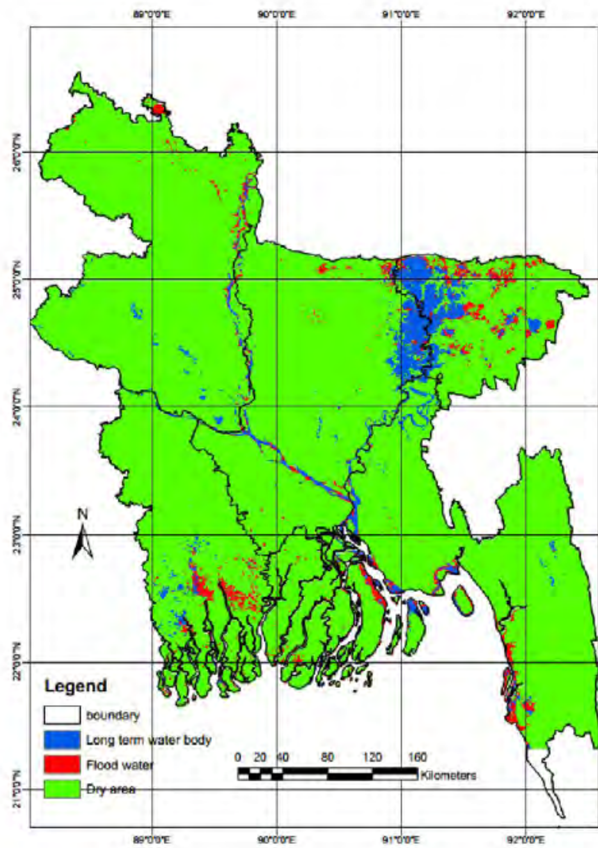


FigA1.57: Flood map of May 04, 2009.



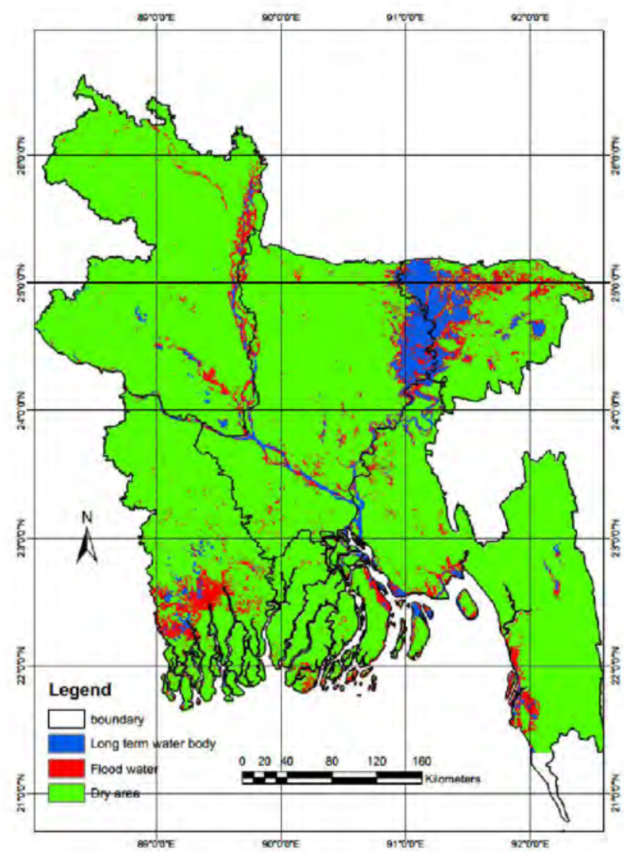
FigA1.58: Flood map of May 22, 2009

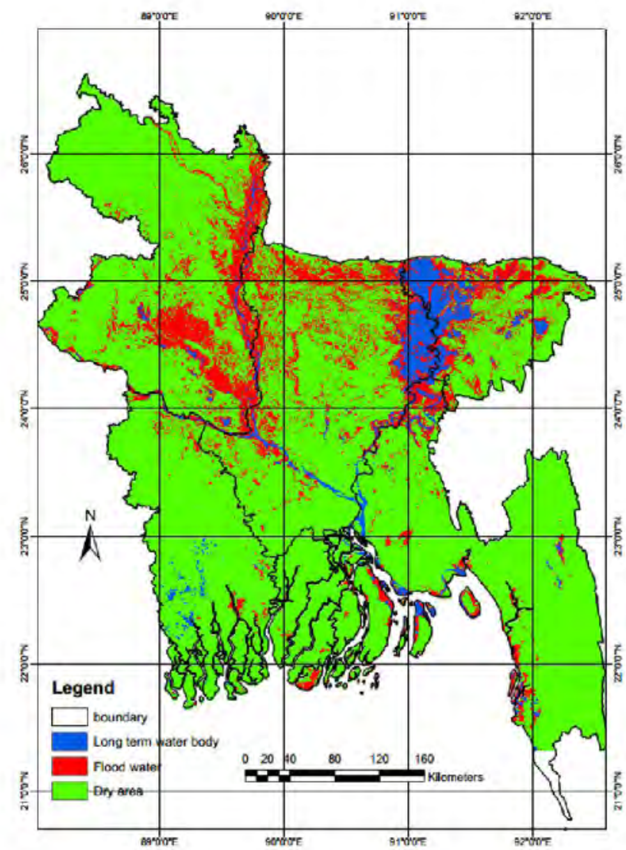




FigA1.59: Flood map of Jun 05, 2009.

FigA1.60: Flood map of Jun 23, 2009.





FigA1.61: Flood map of Jul 18, 2009.

FigA1.62: Flood map of Jul 31, 2009

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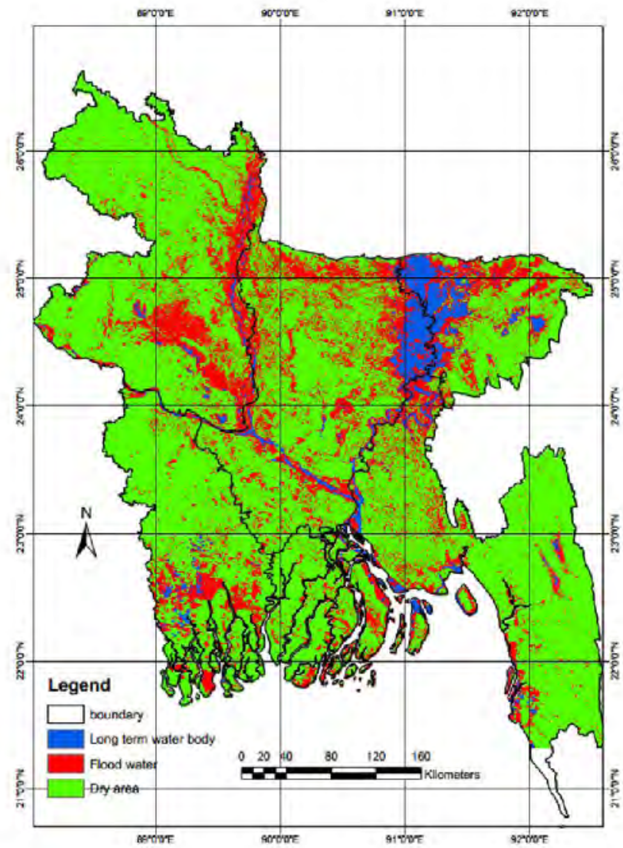

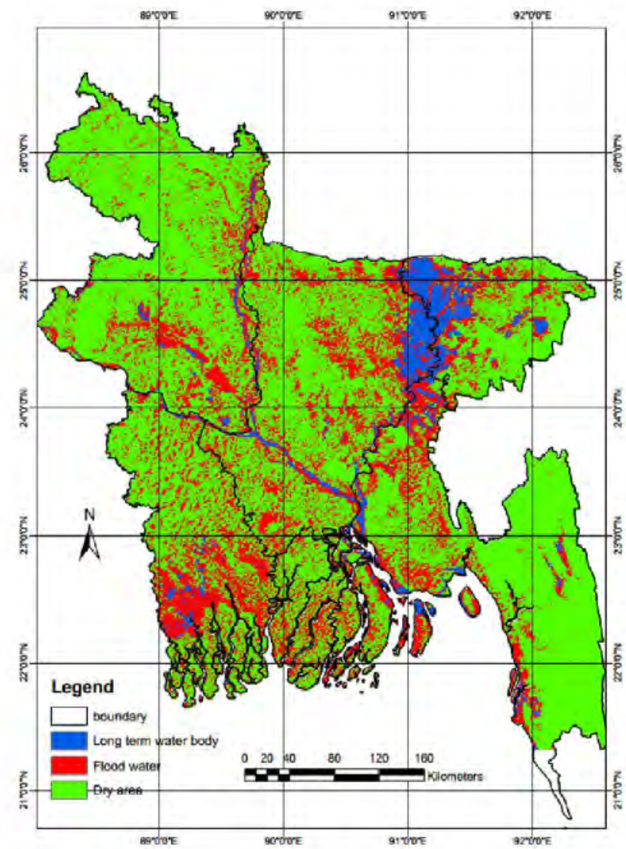

FigA1.63: Flood map of Aug 31, 2009.

FigA1.64: Flood map of Sep 12, 2009

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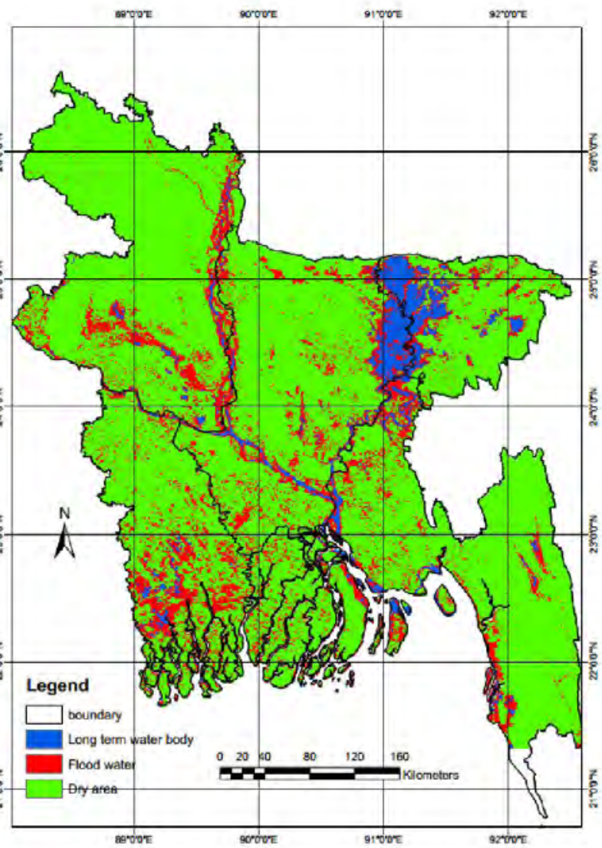
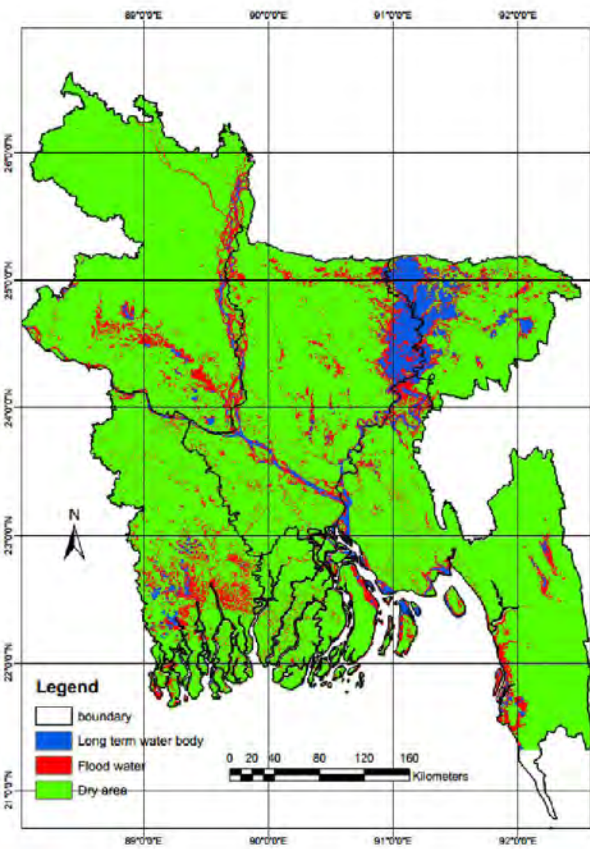
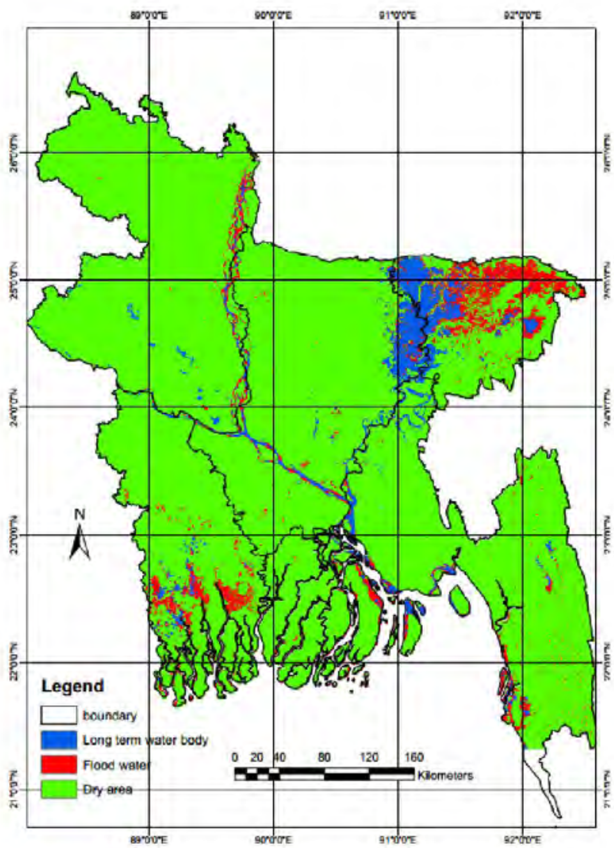
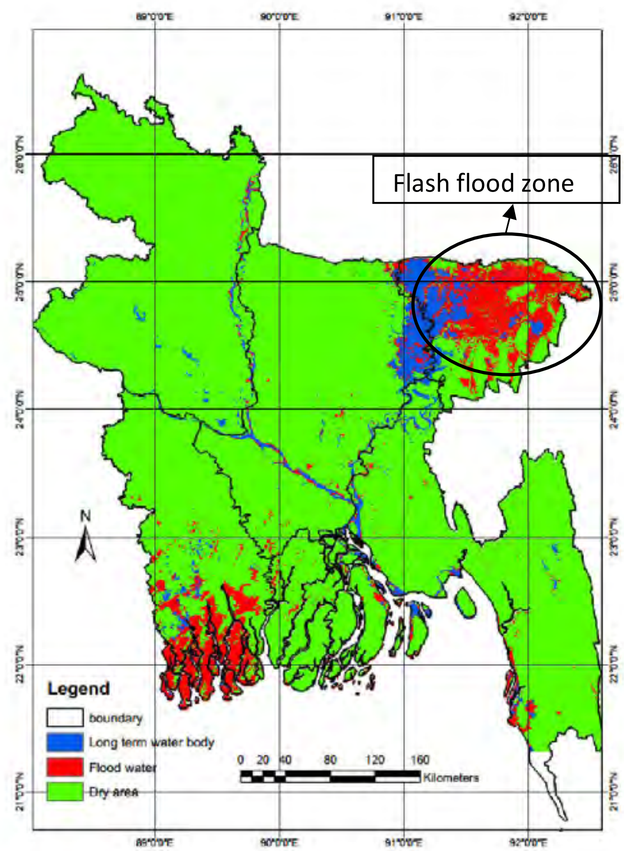


FigA1.65: Flood map of Sep 26, 2009.



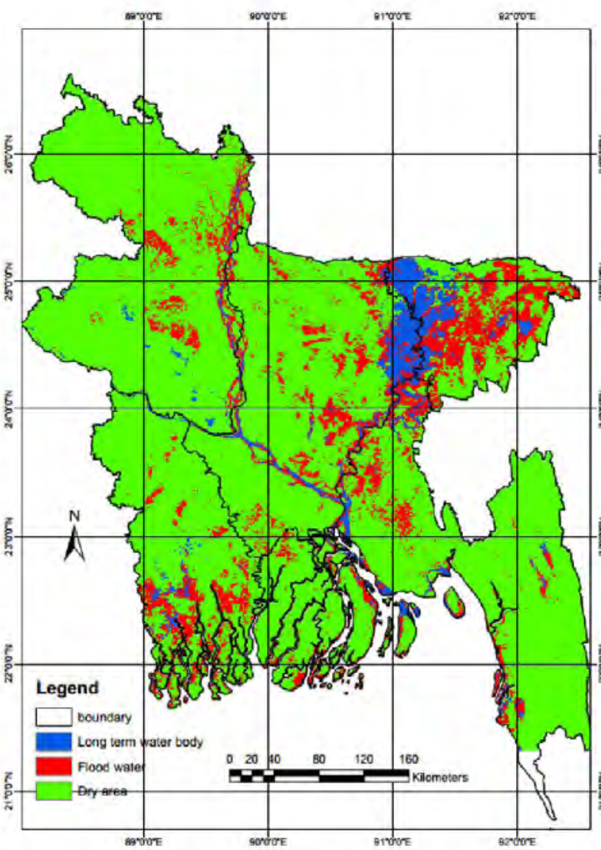
FigA1.66: Flood map of Sep 30, 2009.

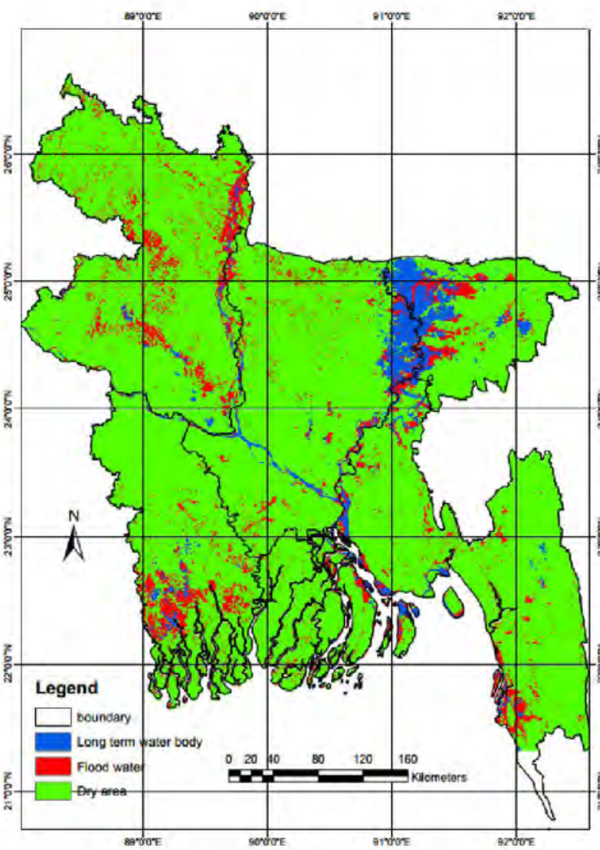




FigA1.67: Flood map of May 07, 2010.

FigA1.68: Flood map of May 15, 2010.





FigA1.69: Flood map of Jun 09, 2010.

FigA1.70: Flood map of Jul 08, 2010

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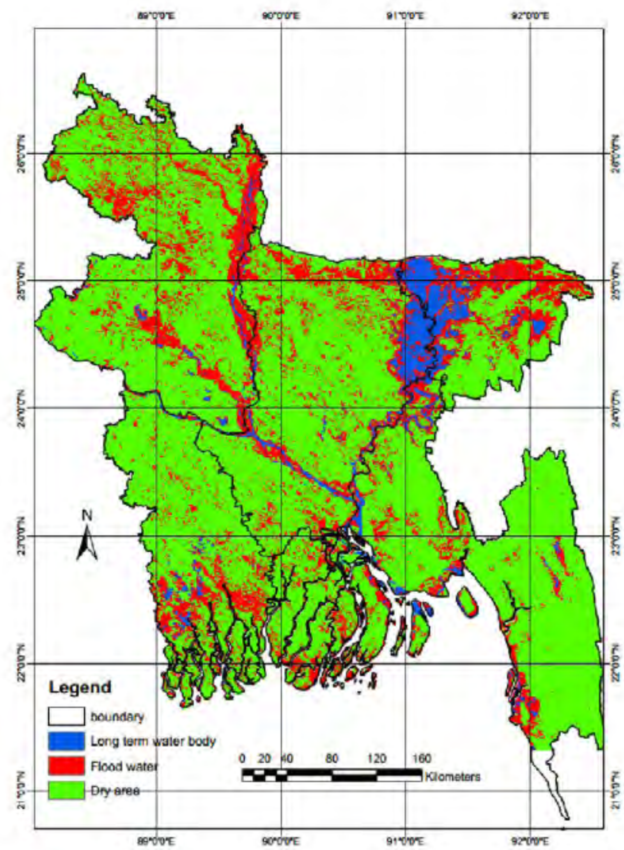
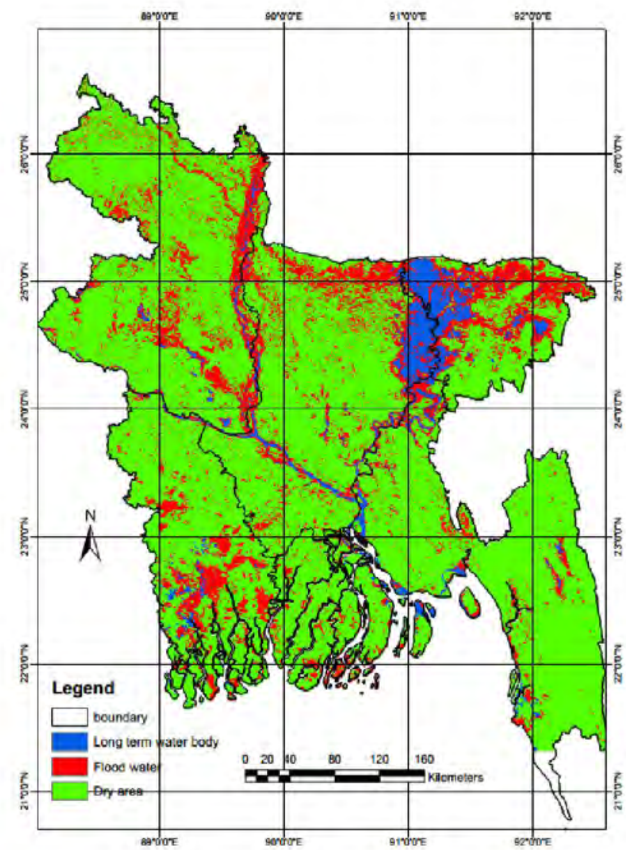
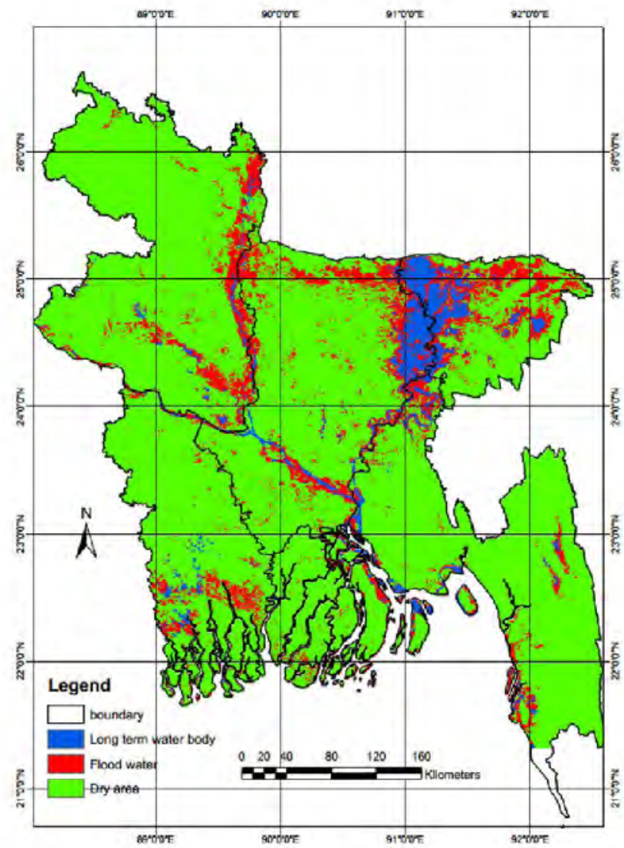


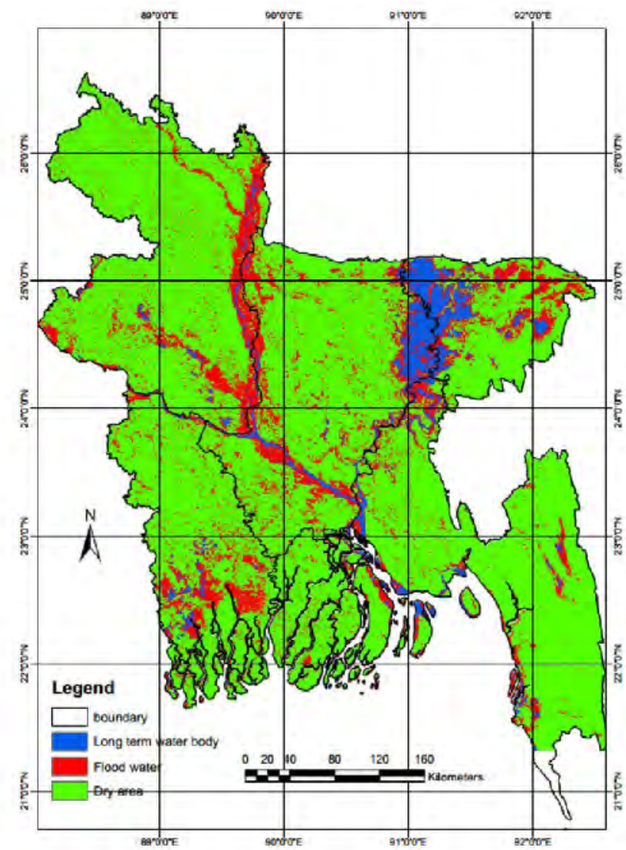


FigA1.71: Flood map of Jul 27, 2010.

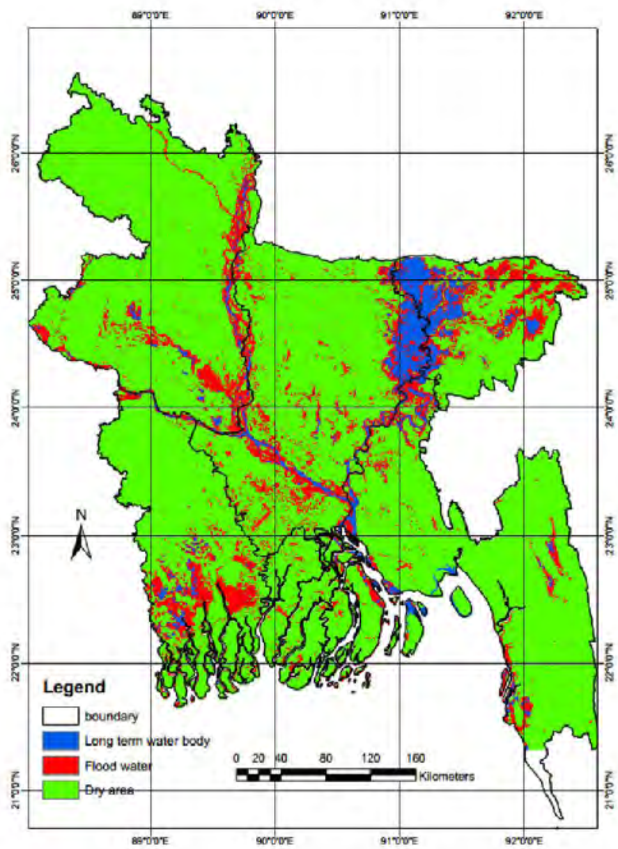
FigA1.72: Flood map of Aug 05, 2010.



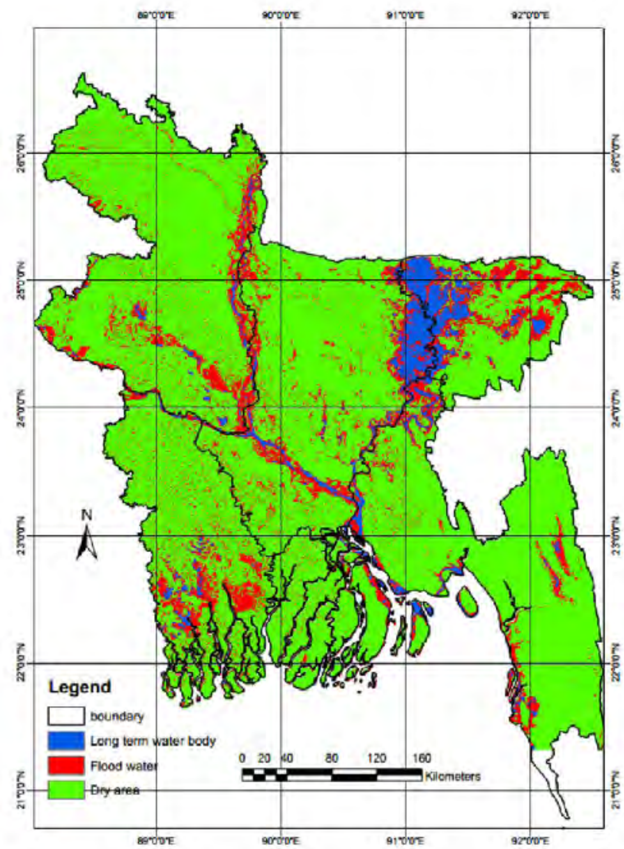
FigA1.73: Flood map of Aug 29, 2010.



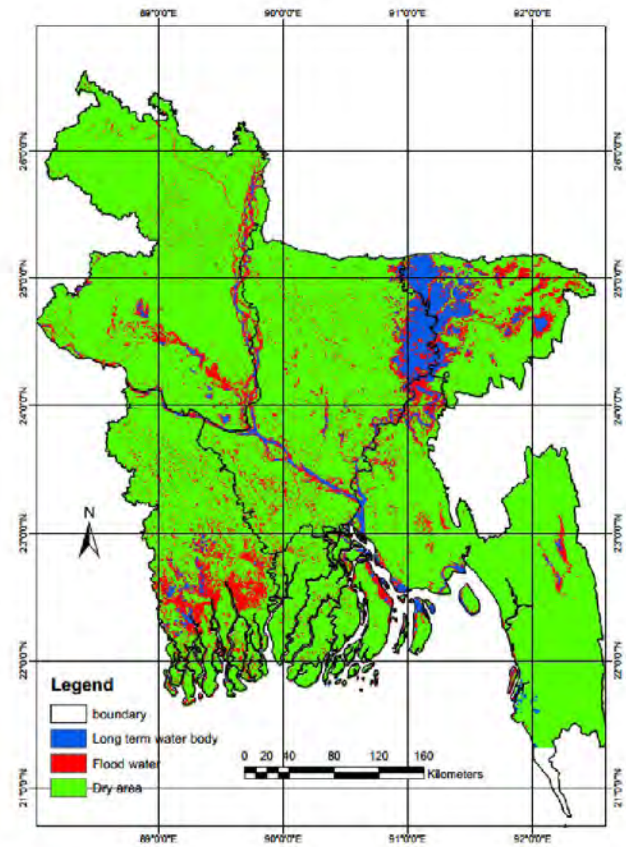
FigA1.74: Flood map of Sep 23, 2010

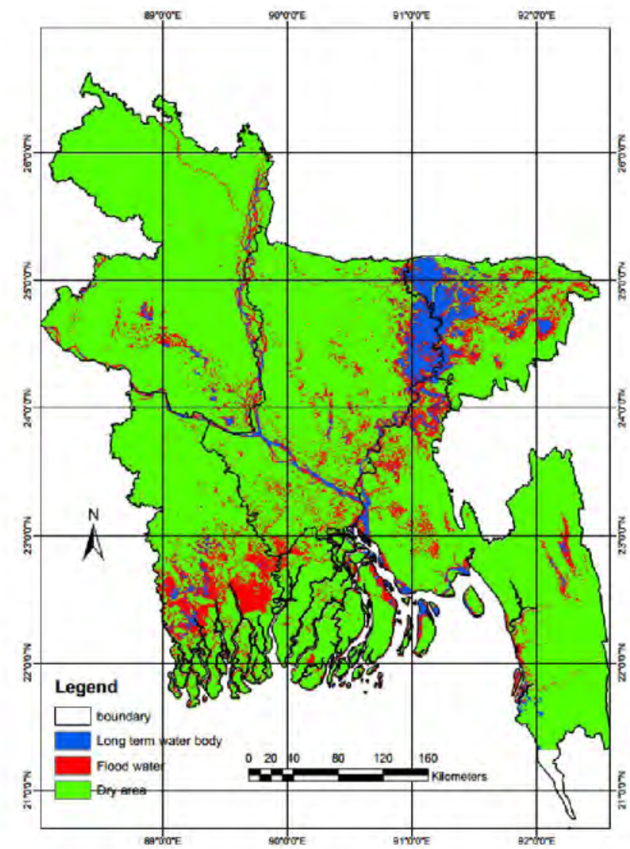


FigA1.75: Flood map of Sep 30, 2010.



FigA1.76: Flood map of Oct 03, 2010.





FigA1.77: Flood map of Oct 18, 2010.

FigA1.78: Flood map of Oct 28, 2010

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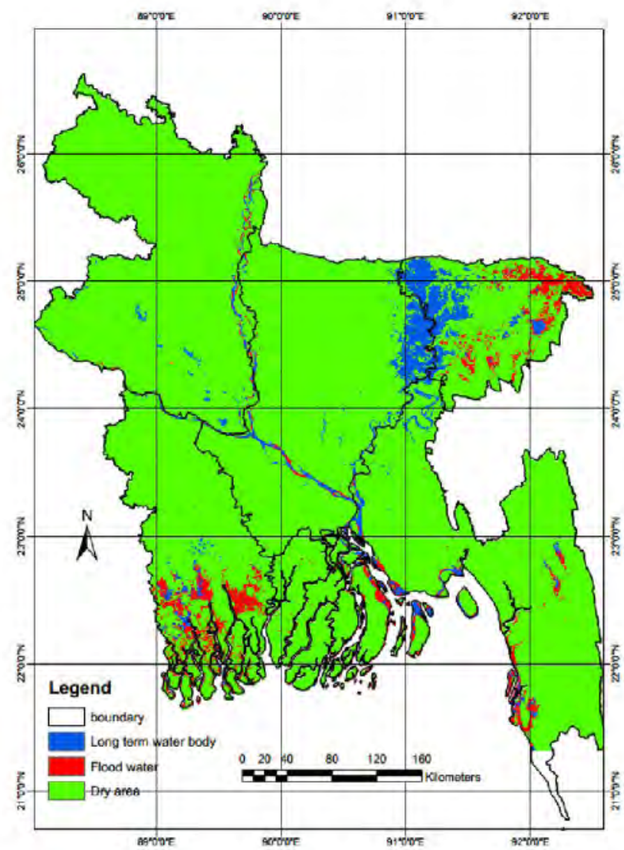

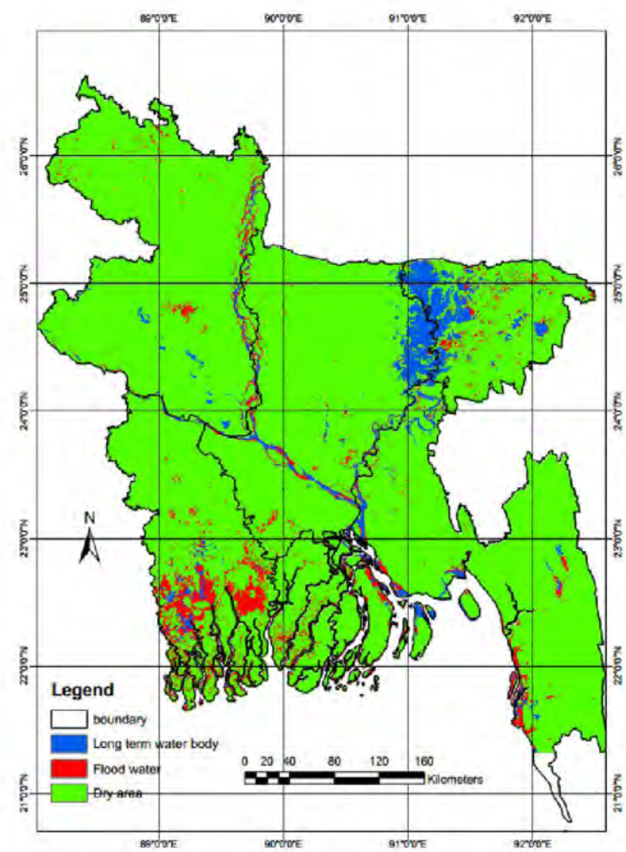

FigA1.79: Flood map of May 13, 2014.

FigA1.80: Flood map of May 29, 2014

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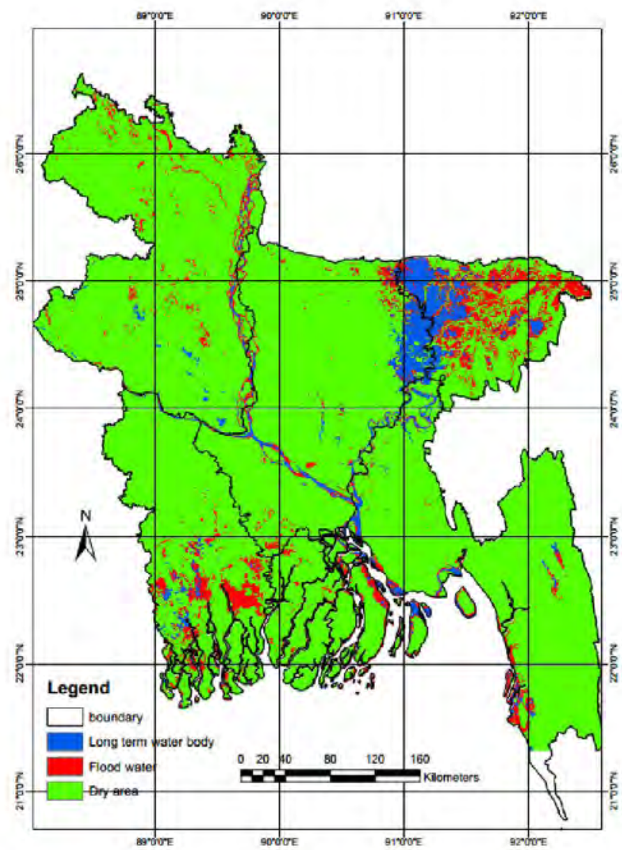
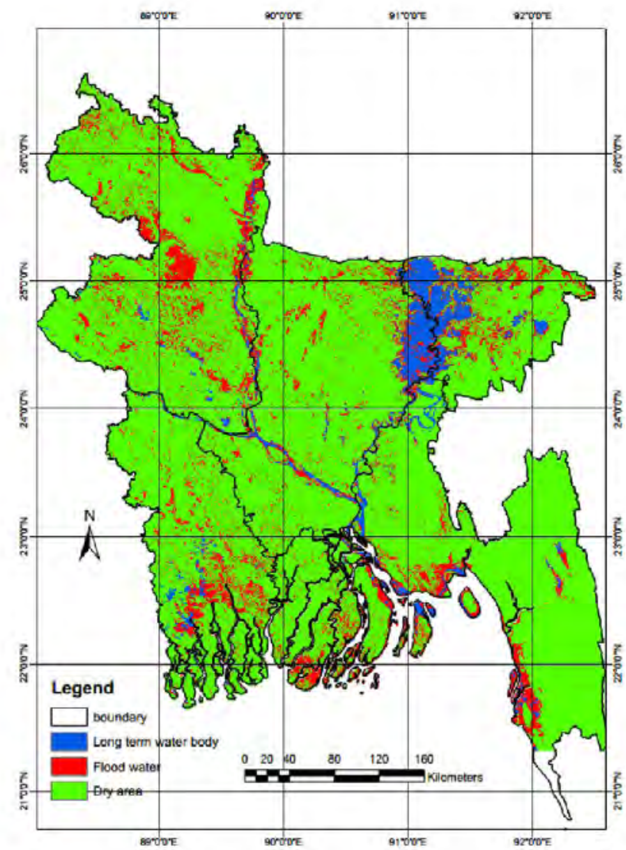


FigA1.81: Flood map of Jun 14, 2014



FigA1.82: Flood map of Jul 25, 2014

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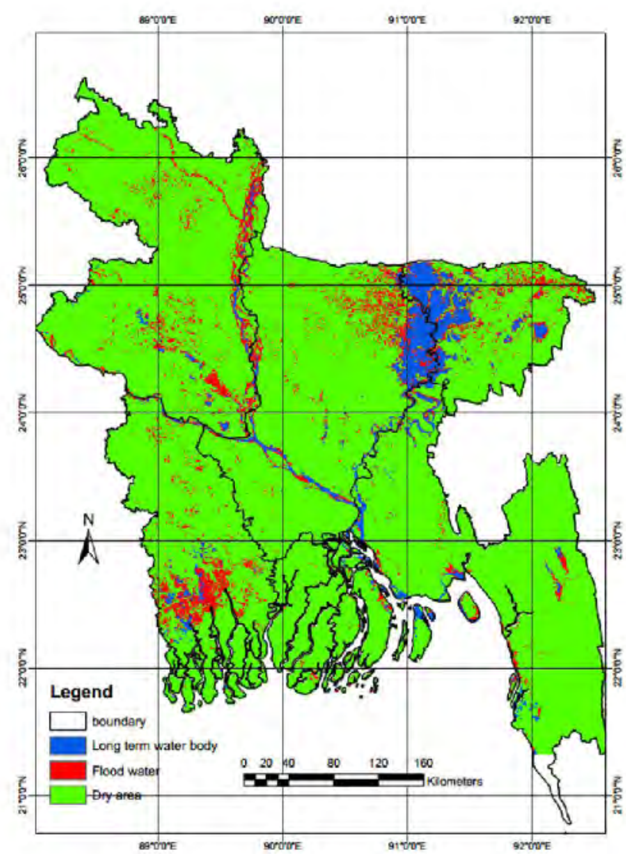
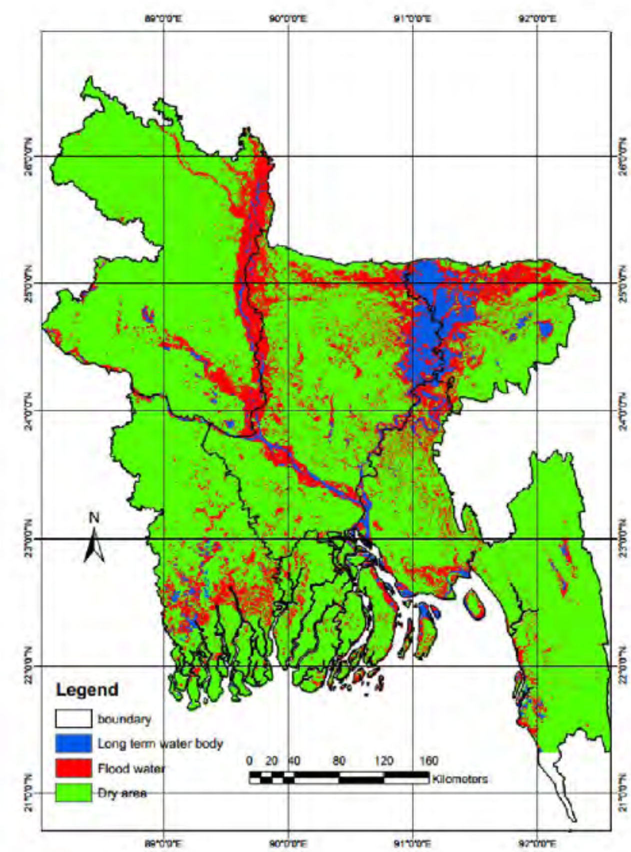
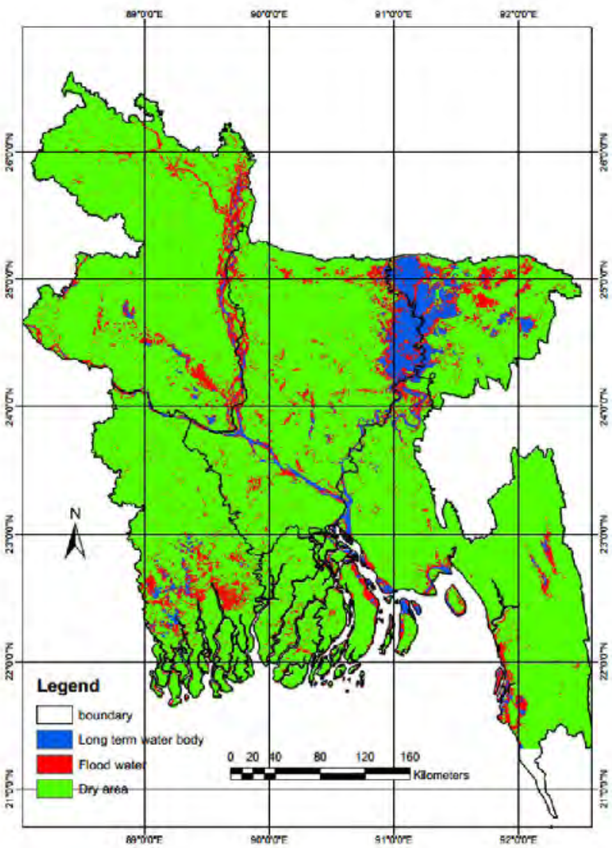
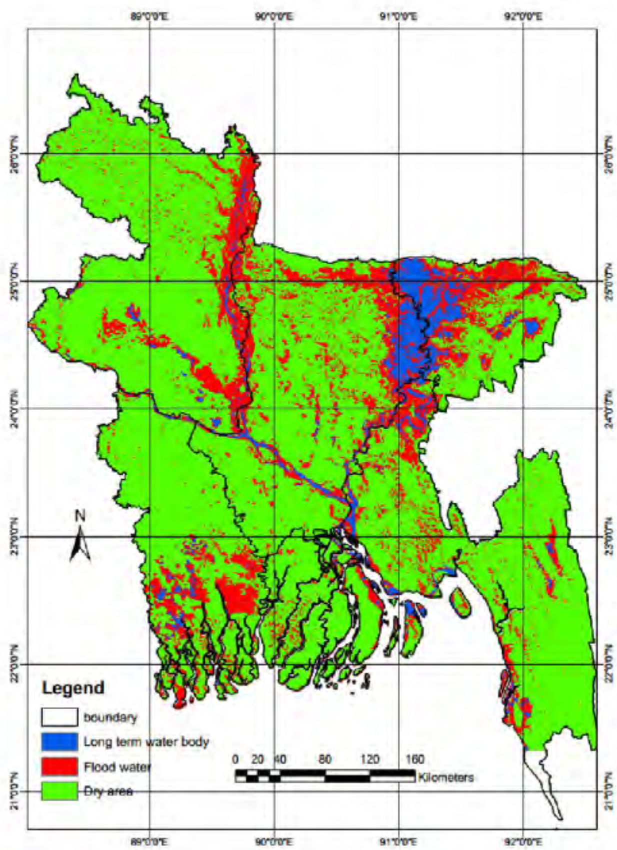


FigA1.83: Flood map of Aug 08, 2014



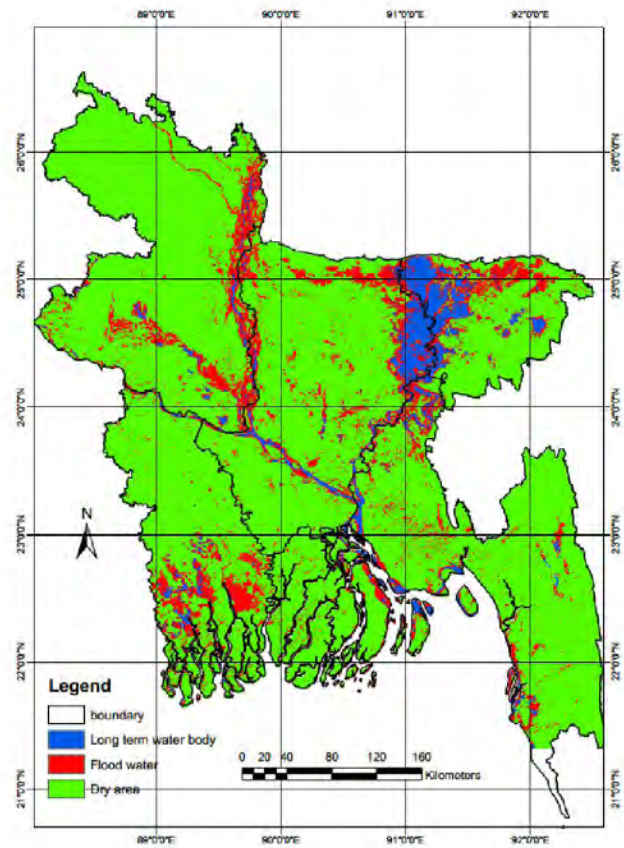
FigA1.84: Flood map of Aug 29, 2014



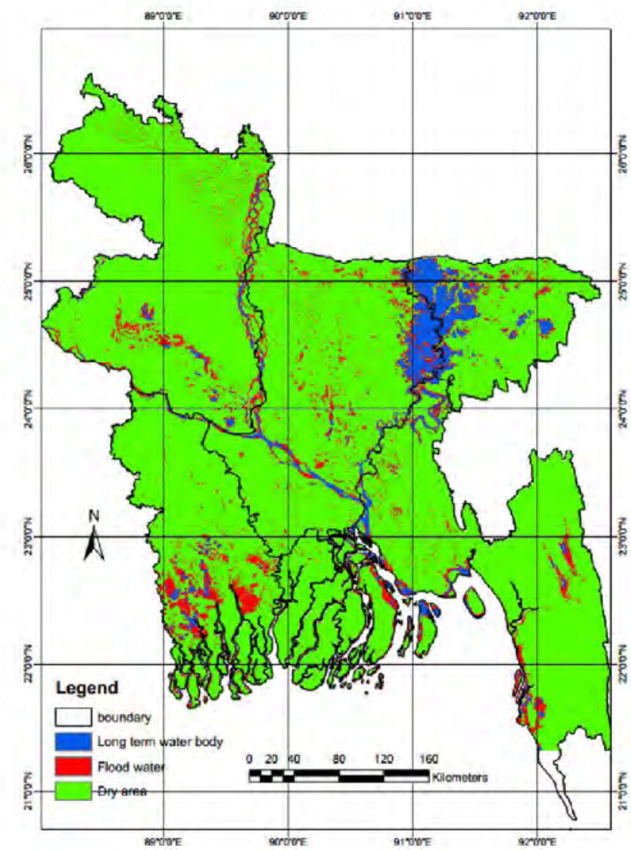


FigA1.85: Flood map of Sep 16, 2014

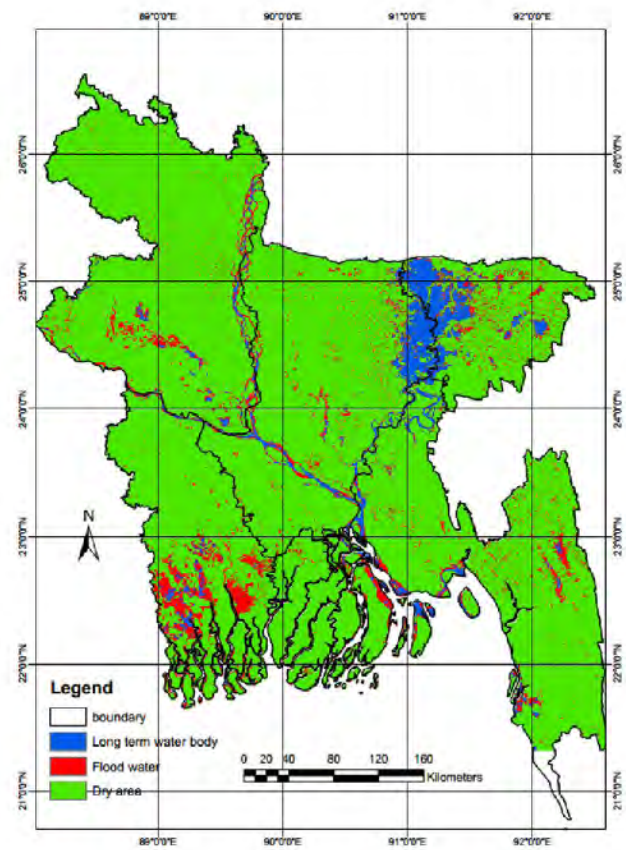
FigA1.86: Flood map of Sep 27, 2014



FigA1.87: Flood map of Oct 02, 2014



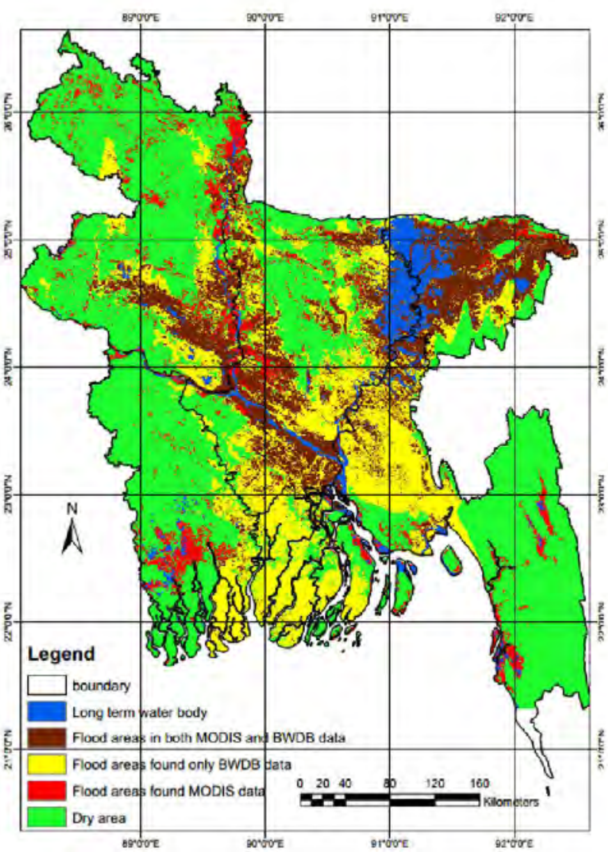
FigA1.88: Flood map of Oct 20, 2014



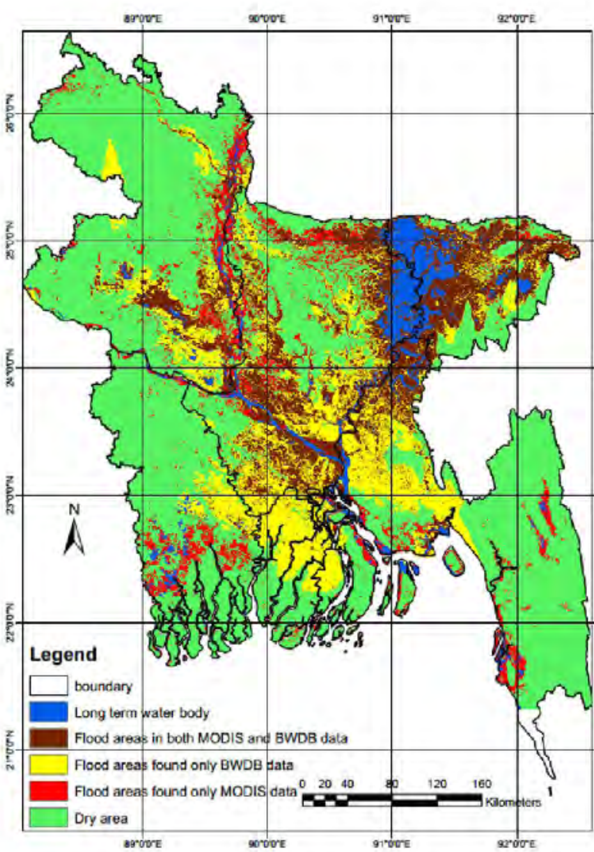
FigA1.89: Flood map of Oct 31, 2014

A2 Comparison between MODIS images and BWDB flood maps

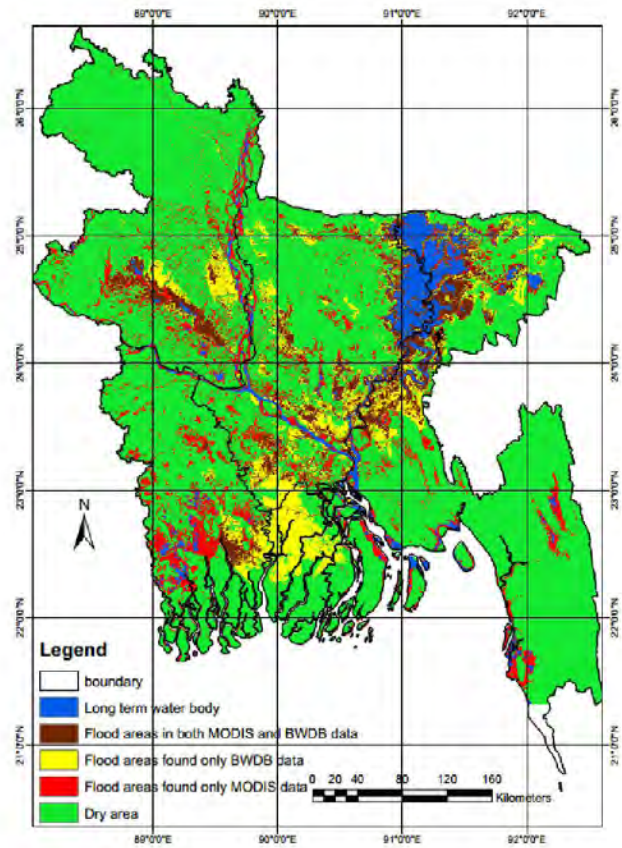
A comparative analysis has been conducted among the data produced by MODIS images and the data generated from inundation maps produced by BWDB. The results are given bellow



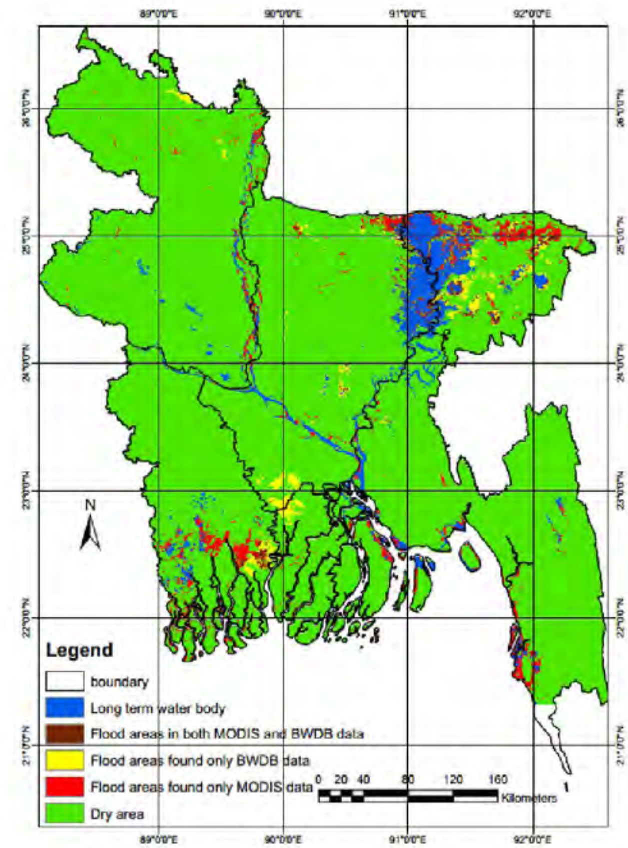
FigA2.1: Comparison between flood inundation map prepared from BWDB data and map prepared from MODIS image on 27.07.2004



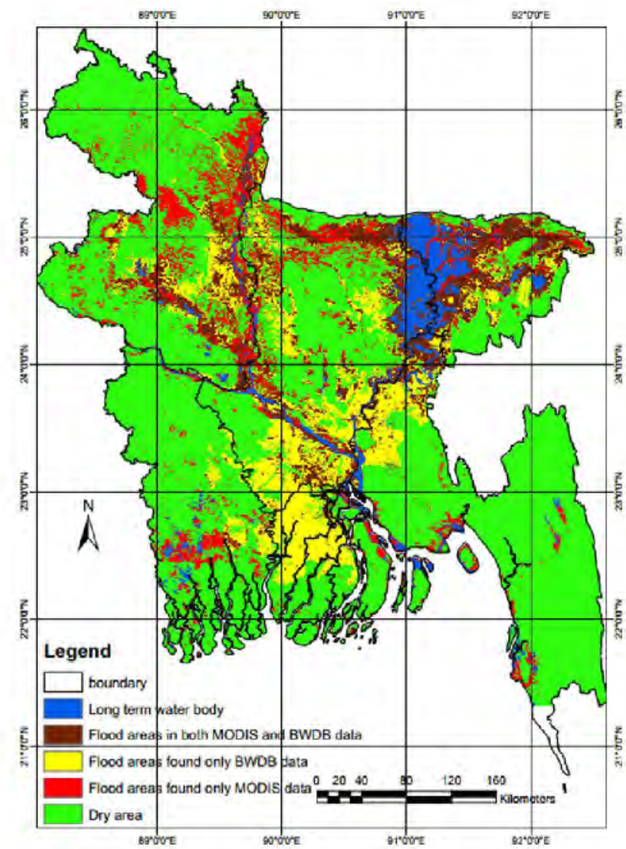
FigA2.2: Comparison between flood inundation map prepared from BWDB data and map prepared from MODIS image on 03.08.2004

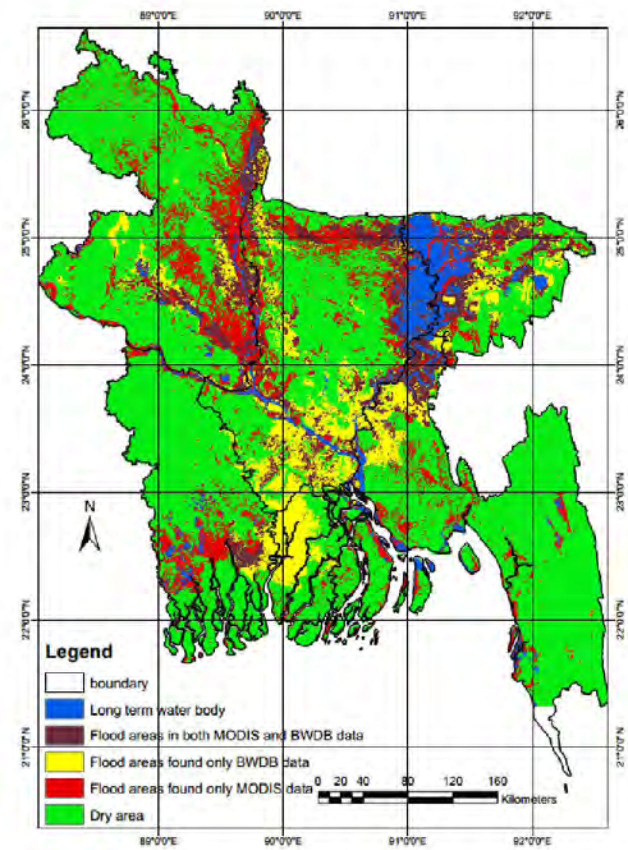


FigA2.3: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 27.10.2004



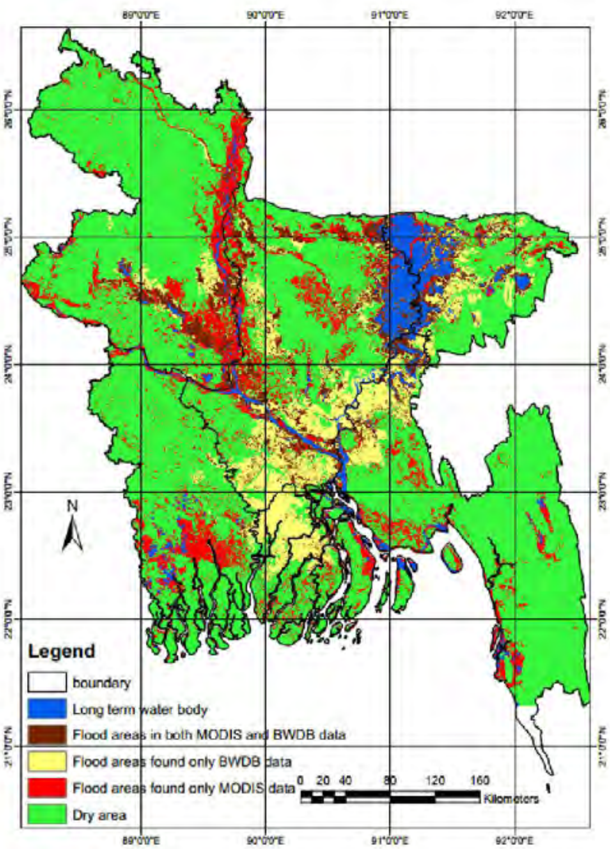
FigA2.4: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 21.06.2005.



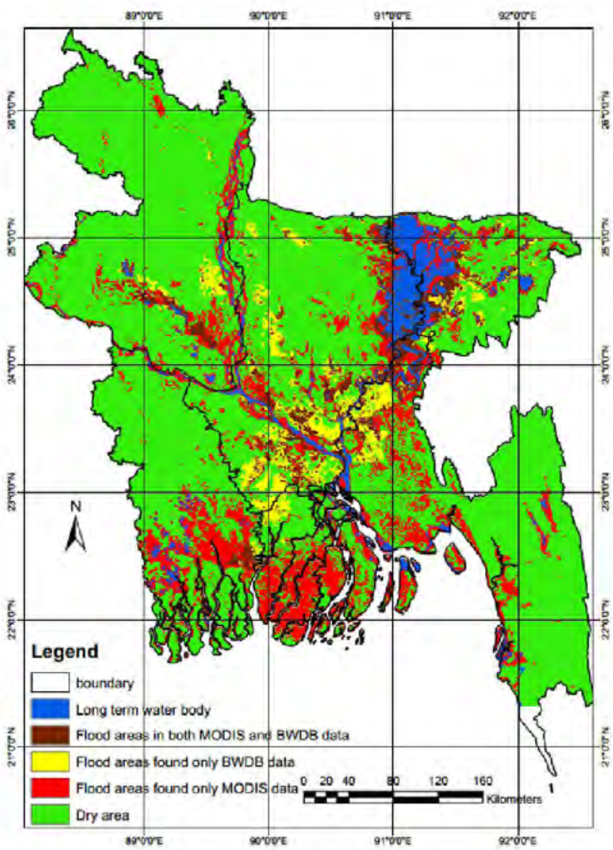


FigA2.5: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 25.07.2005.

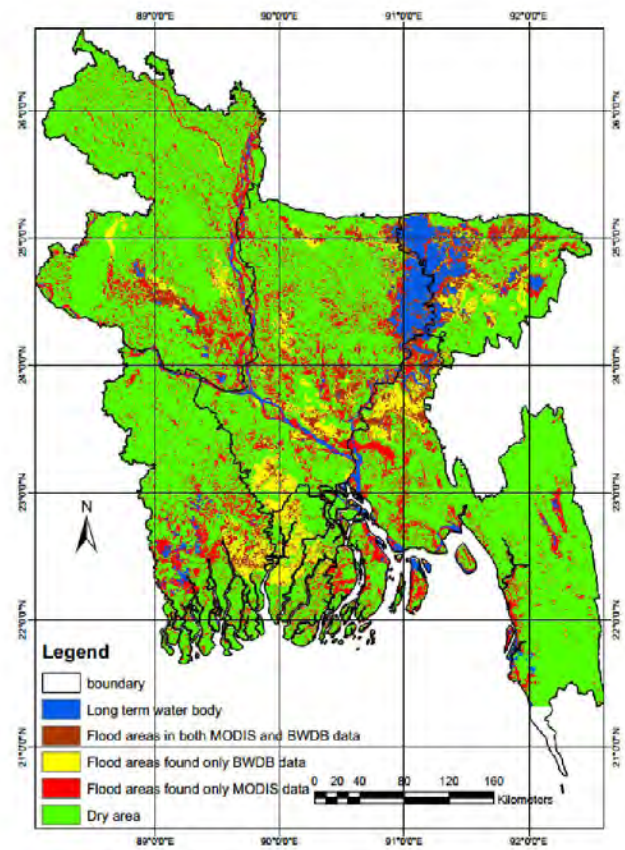
FigA2.6: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 29.08.2005



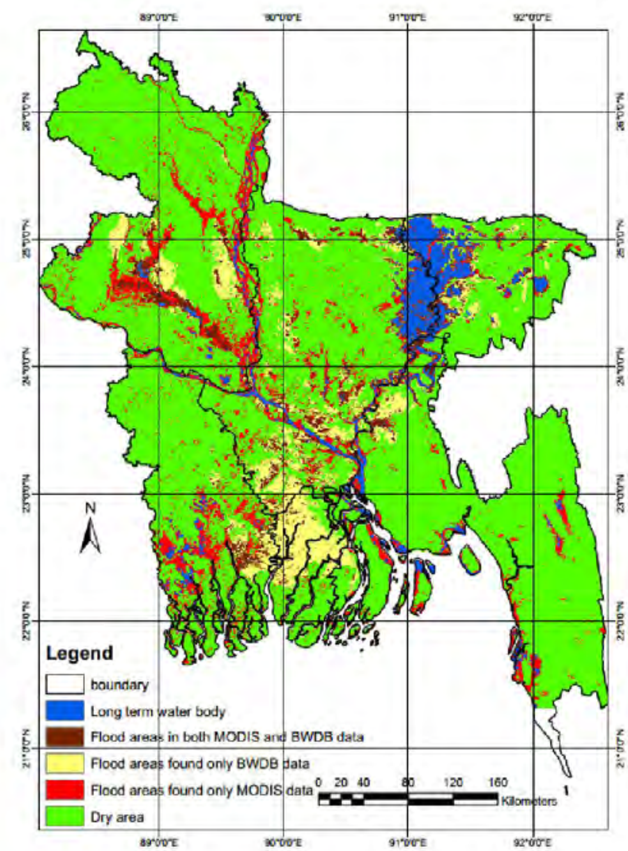
FigA2.07: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 07.09.2005.



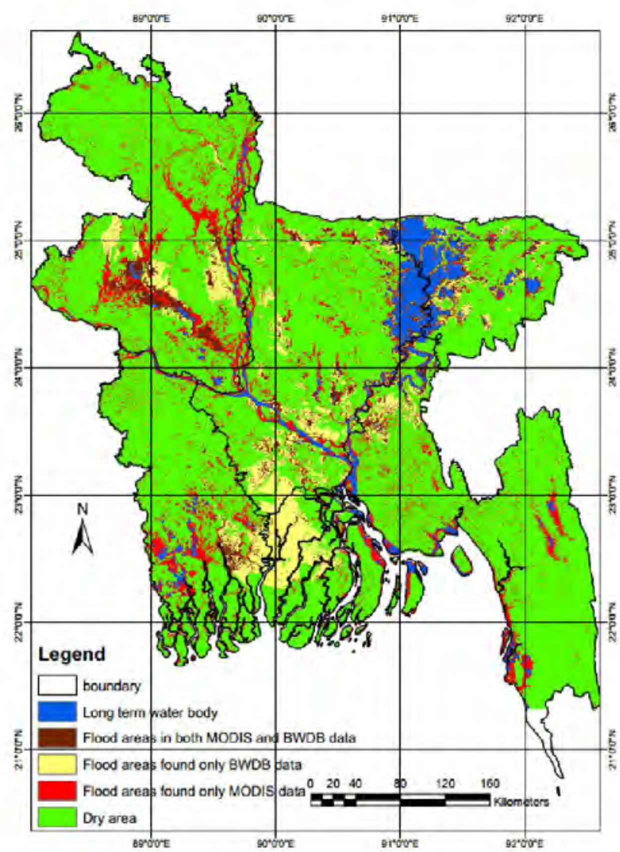
FigA2.08: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 16.09.2005.

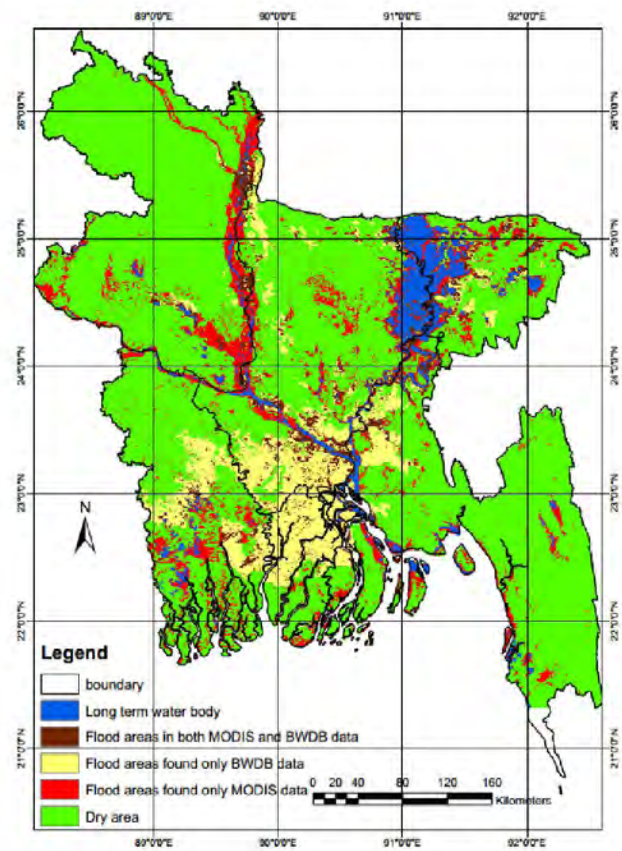


FigA2.09: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 27.09.2005.



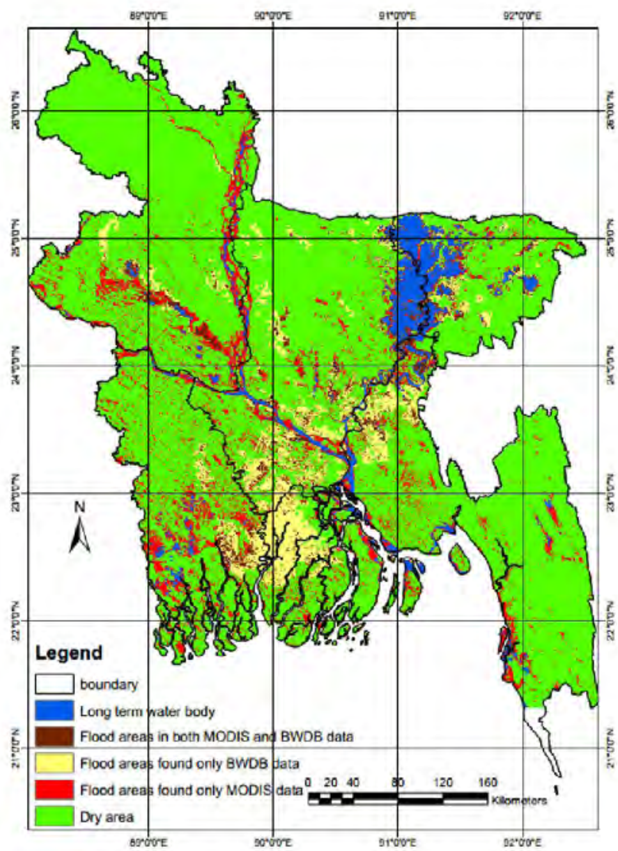
FigA2.10: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 10.10.2005.



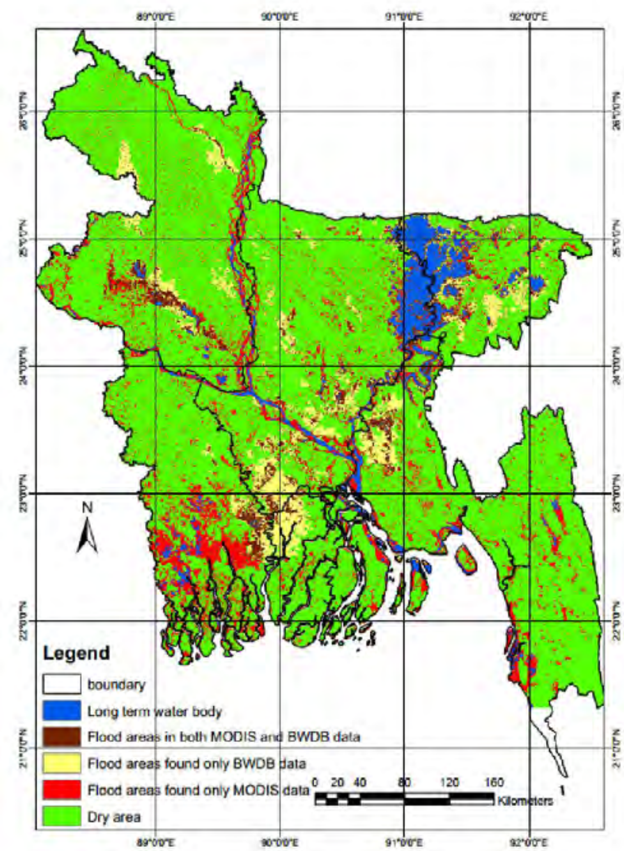


FigA2.11: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 12.10.2005

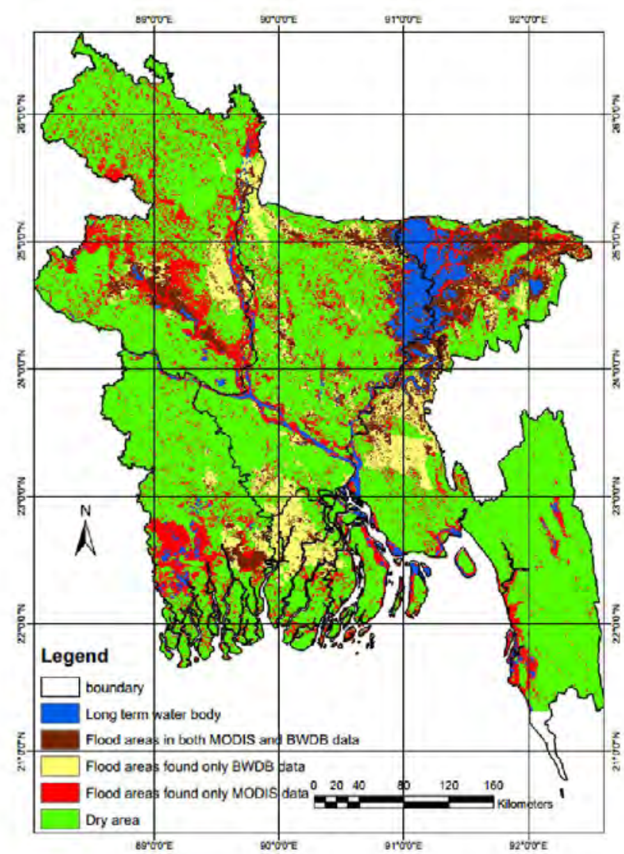
FigA2.12: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 18.09.2006.

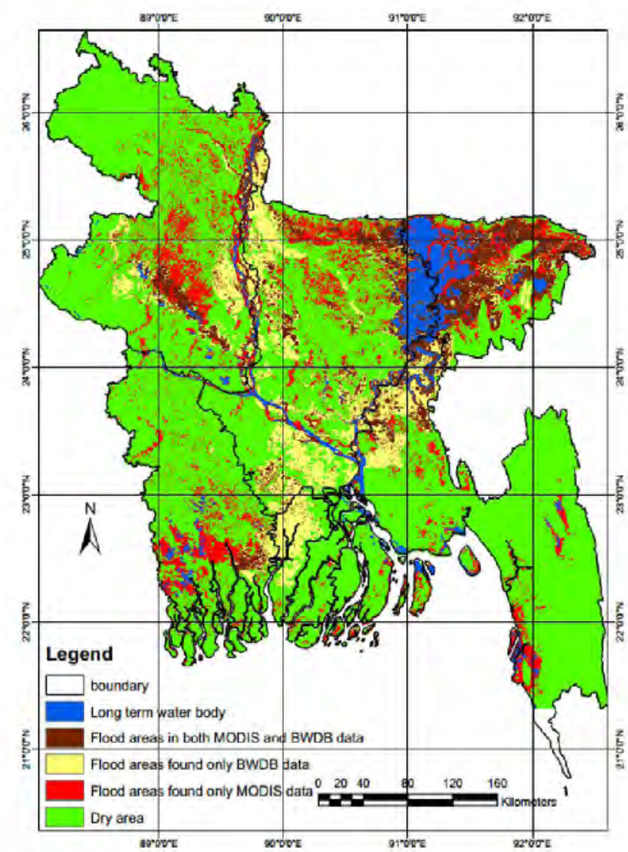


FigA2.13: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 28.09.2006.



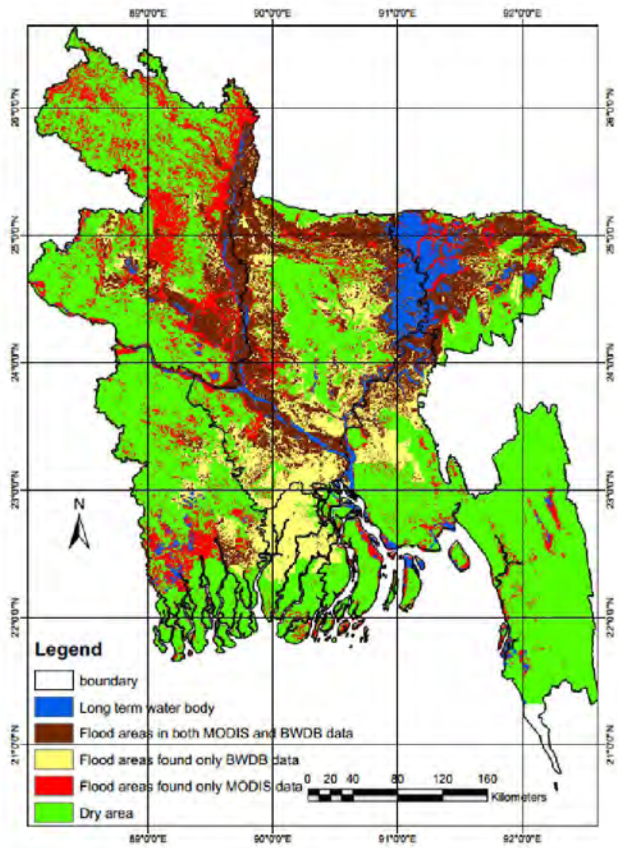
FigA2.14: Comparison between flood inundation prepared by BWDB and map prepared from MODIS image on 08.10.2006.



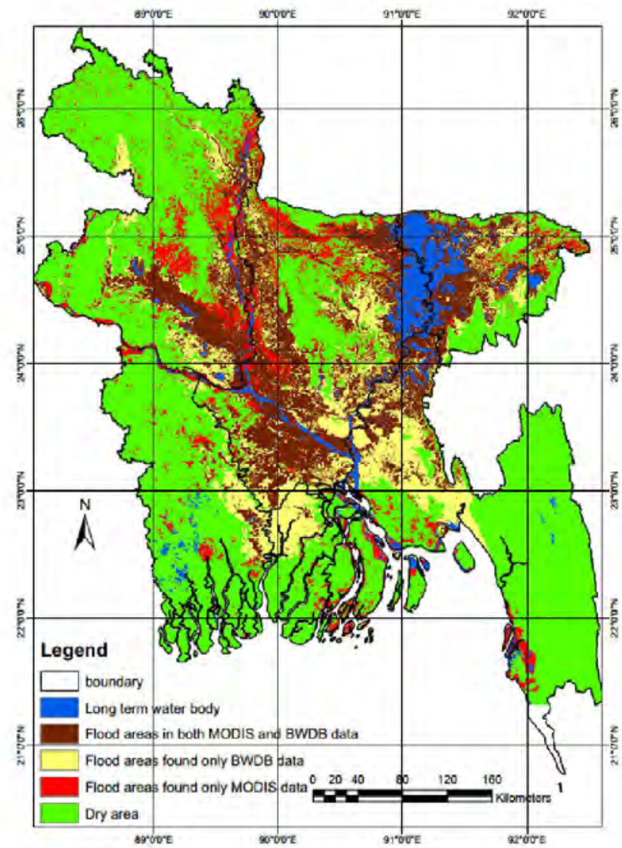


FigA2.15: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 20.06.2007

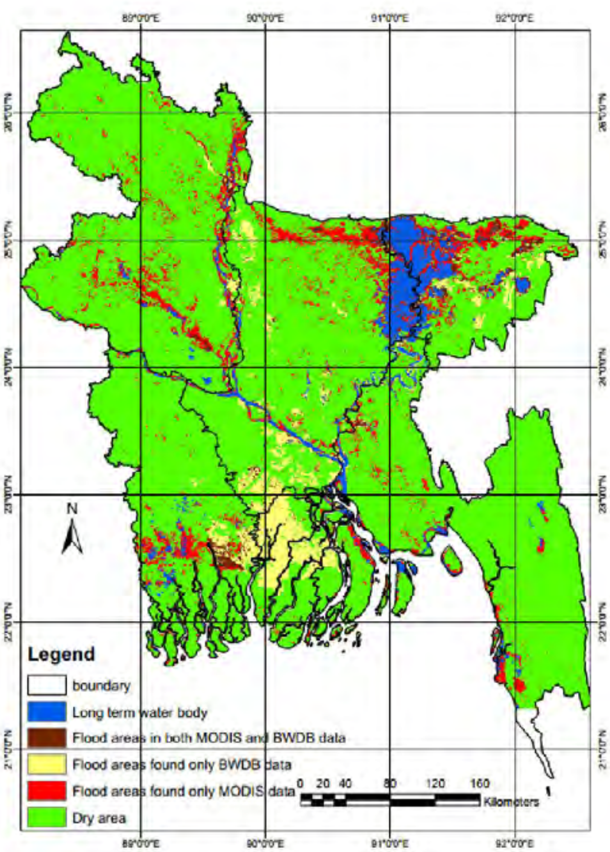
FigA2.16: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 26.06.2007.



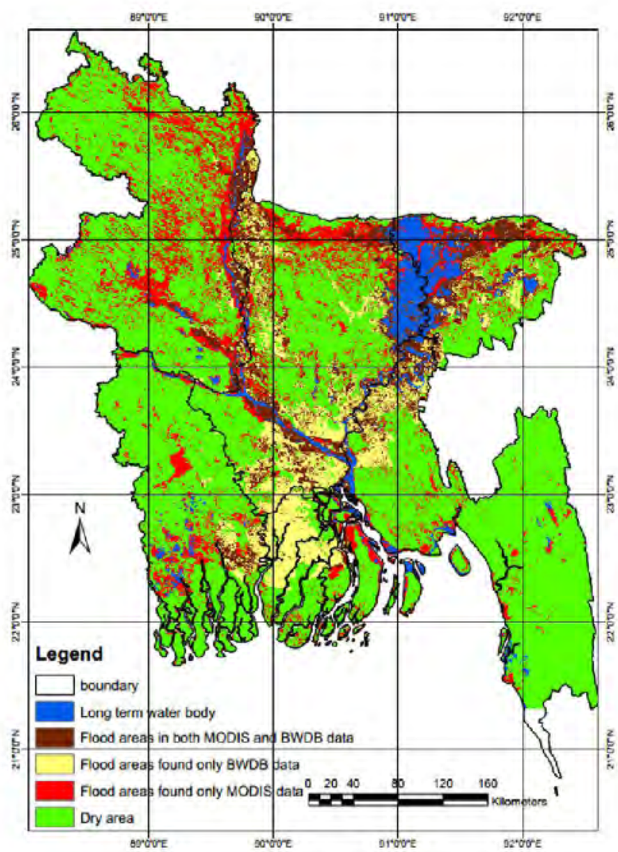
FigA2.17: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 03.08.2007.



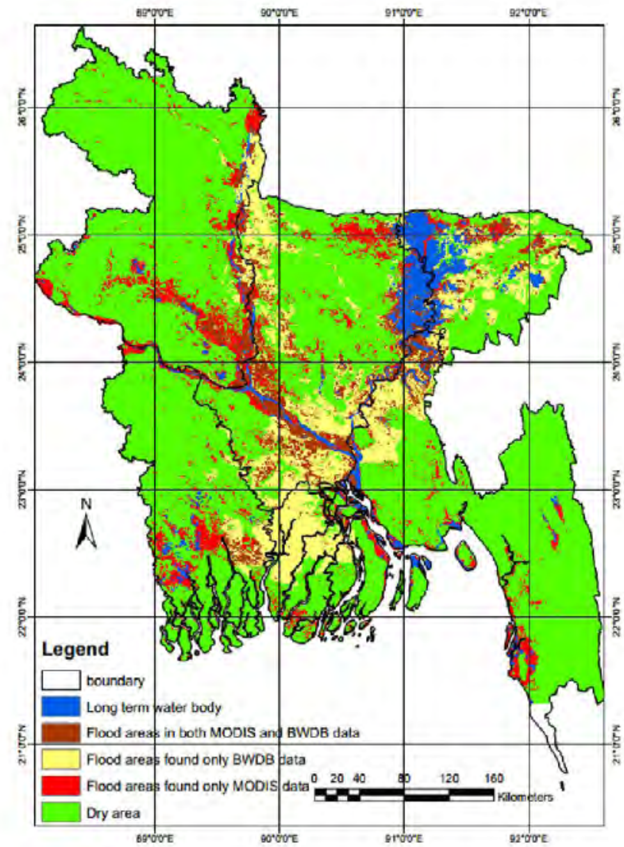
FigA2.18: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 10.08.2007

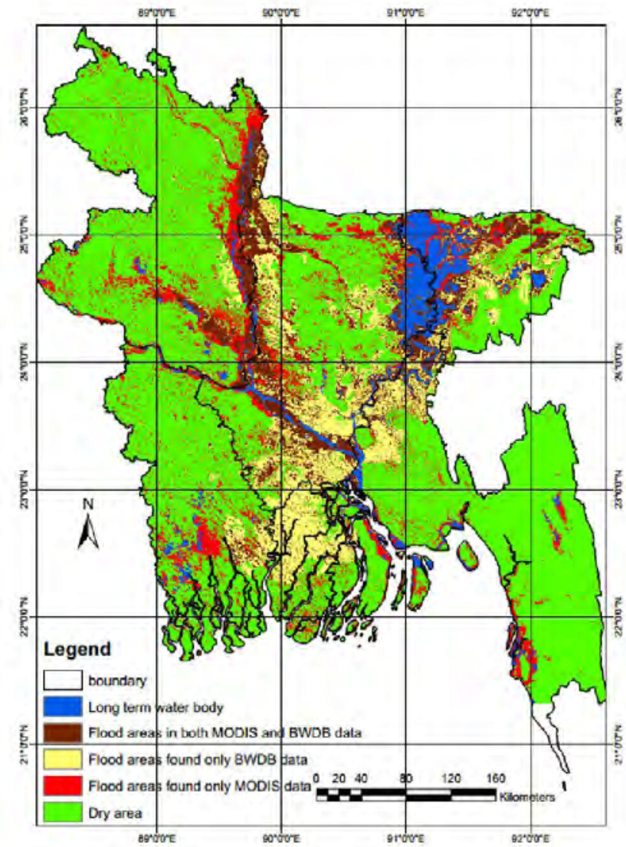


FigA2.19: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 25.06.2008.



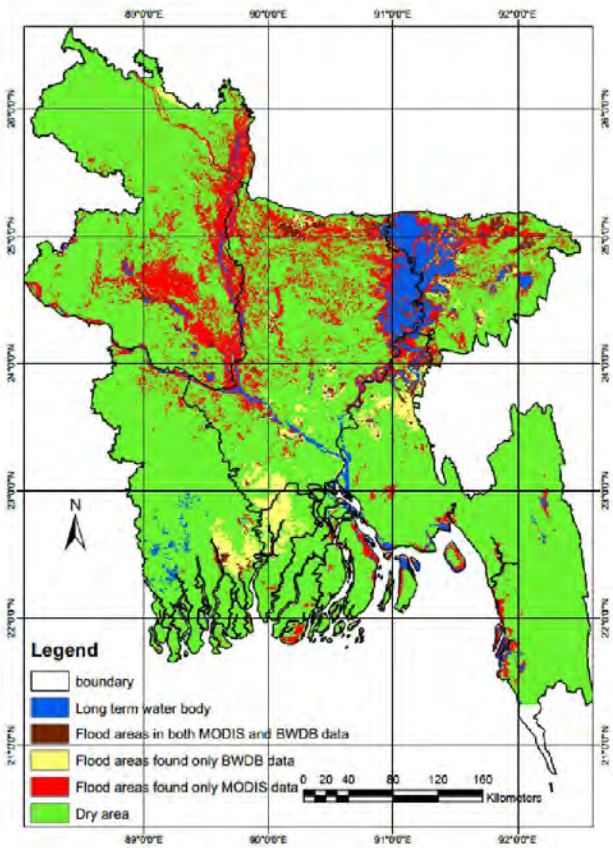
FigA2.20: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 27.07.2008.

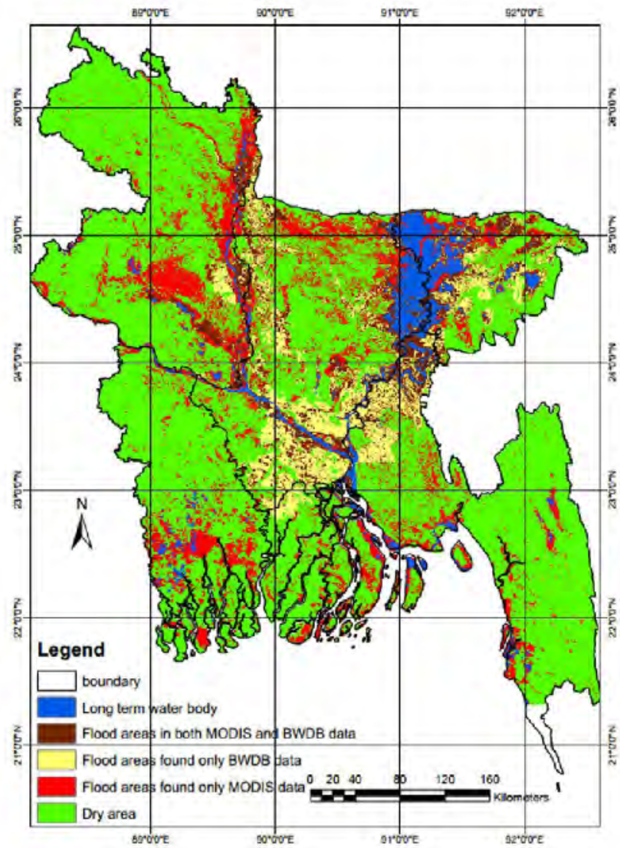




FigA2.21: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 23.08.2008.

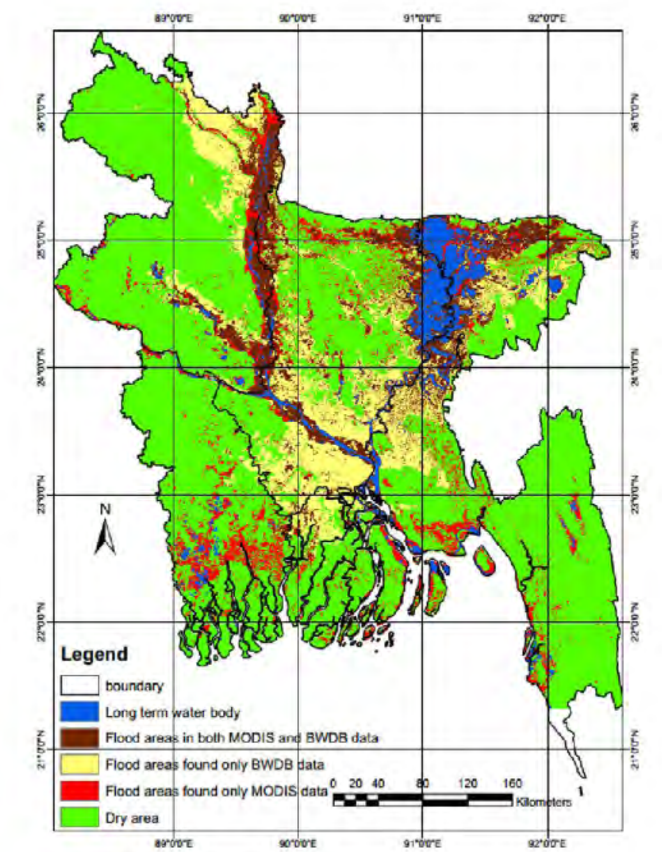
FigA2.22: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 10.09.2008.





FigA2.23: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 31.07.2009.

FigA2.24: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 31.08.2009.



FigA2.25: Comparison between flood inundation map prepared by BWDB and map prepared from MODIS image on 23.08.2014

A3 Comparison of flood inundation area of different years

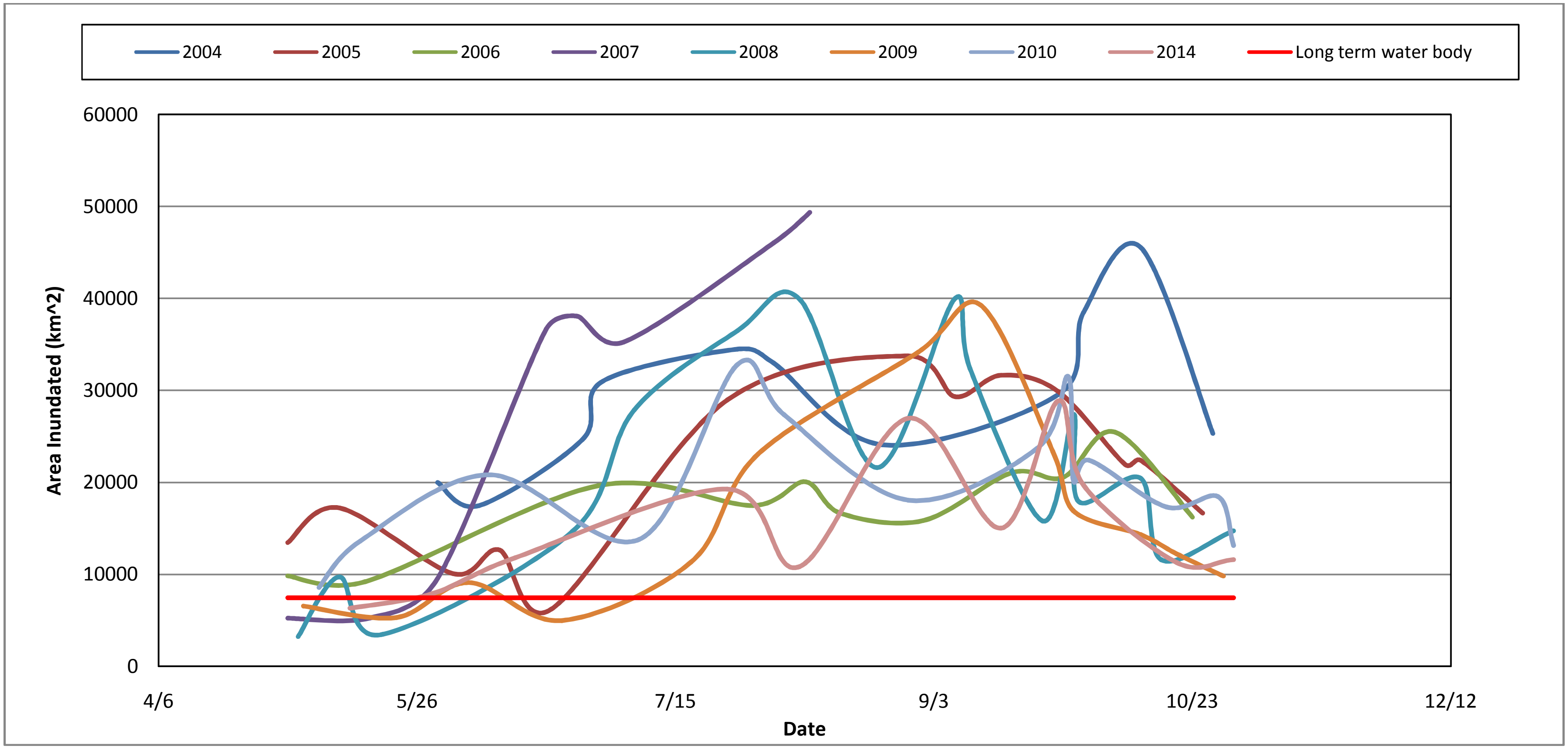


Fig A3.1: Comparison of Flood Inundation areas of different years.

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