GREEN WATER DEFENSE AS FLOOD MITIGATION APPROACH FOR DHAKA DISTRICT

A Dissertation for the Degree of Master in Disaster Management

Submitted By

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Abstract

Dhaka is prone to flood hazard due to its location, topology, climate and proximity to rivers. The main objectives of this study are to delineate the flood extent, find out the flood duration during monsoon, identify the change in land use and find out mitigation measures to reduce the impact of flood hazard in Dhaka. In this report, the flood types, causes of flood, flood history and flood control, and flood mitigation measures for Dhaka district are discussed. The study is based on review of literature, analysis of satellite images and water levels, and interviewing of some key informants. Due to its location, Dhaka is found to be susceptible to both fluvial and pluvial types of flooding. Drainage congestion is another major problem in Dhaka during the monsoon due to unplanned rapid urbanization, poor drainage system and improper maintenance of sewerage and drainage system. At present, Dhaka does not have any integrated long term flood risk management plan. A multi-scale, delta perspective flood mitigation focus, which involves long term adaptive management, is not yet in place. Green water defense, which is an adaptive management approach for delta regions, can be one of the best flood mitigation approaches, for Dhaka, both in city and district scales.

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Abbreviation

ADB	Asian Development Bank
APFM	The Associated Programme on Flood Management
BANCID	Bangladesh National Committee of the International Commission on Irrigation and Drainage
BMD	Bangladesh Meteorological Department
BTM	Bangladesh Transverse Mercator
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
DAP	Detail Area Plan
DEM	Digital Elevation Model
DMDP	Dhaka Metropolitan Development Plan
DN	Digital Number
DWASA	Dhaka Water Supply and Sewerage Authority
EGIS	Environment and GIS Support Project for Water Sector Planning
EPWAPDA	East Pakistan Water and Power Development Authority
FAP	Flood Action Plan
FCD	Flood Control and drainage
FCDI	Flood Control drainage and Irrigation
FFWC	Flood Forecasting and Warning Center
FPCO	Flood Plan Coordination Organization
GWD	Green Water defense
GWP	Global Water Partnership
IBRD	International Bank for Reconstruction and Development
ISODATA	Iterative Self-Organization Data Analysis Technique

ISPAN	Irrigation Support Project for Asia and the Near East
IWFM	Institute of Water and Flood Management
KII	Key Informant Interview
MPO	Master Plan Organization
NWMP	National Water Management Plan
NWP	National Water Plan
OECD	Organization for Economic Co-operation and Development
RAJUK	Rajdhani Unnayan Kartripakkha
RHD	Roads and Highways Department
SAR	Synthetic Aperture Radar
SP	Preparation of Structure Plan
SUDS	Sustainable Urban Drainage Systems
TRM	Tidal River Management
UAP	Urban Area Plan
UNCHS	United Nations Center for Human Settlements
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
USA	United States of America
WARPO	Water Resources Planning Organization
WFMS	Water and Flood Management Strategy
WMO	World Meteorological Organization

Chapter 1
Introduction

1.1 Background

Bangladesh is a natural flood hazard prone country for its unique geographical location. The major trans-boundary rivers, the Ganges, the Brahmaputra and the Meghna drain all their water from more than 90% of their catchment lying outside the country (Islam et al., 2014). Almost every year, a part of the country faces flood, sometimes which goes beyond the limit of people's tolerance. The impact of annual monsoon flooding, on the social, environmental and economic conditions of Bangladesh, is of great concern. This necessitates not only relief and rehabilitation measures but also management of the agencies involved in mitigating the floods and assessing their miseries.

Dhaka is highly prone to flood, due to its location, topology, climate and proximity to rivers. Some of the main factors contributing to flooding Dhaka, include spillover from surrounding rivers, excessive rainfall and limited and congested drainage. River floods generally take place in the low-lying fringe areas outside the protective embankments once in every five to ten years (Barua, 2008). As Dhaka is the capital city of Bangladesh, development is more here than that of the other parts of the country. Many people have migrated and started to live in Dhaka to achieve their desires. Therefore, almost the whole district meet population problem. For this, land development through land-filing is now increasing to meet up the accommodation space for increasing population. Consequently land subsidence is also a parallel event to contribute water logging, which increases the internal drainage problem here. This becomes acute during rainy season, when some areas of the city can be inundated for weeks with inundation reaching as high as 40 to 60 cm (Huq and Alam, 2003). On global scale (Casale and Margottini, 1999), storms and floods are more destructive of natural disasters and cause the greater number of deaths.

Some structural and non-structural measures have been taken by government to mitigate flooding problem both for Dhaka. As Dhaka is expanding rapidly like other south Asian countries it is necessary to have some new adaptive ways to mitigate flood. The study intends to find out the probable mitigation measures and adaptation techniques for Dhaka.

1.2 Objectives of the Study

The study will be carried out for the fulfillment of following objectives:

i. Delineate flood water extent using remote sensing technology.
ii. Find out the duration of flood using river water level.
iii. Find out the land use changes of Dhaka district of last 25 years using remote sensing and GIS technologies.
iv. Find out the probable mitigation measures using Green Water Defense (GWD) approach.

1.3 Importance of the Study

The rural and urban poor of this district, living in slums and shantytowns often in low-lying areas, have limited assets and are amongst the most vulnerable. With rapid and unplanned urbanization as well as habitation, people's vulnerability is likely to increase unless appropriate adaptation measures are put in place. At present, Dhaka does not have any integrated long term flood risk management plan, a multi-scale, delta perspective flood mitigation focus, which involves long term adaptive management, is not yet in place.

1.4 Organization of the Dissertation

This dissertation documents the concepts, carried out in describing and finding out mitigation measures for flood, for Dhaka district, in an integrated approach. Chapter 1 explains the study background, objectives of the study, importance of the study and finally the organization of the dissertation.

A review of the literature related to causes and available solutions and proposes mitigation measures are presented in Chapter 2. The review highlights the history of flood in Dhaka, main causes of flood, current problem for Dhaka due to flood, structural and non-structural measures those are currently in use for Dhaka to control flood and find out some integrated approaches in this issue that could be valid for Dhaka, through a bunch of available publications, reports and some other literature related to this dissertation.

Chapter 3 is very important for this dissertation. Here a short explanation of study area and the full methodology while working on this dissertation are given broadly. The chapter emphases on the methodology to collect and process available data, taking key informant interviews from relevant knowledgeable persons are discussed.

The flood history in Dhaka is described briefly in Chapter 4. It also shows the results and discussion part of this dissertation including the explanation of the delineation of flood water extent and land use changes in Dhaka district over the last 25 years by using GIS and remote sensing technologies and KII survey.

Chapter 5 clarifies the adaptive mitigation measures by Green Water Defense (GWD) of Dhaka. The chapter emphasis on the mechanism of GWD and explains how it works, which areas are mainly appropriate for this solution and how much it is relevant to Dhaka for controlling the adverse impact of flood and flood mitigation as an integrated adaptation approach.

Finally, chapter 6 concludes the whole dissertation with some valid recommendations.

Chapter 2
Literature Review

2.1 Introduction

Due to its location, topology, climate and proximity to rivers, Dhaka is highly prone to flood. As Dhaka is expanding rapidly flood vulnerability is also increasing day by day. According to Balica et al., (2012) Dhaka is amongst the most climate vulnerable mega cities in the world. Moreover, due to the climate change, extent and duration of flooding including the frequency of the events are also increasing. According to the report of World Bank, (2007) Dhaka is expanding at an average 4.24% per year and is projected to be one of the largest mega cities in the world by the year 2020. Dewan and Yamaguchi, (2008) added that, it could be the best illustration of human activities and associated environmental change. Therefore flood management is now a great challenge for Dhaka.

2.2 History of Flood and Flood Control in Bangladesh

Extreme precipitation together with the physical setting of the river basins has caused many severe floods in the last few decades of 20th century and the early decade of 21st century. Dhaka experienced the major floods in 1954, 1955, 1970, 1974, 1980, 1987, 1988, 1998 (Huq and Alam, 2003) and also in 2004. The unusual severe flood events like 1988 and 1998 inundated more than 60% of the country with severe destruction and damages to households, standing crops, livestock and infrastructure (Huq and Alam, 2003).

Considering the impacts of monsoon floods, regular monitoring and a good understanding of the nature of the floods are needed at the onset including the peak and recession periods of floods. In 1957 the Krug Mission (a United Nations Water Control Mission requested by the then Government of Pakistan) recommended to prepare a master plan for flood problems after the severe flood of 1954 and 1955. Consequently, in 1959 the East Pakistan Water and power Development Authority (EPWAPDA) was created to prepare a comprehensive plan for the development and utilization of the water and power resources in East Pakistan (currently Bangladesh). The master plan completed in 1964 (Mazumder, 2005) emphasized large scale flood control, drainage and irrigation projects to enhance agricultural production.

Afterwards in 1972, the International Bank for Reconstruction and Development (IBRD) recommended small-scale short term Flood Control and Drainage (FCD) projects like low lift pump irrigation and small drainage improvements and some medium-scale projects to face or mitigate the problems of flooding during the wet season and the scarcity of water during the dry season. In 1983 the National Water Plan (NWP) project was initiated under the Master Plan Organization (MPO) to formulate a perspective plan (1985-2005) for water resources development. The main objective of NWP was to maximize agricultural production while meeting the basic water needs of the users (Mozumder, 2005). MPO became Water Resources Planning Organization (WARPO) under act no. xii of 1992.

In the two consecutives disastrous flood of 1987 and 1988 huge damage took place in crop production, roads, railways, cities and towns, and more than thousand people lost their lives. In this connection, Flood Plan Coordination Organization (FPCO) was created in 1989 to coordinate Flood Action Plan (FAP) activities and has been merged with WARPO in January 1996. The goals of FAP study were to protect rural infrastructure, agriculture, fisheries; to create effective land and water management and to maintain the navigation along rivers; to increase and improve awareness for flood preparedness and disaster management; to reduce flood flows in major rivers; to recommend structures and embankments to protect the region; to coordinate planning of Roads and railways with embankments along with clear drainage for flood water; and to create global awareness of floods and control efforts for possible relief and monetary efforts.

About 127 coastal polders were constructed for the management of tidal floods in coastal region. However these structural measures of flood management had impacts on nature like impacts on hydraulic system, floodplain ecosystem and water transport function, crop production etc. According to Chowdhury, (2000) flood control embankments cause substantial damage during large and moderate floods; even the damage during smaller floods is also quite high. Due to embankment failure, it results very high damage compared to that in "without embankment" situation (Rahman and Salehin, 2013).

The concept of tidal river management (TRM) is compartmentalization in central Brahmaputra floodplain and partial flood control in the north-eastern part of Bangladesh is established considering the impacts of structural measures in coastal (Rahman and Salehin, 2013). The Government has invested a large amount of fund for flood control and drainage systems through the construction of 12,850 km of embankments, 25,580 km of drainage channels, 4,190 nos sluices and regulators through Bangladesh Water Development Board (BWDB) till 1998 (WARPO, 2001a). The implemented projects were flood control (FC), flood control and drainage (FCD), flood control drainage and irrigation (FCDI); and drainage (D) projects. The main approaches were for the protection of the agricultural lands and urban areas constructing embankments, construction of low height submersible embankments for the north-eastern part of Bangladesh for the protection of boro rice in pre monsoon period from early flash flood, evacuating unwanted rainwater within the embankment through drainage regulators and sluices and providing drainage by pumping (Rahman and Salehin, 2013).

Environment and GIS Support project for Water Sector Planning (EGIS) and its predecessor Irrigation Support Project for Asia and the Near East (ISPAN) have explored the mapping and monitoring of floods from 1993. EGIS monitored flood extent of 1998 flood and the information were provided to different government and non-government agencies active in relief and rehabilitation and in the field of flood disaster management.

The monitoring of the monsoon floods in Bangladesh is presently focused on extreme events and on providing information to support relief and rehabilitation. National agencies such as the Flood Forecasting and Warning Center (FFWC), BWDB (established in 1972) and the Bangladesh Meteorological Department (BMD) regularly monitor hydrological and meteorological conditions at a number of selected river gauges and rainfall stations. FFWC generates information for the flood forecasting and warning system using mathematical modeling techniques and updating the tools for a more dependable and reliable forecasting system.

According to Smith, (1997) accurate information on the extent of water bodies is required for management of flood. Mapping of flood extent and the vulnerable areas not yet identified will be very helpful to measure the losses and to take necessary actions for those areas. In this regard, now-a-days, GIS techniques are broadly used all over the world to model flood hazard using Digital Elevation model (DEM) (Dewan et al., 2004).

2.3 Government Response to Flooding Problem in Dhaka

The FAP (1990-1995) was involved 26 components as the initial stage in long term development for flood control, drainage and river management in Bangladesh. As a part of this the Government of Japan and the Asian Development Bank (ADB) agreed to undertake a study on Dhaka protection FAP 8 in 1990. There were two components of FAP 8 and those are: Flood Action Plan 8A "Greater Dhaka Protection Project- Study in Dhaka Metropolitan Area" and Flood Action Plan 8B "Dhaka Integrated Flood Protection Project". The main focus of FAP 8A was to mitigate flood and storm water drainage improvement for the Dhaka metropolitan area. FAP 8B conducted by Louis Berger International and funded by ADB proposed an integrated flood protection and drainage program for Dhaka city.

The Water and Flood Management Strategy (WFMS) for Bangladesh was developed in 1995 for 5-year to prepare the National Water Management Plan (NWMP) (Mozumder, 2005). Following the FAP 8A study, the "Dhaka Eastern Bypass Study" was undertaken by Halcrow Fox in 1996 with the funding of the World Bank. Together with BWDB, in 1999 the Roads and Highway Department (RHD) started constructing a bypass road along an alignment which was completed in 2006 (Halcrow, 2006). According to WARPO, (2001a), Bangladesh has been divided into five regions, where Dhaka falls within the North Central (NC) region which was established by NWMP in 2001.

In the program of NC region Dhaka flood protection project was started for 23 years in 2003 where the project would be implemented Dhaka integrated flood control embankment (Eastern Bypass Road Multipurpose Project). Another study under this project has been started in 2004 for 22 years on storm water drainage in Dhaka. The objective is to propose infrastructure development. In this regard Dhaka Water Supply and Sewerage Authority (DWASA) has recently prepared the "Storm Water Drainage Master Plan".

In 2004, DAP (Detail Area Plan) was prepared by Rajdhani Unnayan Kartripakkha (RAJUK) with the assistance of United Nations Development Programme (UNDP) and United Nations Center for Human Settlements (UNCHS) under the project "Preparation of Structure Plan (SP), Urban Area Plan (UAP) and Detailed Area Plan (DAP)- Metropolitan Development Plan Preparation and Management in Dhaka" (DAP, 2004). The objectives are to implement the previous Dhaka Metropolitan Development Plan (DMDP), Structure Plan and Urban Area Plan, policies and recommendations. It provides more detailed planning proposals for specific sub-areas compliant with the Structure Plan and the Urban Area Plan.

According to RAJUK, (2010b) Dhaka City west area is protected by a flood control embankment. Moreover, internal drainage is provided by pump stations located at Goranchant Bari, Kallanpur, Narinada and Rampura. There are eleven sluices on the embankment, also serve for draining storm water from the city area. On the other hand, almost the total area of eastern part of Dhaka remains under flood water during monsoon excluding some areas like Uttarkhan and Ujanpur. Generally drainage impediment is a serious issue for the area and it is very difficult to find flood free land in the rainy months.

However, the DND (Dhaka-Narayanganj-Demra) dam and development of Pragati Sarani and Sayadabad road in this area along with rising of Pragati Sarani for flood proofing flow to Narinda khal has practically ceased. Therefore, Mugda, Khilgaon-Basabo, Zirani and Manda khals are to flow towards Rampura khal and drain to the Balu river (RAJUK, 2010b).

Change in Land use is another problem to manage flood control in Dhaka. This should be looked into with intense care.

2.4 Change in Land Use in Dhaka

As Dhaka is expanding rapidly, it is required to have more space for living. Uncontrolled urbanization should be regulated. Water bodies like lakes, beels and low lying lands are now filled up and uncontrolled development in high risk zones together with environmental degradation leads towards increased vulnerability and catastrophic events for the communities living in the floodplains.

For this, water logging is now a great issue in monsoon period. According to Haq and Alam, (2003) land development through land-filling in Dhaka has caused drastic reduction in water storage area and easy passage of the flood water into the river system as well. This becomes acute during the rainy season when some areas of the city can be inundated for weeks with inundation reaching as high as 40 to 60 cm. On the global scale, storms and floods are most destructive of natural disasters and cause the greater number of deaths (Fattorelli et al., 1999). Barua, (2008) argued the embankment without proper pumping system has increased the internal drainage problem of the city resulting into a management problem.

According to WMO/GWP, (2008b), human activities encroach on the natural environment with the progress of urbanization. It disrupts natural drainage patterns and natural watercourses are destroyed as well. The natural retention of runoff by plants and soil is also removed. Thus, the natural water storage capacity of soil is declined.

2.5 International Experiences for Flood Management

The integration of both structural and non-structural measures for flood management is not a recent idea and has been present in numerous water management practices (Petry, 2002). Miller, (1997) cited by Petry, (2002) and Calder and Aylward, (2006) added, the reduction of flood damages requires a combined application of three different strategies to the problem of flooding and are: “keep the flood away from people”- through construction of structural measures and “keep people away from floods”- through land use planning and finally, “accept floods and clean up afterwards”. In company with, Tucci, (2006) structural measures are engineering works implemented to reduce the risk of flooding.

Along with Petry, (2002) the Tucurui Dam and Hydropower station were constructed on the lower course of the Tocantins River which is the tributary of the Amazon in northern Brazil. The Pacaembu underground reservoir was constructed at the adjacent to one of the main Brazilian soccer stadia to regulate the flood flows resulting from intense rainfall events and avoid exceeding the capacity of the existing urban drainage system. A flood protection plan in Taipei was approved in 1973 and implemented until 1996 through constructing 2 reservoirs, 79 pumping stations, 124 water regulation gates, a flood-bypass channel and 68 km of dikes.

In the Netherlands dikes are used for the protection of land from flooding with a safety level; varying between 1:1250 (in the eastern part, where the Rhine River enters the Netherlands) and 1:10000 (at the western part, at the North Sea side) (Schielen and Roovers, 2008). Petry, (2002) added, the two major projects: the Zuiderzeein Project in the northern coastal range and the Delta Project in the south (delta of Scheld River) were implemented during the second half of the twentieth century that strongly contributed to further advances in land reclamation and further progress in managing floods.

Structural measures are not designed to give total protection (Tucci, 2006). Patel and Dholakia, (2010) added, non-structural measures are essential together with structural measures to achieve entire efficiency, effectiveness and economy of development. Flood forecasting and warnings are very helpful for the management of flood. BANCID (1995), explained the opinion, like, “Flood forecasting and warning has been identified as a key component that could exert major benefits on numerous aspects of national life, with considerable potential for improving the national economy. As such it is recognized as a highly cost effective non-structural measures”. Parker and Fordham, (1996) and Plessis, (2002) added that flood forecast, warning and response system are implemented to reduce material, human and cultural losses in Europe and South Africa.

According to Islam et al., (2014) nowadays, flood monitoring based on remote sensing and GIS is a well-established activity for flood management all over the world. Wei, (2012) supplemented that the multisource satellite remote sensing data are now covering many aspects of flood monitoring and development was found feasible.

Menzel et al., (2003) expressed his opinion on watershed management as flood management which includes land use soil conservation to minimize surface run-off, erosion and sediment transport. Karen et al., (2009) have given extensive reviews on this issue also.

However, Tu and Nitivattananon, (2010) argued, adaptation strategies of flood can be another option to manage flood. The adaptation techniques might be like increase in efficient use of water and reduce the water pollution, create floodwater and rainwater storage facilities to reduce water overflow and reuse rainwater for irrigation and other utility purposes, improving water treatment like management of waste water management and urban planning and infrastructure development.

According to the report of WMO/GWP (2008a) flood risks cannot be avoided and should be managed in an integrated way- risk assessment, planning and implementation of measures, evaluation and risk reassessment.

2.6 Green Water Defense as Mitigation Approach for Flood

Based on the principle of "Living and building with nature" Green Water Defense (GWD) is an adaptive approach of water sector to green growth and sustainable development which is cost-effective as well as eco-friendly (Li et al., 2012). Marchand et al., (2012) added that this approach is more appropriate for delta regions as the climatic influences are more here. Moreover, Green Water Defense addresses flood protection through a structural and non-structural measures based on the requirements of different specific areas. Marchand et al., (2012) found this approach is more feasible and effective and also cheaper than that of the other traditional solutions because it serves multiple purposes.

The best practices of this approach are now present in the Netherlands, United States of America (USA) and other Organization for Economic Co-operation and Development (OECD) countries. To protect the most densely populated area, Dutch government gave an enormous effort in building dikes, and embankments along the Rhine River in the Netherlands. According to Marchand et al., (2012), the designed project "Room for the River" had the basic measures to lessen the water levels in the flood plain including lowering groynes, deepening low flow channel, removing obstacles, lowering floodplain dike relocation, setting back dikes on a large scale, detention reservoir, reduce lateral inflow, high water channel and strengthening dikes. The main goal of the project was to maintain the safety of the land against flooding from the river for higher river discharges. Besides these, the project also had the focus on increasing the landscape diversity between river branches, strengthening the openness of the river with its characteristic waterfronts, conserving and developing the scene, ecological, geological, cultural and historic values, improving the environmental quality and promoting the use of the main navigable waterways. The Dutch "Room for the River Waal" programme received the excellence on the Waterfront Honor Award in 2011 that presented every year by the Waterfront Center (Marchand et al., 2012). Furthermore, the Netherlands government had took some other initiatives like open water storage such as parks and canals, subsurface storage like parking garages that can be used at a time for storing heavy rain water and car parking, water plazas, separated sewerage or drainage system for individual houses and green roofs such as plantation on the roof top of buildings.

In Louisiana the first program "comprehensive approach to restore and prevent the coastal wetlands" was took place in 2010 for coastal restoration under the public law 101-646, the Coastal Wetlands Planning, Protect and Restoration Act (CWPPRA) which was passed in November 1990 (Marchand et al., 2012).

According to Opperman et al., (2011), floodplain protection and reconnection produces diverse benefits which reduce flood risks help in water supply, hydropower and environmental flows which is practiced in California under the Sacramento River Flood Control Project "The Yolo Bypass (California)". Six major reservoirs those manage floodwaters in the Sacramento River basin during the flood peak. Two-thirds of the Bypass area is in seasonal agriculture. The Bypass supports a large number of wading birds and waterfowl and provides habitat for 15 native fish species during inundation period (Opperman et al., 2011). Sommer et al., (2001) added that, the Bypass is important as rearing habitat for juvenile Chinook salmon and spawning habitat for Sacramento split-tail.

Traditional measures, like structural measures, such as river training, construction of embankments and retention by reservoirs are being concentrated for flood management for a long time. However, it is now well recognized that structural measures alone cannot solve flood problem (Merz et al., 2010). They also added, the idea of "living with floods" acknowledges the illusion of complete safety against floods which leads a strong focus on declining vulnerability to flood. Integrated measures should be taken in place to control flood and to minimize the impact of flood.

In this regard, in various countries in UK and Germany sustainable urban drainage systems (SUDS) approaches have been implemented and are now operational for flood control in urban areas (Zevenbergen et al., 2010).

As mangroves can easily adapt to changing environmental conditions due to climate change, and mangroves have been proven as successful to protect and stabilize coastal areas and provide substantial timber production (Field, 1998), mangrove restoration is now an activity that fits very well with the concept of "Building with nature" (Marchand et al., 2012). According to Saenger and Siddiqi, (1993) which was cited in (Field, 1998), about 120,000 ha of mangroves have been planted since 1966 in Bangladesh.

In Singapore, an ABC Water Master Plan was developed in 2007 (Li et al., 2012), that was a guide to transform the city's drains, rivers and reservoirs into vibrant, picturesque and clean flowing streams and lakes those are well included with the environment (PUB, 2009). At the treatment level of this plan, integrated measures like vegetated swales, bio-retention swales and basins, cleansing biotopes and constructed wetlands were used. In the northeastern part of Singapore a floating wetland was constructed (2500 m^2) which is situated at the Sengkang Riverside, which the largest manmade wetland and used for recreational purposes and also for flood storage during heavy rainfall (Li et al., 2012). In that park there is a pond as a water reservoir. According to Li et al., (2012), if the volume of water flowing in is larger than the basin capacity during excessive rainfall, the water will be redirected through a bypass into the pond to prevent damage to the wetland. The pond eventually released through the outlets within two or three days. According to PUB, (2011), eleven projects are completed by the end of 2010 and over 100 projects are assigned in the next 15-20 years in Singapore. Such concrete and targeted efforts have been substantially improve the drainage system capacity and flood security in Singapore (Li et al., 2012).

In Japan multi-functional facilities like retarding basins, underground floodways and super levees are used widely those provide from earthquake and flood control capability. The advanced flood forecasting and early warning systems are established in different river basins in Japan (Li et al., 2012).

According to Kloss and Calarusse, (2006), each year USA faces billions of gallons of storm water runoff and combined sewer overflow (CSO)s due to rain and snow those fall on urban areas. On this regard two systems are currently in use and those are: separate storm water system that collects storm water only and storm water with its pollutants are released into water through pipes; and combined sewer system which collect storm water in the same set of pipes and transmit it to a municipal waste water treatment plant so that pressure on sewage system reduces maintaining hygiene. In North America cities are introduced green infrastructure as a component of comprehensive storm water management plans to reduce storm water runoff.

As Dhaka is very much prone to flood, due to climate vulnerable zone, it is required to have such mitigation approaches for Dhaka district to manage both fluvial and pluvial flood.

Chapter 3
Study Area and Methodology

3.1 Description of the Study Area

Dhaka, the capital city of Bangladesh, is under Dhaka district which is located in central part of Bangladesh. It is the densest district of Bangladesh and the total area is about 1,464 sq km. The area is located latitude of 23.79° N and longitude of 90.30°E. The district consists of 46 thanas, 208 unions including 98 Wards. The district shares its border with Gazipur and Tangail to the North; Munshiganj and Rajbari to the South; Narayanganj to the East and Manikganj to the West. There are 2 city corporations covering about one fifth area of the district.

The Dhaka district is surrounded by the rivers, Balu, Bangshi, Buriganga, Dhaleshwari, Lakhya, Tongi Khal and Turag. Dhaka elicits an average of 1875 mm (73.8 in) of rainfall per year, or 156.3 mm (6.2 in) per month. The high flow of the trans-boundary river, the Brahmaputra-Jamuna coincide with heavy rainfall during monsoon, the rivers in and around this district, overflows the low-lying fringe areas and causes flood in Dhaka.

Moreover, population problem is now an important issue here. Many people migrate here from other areas of the country, in search of better livelihoods. For this, it is expanding rapidly with dense population, that causes drainage congestion. In addition, Dhaka is now suffering in poor drainage congestion also. Land filling is another cause for proper drainage of rain water during monsoon. Thus, it is now getting more vulnerable to disaster like floods and earthquakes, for land filling and over population.

After having the flood protection embankment within the DND boundary, Dhaka west is now safe from fluvial flood. However, the scenario is opposite for the non- protected area like Dhaka East. As flood plain, as well as agriculture land, is decreasing over the three decades, food production is now also in threat. For this, it is required to have proper mitigation measures against flood and water congestion and selected as the study area of this dissertation.

3.2 Methodology of the Study

The overall methodology of the study consists of three parts and these are literature review, data collection and taking interviews. The flow diagram of the whole methodology is given in **Figure 3-1**.

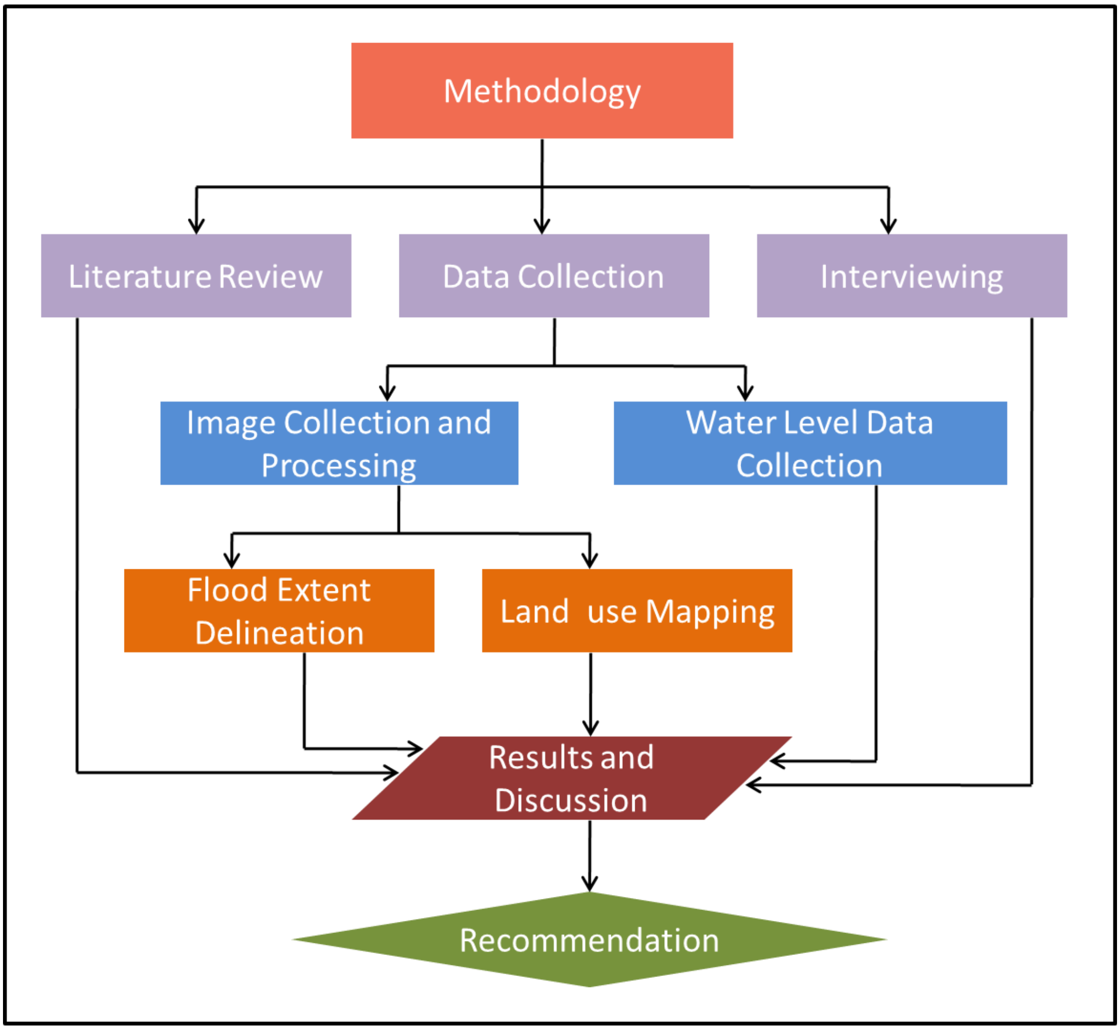


Figure 3-1: Schematic diagram of methodology of this study

3.2.1 Literature review

Potential measures for flood mitigation were identified through a systematic review of available literature. Searching the available literature, in journals, research reports or other publication was done in Google Scholar, by the key words (Dhaka and Flood) which were open accessed. From several documents, only seven were taken from that website. Similarly, from Science Direct and Springer website eight and seven related documents were selected and collected accordingly for the literature review part of this dissertation. However, some other reports (FAP 8A, FAP 8B), flood report of 2001 and 2002 were collected from the CEGIS archive. Some books were also collected from the CEGIS library and IWFM Library, BUET. The report of DAP (Detail Area Plan) and some other documents (around 30) were taken by browsing in Google Search.

After collecting all the available documents, unification and synthesis were done and found out the importance of this study. Furthermore, some other international and national studies (around 20) were reviewed to find out the probable mitigation measures for both the rural and urban inhabitants of Dhaka district. Only related documents were reviewed and used for this dissertation report.

3.2.2 Data collection

Data collection part is consists of image collection and water level data collection of Dhaka district.

3.2.2.1 Satellite image collection and processing

Two types of satellite images were collected from the Remote Sensing Division of CEGIS. To understand the area extent of flood Dhaka district, available RADARSAT images of 7 years (1998, 2000, 2001, 2002, 2003, 2004 and 2007) were collected from CEGIS. Landsat images were collected for identify the land use/ cover changes over the time period of 1989 to 2014. In this part, the two types of satellite images were processed as well as classified in two different ways. The procedure of processing both satellite images are given below-

- *Flood extent delineation*

Different time series of similar year were available in CEGIS. To understand the flooded and non- flooded areas and flood duration of a year, each image was classified into two classes. The whole process was done by using ERDAS IMAGINE software, which is specially used for satellite image processing as well as analyzing satellite image data (ERDAS Field Guide™, 2008).

The major processing steps followed in processing the images were: image to image registration (co-registration), filtering and geo-referencing. There are two major steps in analyzing an image using the above software are image processing image classification (**Figure 3-2**).

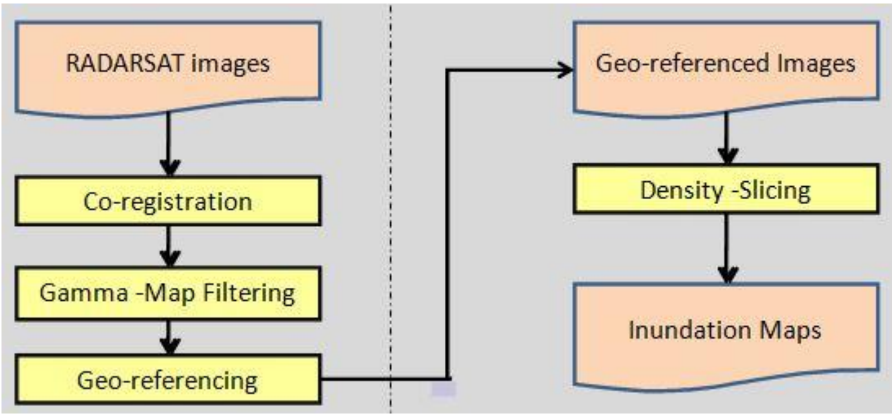


Figure 3-2: Schematic diagram of RADATSAT image processing steps for inundation mapping

In many cases, images of one area that are collected from different sources must be used together. To be able to compare separate images pixel by pixel, the pixel grids of each image must conform to the other images in the data base. The tools for rectifying image data are used to transform disparate images to the same coordinate system. Registration is the process of making an image conforms to another image.

After co-registration, all RADARSAT images were filtered using a 3x3 Gamma-Map filter to reduce speckle noise in the images. The filtered SAR images were then geo-referenced into the BTM projection system. The accuracy of the geo-referencing was found to be within a pixel.

Geo-referencing refers to the process of assigning map coordinates to image data. The image data may already be projected onto the desired plane, but not yet referenced to the proper coordinate system. Rectification, by definition, involves geo-referencing, since all map projection systems are associated with map coordinates. Image-to-image registration involves geo-referencing only if the reference image is already geo-referenced. Geo-referencing, by itself, involves changing only the map coordinate information in the image file. The grid of the image does not change.

Bangladesh Transverse Mercator (BTM) projection parameters are as follows:

Projection Type:	*Transverse Mercator*
Datum:	*Everest 1830*
Spheroid:	*Everest 1830*
Latitude of Origin:	*0.000000*
Central Meridian:	*90.00000*
Scale Factor:	*0.999600*
False Easting:	*5000000*
False Northing:	*-2000000*
Linear Unit:	*Meter*

The Datum and Spheroid (Everest 1830) have the following parameters:

Semi major Axis:	*6377276.34499999970*
Semi minor Axis:	*6356075.41314024010*
Inverse Flattening:	*300.801699999999980*

After geo-referencing, each image was classified into two categories: “Open Water Flooding” and “Non-Flooded Area”. The C band of RADARSAT-1 data cannot penetrate vegetation canopy (CEGIS, 2014). Previous experience of CEGIS indicates that it is not possible to detect floodwater under the cover of forests, settlements and homestead trees, and crops with more than 30% canopy. Hence “open water flooded area” is used instead of “flooded area”.

Each individual image was classified separately using density slicing technique. This technique grouped the digital number (DN) into two classes, “open water flooded area” and “others”. The DN threshold used to separate open water flooded area from the other land cover was identified. It was seen that the low valued DNs (i.e. the darker pixels) represented the open water category. After identification of open water flooded area, the rest of the digital numbers were classified as “Non-Flooded Area”. This group contained the combination of everything else that included urban and rural settlements, high canopy forests, agricultural crops without water underneath, and crops having greater than 30% canopy with water underneath. Finally, all classified flood maps were filtered using neighborhood majority functions with 3 x 3 window size.

After classification, area calculation was done. From the flooded areas the duration of flood was found out for that year. Analyzing the flood water extent of various dates of 1998, 2000, 2001, 2002, 2003, 2004 and 2007, maximum flood extent was delineated for those years individually. Using all the maximum flood extents of those years, a map was prepared based on the proneness of flood hazard.

In this research, an indicator based participatory approach was used for flood vulnerability assessment of the study area with respect to union boundary (administrative unit) by using following equation-

$$VI = \sum_{i=1}^{N} \frac{FF * IA}{A} * SD$$

Where,

VI= Vulnerability index

FF= Flood Frequency of each union

IA= Total Inundated area

SD= Settlement Density

A= Union Area

N= Number of union

The information used in this study, was based on the analysis of geo-data, such as settlement and maximum flood water extent and flood hazard prone area maps, derived from satellite images and GIS data as well as census data. After then union based maximum flood inundated area and settlement density is calculated in spatial database. Flood intensity of each union is calculated by total inundated area and frequency weight whereas flood frequency is weighted into 0 to 5 (5 is the maximum occurrence and 0 is the no flood affected area). For the intensity normalization each union, intensity score is divided by the respective union area. Finally Vulnerability index is calculated by multiplying intensity score with settlement density. For the practical implementation, above index was normalized by dividing the maximum vulnerability index score of the union to make the maximum vulnerability value is 1.

- *Land use mapping*

Land use/ land cover of Dhaka district was mapped from a digital image classification of Landsat 4/5 images of 1989, 1997, 2010; Landsat ETM images of 2003; and Landsat 8 images of 2014. All the images were geo-referenced images and were collected from CEGIS archive. All the images have 30m spatial resolution.

Both visual and digital interpretation techniques were used to derive the Land use/Land cover information from these images. Field surveys were conducted to collect ground truth data for the information on current land use/ land cover, which are used for interpreting digital classification. Finally, land use/ land cover maps were produced by digital classification with the help of ground truth data. The methodology of land use/ land cover map preparation from satellite images is given below in **Figure 3-3**.

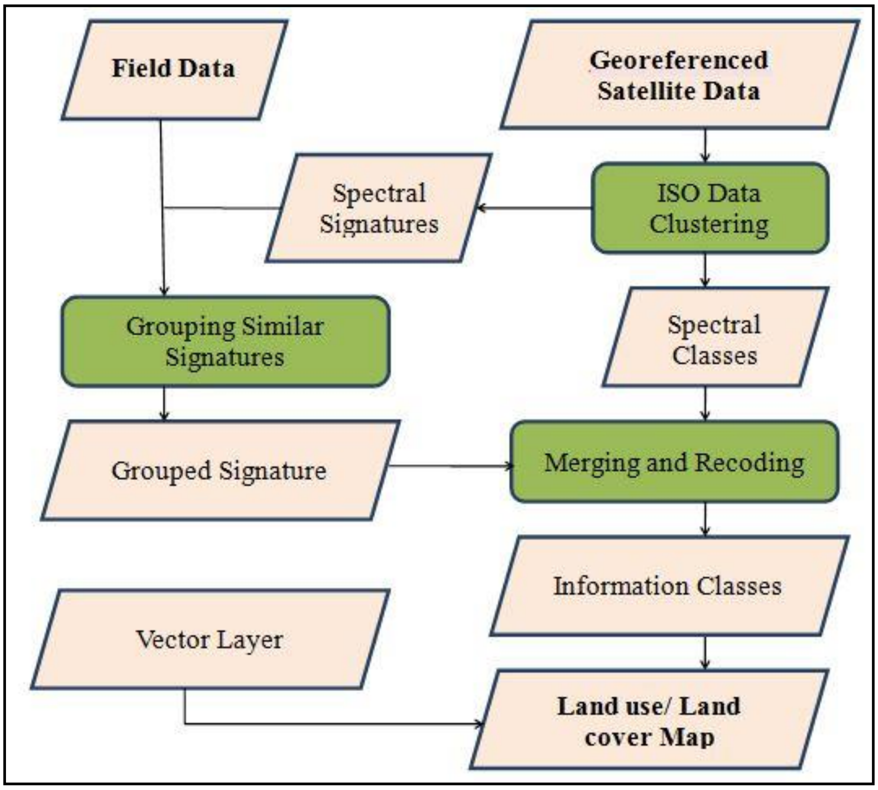


Figure 3-3: Schematic diagram of LANDSAT image processing steps for land use and land cover mapping

After visual interpretation, a digital unsupervised classification was done to derive different land uses/ land covers from satellite images. At first, 50 spectral classes were generated using an unsupervised classification method. ERDAS IMAGINE uses the ISODATA algorithm to perform an unsupervised classification. ISODATA stands for "Iterative Self-Organizing Data Analysis Technique." It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. "Self-Organizing" refers to the way in which it locates the clusters that are inherent in the data. The ISODATA clustering method uses the minimum spectral distance formula to form clusters. It begins with either arbitrary cluster means or means of an existing signature set, and each time the clustering repeats, the means of these clusters are shifted. The new cluster means are used for the next iteration. The ISODATA utility repeats the clustering of the image until either a maximum number of iterations have been performed, or a maximum percentage of unchanged pixels have been reached between two iterations.

The mean signature plot for each class was verified with ground truth data which was collected from the project of Ministry of Land of CEGIS. The similar spectral classes were grouped together and labeled with a land use/ land cover based on ground truth data. Finally, information classes such as Agricultural Land, Current Fallow Land, Bare Soil / Sand and Water were derived from 50 spectral classes. The settlement and forest parts were taken from the vector layer data collected from the CEGIS archive.

The descriptions of land use of Dhaka district are given as follows:

Agricultural land: Agriculture land is flat lands comprising many continuous plots and found in plain lands which may have crop or may be grass. It was identified by its finer texture and specific shape (mostly rectangular form) in the satellite images. Field information and geographic knowledge also helped identify and interpret the agriculture land from the satellite images.

Current Fallow: These are the flat lands which were found fallow in that specific date of image. Most of the cases it is seen that in other months the lands are full of crop.

Bare Soil/ Sand: Describe open areas covered by unconsolidated material. The unconsolidated material is generic-sized although this class was usually associated with fine-grain deposits along the lower reaches of the main rivers valleys or in the valley floor (such as along the Brahmaputra River). Sand dunes (beach), the mudflat areas, i.e. moist mud areas, which lie between low tidal and high tidal influences, are included in the class. Bare land includes the lands without vegetation those are visible on the satellite images.

Water: All types of water bodies those include lakes, ponds, ditches, rivers and canals which are perennial water bodies being visible in satellite images are considered as water.

3.2.2.2 Flood duration delineation with water level data

All the water level data and danger level of the stations located within the district were collected from BWDB. The data were available from 1998 to 2007 of the months from June to October. The specific stations were Demra (SW7.5) on the Balu River, Nayarhat (SW14.5) on the Bangshi River, Mill Barak (SW42) and Hariharpara (SW43) on the Buriganga River, Savar (SW69) and Kalatia (SW70) on the Dhaleshwari River, Demra (SW179) on the Lakhya River, Tongi (SW299) on the Tongi Khal and Mirpur (SW302) on the Turag River.

First of all, one station was taken for analysis. The highest water levels for that station were arranged showing the danger level and found out in which year it crossed the danger level.

This is because, if the water level does not cross the danger level in a year, we cannot say it as a flood year. All the water levels of that station were plotted and made a hydrograph. After getting the flooded year, water level versus month curve helped find out the duration of flood of that specific flooded year.

The similar process was done for all the stations for respected flooded year.

3.2.3 Key person interviewing

Eight key informant interviews (KII) have been taken for the authenticity of this study. The KIIs have been taken from the following key persons:

- Executive Engineer Flood Forecasting and Warning Center (FFWC), Bangladesh Water Development Board (BWDB).
- Former Director General, Water Resources Planning Organization (WARPO).
- Former Additional Director General, BWDB.
- Water Resources Expert, Water Resources Division, CEGIS.
- Director, Climate change Study and Disaster Management Division, CEGIS.
- Deputy Managing Director (Operation and Maintenance), DWASA.
- Chief Engineer, Project and Design, RAJUK.
- Superintending Engineer, Dhaka South City Corporation.

These key persons explained about the suitability of these adaptive approaches for Dhaka. They also explained, what would be the drawback and what measures should be taken in place to apply this approach for Dhaka.

Chapter 4
Floods in Dhaka

4.1 Causes and Types of Flood

The distributaries of the two major rivers, the Brahmaputra and the Meghna surround the Dhaka district. The district is composed of low-lying areas and alluvial traces. The highest water levels in the surrounding rivers are affected by the discharge of the Brahmaputra-Jamuna River, local rainfall and also the backwater from the Meghna River when heavy rainfall occurs in the north eastern part of Bangladesh and a high tide in the Bay of Bengal usually in August – September (FAP 8A, 1991). Sometimes these may cause floods in Dhaka mostly when heavy rains coincide with the peak discharge of those rivers.

However, now-a-days drainage congestion is the main problem in Dhaka. Population growth is the impulsive factor for urban flooding in Dhaka. As a result, land- filling for developing land causes reduction of water storage as well as the easy passage of the flood water into river system. Thus, urban flood occurs in Dhaka.

Floods result from a combination of the following factors,

- **Meteorological factors:**

    i. Rainfall
    ii. Cyclonic storms
    iii. Small-sale storms
    iv. Temperature

- **Hydrological factors:**

    i. Soil moisture level
    ii. Groundwater level prior to a storm
    iii. Natural surface infiltration
    iv. Presence of impervious cover
    v. Channel cross- sectional shape and roughness
    vi. Presence or absence of over bank flow channel network
    vii. Synchronization of runoffs from various parts of watershed
    viii. High tide impending drainage

- **Human factors aggravating natural flood hazards:**

    i. Land use changes (e.g. surface sealing due to urbanization, deforestation) increase runoff and may be sedimentation
    ii. Occupation of the flood plain obstructing flows
    iii. Inefficiency or non-maintenance of infrastructure
    iv. Poor drainage system
    v. Climate change affects magnitude and frequency of precipitations and floods
    vi. Urban microclimate may enforce precipitation events

According to the factors, floods can be divided into two types in Dhaka and those are: local floods and riverine floods.

Local floods generally occur due to very high rainfall during the rainy season and confined to small geographical areas and are normally not of long duration. Built environments like cities

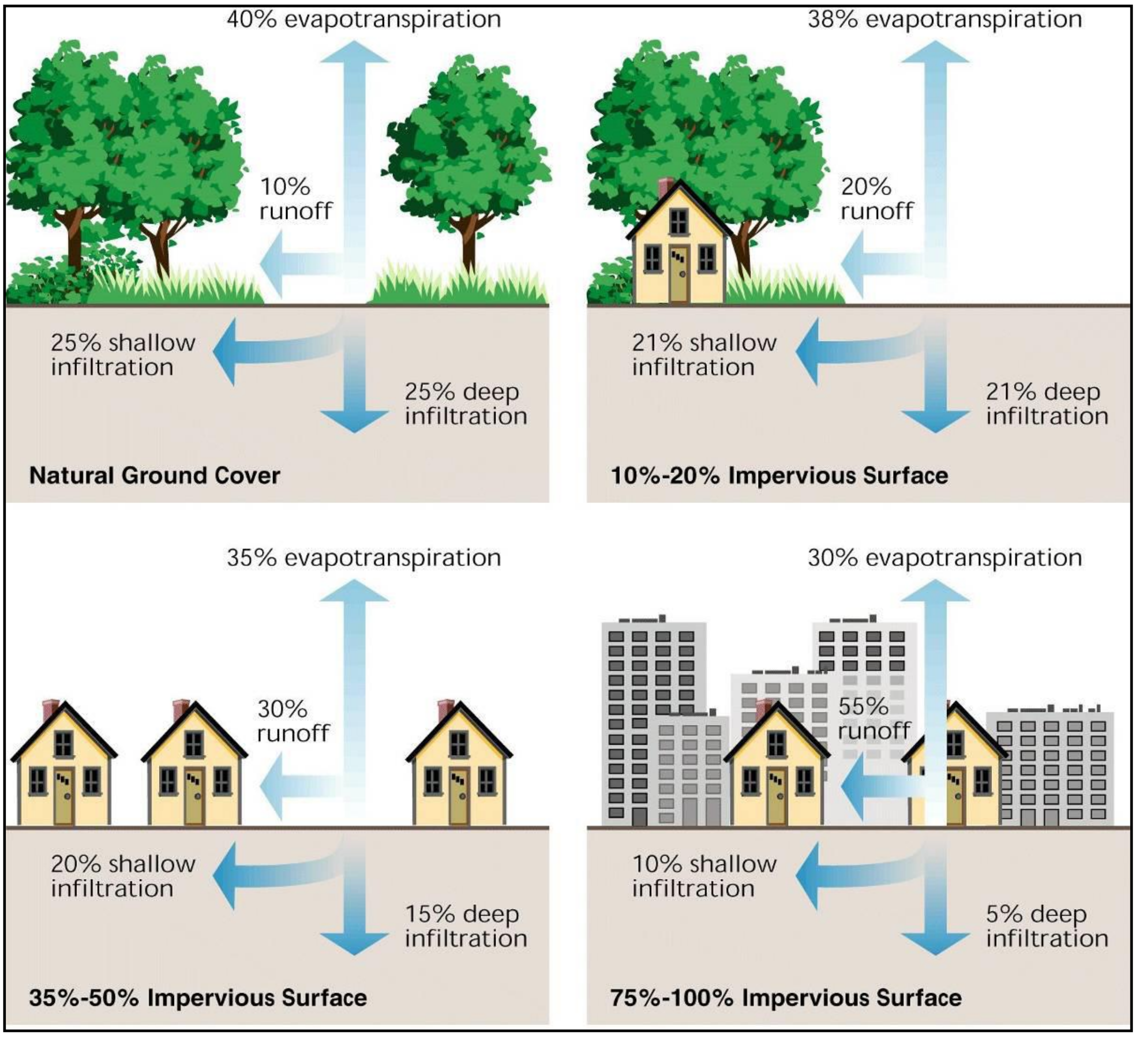


Figure 4-1: The influence of urbanization on different components of the water cycle[1]

generate higher surface runoff which exceeds local drainage capacity and causes local floods. **Figure 4-1** shows how runoff increased and infiltration decreased due to urbanization. Unfortunately, in Dhaka, drainage facilities are not well enough due to lack of cleaning and maintenance of the drainage systems. Rubbish and solid waste clog and reduce the drainage capacity and increase surface runoff. Furthermore, rising in groundwater or surface flows can be other causes of local floods. Local floods may last for weeks and result in widespread destruction. Flood plains are subjected to annual flooding.

[1] *Source: http://www.nrcs.usda.gov/technical/stream_restoration/Images/scrhimage/chap3/fig3-21.jpg*

River floods generally occur when the river runoff volume exceeds local flow capacity. River floods are usually long lasting and last for a few weeks or even a month. Most of the cases flood plains are flooded during the monsoon (WMO/GWP, 2008b).

4.2 Food Duration

To find out the flood duration of Dhaka, the water level of the rivers surrounding the district were collected from BWDB. The water levels were available for the years from 1998 to 2007. In a flood year the water level exceeded the danger level of those rivers. Following figures show the hydrographs of the water level of Balu River at Demra station, Bangshi River at Nayarhat station, Buriganga River at Mil Barak and Hariharpara station, Tongi Khal at Tongi station, Turag River at Mirpur station, Lakhya River at Demra station and Dhaleshwari River at Savar and Kalatia stations in 1998.

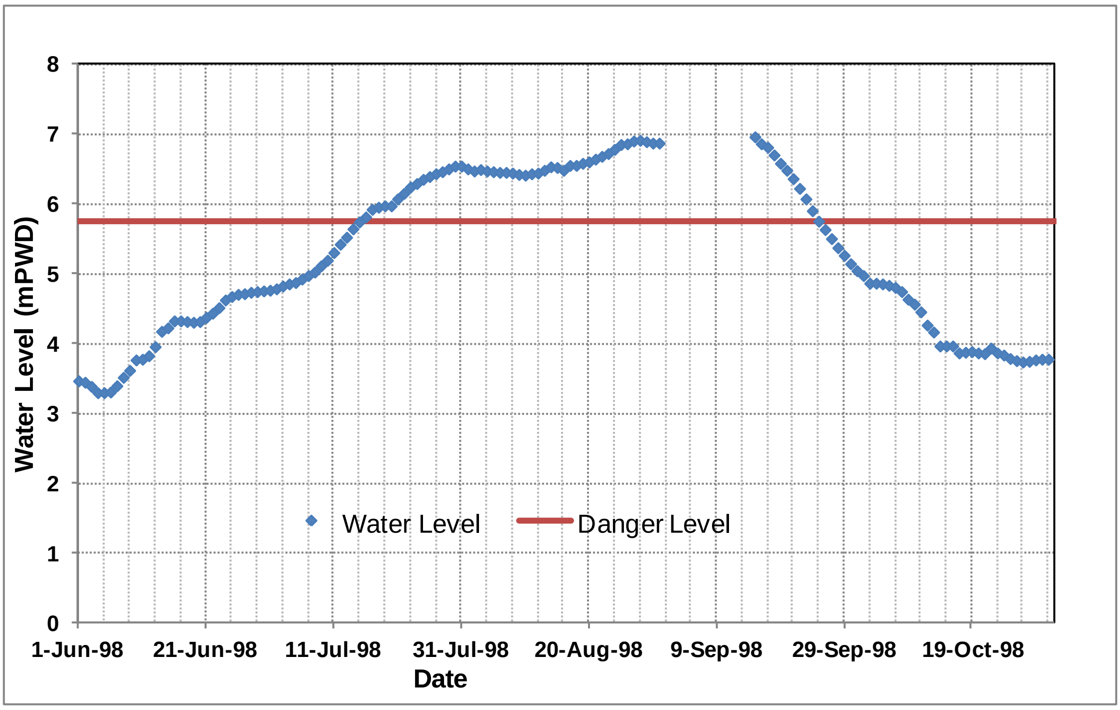


Figure 4-2: Water level hydrograph of the Balu River at Demra

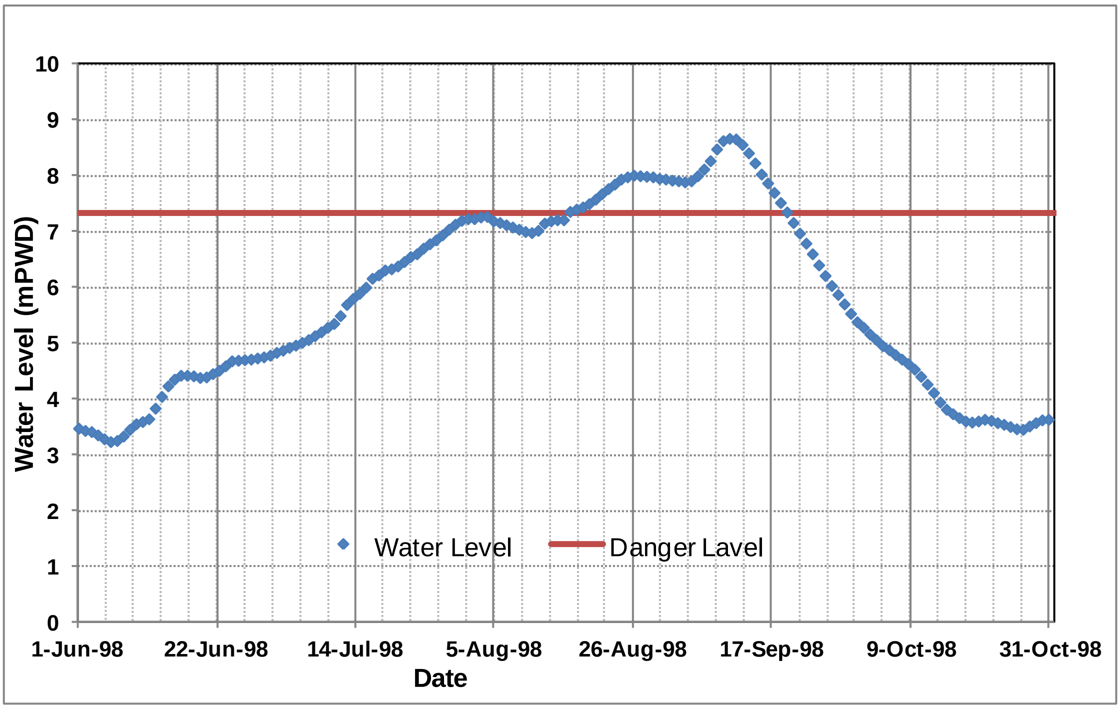


Figure 4-3: Water level hydrograph of the Bangshi River at Nayarhat

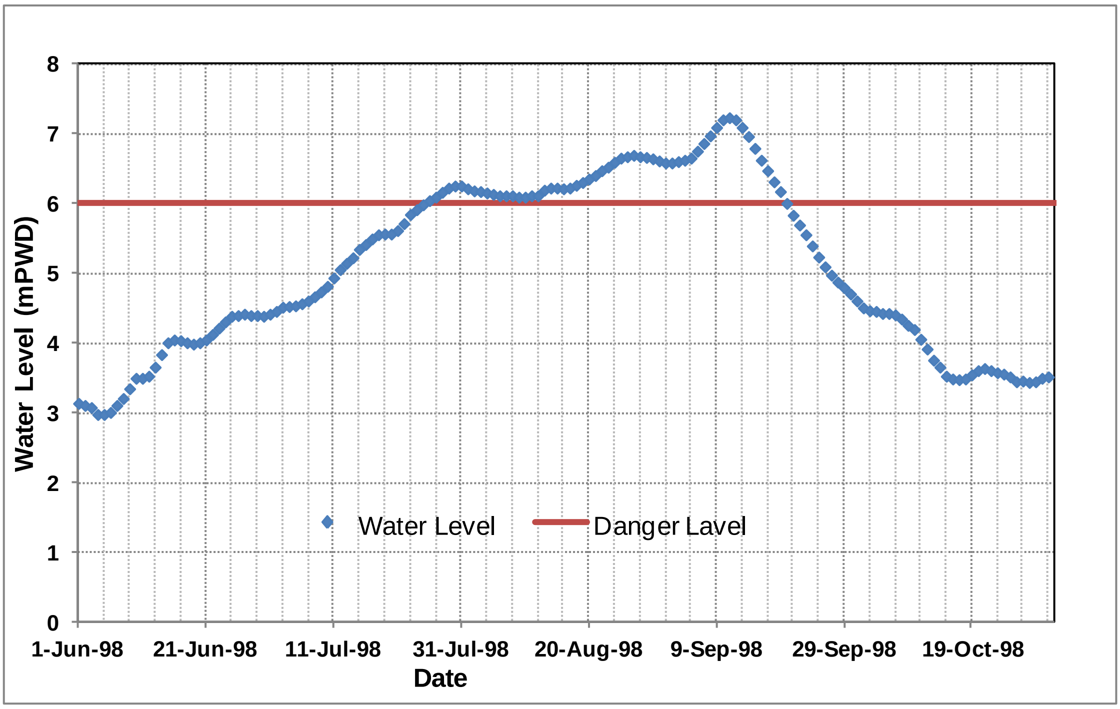


Figure 4-4: Water level hydrograph of the Buriganga River at Mill Barak

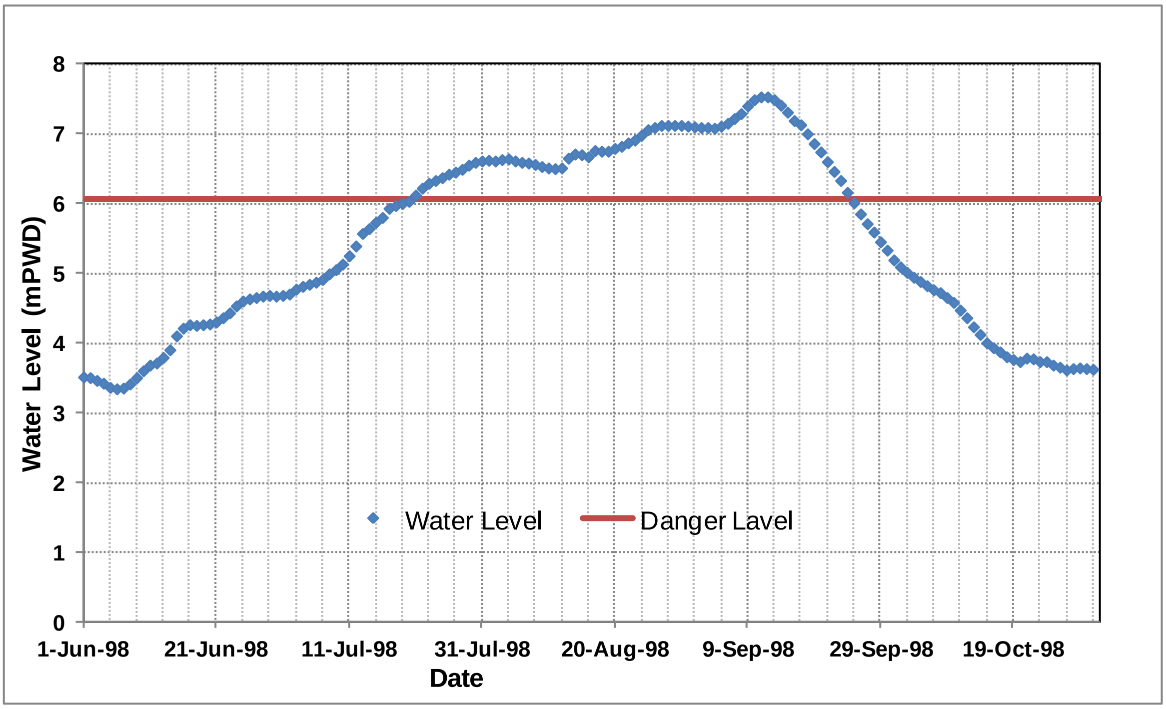


Figure 4-5: Water level hydrograph of the Tongi Khal at Tongi

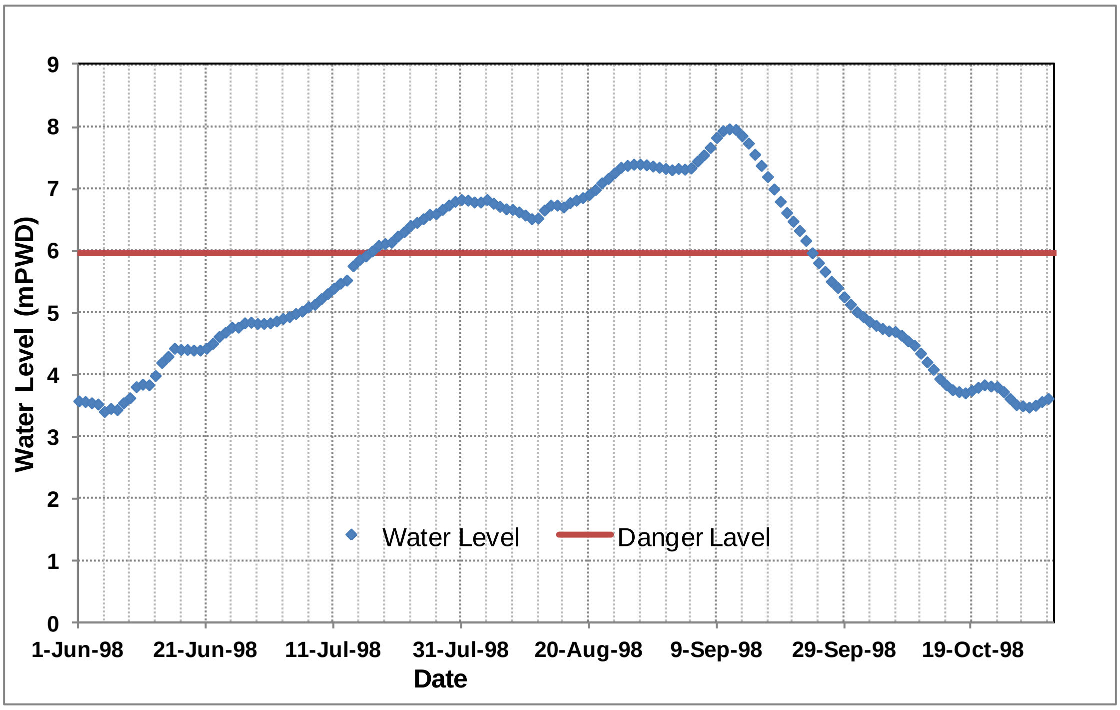


Figure 4-6: Water level hydrograph of the Turag River at Mirpur

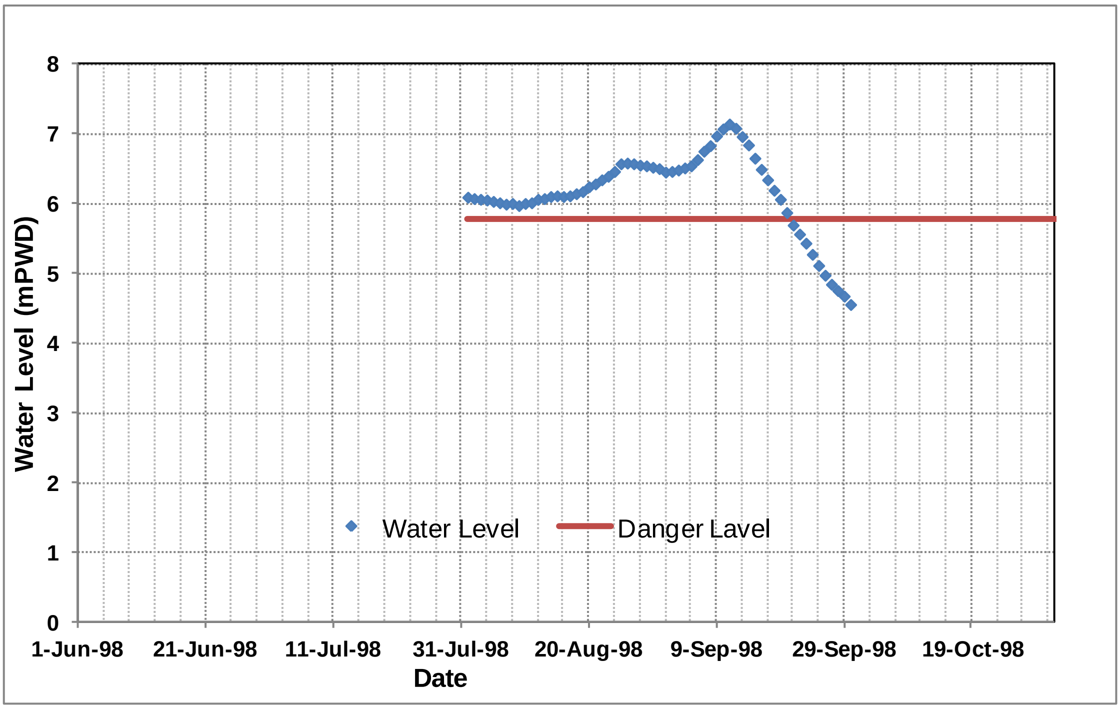


Figure 4-7: Water level hydrograph of the Buriganga River at Hariharpara

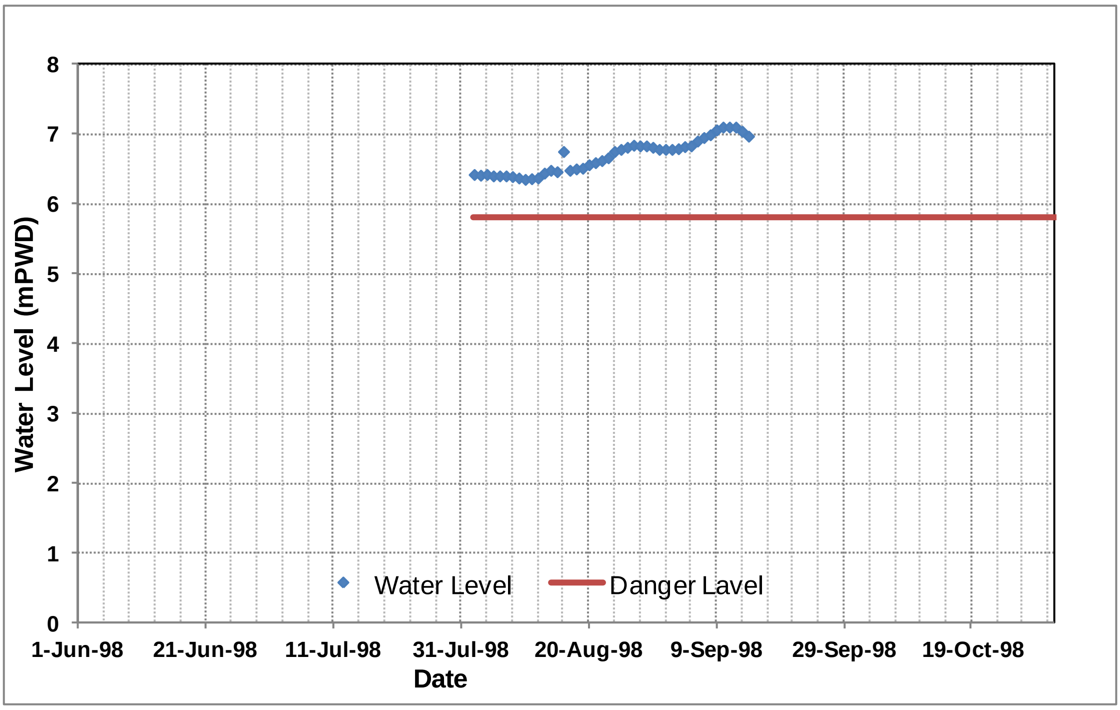


Figure 4-8: Water level hydrograph of the Lakhya River at Demra

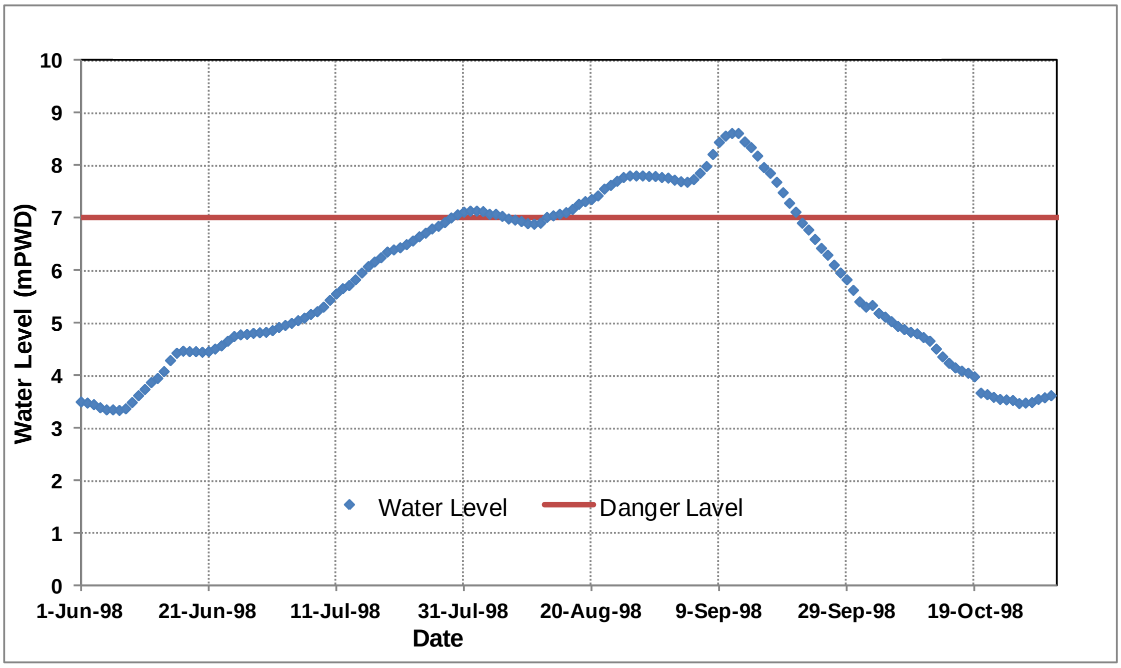


Figure 4-9: Water level hydrograph of the Dhaleswari River at Savar

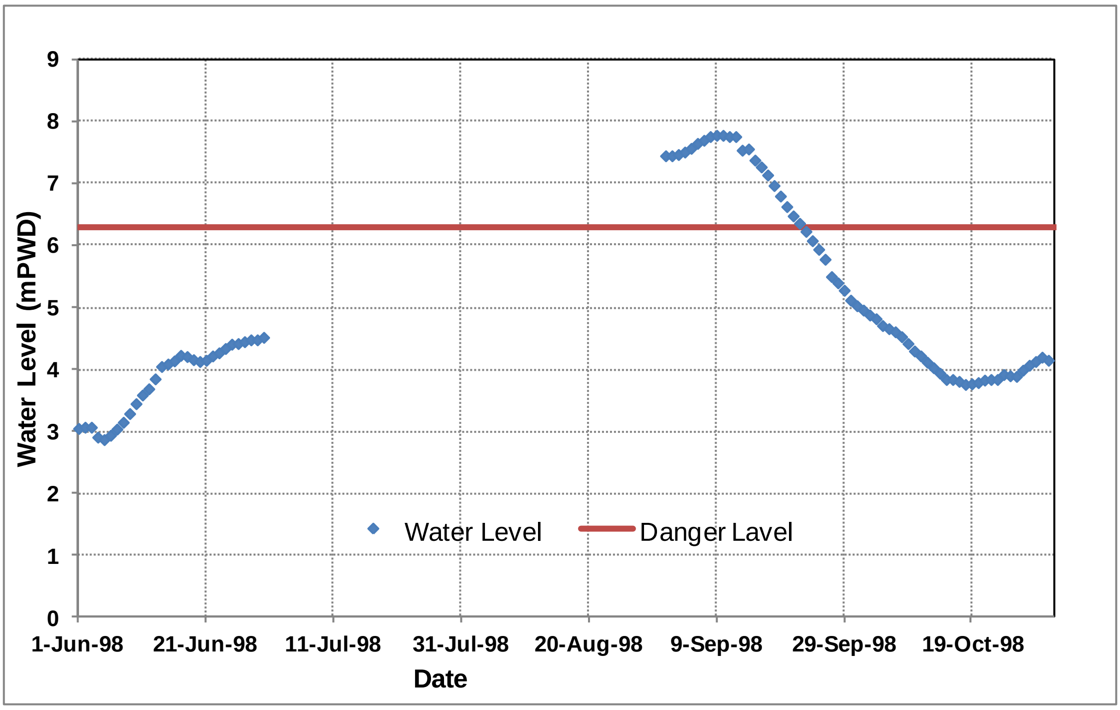


Figure 4-10: Water level hydrograph of the Dhaleswari River at Kalatia

The above figures show, in the flood year, 1998, the duration of flood was from mid-July to mid-September. The hydro graphs of the rivers for the other years are given in ANNEX A section of this report.

In the figure of the hydrograph of the Balu River at Demra station, in the ANNEX A part it is seen that in 1998, 1999, 2002, 2003, 2004, 2005 and 2007 the water level was higher than that of the danger level of the Balu River (**Figure A 1 and A 2**). The water level was the highest in 1998 and in 2004. In 1998 the duration of flood was from mid-July to mid-September (**Figure A 3**), whereas in 2004 the flood duration was from mid-July to mid-August (**Figure A 4**).

Similarly, from the hydrograph of the Bangshi River at Nayarhat station and Dhaleswari River at Savar station, in the ANNEX A part, it is seen that only in 1998 the water levels crossed the danger level (**Figure A 5 and A 6**). In this year, the duration of flood was from mid-August to last of September. For the Buriganga River, the water level crossed the danger level at Mill Barak station in 1998 and 2004 (**Figure A 8 and A 9**). The hydrographs of this station show that in 1998 (**Figure A 10**) and 2004 (**Figure A 11**) the duration of flood was from mid-July to mid-September and from mid-July to early August respectively.

For the Tongi Khal, the scenario was like the Buriganga River at Mill Barak station (**Figure A 12 and A 13**). In 1998 the flood duration was from mid-July to the last of September. However, in 2004, it was from mid-July to mid-August (Figure **Figure A 15**).

For the Turag River, the maximum water level crossed the danger level in 1998, 1999, 2000, 2002, 2003 and 2004 at Mirpur station (**Figure A 16 and A 17**). In addition, it was seen that in 1998 the flood duration was longer and the water level was the higher than that of in 2004 (**Figure A 18 and A 19**).

The water level of the Dhaleswari River crossed the danger level only in 1998 at Savar station (**Figure A 27 and A 28**) and the flood duration of this year, was from last of July to mid-September (**Figure A 29**).

At Hariharpara station, the water level of the Buriganga River crossed the danger level only in 1998 (**Figure A 20 and A 21**). However the Lakhya River crossed the danger level in 1998, 1999, 2000, 2002, 2003, 2004 and 2005 at Demra station (**Figure A 23 and A 24**). Moreover, the Dhaleswari River crossed its danger level in 1998, 1999, 2000, 2001, 2003 and 2004 at Kalatia station (**Figure A 30 and A 31**). Due to unavailability of data of these stations it was not possible to find out the flood duration properly in those flood years.

From the above figures and the water level data of BWDB, it can be concluded that most of the cases flood season starts from mid-July and ends at mid-September.

4.3 Flood Extent

To delineate the flood water extent RADARSAT ScanSAR images were used of 1998, 2000, 2001, 2002, 2003, 2004 and 2007. After classification of the satellite images the Flood Extent Maps are shown in the following figures.

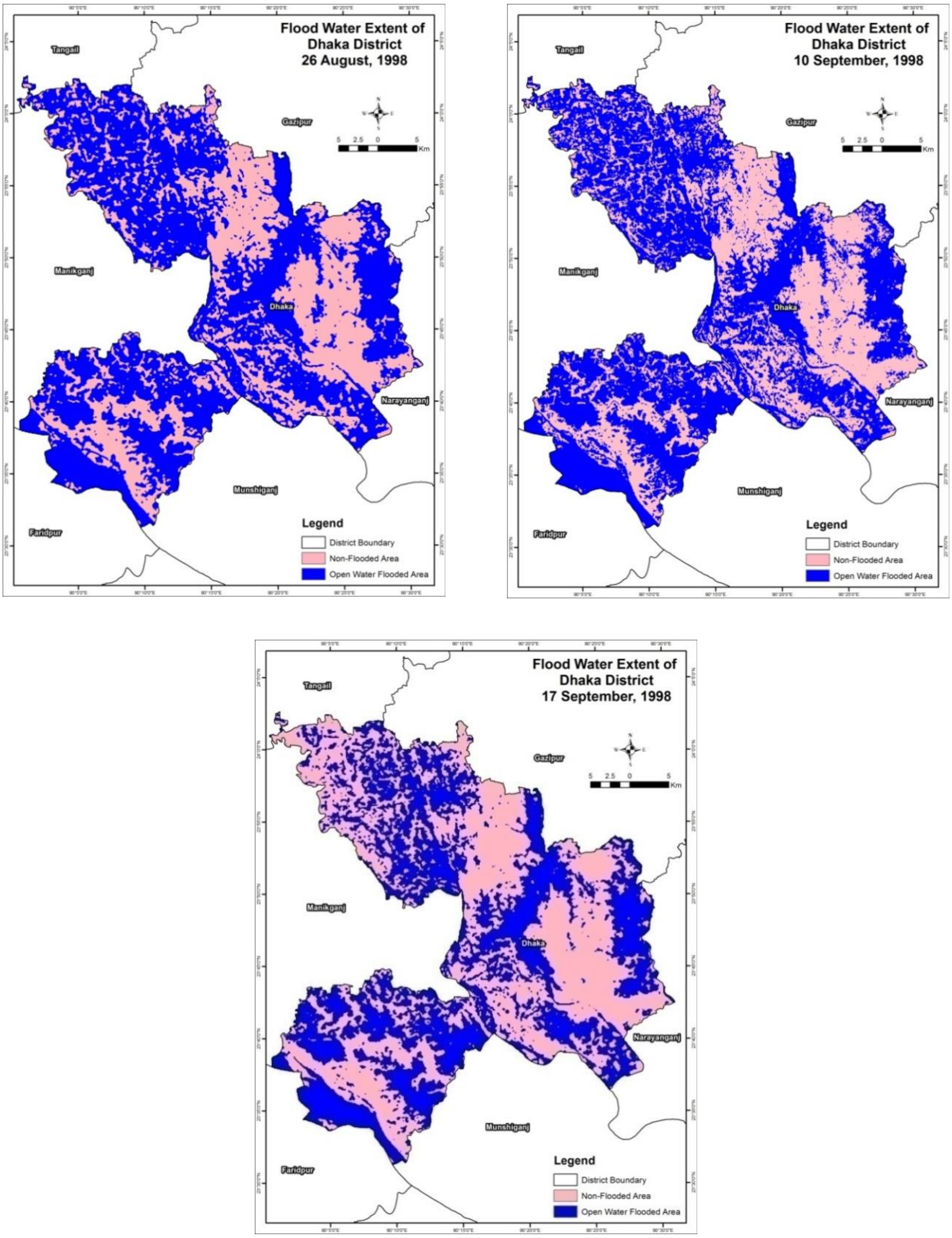
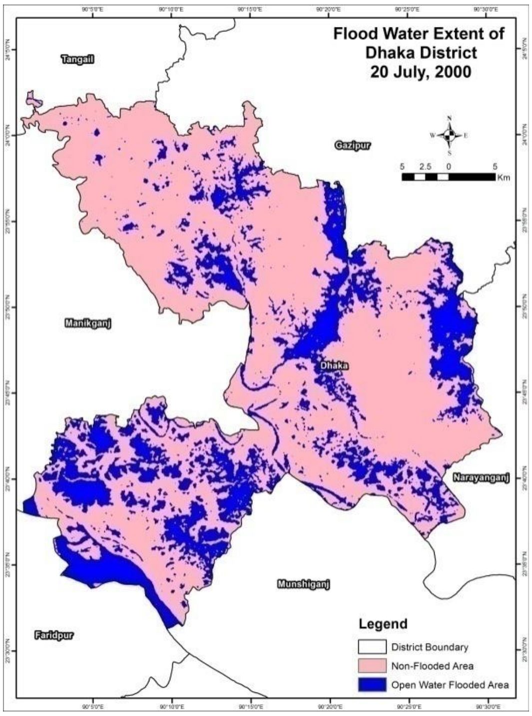
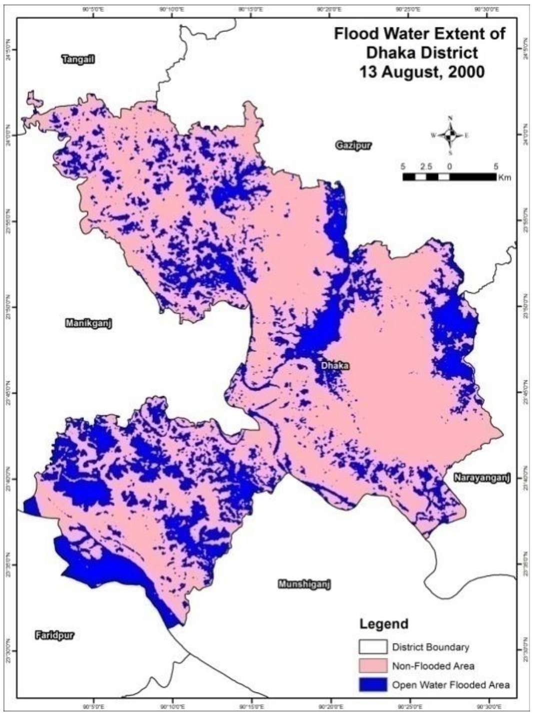
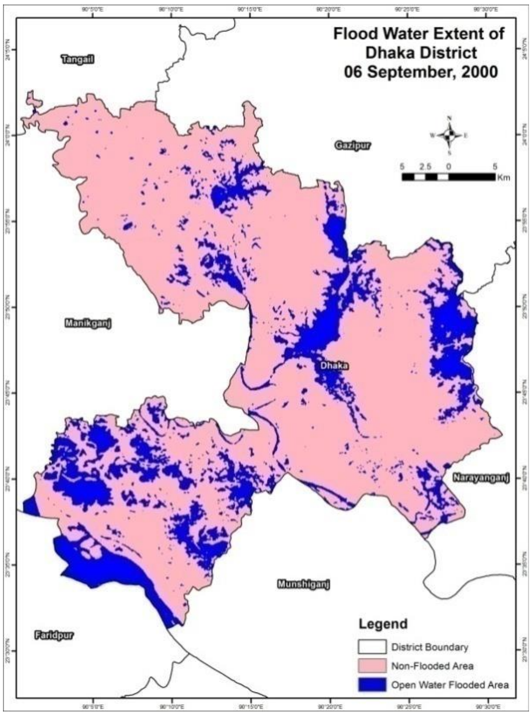


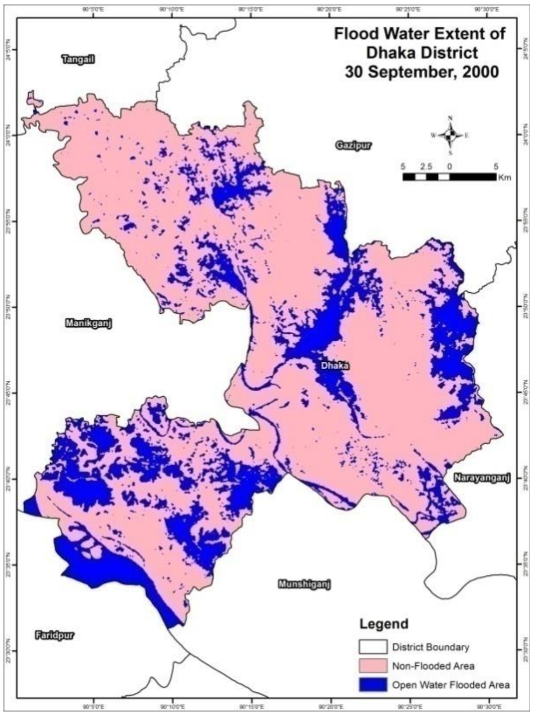
Figure 4-11: Classification of images of 1998

From the above figure, it is seen that after 10th September, 1998 flood water decreased gradually. Almost full of the district was under flood water in 1998 excluding some high lands.


Flood Water Extent of
Dhaka District
20 July, 2000
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
5 2.5 0 5
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
13 August, 2000
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
5 2.5 0 5
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
06 September, 2000
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
5 2.5 0 5
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
30 September, 2000
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
5 2.5 0 5
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area

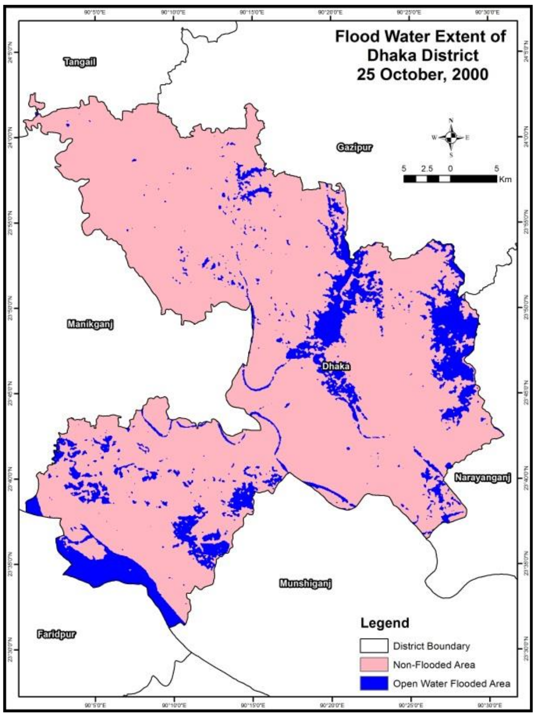
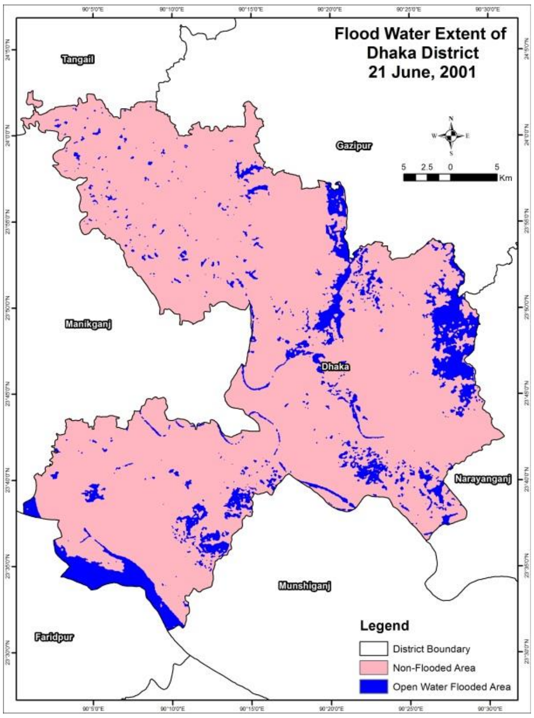
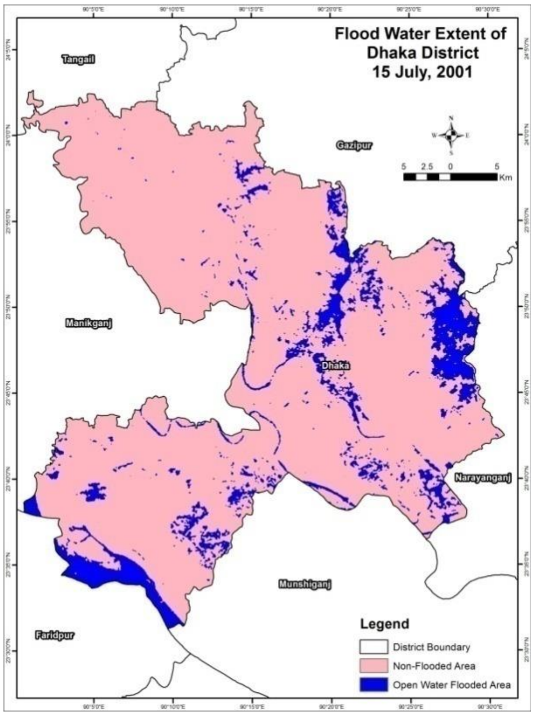


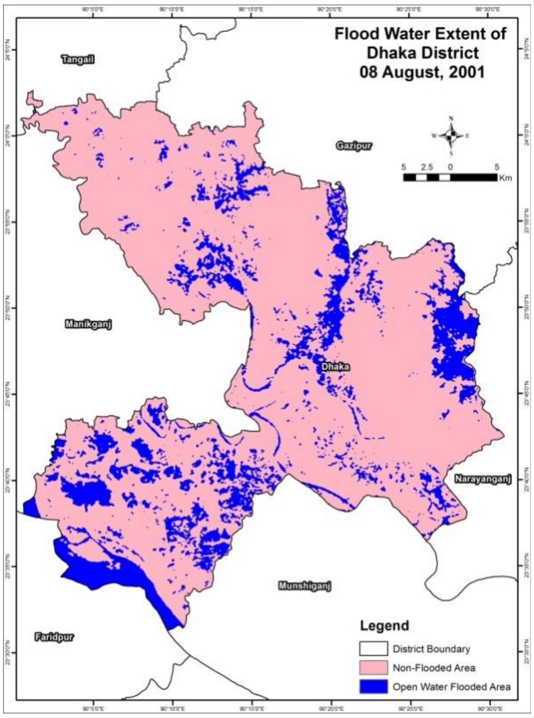
Figure 4-12: Classification of images of 2000 (continued)

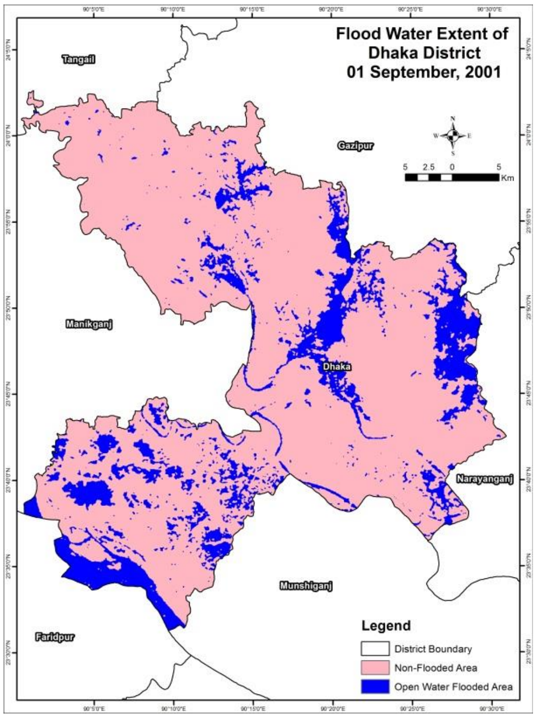
Figure 4-12 shows the classification of the images of 2000. From the figure it is seen that, in August open water flooded area increased from the extent area of July. Then it decreased gradually in September and in October water was only present in the low lying area of Dhaka. The year, 2000 was not a flood year but the floodplains and some low-lying fringe areas were inundated during this year.

The scenario is similar for 2001 which was not a flood year. However, some places were inundated during monsoon.


Flood Water Extent of
Dhaka District
21 June, 2001
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
15 July, 2001
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
08 August, 2001
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
01 September, 2001
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Km
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area

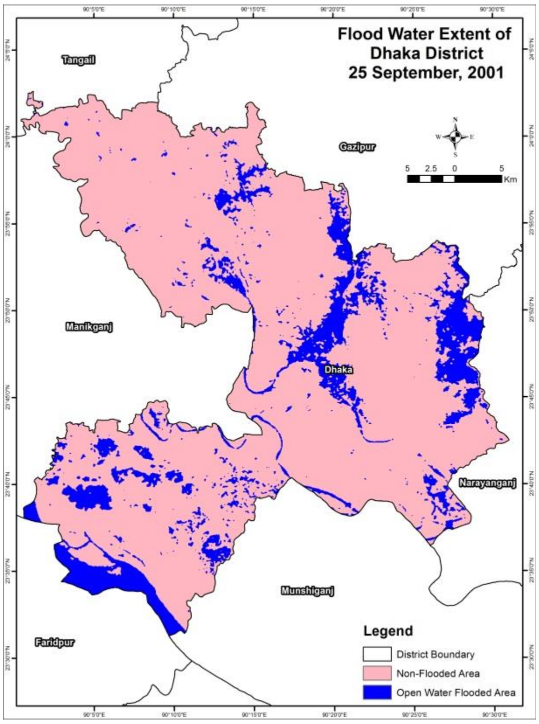
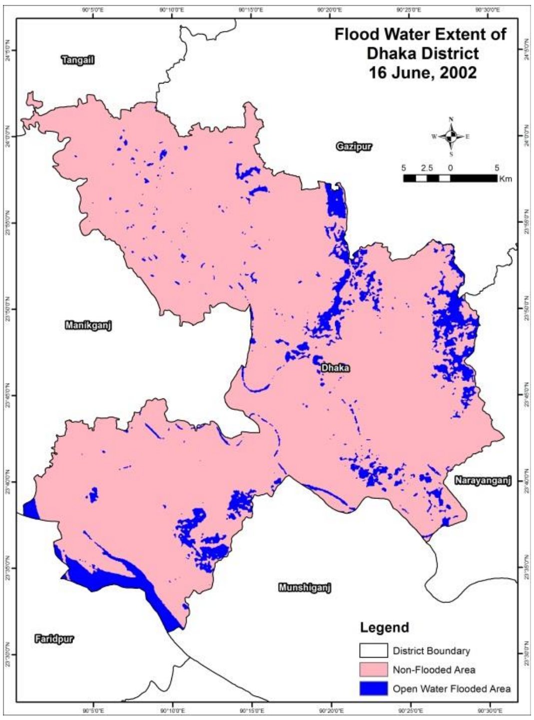
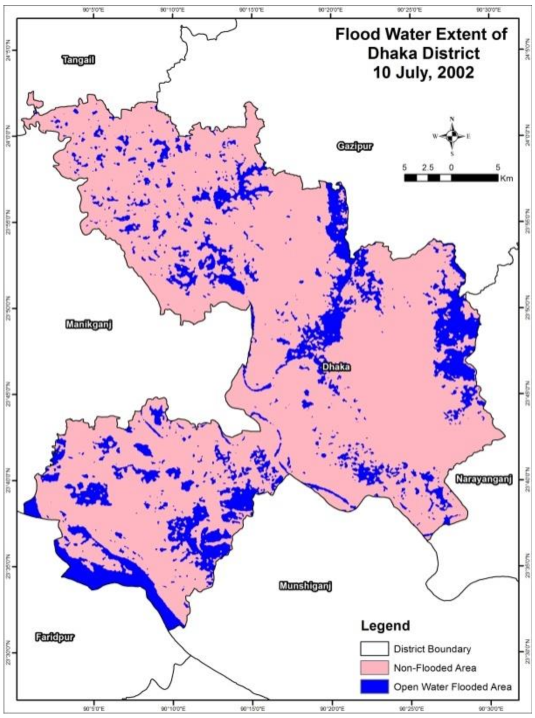
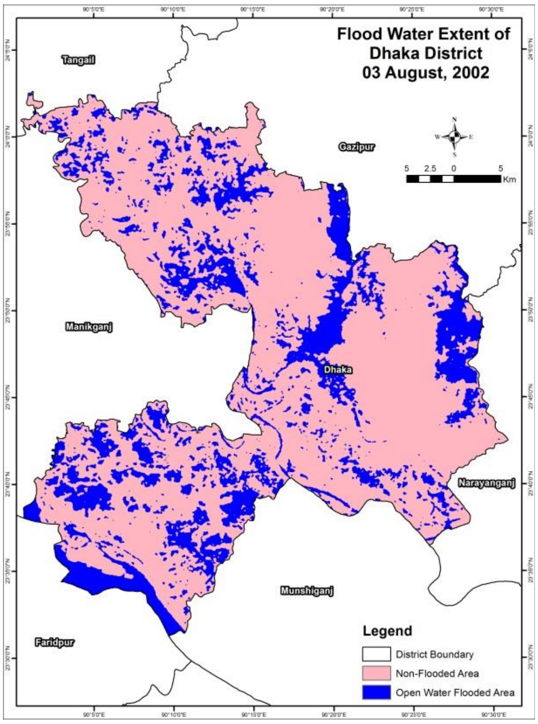


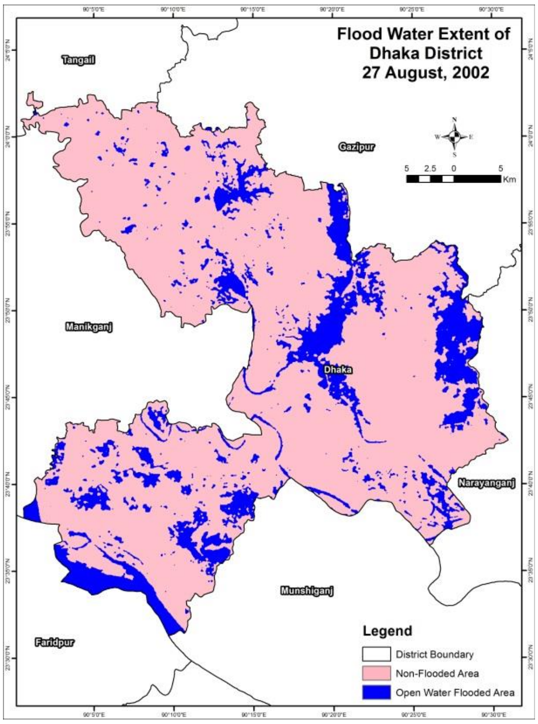
Figure 4-13: Classification of images of 2001 (continued)

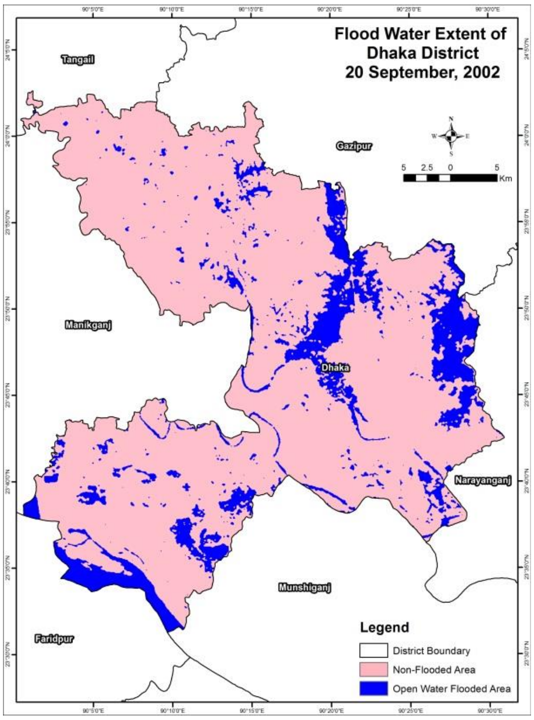
Figure 4-13 shows the changes of open water flood extent in 2001 from June to September. Here, from the figures it is seen that from mid-July to mid-September the open water flooded area has the larger area compare to other months.

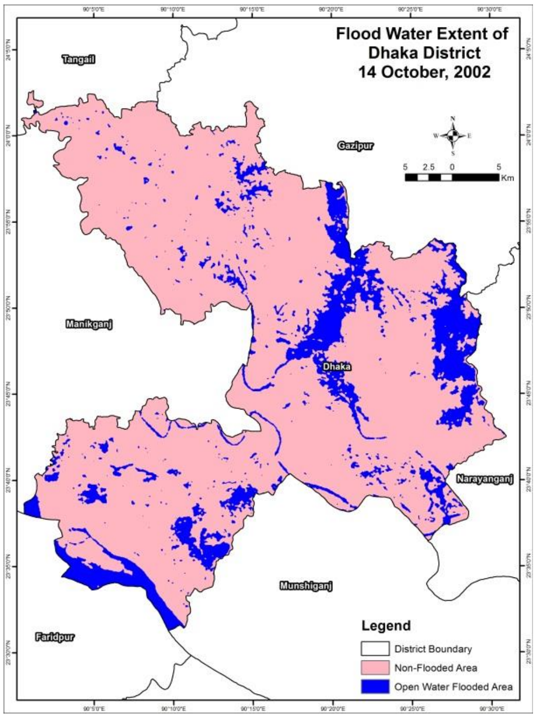





Flood Water Extent of
Dhaka District
03 August, 2002
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
27 August, 2002
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
20 September, 2002
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area


Flood Water Extent of
Dhaka District
14 October, 2002
Tangail
Gazipur
Manikganj
Dhaka
Narayanganj
Munshiganj
Faridpur
Legend
District Boundary
Non-Flooded Area
Open Water Flooded Area

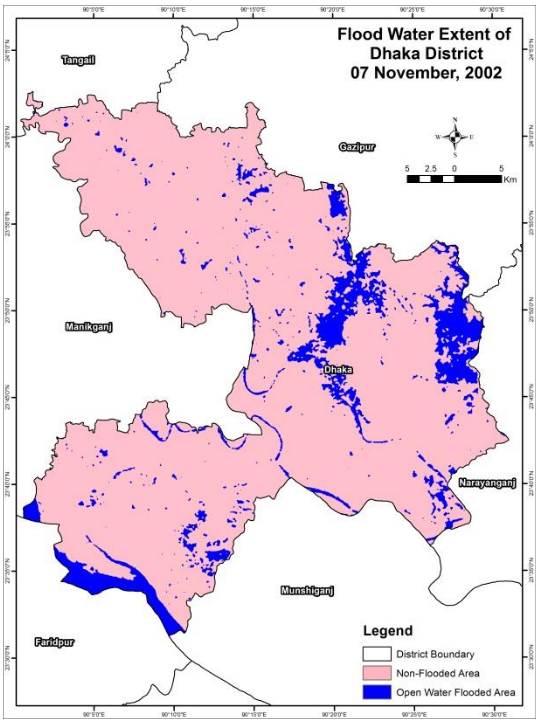
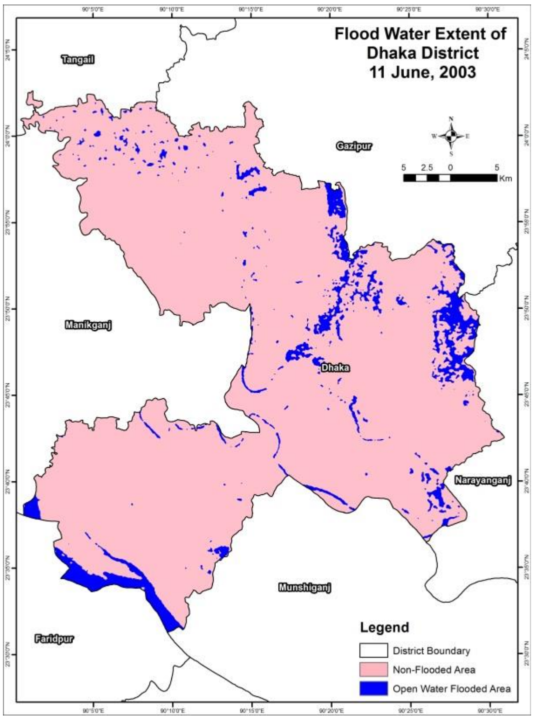
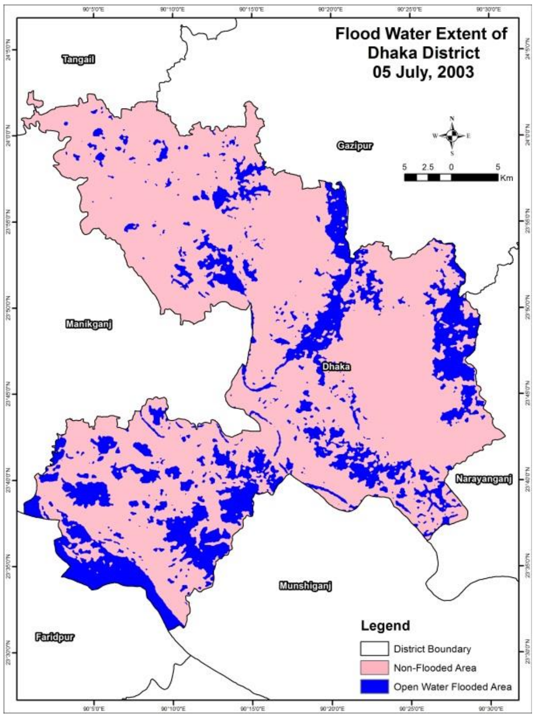


Figure 4-14: Classification of images of 2002 (continued)

In the year 2002, (**Figure 4-14**), it can be said that the extent of open water flooded area is the smallest in June and November. It increased after June and in mid-July to mid- August the extent was the highest then it decreased gradually after mid- August. Similar result was found for 2003 (**Figure 4-15**).





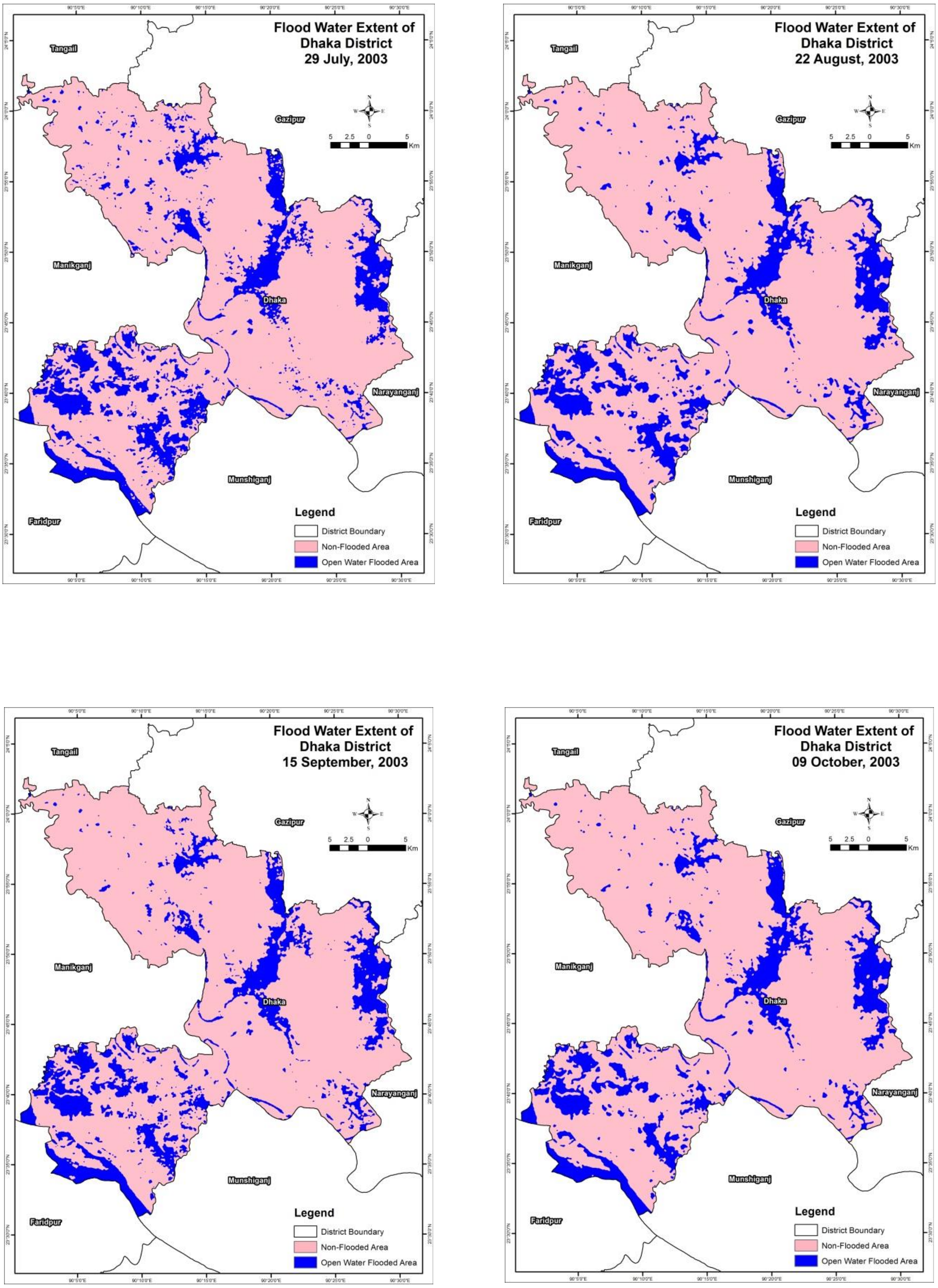


Figure 4-15: Classification of images of 2003 (continued)

The classification of images of 2004 of 29 June, 23 July, 16 August and 9 September are shown in the **Figure 4-16**. Here, in 2004, it is visualized that in July the water extent was the highest compare to the other dates.

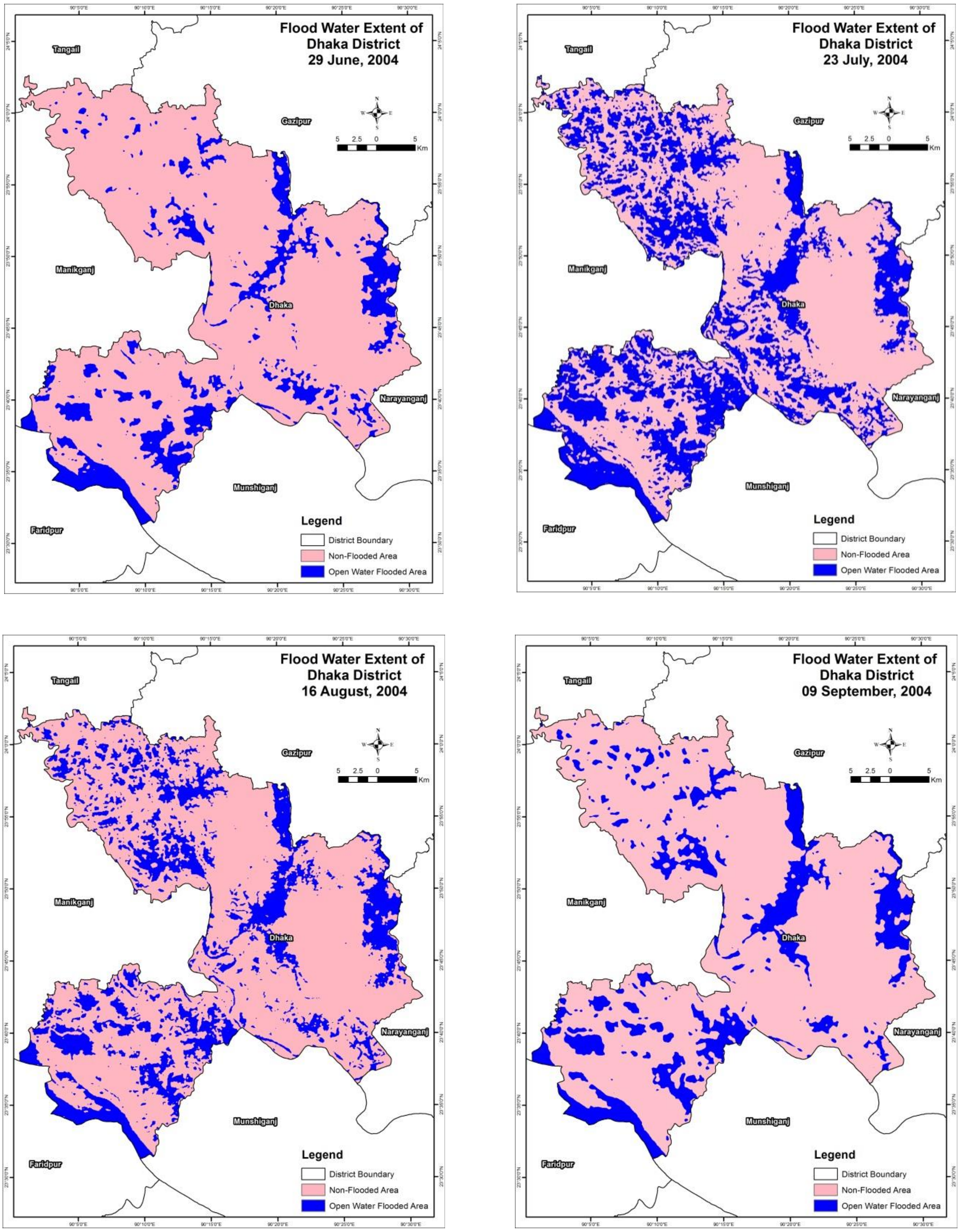


Figure 4-16: Classification of images of 2004 (continued)

Unfortunately, only one image was available in CEGIS archive so that the trend of water extent over the monsoon period it could not be shown. The following figure shows the only classification image of 2007 of open water flooded Area on 03 August.

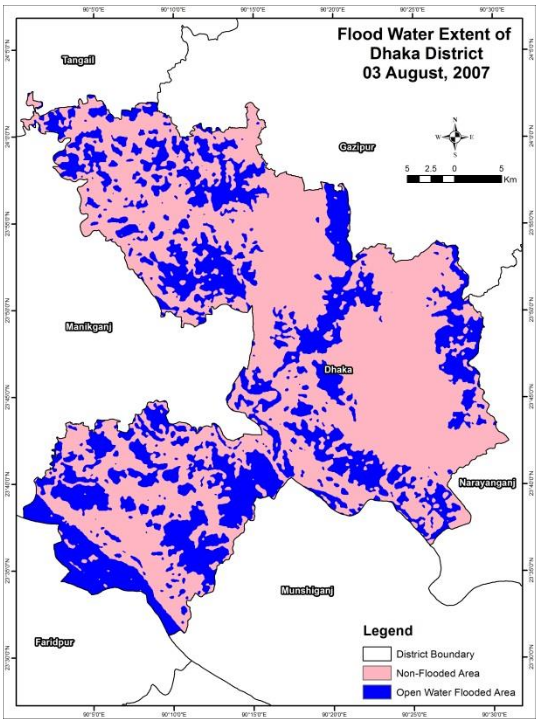


Figure 4-17: Classification of images of 2007

4.3.1 Combined flood hazard

Analyzing all the scenarios of the classification data it can be said that, the mostly and often flooded area (**Figure 4-18**) are mostly prone to flood due to extent. The areas were declared as flood prone zone, finding out how much flood occurred in those areas in 1998, 2000, 2001, 2002, 2003, 2004 and in 2007. Over this time period, the areas were declared as flood prone zone, in which flood occurred in minimum 4 or more years those were selected for this study.

In **Figure 4-18**, the pink area represents the area in which no flood occurred in any year and the darkest blue areas represent the Perennial Water Bodies. The blue shaded areas represent the areas in which open water flooded areas were present, in how many years. Those areas were declared as rarely flooded area, if flood occurred in those areas in one year only. Occasionally flood affected areas are declared as this name if the areas were affected by flood in two or three from the selected years. The flood affected areas were named as often flood affected area if flood occurred in those areas in 4 or 5 years. The areas are declared as mostly flooded areas in which the selected six or seven years (1998, 2000, 2001, 2002, 2003, 2004 and 2007) open water flooded areas were present. That means based on water extent and in every monsoon these areas are flooded by rainfall or overflow of river water or lack of proper drainage.

From the **Figure 4-18,** it is clear that the low-lying fringe area and flood plains are present at Savar, Dhamrai, Nawabganj, Khikhet, Demra and Badda. The western part of Dhaka city is well protected. However, the eastern part does not have any protection for flood unlike the western part. The low-lying fringe areas of the district as well as the eastern part of the city should be taken under consideration for the management of flood.

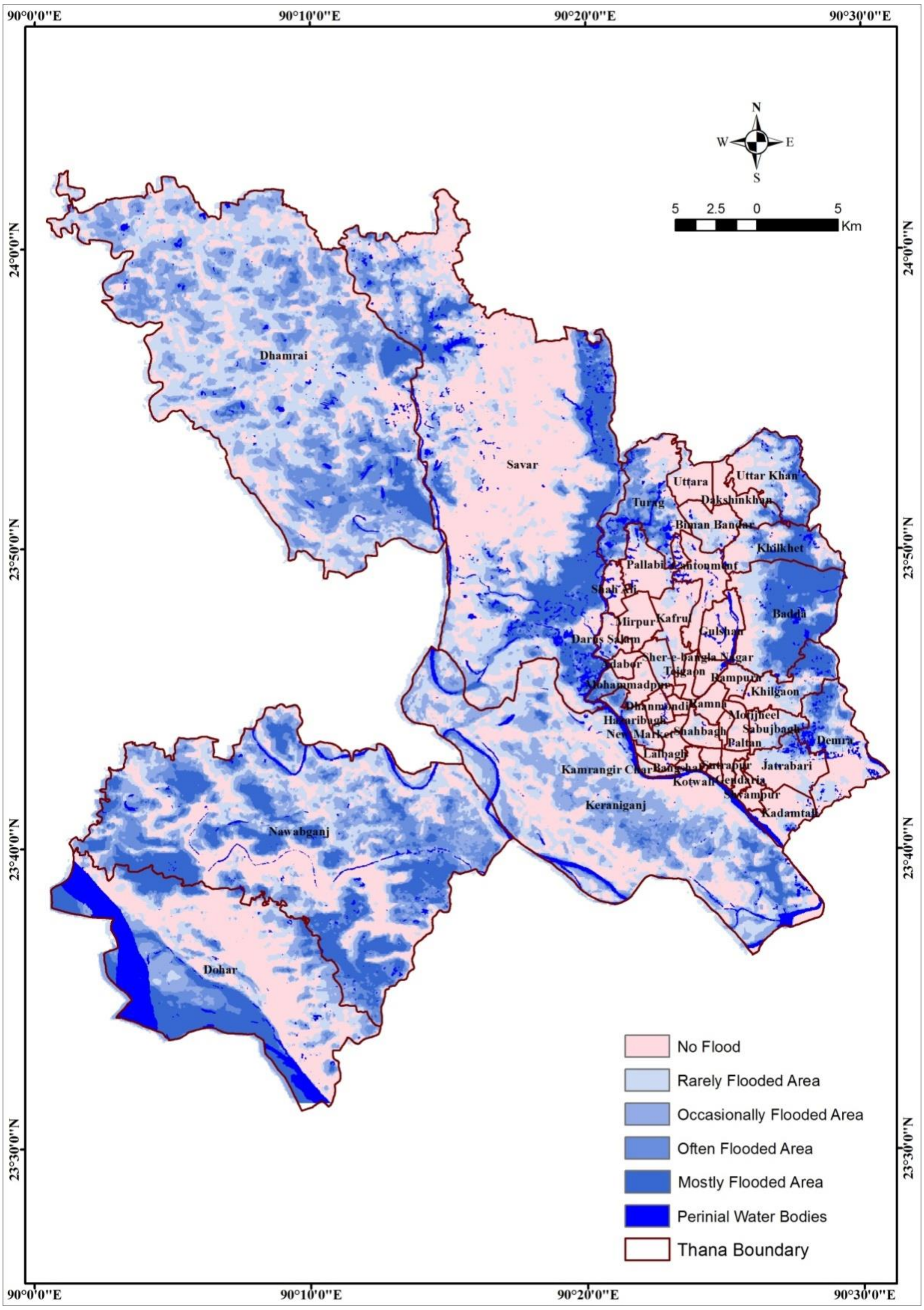


Figure 4-18: Flood vulnerability in Dhaka

4.4 Land Use Changes

To find out the land use changes in Dhaka district Landsat satellite images of 1989, 1997, 2003, 2010 and 2014 were used. After classification, the area statistics of land uses were generated for each year to understand the land use change trend within Dhaka district. The area coverage of each land use was measured in hectares.

4.4.1 Land use of Dhaka district of 1989

The land use statistics of Dhaka district of 1989 are given in **Table 4-1**. The table shows that the highest percentage of area was fallow land in 1989 and the lowest was forest and they were 37.26% and 0.01% accordingly. As the image of 1989 was dry season images and the date was 12 January, 1989 and the cultivated land was only 24.16%. 25.63% and 11.23% of area was for settlement and water respectively.

Table 4-1: Land use class of Dhaka district of 1989

Land use 1989		
Land use class	**Area (ha)**	**Area (%)**
Water	16601.00	11.23
Settlement	37883.00	25.63
Agriculture	35710.00	24.16
Current Fallow	55074.00	37.26
Bare Land/ Sand	2533.00	1.71
Forest	19.00	0.01
Total	**147820.00**	**100.00**

4.4.2 Land use of Dhaka district of 1997

The image used for 1997 was also dry season image and of the month, January. In this month most of the land was fallow and the highest percentage of total area of about 35.10 (**Table 4-2**). All the statistics are shown in the following table. Here, it is found that settlement area have increased in 1997 from the year 1989. The percentage of settlement area was 30.21 in 1997. Similar to 1989, in 1997 the lowest percentage of area was forest, which was 0.01.

Table 4-2: Land use class of Dhaka district of 1997

Land use 1997		
Land use class	**Area (ha)**	**Area (%)**
Water	15688.00	10.61
Settlement	44651.00	30.21
Agriculture	33308.00	22.53
Current Fallow	51878.00	35.10
Bare Land/ Sand	2278.00	1.54
Forest	17.00	0.01
Total	**147820.00**	**100.00**

4.4.3 Land use of Dhaka district of 2003

The land use statistics of 2003 are given in the following table. The highest and the lowest percentage of area were the fallow land and forest respectively. The percentages were 39.55 and 0.03. The percentage of the area of settlement, water and bare land/sand were 35.48, 4.85 and 1.57 accordingly.

Table 4-3: Land use class of Dhaka district of 2003

Land use 2003		
Land use class	**Area (ha)**	**Area (%)**
Water	7162.00	4.85
Settlement	52448.00	35.48
Agriculture	27374.00	18.52
Current Fallow	58460.00	39.55
Bare Land/ Sand	2325.00	1.57
Forest	51.00	0.03
Total	**147820.00**	**100.00**

4.4.4 Land use of Dhaka district of 2010

The land use statistics of Dhaka district of 2010 is given in the **Table 4-4**. In this year interestingly the percentage of the area of settlement increased highly and the percentage was the highest than that of the other area. The percentage of settlement area was 39.66 in 2010. The percentage of water, agriculture, fallow land, sand and forest were 4.26, 17.16, 34.78, 4.11 and 0.02 respectively in 2010. If we give a look on the percentage area of bare land/ sand in 2010 (**Table 4-4**), it can be said that the area increased more compared to 1989, 1997, 2003 and also 2014 (**Table 4-1, Table 4-2, Table 4-3 and Table 4-5**) which indicates between 2003 and 2010 most of the floodplains and water bodies were filled up. From the

Table 4-4: Land use class of Dhaka district of 2010

Land use 2010		
Land use class	**Area (ha)**	**Area (%)**
Water	6300.00	4.26
Settlement	58627.00	39.66
Agriculture	25365.00	17.16
Current Fallow	51418.00	34.78
Bare Land/ Sand	6080.00	4.11
Forest	30.00	0.02
Total	**147820.00**	**100.00**

classification of images (**Figure 4-19**) as well as from field data it was found that the filled up areas are using for housing projects and buildings and apartments are constructed being constructed.

4.4.5 Land use of Dhaka district of 2014

In this year, the change in land use, in percentage is given in the following table (**Table 4-5**). In this year, the highest percentage of total area was for settlement and which was 45.38 and the lowest one was for bare land/ sand area which was 2.03. As the images of 2014 were of the month of March more crops are found in the field.

Table 4-5: Land use class of Dhaka district of 2014

Land use 2014		
Land use class	**Area (ha)**	**Area (%)**
Water	8641.00	5.85
Settlement	67074.00	45.38
Agriculture	39345.00	26.62
Current Fallow	29765.00	20.14
Bare Land/ Sand	2995.00	2.03
Total	**147820.00**	**100.00**

4.4.6 Summary of the change in land use in Dhaka district

Figure 4-19 shows the changes in land use in Dhaka district from 1989 to 2014. From the figure it is clear that the settlement is growing rapidly in the eastern part of Dhaka. Moreover, Northern and North-Eastern part of this district are comparatively low lying land than that of the other parts. Most of the seasonal wetlands and beel areas in 1989 and 1997, were invisible in the other years because of land filling and fallow land was present in the classification of

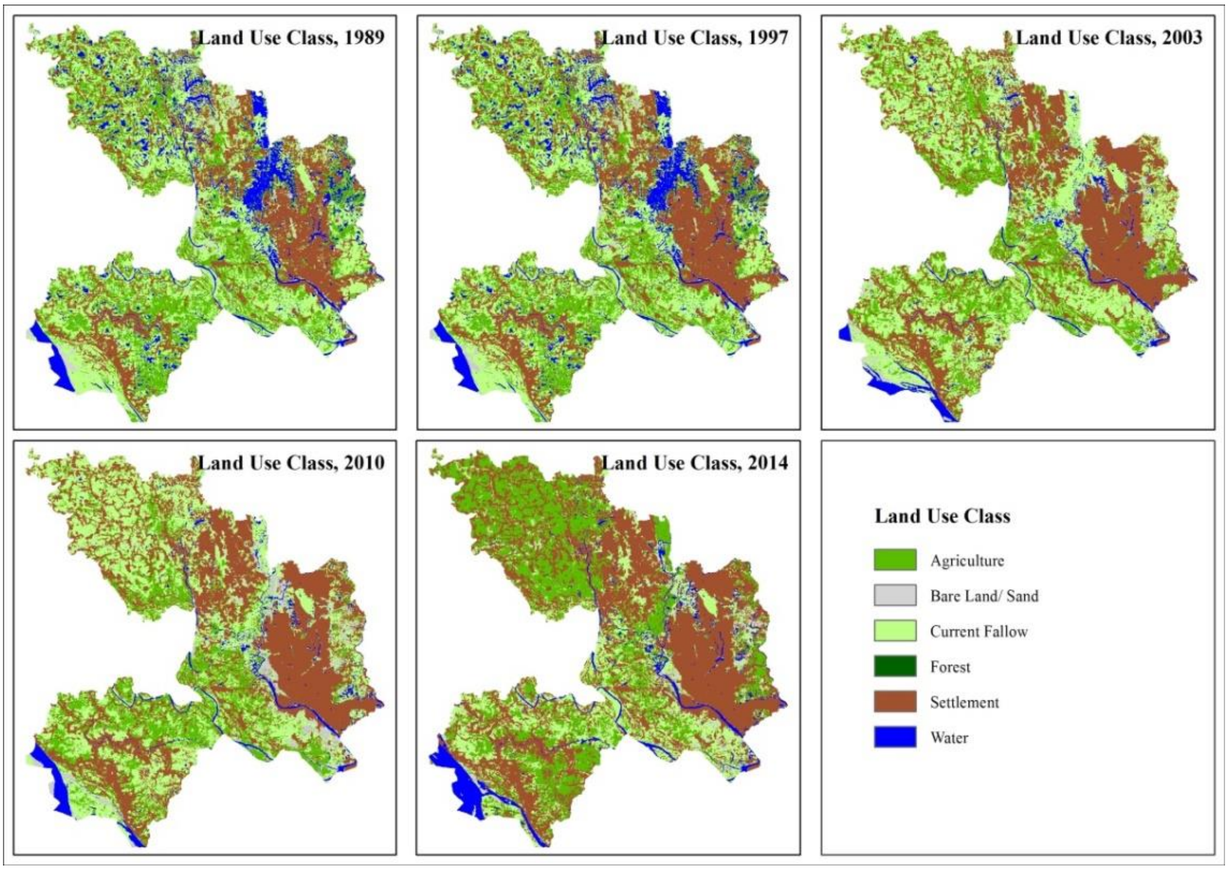


Figure 4-19: Changes in land use of Dhaka district

of other years. Moreover, in 2010 and 2014 it is found that those filled up areas were covered by settlement. Water body area decreased from the period of the year from 1989 to 2014. Interestingly, the forest cover area was totally absent in 2014 and the area was filled up with settlement.

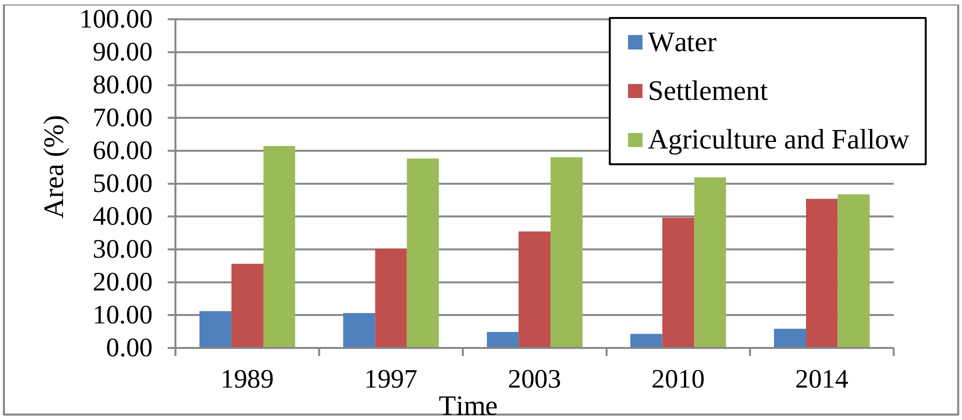


Figure 4-20: Bar graph of land use of Dhaka district

Figure 4-20 shows the land use changes in Dhaka district from 1989 to 2014. It is seen from the figure that, most of the changes were in the agriculture and fallow land, settlement and water bodies. For this reason, the bar diagram is prepared based on this three land use classes. From the bar diagram it is very clear that over the period from 1989 to 2014, water bodies have decreased gradually. Agriculture and fallow land also have decreased from 1989 to 2014. However, the settlement has increased rapidly in the same period.

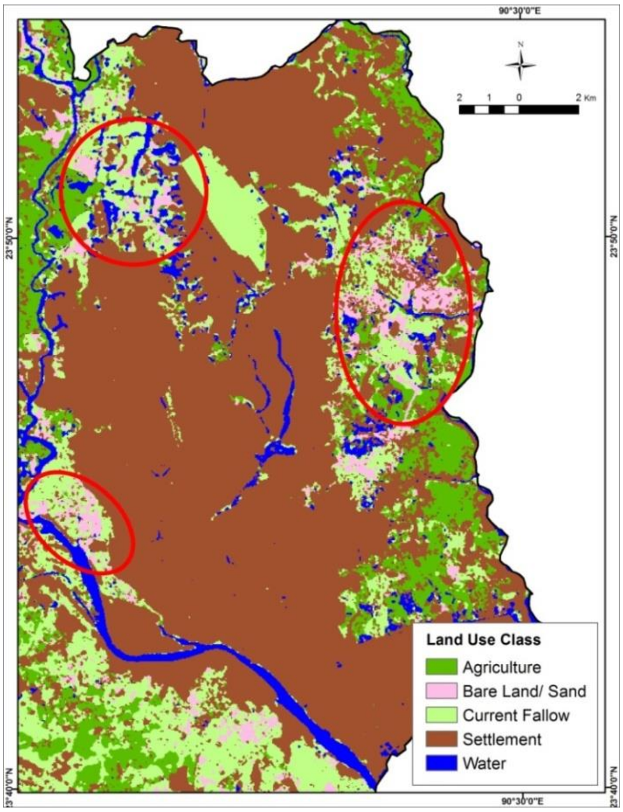
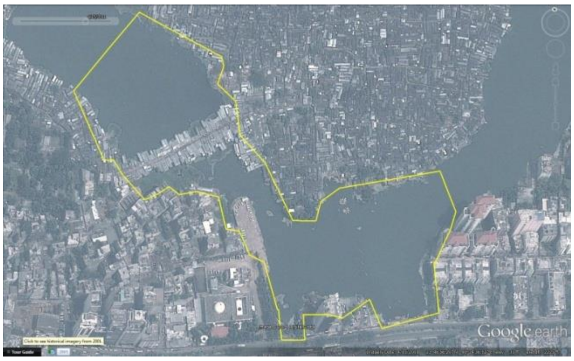


Figure 4-21: Landfill areas at the core areas of Dhaka city

From the changes of land use of Dhaka district in **Figures 4-19 and 4-20** it is seen that the eastern part of Dhaka is growing up gradually with dense settlement. The wetlands as well as floodplains are filled up with sands (**Figure 4-21**) and the urbanization is growing up in these areas. The red marked areas are the land filling areas shown in **Figure 4-21**. Floodplains are lost in most of the areas of this district. This causes flood during the monsoon due to lack of holding capacity of huge water in the floodplains and wetlands like beels and lakes. Gulshan lake is one of the gadgeted water bodies by the government. The lake is also filled up and

Date: 12 July, 2006

Date: 27 February, 2010



Date: 15 April, 2011

Date: 06 April, 2013

Date: 20 March, 2014

Date: 22 March, 2015

Figure 4-22: Unauthorized land filling and settlement growth

unauthorized settlements are built up. The **Figure 4-22** shows the lake is being filled up gradually over last 4-5 years. These water bodies should be protected with regulatory measure.

Only structural measures are not sufficient for flood management in Dhaka district. An integrated flood management using green water defense as an adaptive flood mitigation approach could be the best alternative and complementary practice for Dhaka district for the management of fluvial as well as pluvial floods.

Chapter 5

Green Water Defense for Flood Management in Dhaka: A New Approach

5.1 Green Water Defense Approach for Flood Management

Green Water Defense (GWD) is an adaptive management approach which seeks to integrate natural forces and artificial interventions, and to balance incentive based and supply-driven measures, with minimum footprints and externalities in sustainably providing water services and managing related climate risks. Contrary to the conventional approach, GWD makes full use of the ecosystem services and balances structural and non-structural measures based on cost-effectiveness. The main focus of GWD is on adaptive management of physical scarcity.

In a study of The World Bank in collaboration with UNEP and others, GWD was promoted as an innovation to traditional ways of flood protection in which the protection is explained in a more holistic and natural way (Marchand et al., 2012). According to them, it is designed in a balanced structural and non-structural approach which is also eco-friendly. The main concepts are:

(i) types of flood hazard,

(ii) use of ecosystem processes and services and

(iii) measures related to the spatial occupation layer.

GWD highlights interaction between three layers: occupation layer which emphasizes on land and water, infrastructure layers are about building structure for flood protection such as dikes, zoning regulators etc. and the base layer describes how to manage air, water and soil (**Figure 5-1**).

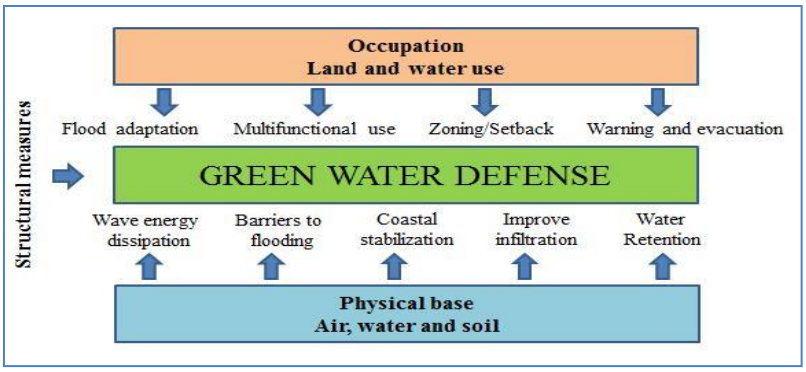


Figure 5-1: Green water defense integrating the three layers of delta

Source: (Marchand et al., 2012)

5.1.1 Types of flood hazard

GWD will work on three types of flood hazards:

i. coastal floods those are caused by storm surge, tidal action or tsunami.

ii. fluvial or riverine floods those are originated from a river discharge and leads spill over onto the flood plain and sometimes excessive rainfall, thunderstorm etc. cause flash floods which is the special case of fluvial flood; and

iii. pluvial or rainfall floods those are usually occurred during monsoon period by excessive rainfall, failure of pumping stations and blockage in sewerage line and those cause drainage congestion in the urban areas.

5.1.2 Use of ecosystem processes and services (The base layer)

Ecosystem services are such benefits those are obtained from ecosystems. Ecosystem helps to modify and regulate hydrological and meteorological processes and affect the positive as well as the negative consequences of flood and storms. The functions of ecosystems range from the regulation of surface and sub-surface flow to the modification of wave dynamics in coastal and near-shore areas (Marchand et al., 2012). According to Mirzaet al., (2005) one of the important ecosystem services is to control floods and storm. On this lens ecosystem services are categorized into:

(i) Wave energy dissipation through coral reefs, vegetation and geomorphology

(ii) Barrier to flooding and elevated areas

(iii) Coastal Stabilization, erosion control and sediment retention for deltas

(iv) Reduction of water logging, improving infiltration and drainage, and

(v) Lowering of flood levels/ room for the river/ flood water retention

Brief discussion of each of the services is given below.

5.1.2.1 Wave energy dissipation through coral reefs, vegetation and geomorphology

In the coastal region where storm surges and tsunamis are destructive forces of nature reduction of high wave is very important for coastal environments. Coastal ecosystem like mangroves, coral reefs, seag6rass beds and salt marshes are such elements those can physically exert an effect of waves causing a hydraulic resistance that can break the waves and reduce the velocity and energy of the waves (Marchand et al., 2012). According to Hong and San, (1993) plantation is the way that helps in natural regeneration of some species.

5.1.2.2 Barrier to flooding and elevated areas

According to Marchand et al., (2012), geo-morphological features like dunes and river levees are natural flood protection systems by proving barriers to flooding and higher areas to keep dry feet. Although naturally formed dunes are usually characterized by small inlets and washovers, man often has closed these sea intrusions and thus formed a continuous high dune area that effectively protects the hinterland from flooding.

5.1.2.3 Coastal stabilization, erosion control and sediment retention for deltas

Due to strong winds, high waves and high tides and storm surge condition, coastal erosion is occurred. Coastal vegetation like mangroves plays a significant role in mitigating coastal erosion and promoting sediment deposition (Marchand et al., 2012).

Natural sediment dynamics play an important role in delta formation and sustainability (Marchand et al., 2012). Deltas are young landforms shaped by the interplay of coastal and riverine process compared to other lands. However, many of the deltas are now suffering from sediment deflects. This results from sediment starvation due to upstream developments and flood control measures. By preventing regular flooding of the delta, the river is not able to deposit sediments any longer. By protecting people from floods, environment is losing the benefits of flooding.

Mangroves are tidal forests those have protective functions:

(i) wave attenuation, mitigation of hydraulic forces of storm surges and tsunamis,

(ii) storm protection through windbreak and

(iii) shoreline stabilization, sediment retention and erosion control.

5.1.2.4 Reduction of water logging, improving infiltration and drainage

Vegetation leaves can hold part of rain water and act as an umbrella that reduces raindrop impacts on soils and decrease the risk of soil erosion and landslides in the catchments and urban areas (Marchand et al., 2012). Vegetation roots strengthen the soil and improve soil texture, which increases the water retention capacity. Organic matter from roots and leaves improves soil structure and increases both infiltration rates and water-holding capacity (Mirza et al., 2005).

Nowadays urban areas suffer from water logging and flood problems. Hydraulic processes in the urban areas are complex and relate both to water quality and quantity. One of the most conspicuous differences of urban areas from natural or agricultural area is the high percentage of impervious surface that can cover up to 75 to 100 % of the urban area (Marchand et al., 2012). Zevenbergen et al., (2011) added, this can lead to more than half of the precipitation flowing down as quick run-off, compared to 10% under natural conditions. Permeable paving for roads and parking lots, urban wad and more green space can lead to an increase of infiltration capacity, thereby reducing the flood hazard. Green areas such as parks and water bodies also act as (temporary) retention areas. Zevenbergen et al., (2011) also indicated that, to reduce peak flows from surface runoff, process of storm water infiltration facilities and other best management practices termed as the sustainable urban drainage systems (SUDS) have, increasingly been implemented since the late 90's.

According to Marchand et al., (2012), green roofs are also rapidly growing in popularity. Green roofs do not only provide a habitat for insects and birds in a highly urbanized area, but also have a capacity of annually immobilizing up to 200 gm of dust and harmful air particles, purifying nitrates and other pollutants in the water and are capable of fifty to ninety percent of rainfall retention (Reinberger, 2009). In Germany people are using their properties as incorporate green infrastructure (**Figure 5-2**).

Figure 5-2: Roof top gardening and management of water

Source: (Marchand et al., 2012)

5.1.2.5 Lowering of flood levels/ increasing room for the river/ flood water retention

River floodplains and wetlands act as a natural buffer during high river discharges by enabling horizontal expansion of water mass, thereby reducing the height of water levels (Marchand et al., 2012). Lowland and delta rivers nowadays are often embanked in order to protect agricultural fields and urban areas from flooding. Restored wetlands can be created to act as a buffer and give the advantage of natural water treatment, improving the quality of the out-flowing water.

In the northern part of Singapore the largest floating wetland (approximately 2500m^2) has been created artificially which treats storm water runoff and natural sewage (Li et al., 2012). The coarse particles in the water are filtered in two sedimentation basins. If the volume of water flowing in is larger than the basins capacity, the water will be redirected through a bypass into the pond without being filtered through the macrophyte plants that thrive in marshlands, like reed, cattails and, through photosynthesis, absorb nutrients and release oxygen. This is necessary to prevent damage to the wetland. After the sedimentation process, water flows slowly into the macrophyte zone (Li et al., 2012).

Figure 5-3: Floating water treatment plant in Singapore

Source: (Marchand et al., 2012)

These wetlands also provide a new habitat for fish and birds. It strengthens the local ecosystem and increases biodiversity. The roots of the plants clean the water and absorb pollutions from the reservoir, and improve the water quality (Marchand et al., 2012).

5.1.3 Planning and adaptation measures (The occupation layer)

According to (Marchand et al., 2012), in this layer GWD talks about the reduction of the vulnerability of the human society to floods which are often named as non-structural measures, including:

i. Flood adaptation which consists of structural measures and coping mechanisms by which people can adapt their way of living in both regular and incidental flooding;

ii. Zoning and coastal setback lines that define as the landward limit of a buffer zone along the coastline where building restrictions or prohibitions area applied which allows room for coastline dynamics;

iii. Multifunctional use of infrastructures such as dikes that can use as flood protection purposes and also for transport purposes, parking garages or sporting fields can be used for temporary water storage; and

iv. Warning and evacuation that can be develop as an early warning system predicting floods through a combination of real time data collection and model application that can reduce number of casualties.

5.2 Green Water Defense Approaches for Urban Areas

From the above discussion it becomes clear that not all measures are applicable everywhere under all condition. Different measures are appropriate for different specific cases. Usually for urban areas fluvial and pluvial flood management are appropriate. List of measures that can be taken for fluvial flood and pluvial flood management are shown in the following diagrams (**Figure 5-4 and 5-5**).

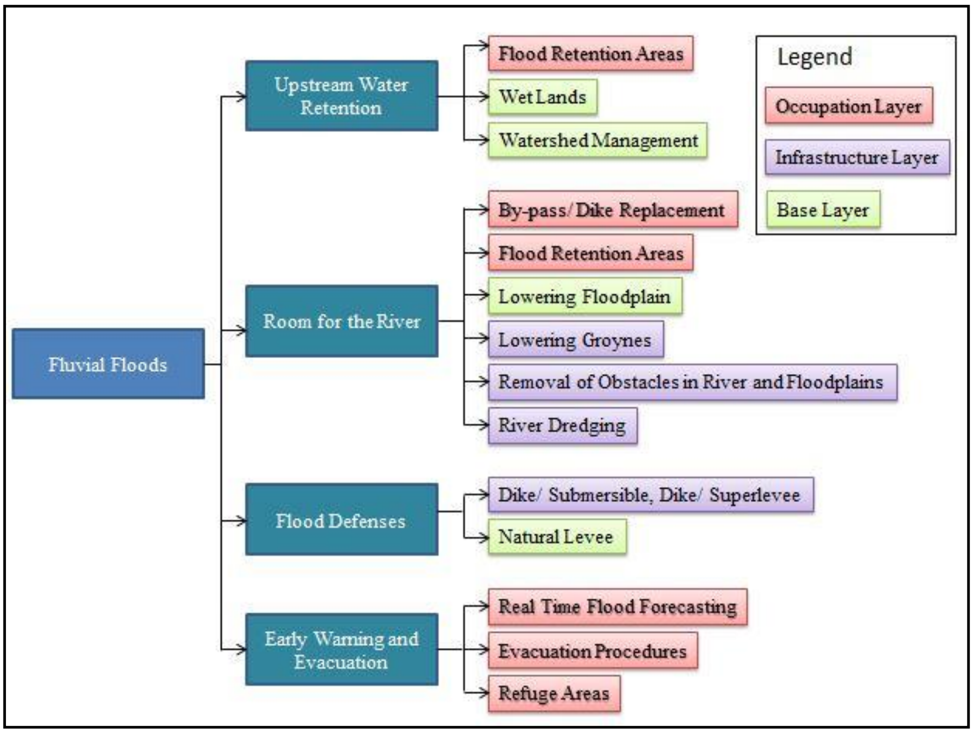


Figure 5-4: Green water defense on fluvial flood management

Source: (Marchand et al., 2012)

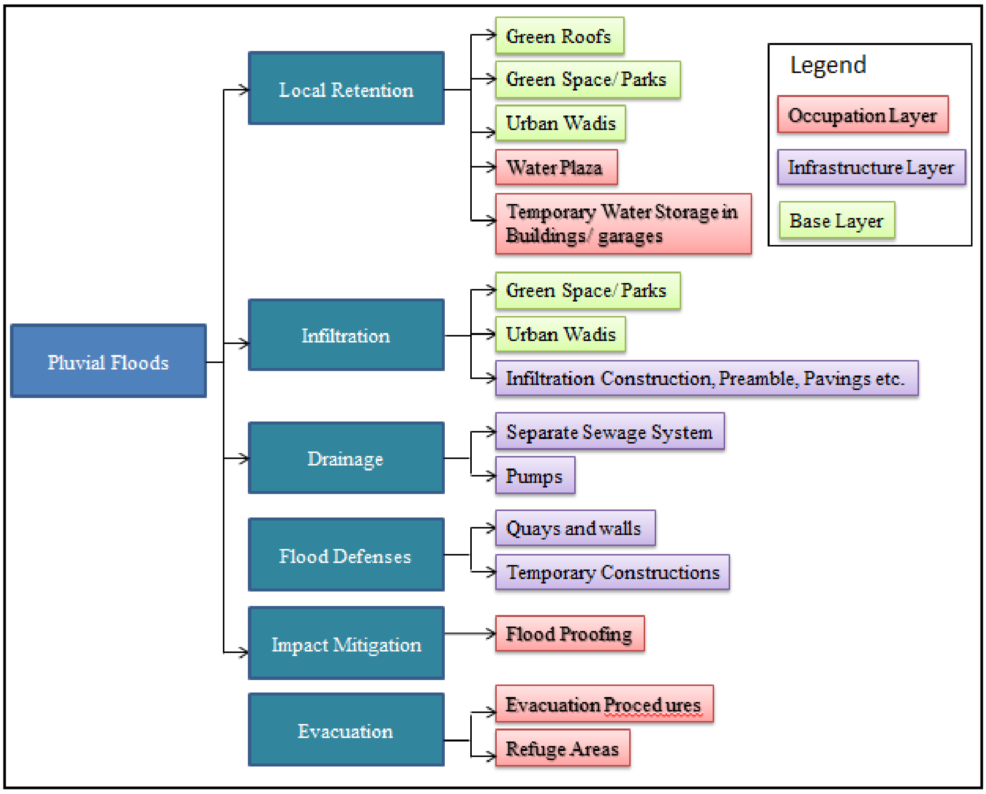


Figure 5-5: Green water defense on pluvial flood management

Source: (Marchand et al., 2012)

5.3 Proposed Green Water Defenses for Dhaka

As Dhaka district is very much prone to flood hazard due its location in delta, flood management using GWDs can play an important role for this district. Over the last three decades, it is seen that water bodies have been decreasing gradually causing water logging especially during monsoon period (**Figures 4-19 and 4-20**). Moreover, the floodplains have also been reducing and the areas getting full with settlements. For this reason, Dhaka is facing flood problems very much. Dhaka is associated with both fluvial and pluvial flood hazards and these can be mitigated by GWDs.

5.3.1 Green water defense for fluvial floods

The Balu, the Buriganga, the Lakhya, the Turag and the Tongi Khal are the river systems which have surrounded Dhaka. The river beds are filled up with sand due to sedimentation as well as human interventions. The river widths are also reduced as they are being encroached by the people. For this, in monsoon period the rivers do not have enough space for smooth passage of flood water and, hence, overflow of the bank occurs.

Four different types of actions can be taken up for fluvial flood management (**Figure 5-4**) and these are: upstream water retention, creating room for the rivers, flood defenses, and early warning and evacuation.

The rivers in and around Dhaka, are being off-taken from the two major rivers, the Brahmaputra-Jamuna and the Ganges-Padma in the upstream. These rivers are mostly sand braided and carry huge amount of sediments which fill the river bed and cause spillover during monsoon. As a part of holistic approach, the up-stream rivers should be well taken care of, for best management of Dhaka watersheds.

Keeping room for the rivers as a GWD approach is also applicable for the rivers in and around Dhaka district. This can be achieved through regular and proper dredging of the rivers. Unauthorized settlements and structures occupying the riverbanks and reducing the river width should also be immediately removed with hard hand.

Flood defense is another measure for fluvial flood management. The western part as well as the northern part of Dhaka city are embanked and can be said as risk free from fluvial floods. However, at the eastern part including Badda, Khilkhet, Khilgaon, Sabujhbagh and Demra (**Figure 5-6**) are most vulnerable areas and no flood protection measure is present. Moreover, the floodplains are filled up and unauthorized settlements are built in the floodplains which are intensifying the flood problem during monsoon. **Figure 5-6** shows the area vulnerability due to flood hazard.

As there is no protection is present unlike the western part of Dhaka city, flood protection measures like embankment can be built at the eastern part of the city. Recently BWDB proposed a project named “Eastern Bypass” which is an embankment-cum-four lane road should also be implemented as early as possible.

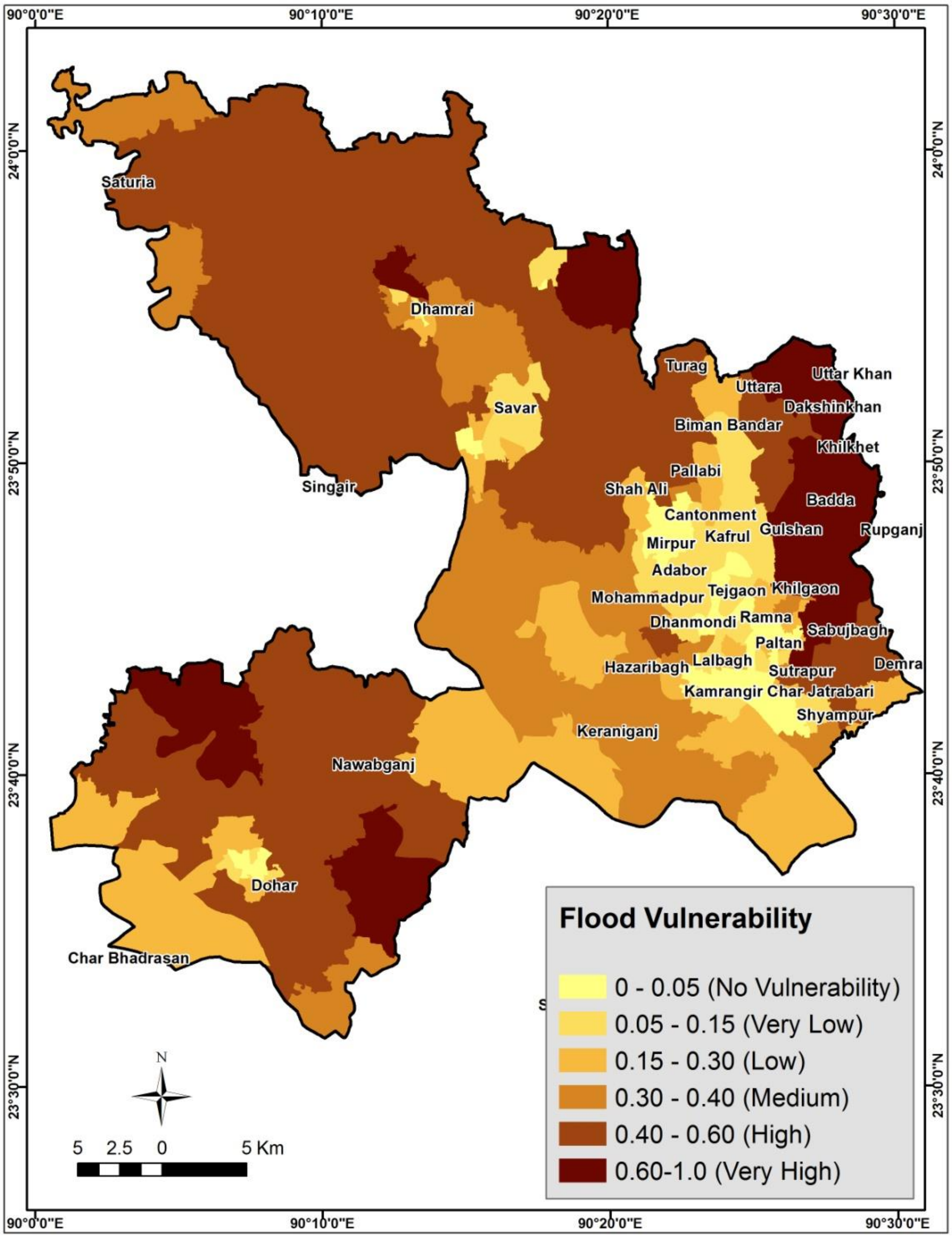


Figure 5-6: Flood Vulnerability in the flood plain in Dhaka

The vulnerable areas should be under consideration to mitigate flood. The floodplains should be protected and new wetlands should be developed to use as water reservoir during monsoon.

Early warning system is already practiced in Bangladesh. The flood forecasting and warnings can be made quite accurate by using dependable data source and reliable model. Currently sometimes errors are made while taking the hydrologic readings which cause unwanted result for flood forecasting. These should be done with great care; otherwise, people cannot rely on the forecasts and warnings provided by the Flood Forecasting and Warning Center (FFWC) of BWDB.

5.3.2 Green water defense for pluvial floods

As Dhaka is expanding rapidly, unplanned urbanization has been happening in Dhaka city. People migrate here from other areas of the country in search of better livelihoods. As trees are cut off, run off from storm water is increasing in the core city. Moreover, current sewage system cannot drain additional rain water properly. For this, pluvial flood management can supplement the flood management for Dhaka.

According to GWD, pluvial flood management is categorized into six components and these are: local retention, infiltration, drainage, flood defenses, impact mitigation and evacuation (**Figure 5-5**).

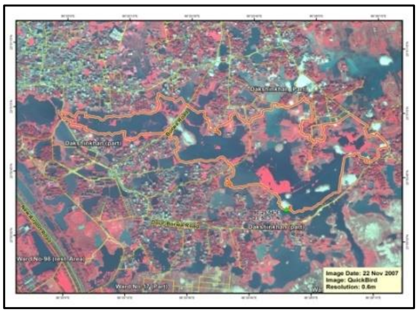
Green roofs, green spaces, parks, urban wadis, water plazas and temporary water storage in buildings/garages are the options for local retention. Green roofs can retain rainwater, reduce heat stress, improve air quality and increase insulation of buildings. Moreover, people can plant vegetables or fruits to fulfill their regular needs so that they may have pure and fresh food from their own gardens. Roof top gardening as GWD approach can also play a very important role as a part of pluvial flood management.

Green areas, such as parks and water bodies, can act as retention areas and can improve the infiltration capacity. Government should create open areas as parks with wetlands where people will also get spaces for recreation and flood will be managed in the core Dhaka city.

Moreover, land filling areas are increasing day by day. The water bodies are filled up and as a result water storage capacity is declining day by day. The existing water bodies cannot hold the excessive water during monsoon and pluvial flood occurs during this period.

The land development process at Ashiyan City was monitored by Center for Environmental and Geographic Information Services (CEGIS) using high resolution satellite images from 2007 to 2013. The project area was at the latitude and longitude of 23˚50'37" N and 90˚25'54" E respectively (Orange marked area in the figure). The **Figure 5-7** shows the gradual development of land filling activities in the Ashiyan City project in 2007, 2008, 2009, 2010, 2011, 2012 and 2013.

In fact, now the entire project, which is about 43 acres, has been turned into a housing project without keeping any flood water storage provision. The government has already taken initiatives to close this project. The government should take necessary actions against this type of unauthorized land filling those are placed now-a-days.



Date: 22 November, 2007

Date: 06 November, 2008

Date: 04 February, 2009

Date: 27 February, 2010

Date: 23 March, 2010

Date: 01 November, 2011

Date: 27 February, 2012

Date: 31 January, 2013

Figure 5-7: Land development process in Ashiyan city

Rain water harvesting can be another good option to harvest water which can be used for the household as well as other works. If provisions are developed for harvesting rain water in every house, the additional water can be used as household purposes and car washing purposes and the water will not come to the streets and drains will not overflow.

Separated sewage systems, i.e. construction of septic tank and soak well, should be made mandatory for every individual house. Awareness should be developed for minimum use of water. Thus the pressure on sewage line will be reduced and in monsoon sewage system can also be managed properly. Proper maintenance should be taken in place for this approach. The wastewater should be managed and can be used as recreation park for urban people.

5.3.3 Summary of suggestions and recommendations from the key informants

Eight key informant interviews (KII) were conducted for this study. While taking the interviews, various people suggested and recommended for various issues. Most of the informants were talking about roof top gardening and rainwater harvesting as these approaches are mostly in household level and these can be taken by general people if they can be made aware of these approaches.

On the other hand, some were talking about room for the rivers and creating new wetlands. They also added that permissions from various ministries are required to implement any new approaches and whatever the issues are for. For this it is not very easy to implement any new approach very quickly. There should be a proper plan and the plan should be approved as per government approved methodology.

Furthermore, some key informants told about the protection of eastern part of Dhaka. According to their views it is very important to protect the eastern part from flood. They also told about the unauthorized occupied riverbank, which should be removed. The rivers should be dredged to hold the water during monsoon.

According to a Former Additional Director General, BWDB, GWD is a very good and integrated adaptive eco-friendly approach and can be appropriate for Dhaka. Roof top gardening is a very nice idea which is already adapted by many people for the decoration and beautification of their house. Rainwater harvesting is also a very good approach but it can be applicable only when, appropriate filtering system is present in such case.

In addition, Director, Climate Change and Disaster Management Division, CEGIS suggested about rainwater harvesting the rain water harvesting should be applied through a proper planning. In his view, this approach can be appropriate for Banani and Baridhara DOHS because of their well-planned locations. People can harvest water for individual household; however, for unplanned location such as Old Dhaka and its surroundings, the approach will not be applicable. However, for developing areas like Uttara and Bashundhara areas there should be a proper plan to have such approach. This rain water should be used only for household work but not for drinking. The harvesting plant should have such mechanism by which people can use this water in wet season, and in dry period it will be off.

Deputy Managing Director (Operation and Maintenance), DWASA said that GWD is a new integrated approach and would be a very good initiative if it is taken for Dhaka. However, it is an issue of cost if separate sewage system is done or wastewater management is taken in place. Government permission and fund is required for this issue. Views of general people should also be taken into consideration.

The Former Director General, WARPO, a key informant, of this study, provided opinion in favor of GWD as, *"It is really appreciable for taking such innovative idea for flood management. For an eco-friendly and environment friendly capital city, flood management through GWD approach is not only a new outlook but also has become very much essential. As such it is highly recommended to adopt this flood management approach for the capital city without further delay. A detailed feasibility study can also be initiated as early as possible."*

Chapter 6
Conclusions and Recommendations

6.1 Conclusions of the Study

As Dhaka is prone to flood, due to its geographical location and is growing up rapidly with an unplanned urbanization, flood is a great concern here. In this study, remote sensing technology has been used to find out the flood water extent during monsoon so that it was easy to find out the flood prone zone, due to flood, according to the extent of flood water during monsoon. Land use changes in last 25 years have been find out through the remote sensing and GIS techniques. It helped to identify the changes over the period of time so that it was clear that which areas would be taken under consideration to have initiatives for flood mitigation.

As the capital city of Bangladesh, Dhaka needs proper mitigation measures for it. Flood management is now getting more crucial. To reduce impacts of flood it is time to have more integrated approaches to solve this problem. Although some structural and non-structural measures have already been taken up for flood management in Dhaka, the measures are not sufficient to save all the vulnerable people from the adverse impacts of floods. Moreover, drainage congestion is now becoming another problem mainly in city areas during monsoon. It is not possible to prevent flood hazard but can take adaptation as a mitigation measure to have less impacts on lives and properties.

Green water defense is a very useful measure and also cost effective to mitigate flood in Dhaka, by which, the problem can be managed successfully, if properly used. It focuses not only on one solution but also focuses the flood management including water management through holistic and natural way. It is more adaptive unlike traditional measures; those are costly and required proper maintenance. It can be used in multi-purposes having eco-friendly manner. It talks about both structural and non-structural measures; those can be used, based on the requirements of specific purposes.

Many countries in the world are now using this technique like rain water harvesting, roof top gardening and wastewater management to mitigate flood or lessen its adverse impact. Our government can take some initiatives like other countries, to have GWD measures for Dhaka. As this technique is eco-friendly and cost effective, it will work successfully in Dhaka.

6.2 Limitations of the Findings

In this study, Radarsat-1 ScanSAR images were used to identify the flood water extent. The images were of coarse resolution, so that the results were not fully accurate. Furthermore, the C band of RADARSAT-1 data cannot penetrate vegetation canopy (CEGIS, 2014). Previous experience of CEGIS indicates that, it is not possible to detect floodwater under the cover of forests, settlements and homestead trees, and crops with more than 30% canopy. Moreover, if digital elevation model (DEM) could be used, it would be more relevant to find out the flood risk zone in Dhaka by using remote sensing technology, so that the study could be more rich and interesting. However, for its coarse resolution, DEM was not used for this study. Only eight key informative interviews (KII) were taken for this study. If more KIIs could be taken, the study could be more authentic.

6.3 Recommendations from the Study

This report provides knowledge on integrated flood mitigation measure as GWD. This knowledge should be disseminated to the government of Bangladesh through proper channel. Different donor agencies should help to take this approach for the only megacity of Bangladesh. Environmental Impact Assessment should be done before taking this approach. Awareness should be built on general people's mind to take some initiatives in household levels (roof top gardening, tree plantation etc.). As the World Bank has proposed first, to have this approach for delta regions, they are recommended to actively promote knowledge sharing.

In national level, government should take initiatives to have such integrated adaptive approach by planning demo project first and then go for active moves. Already the government of Bangladesh has taken such initiative like "Hatir Jheel Project" to have proper channel to drive rain water to the river. Taking some other initiatives government can help people from the adverse impact of flood.

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ANNEX - A

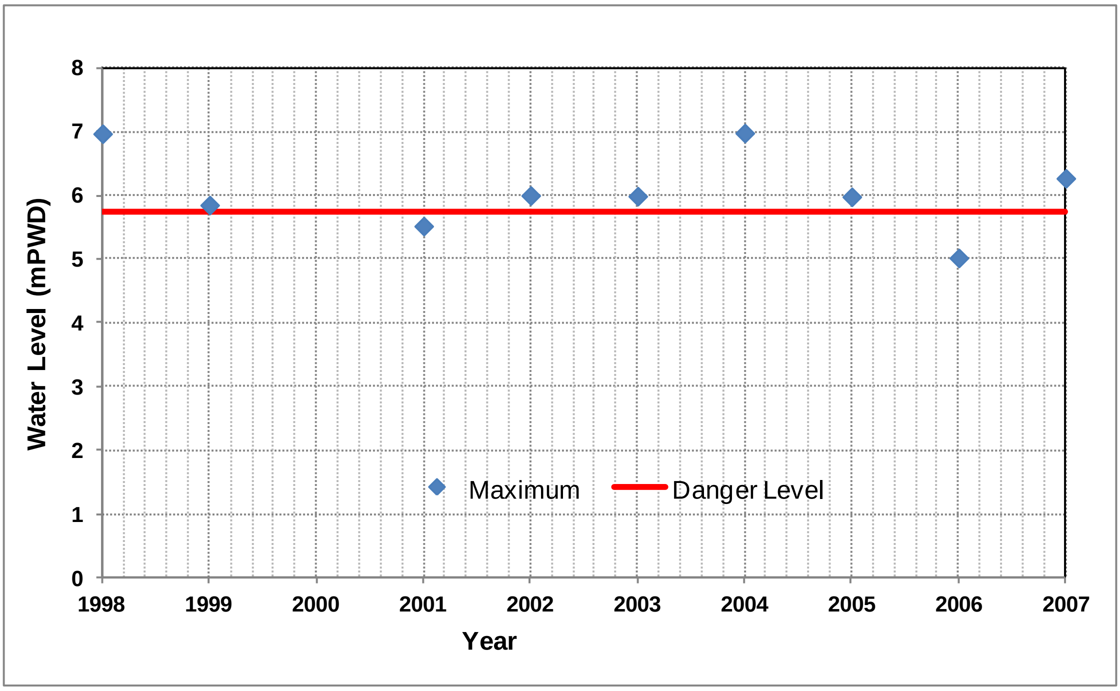

Figure A 1: Annual maximum water level of the Balu River at Demra in comparison to its danger level

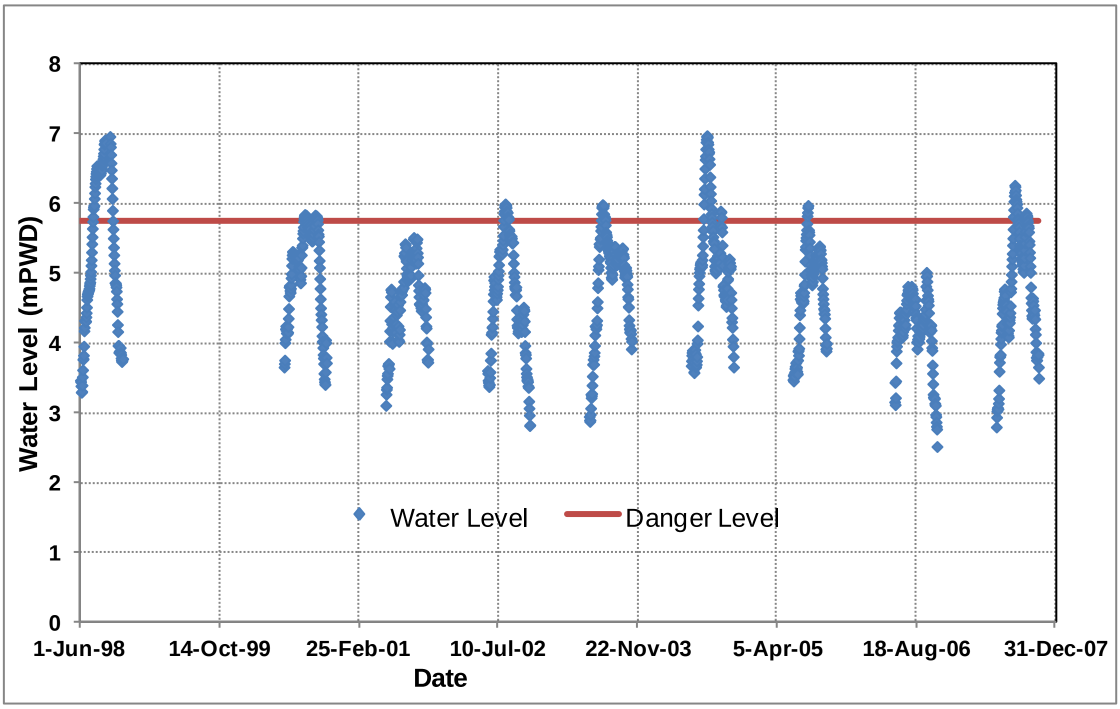

Figure A 2: Annual water level of the Balu River at Demra in comparison to its danger level

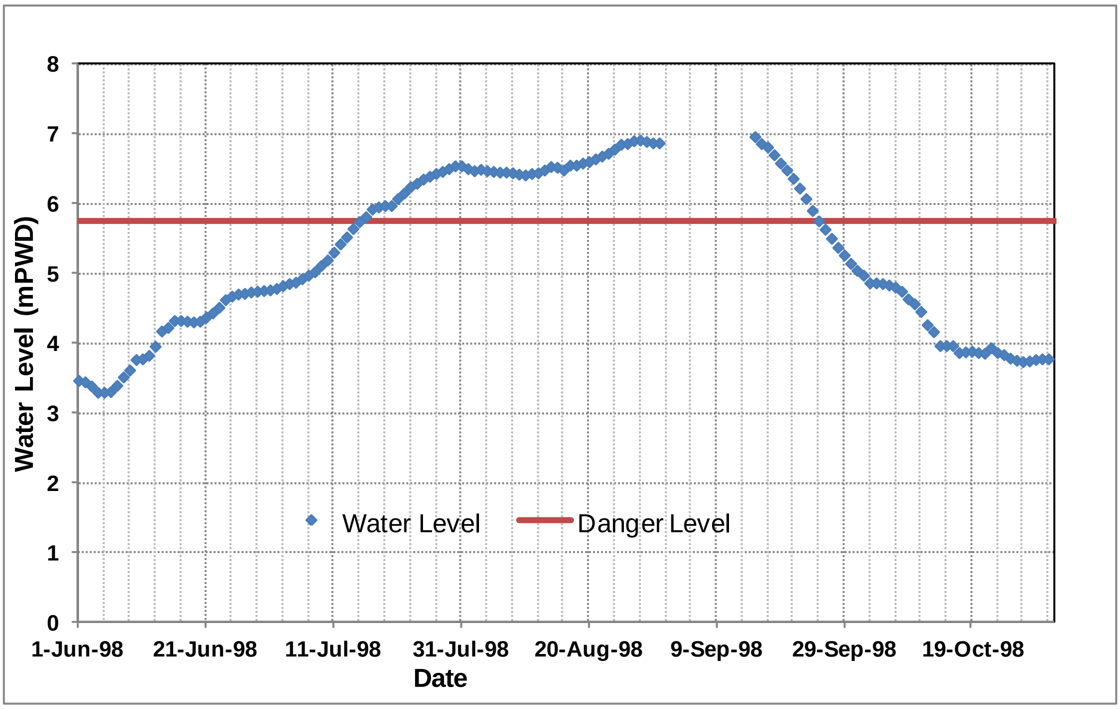

Figure A 3: Water level of the Balu River at Demra in comparison to its danger level in 1998

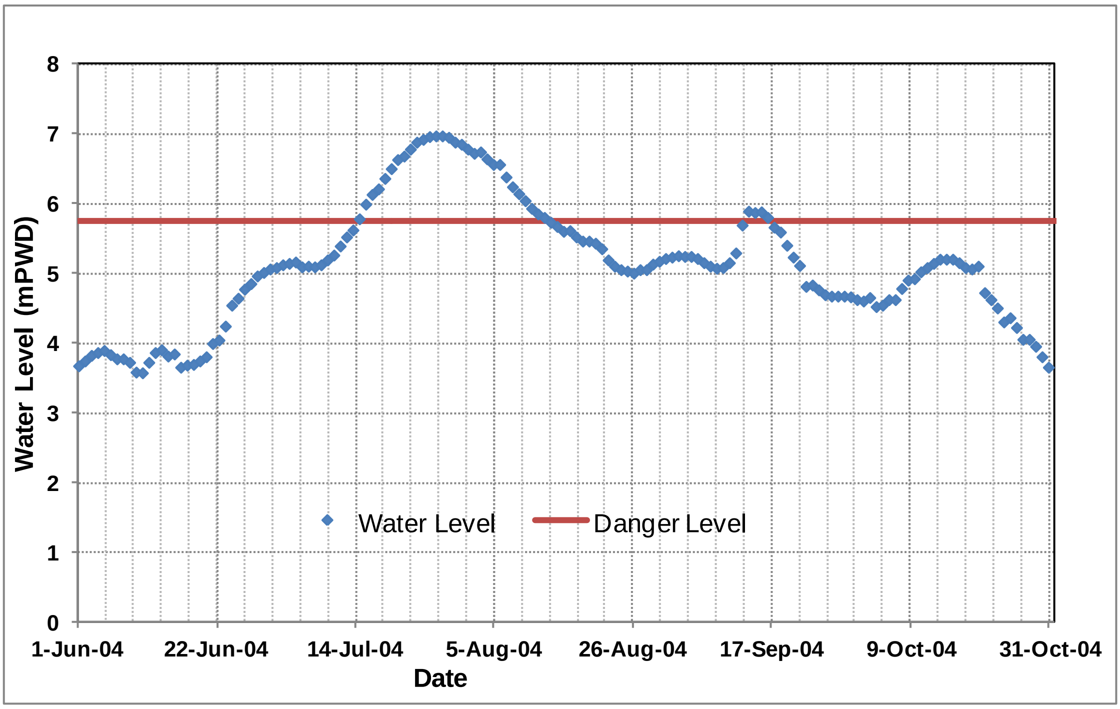

Figure A 4: Water level of the Balu River at Demra in comparison to its danger level in 2004

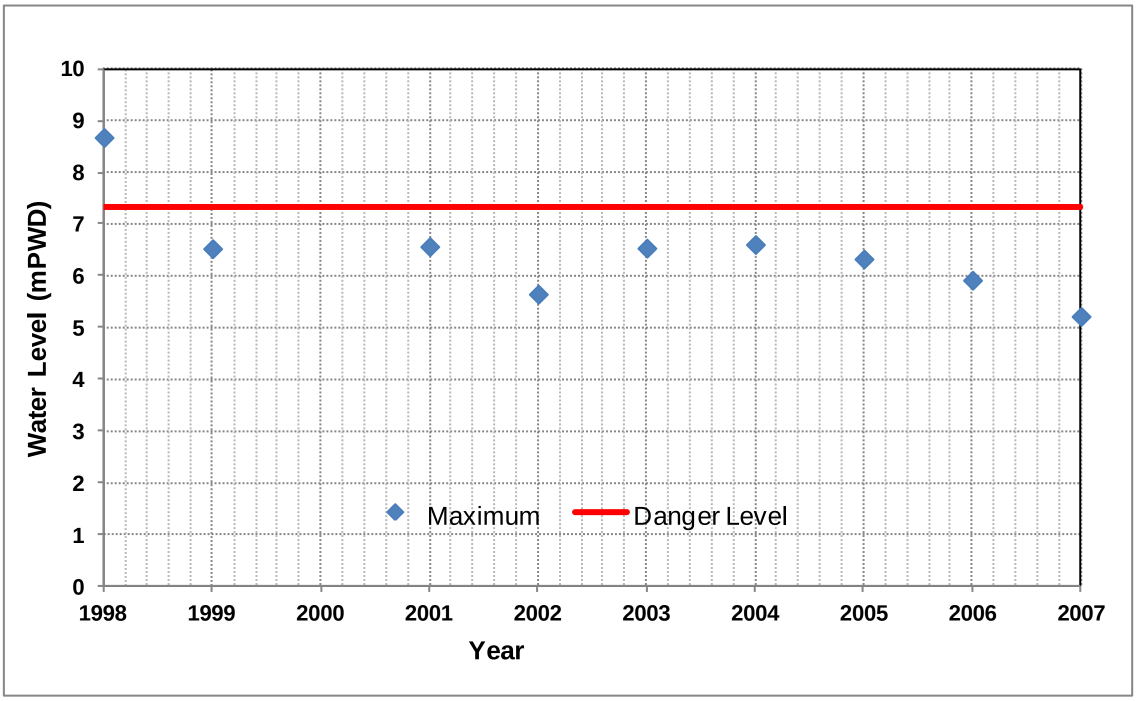

Figure A 5: Annual maximum water level of the Bangshi River at Nayarhat in comparison to its danger level

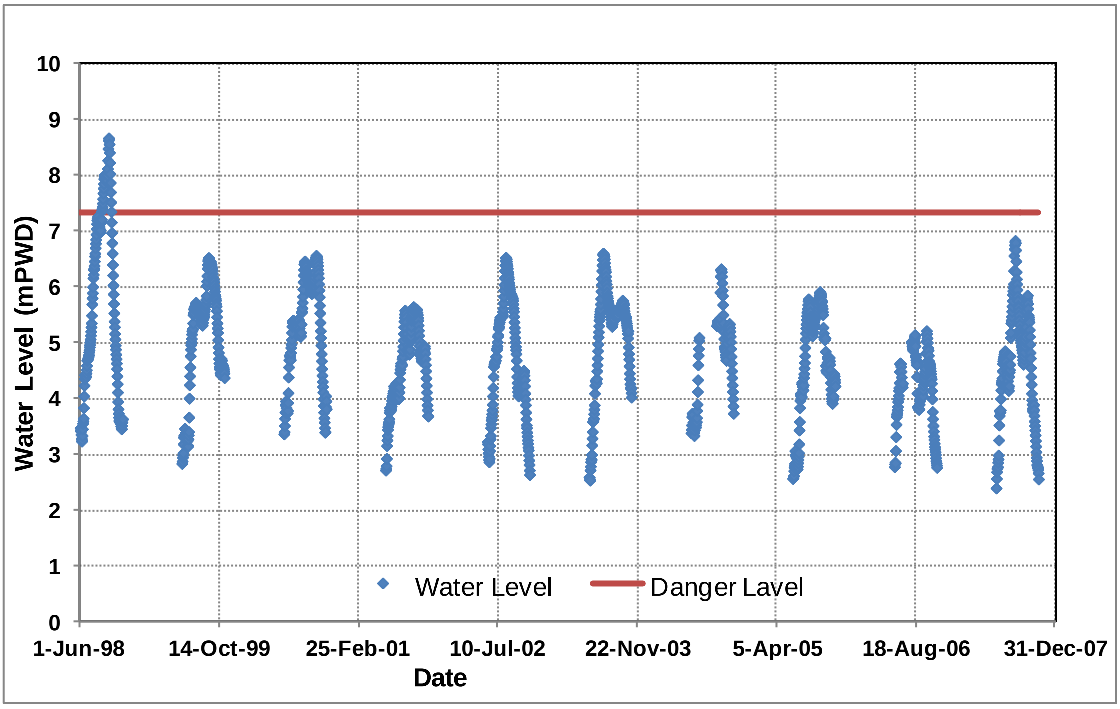

Figure A 6: Annual water level of the Bangshi River at Nayarhat in comparison to its danger level

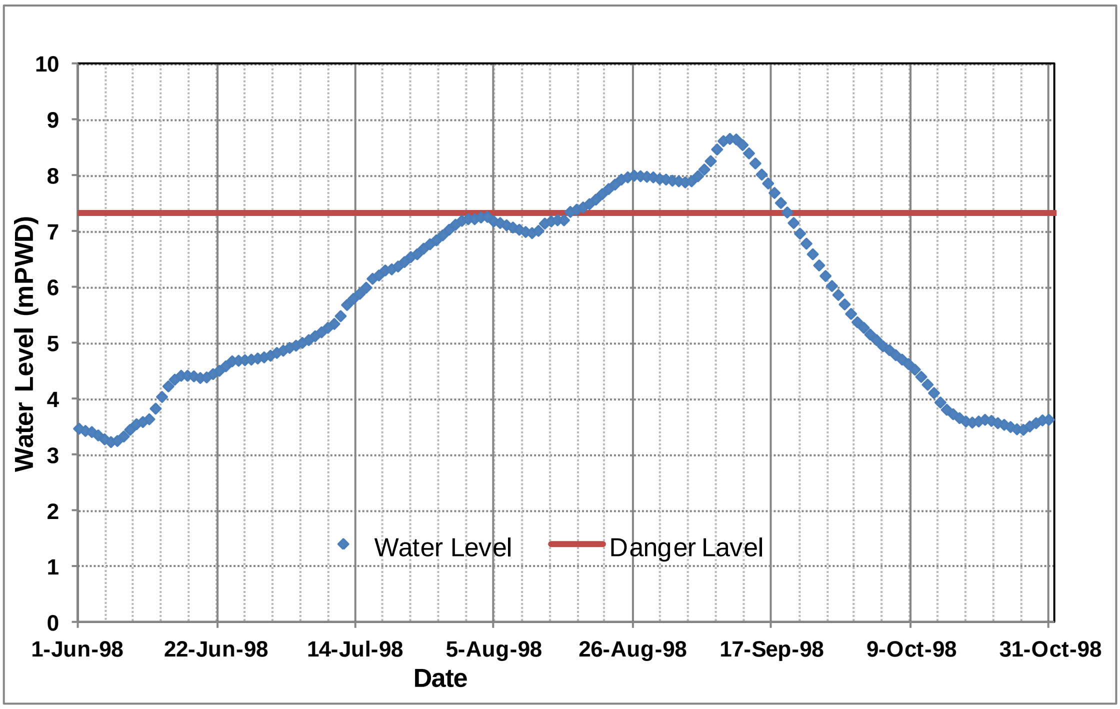

Figure A 7: Water level of the Bangshi River at Nayarhat in comparison to its danger level in 1998

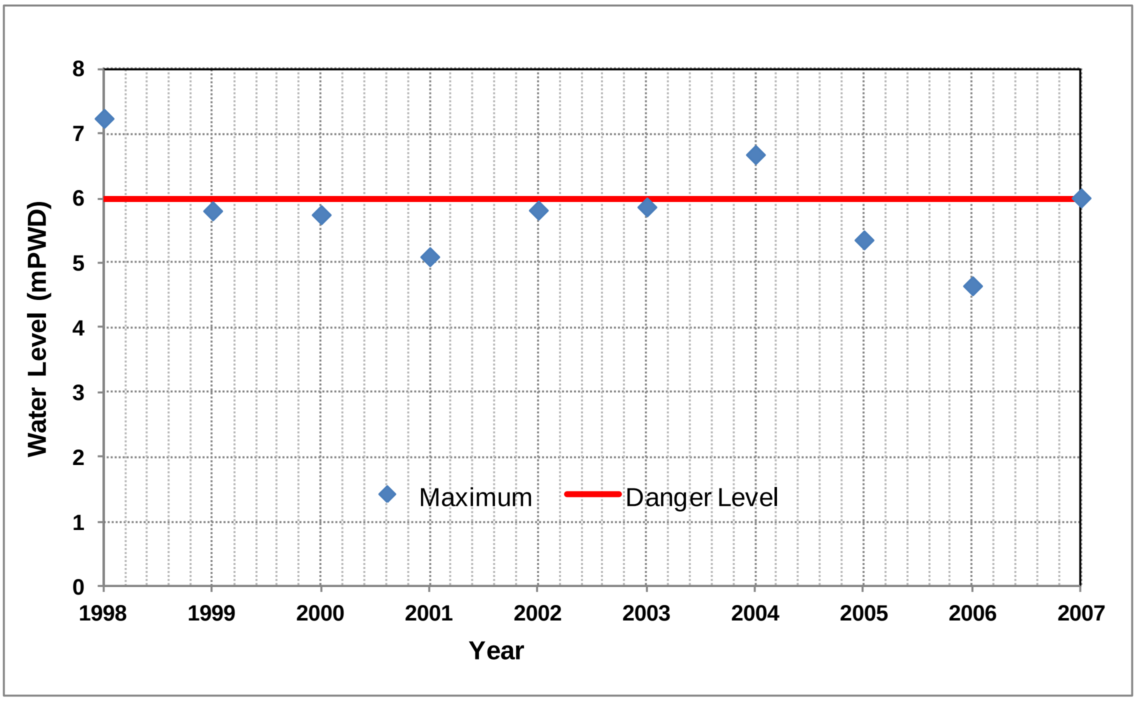

Figure A 8: Annual maximum water level of the Buriganga River at Mil Barak in comparison to its danger level

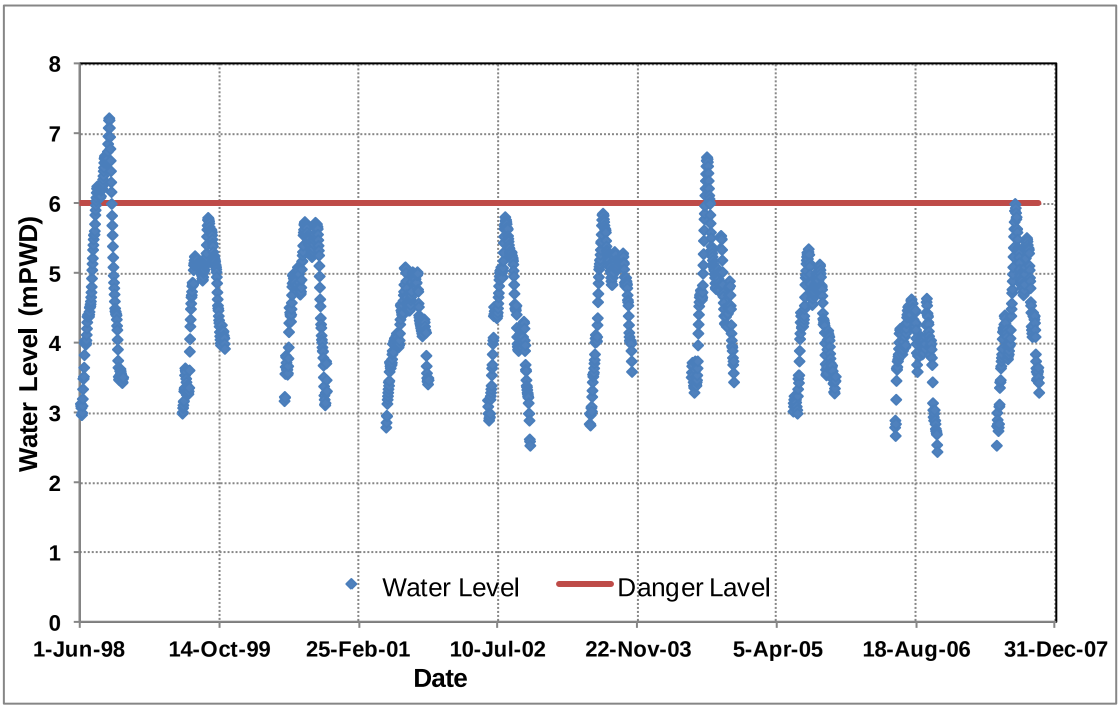

Figure A 9: Annual water level of the Buriganga River at Mil Barak in comparison to its danger level

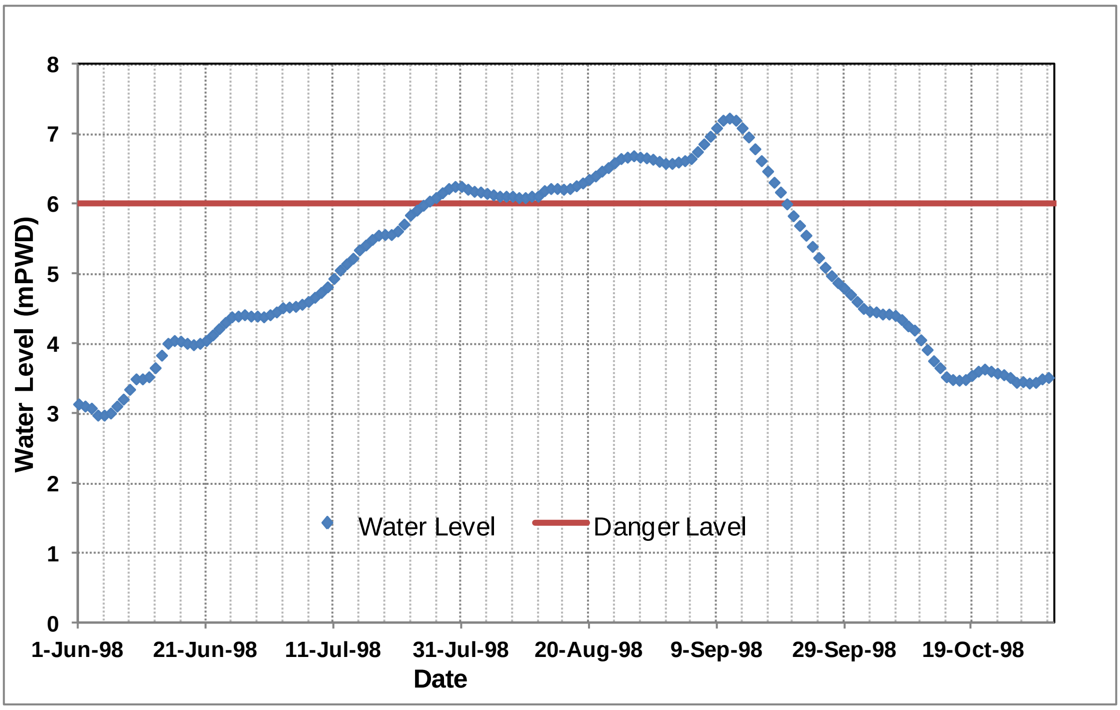

Figure A 10: Water level of the Buriganga River at Mil Barak in comparison to its danger level in 1998

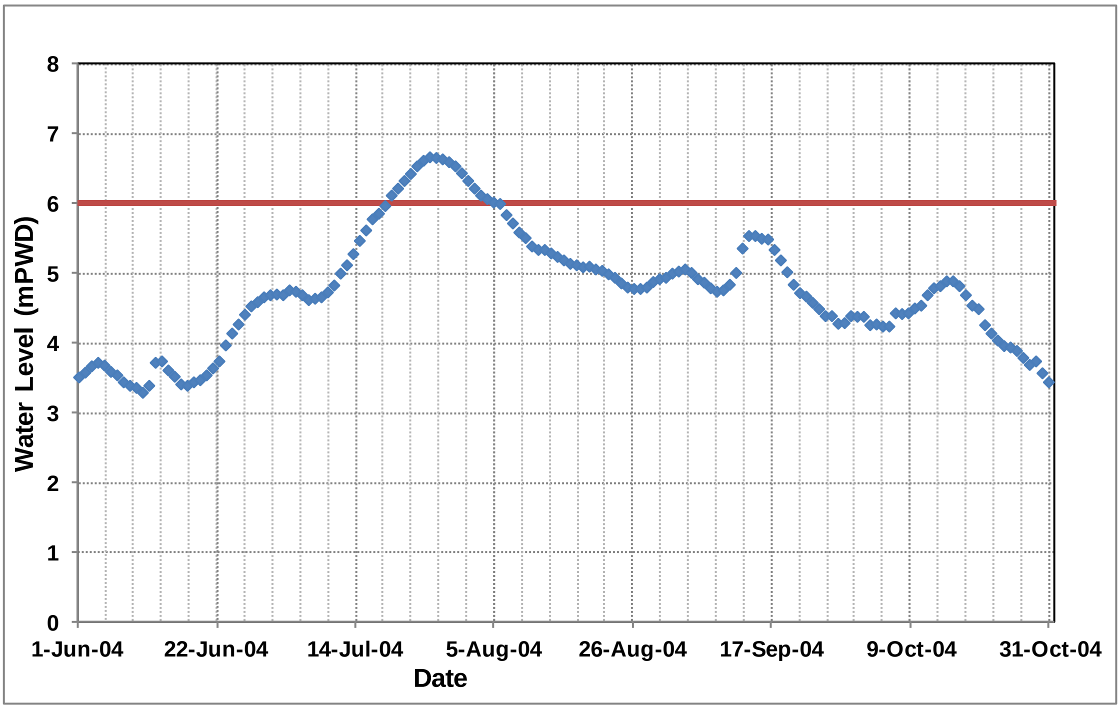

Figure A 11: Water level of the Buriganga River at Mil Barak in comparison to its danger level in 2004

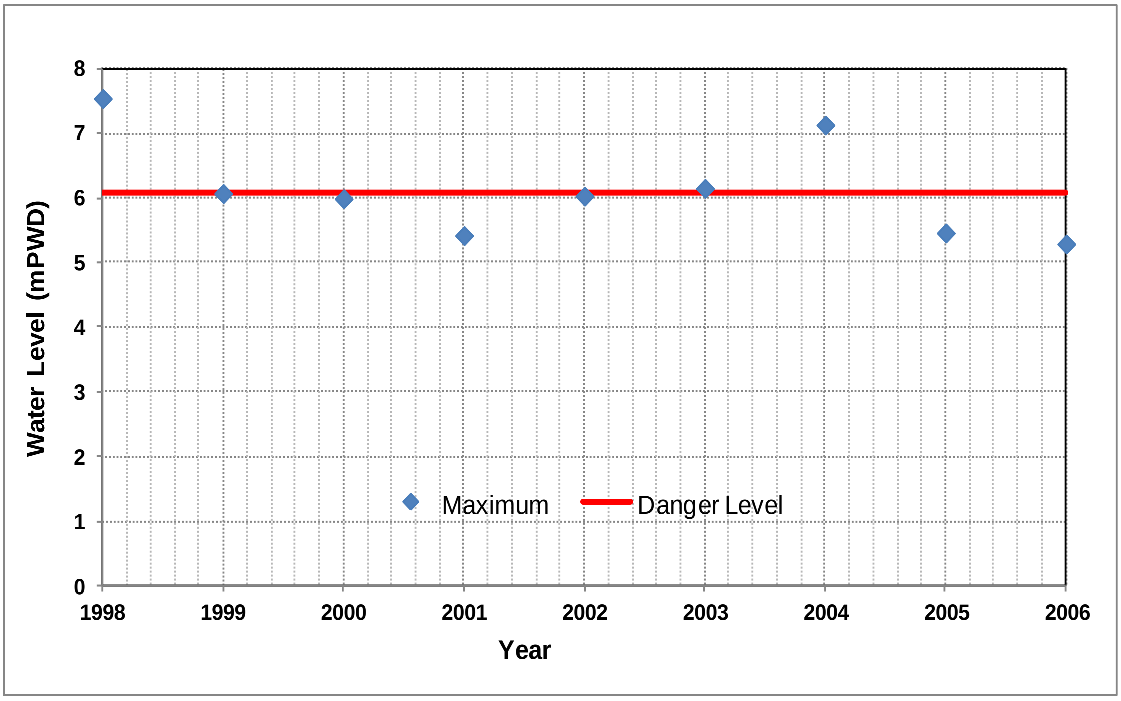

Figure A 12: Annual maximum water level of the Tongi Khal at Tongi in comparison to its danger level

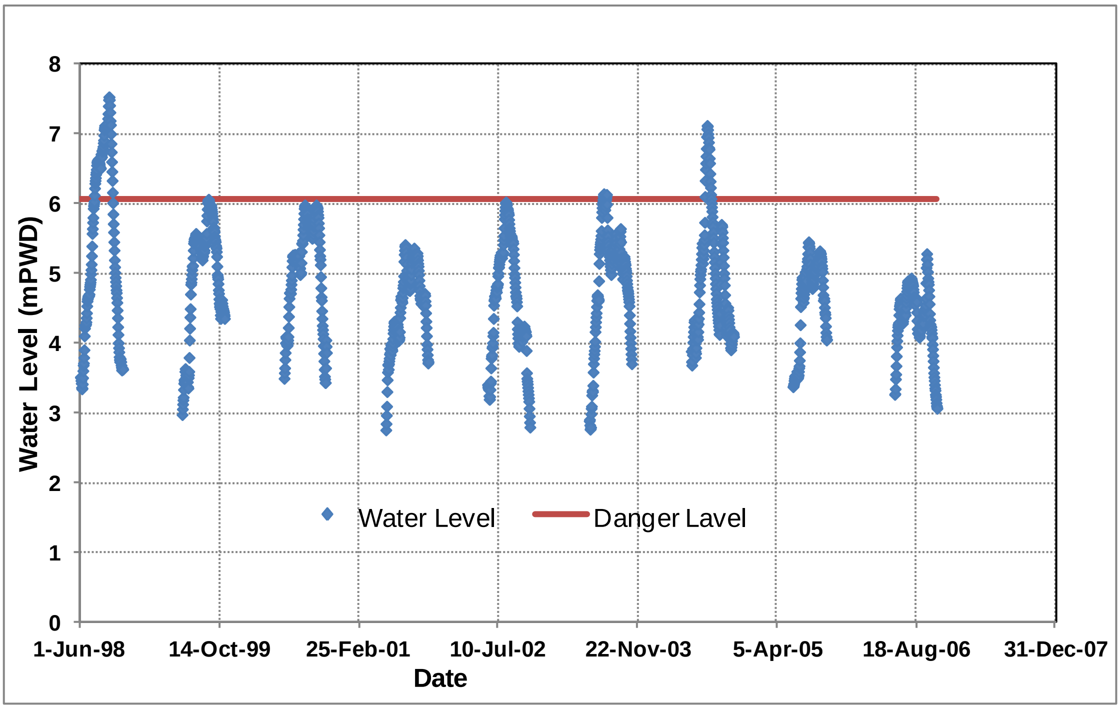

Figure A 13: Annual water level of the Tongi Khal at Tongi in comparison to its danger level

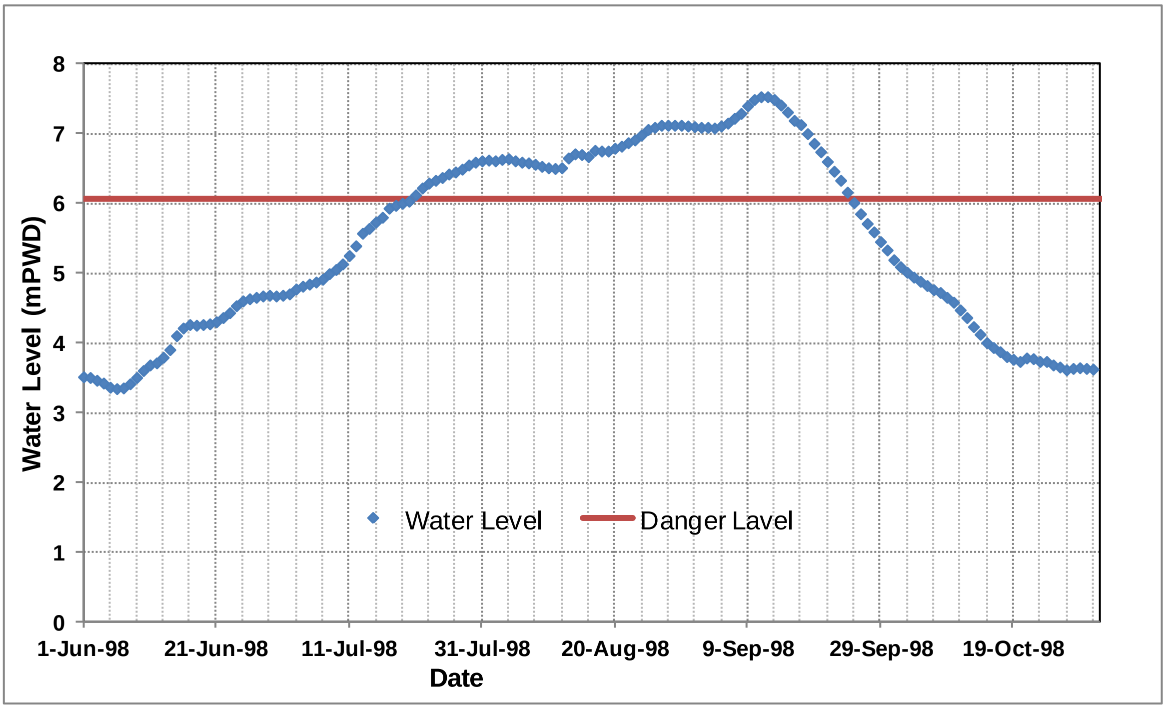

Figure A 14: Water level of the Tongi Khal at Tongi in comparison to its danger level in 1998

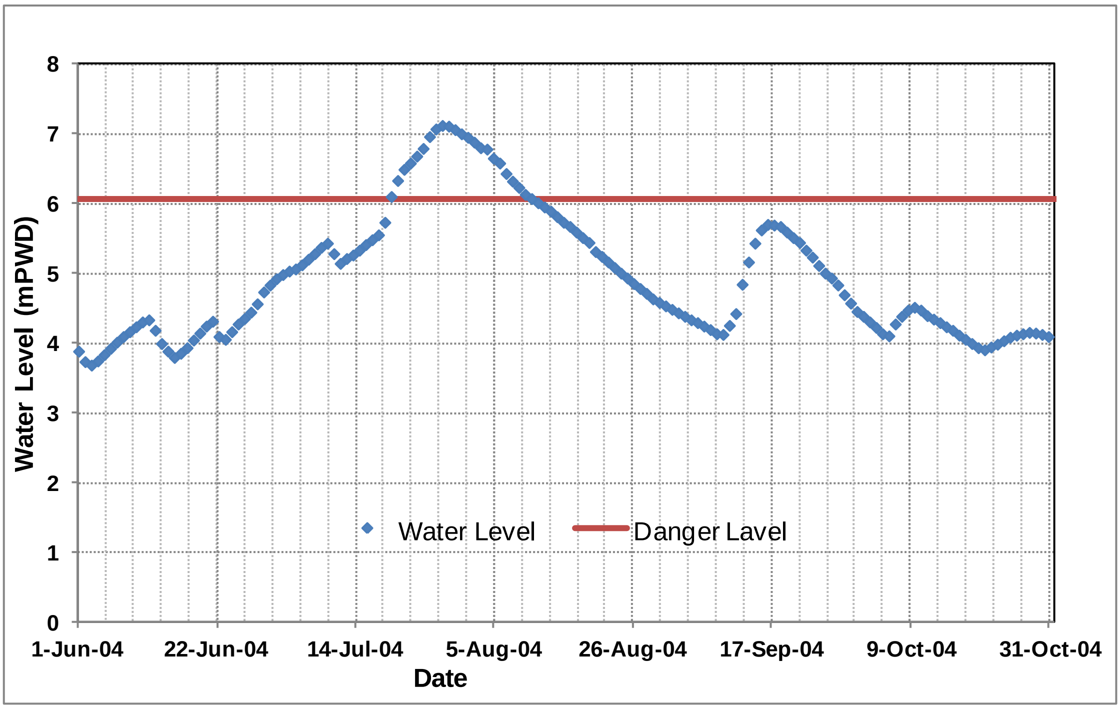

Figure A 15: Water level of the Tongi Khal at Tongi in comparison to its danger level in 2004

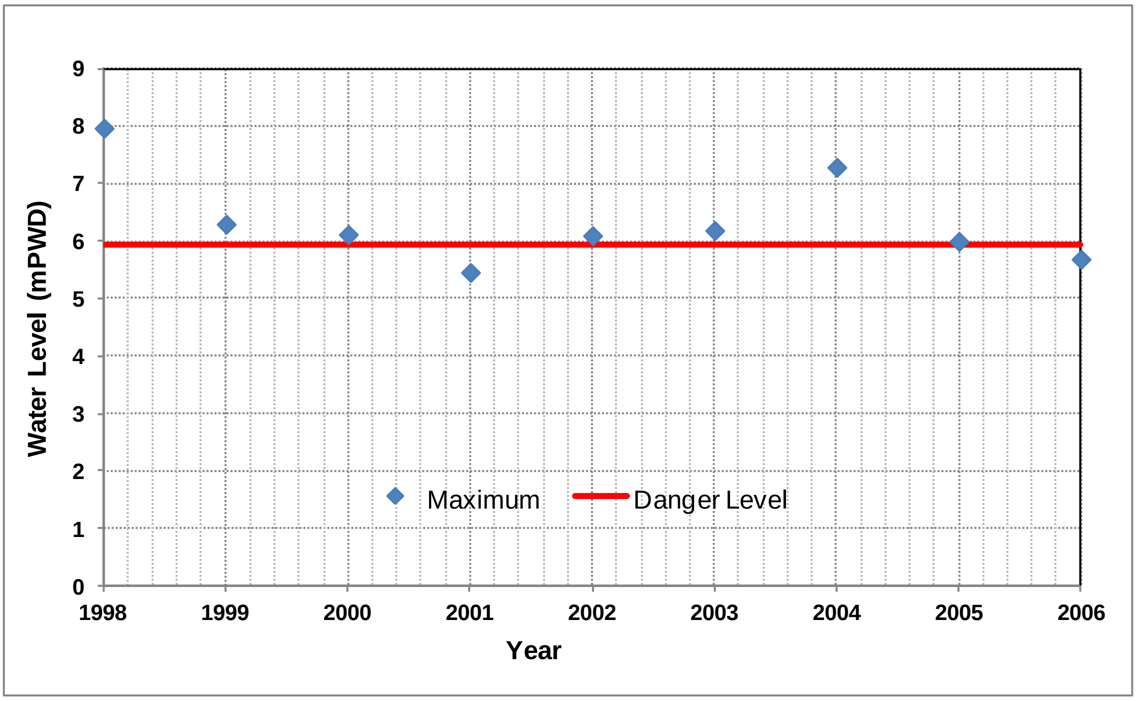

Figure A 16: Annual maximum water level of the Turag River at Mirpur in comparison to its danger level

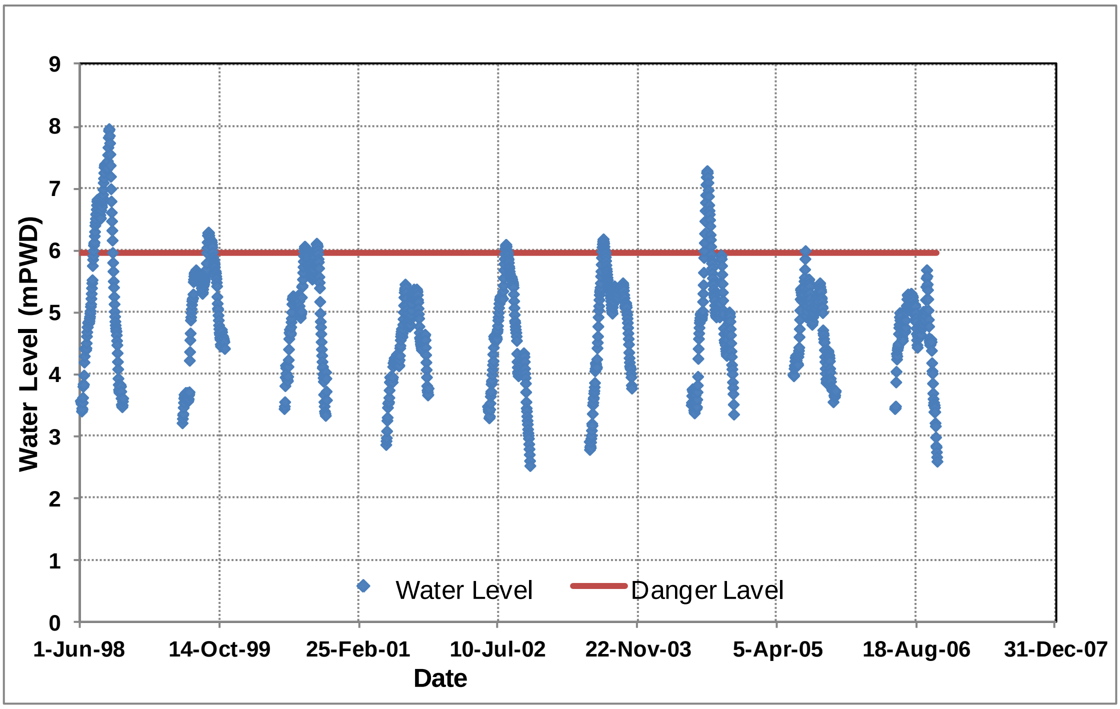

Figure A 17: Annual water level of the Turag River at Mirpur in comparison to its danger level

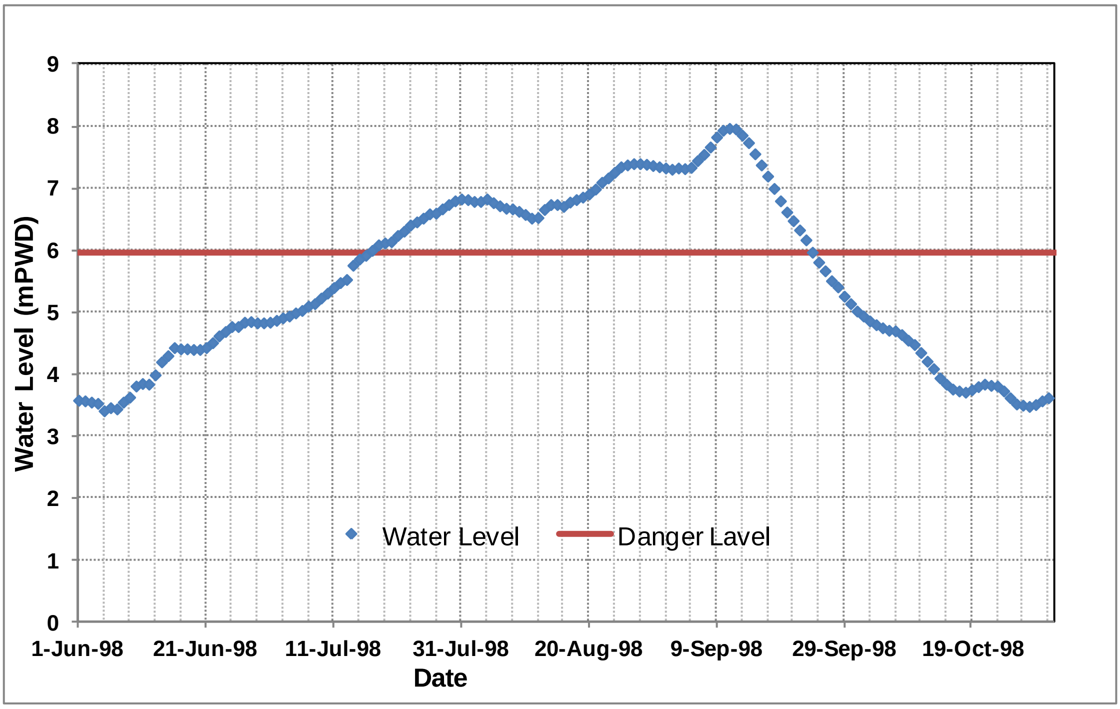

Figure A 18: Water level of the Turag River at Mirpur in comparison to its danger level in 1998

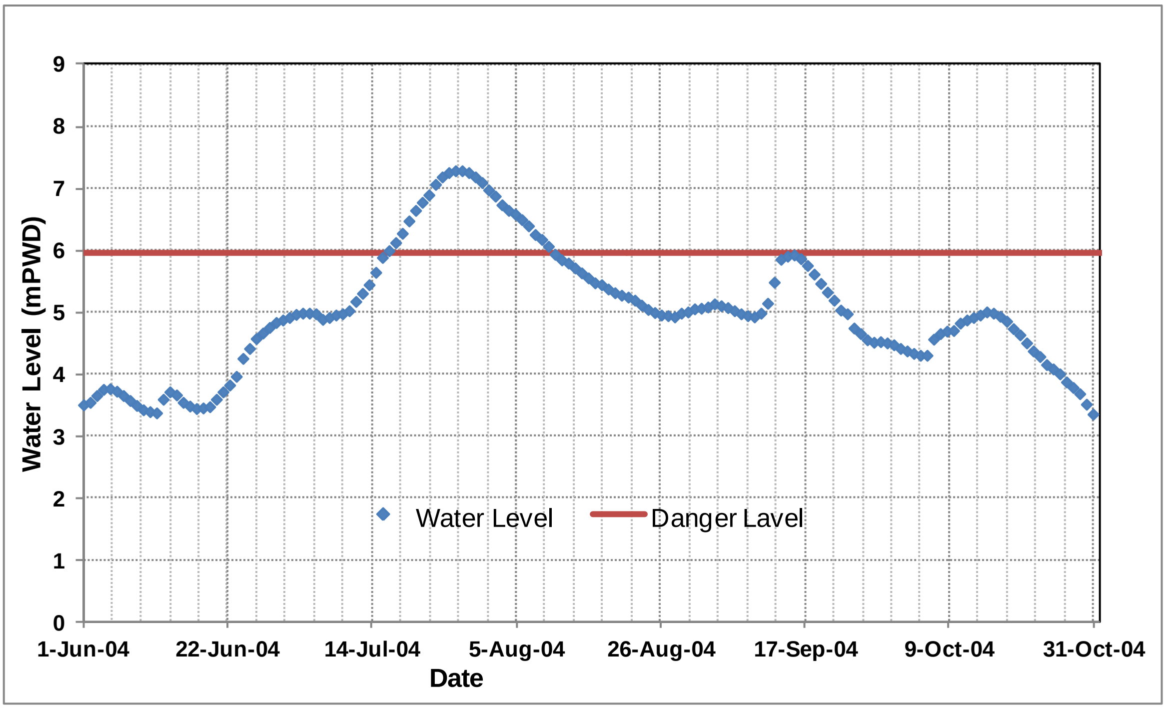

Figure A 19: Water level of the Turag River at Mirpur in comparison to its danger level in 2004

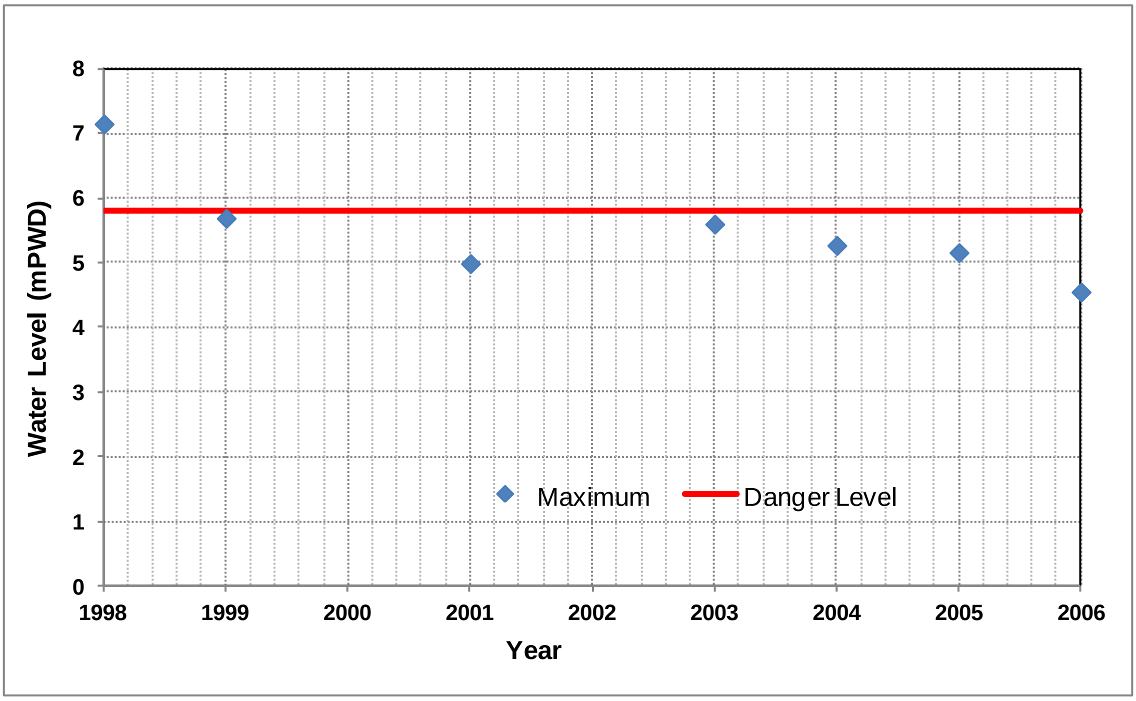

Figure A 20: Annual maximum water level of the Buriganga River at Hariharpara in comparison to its danger level

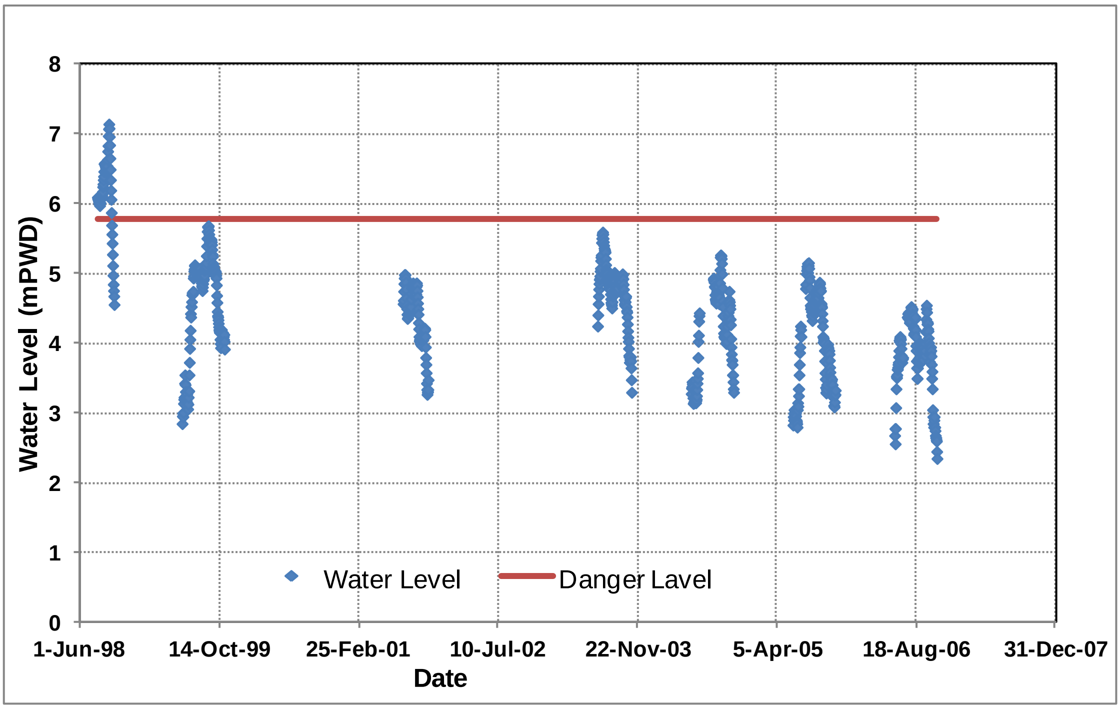

Figure A 21: Annual water level of the Buriganga River at Hariharpara in comparison to its danger level

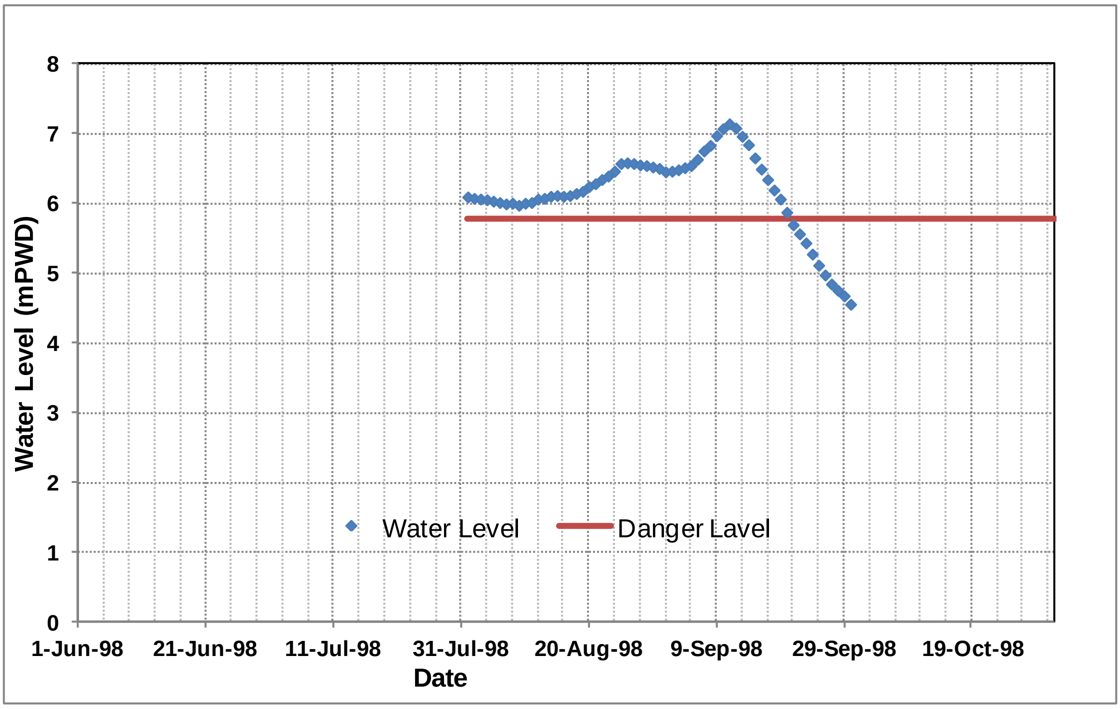

Figure A 22: Water level of the Buriganga River at Hariharpara in comparison to its danger level in 1998

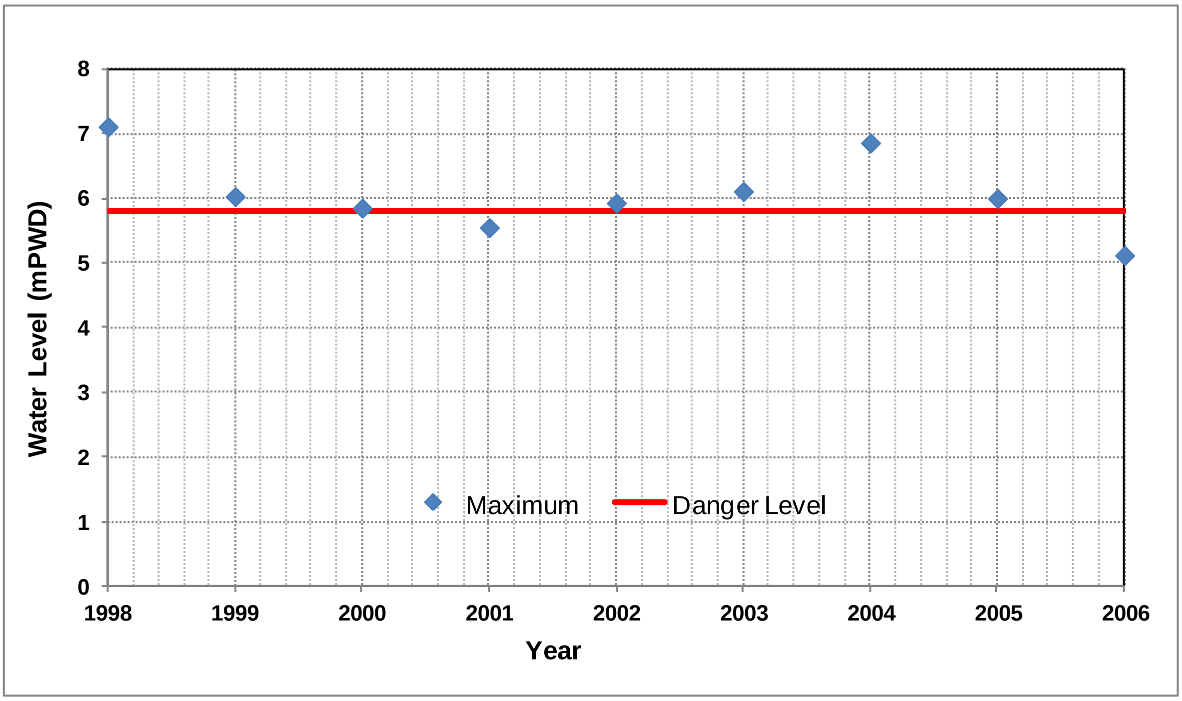

Figure A 23: Annual maximum water level of the Lakhya River at Demra in comparison to its danger level

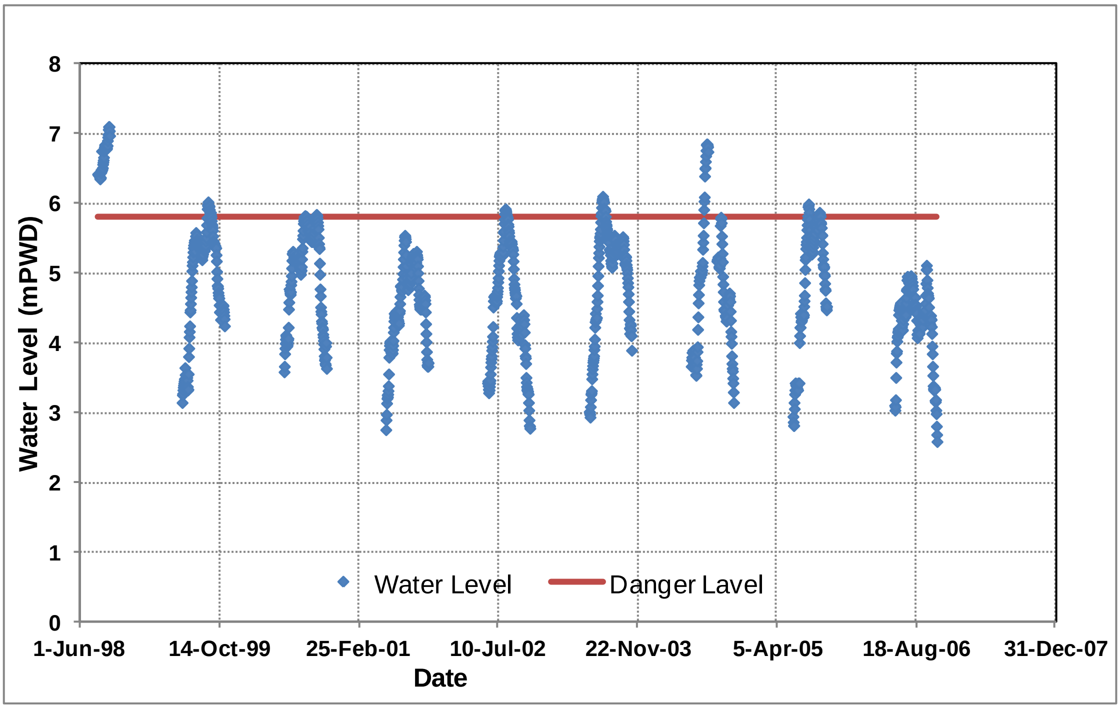

Figure A 24: Annual water level of the Lakhya River at Demra in comparison to its danger level

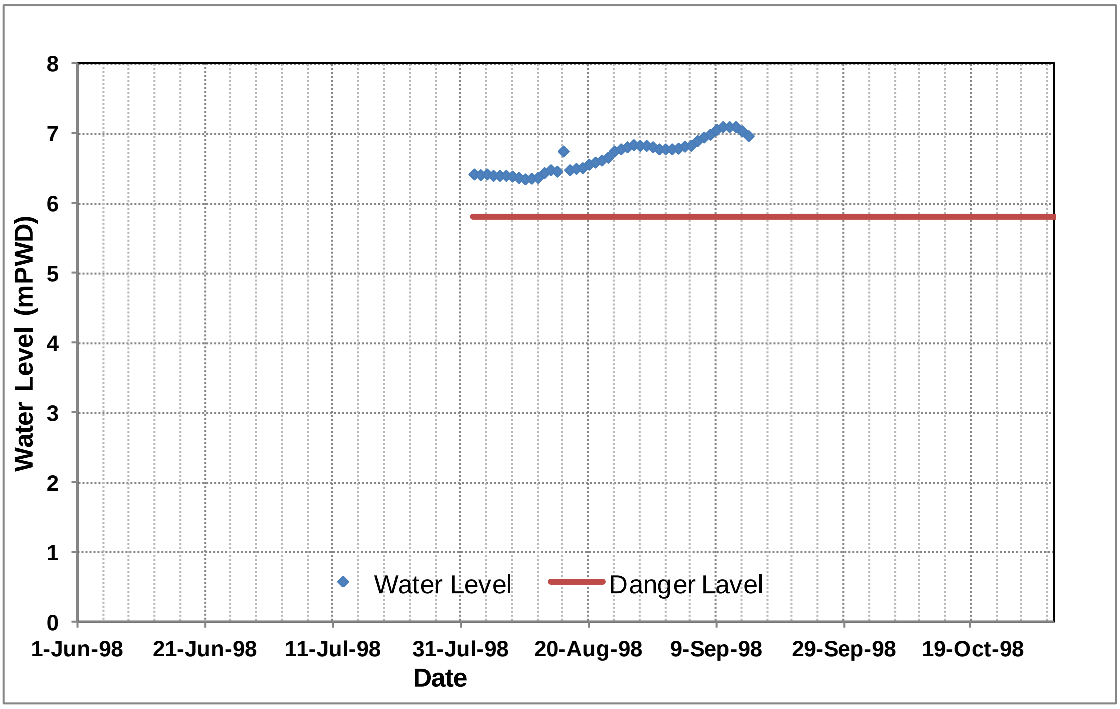

Figure A 25: Water level of the Lakhya River at Demra in comparison to its danger level in 1998

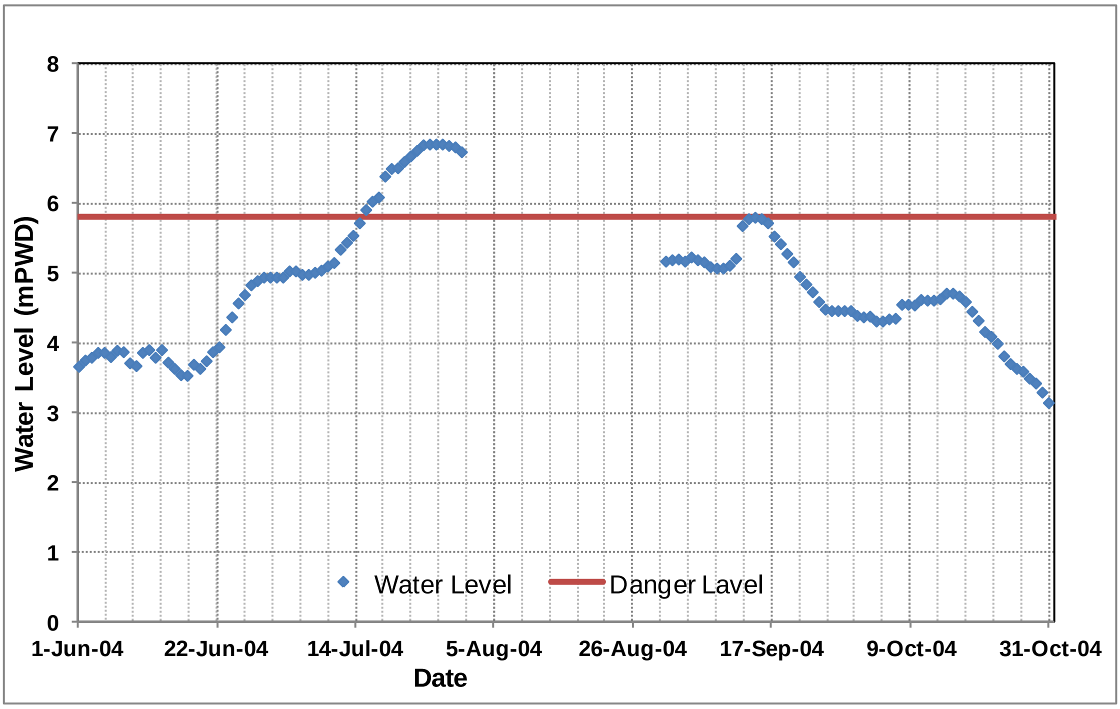

Figure A 26: Water level of the Lakhya River at Demra in comparison to its danger level in 2004

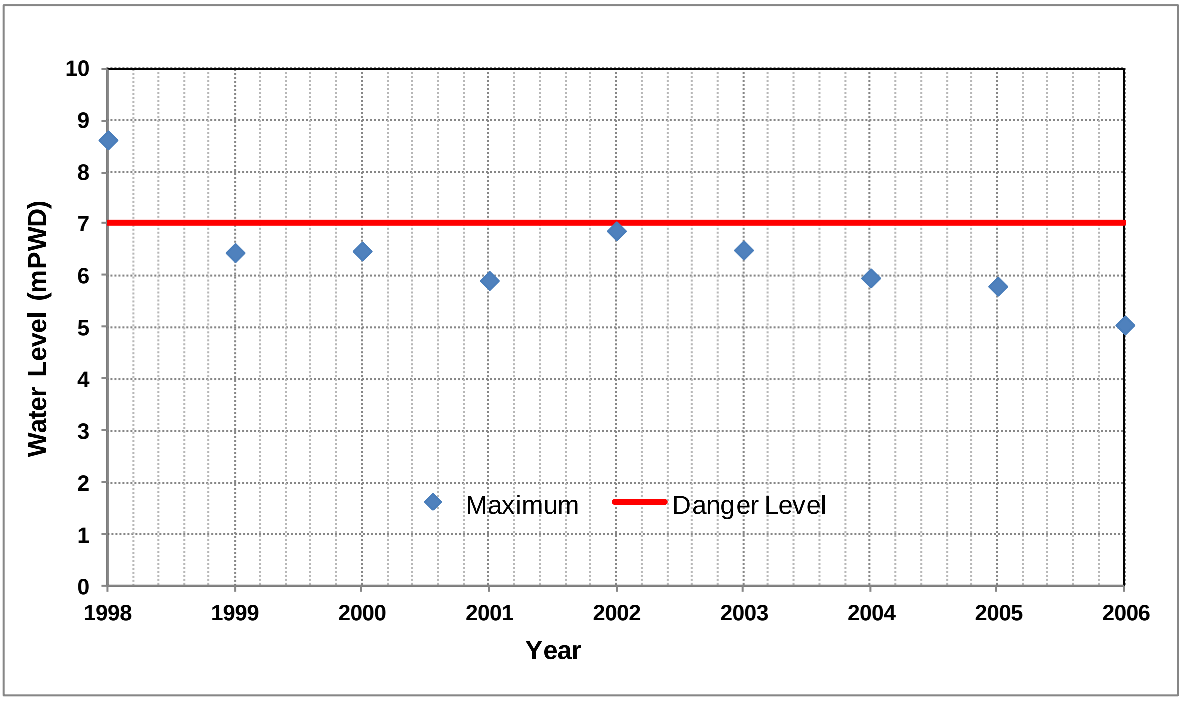

Figure A 27: Annual maximum water level of the Dhaleswari River at Savar in comparison to its danger level

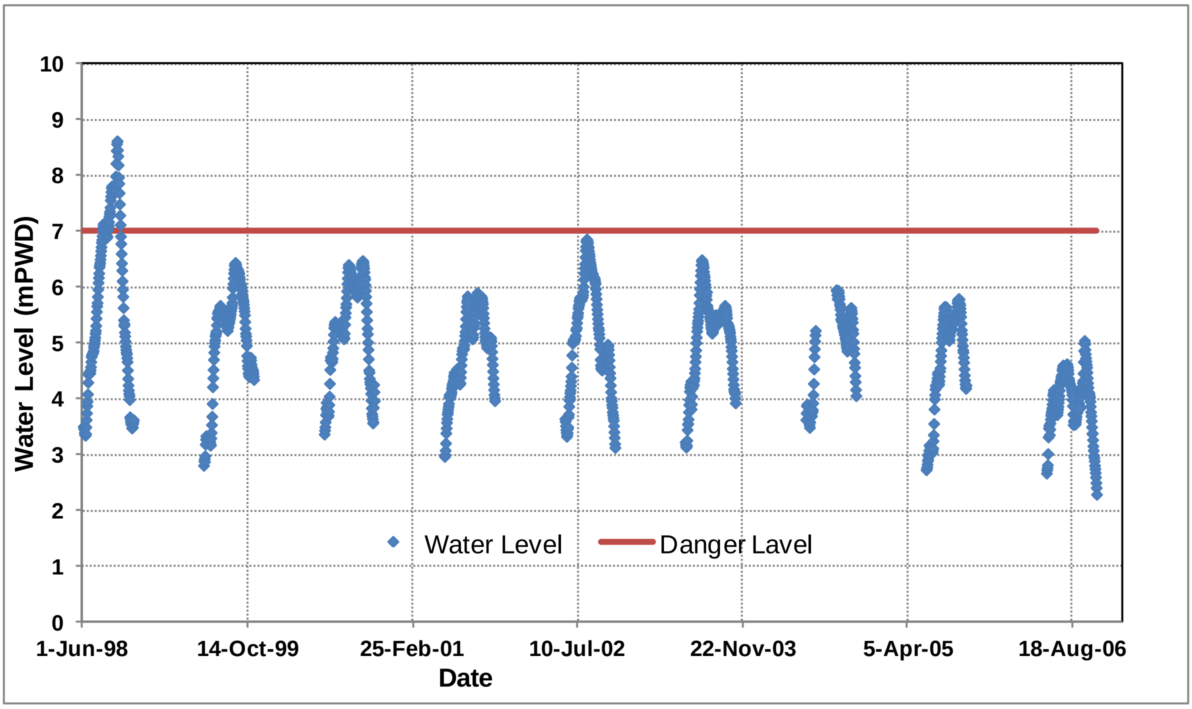

Figure A 28: Annual water level of the Dhaleswari River at Savar in comparison to its danger level

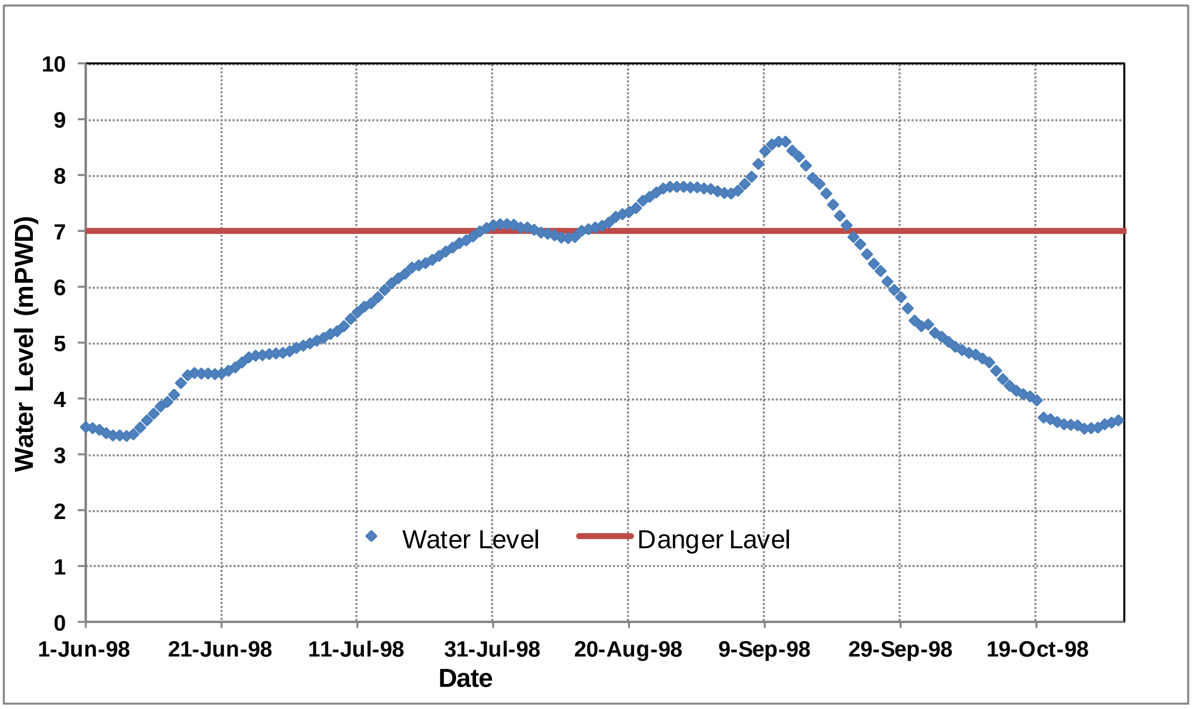

Figure A 29: Water level of the Dhaleswari River at Savar in comparison to its danger level in 1998

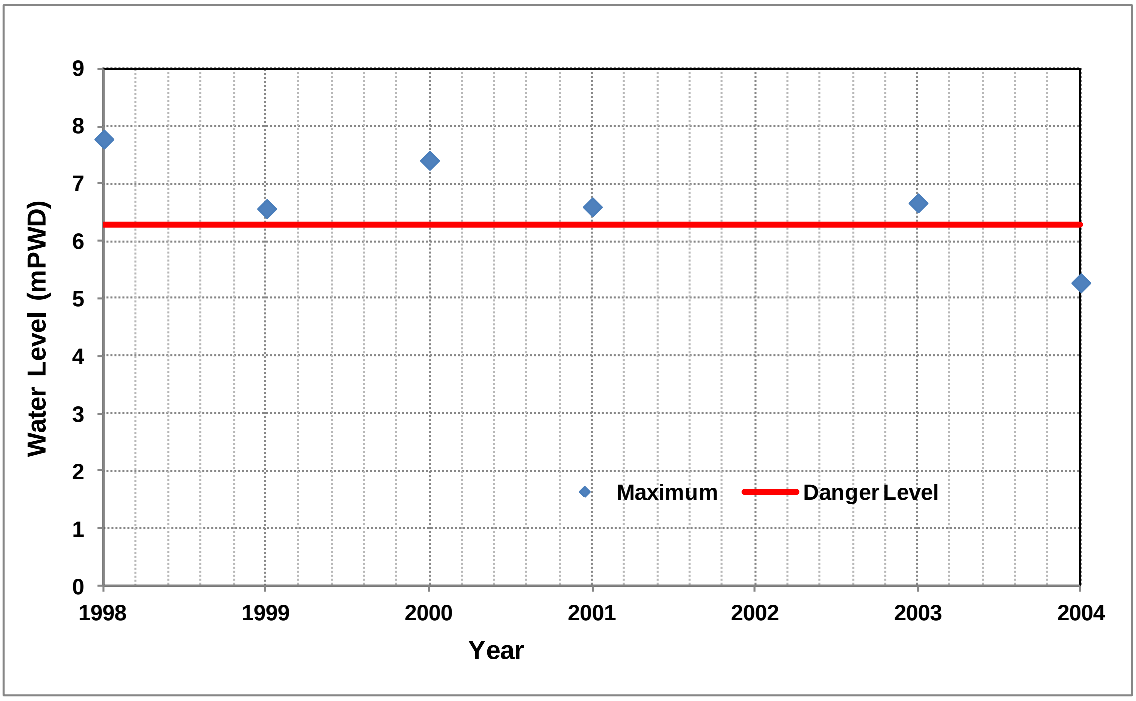

Figure A 30: Annual maximum water level of the Dhaleswari River at Kalatia in comparison to its danger level

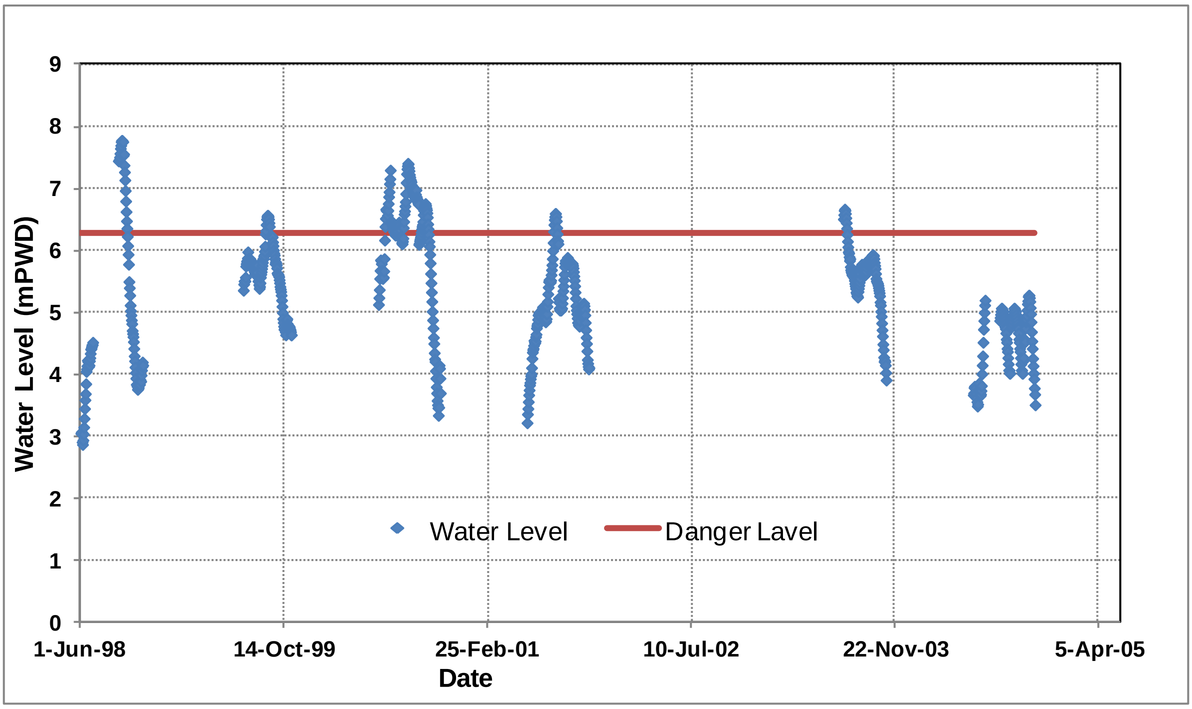

Figure A 31: Annual water level of the Dhaleswari River at Kalatia in comparison to its danger level

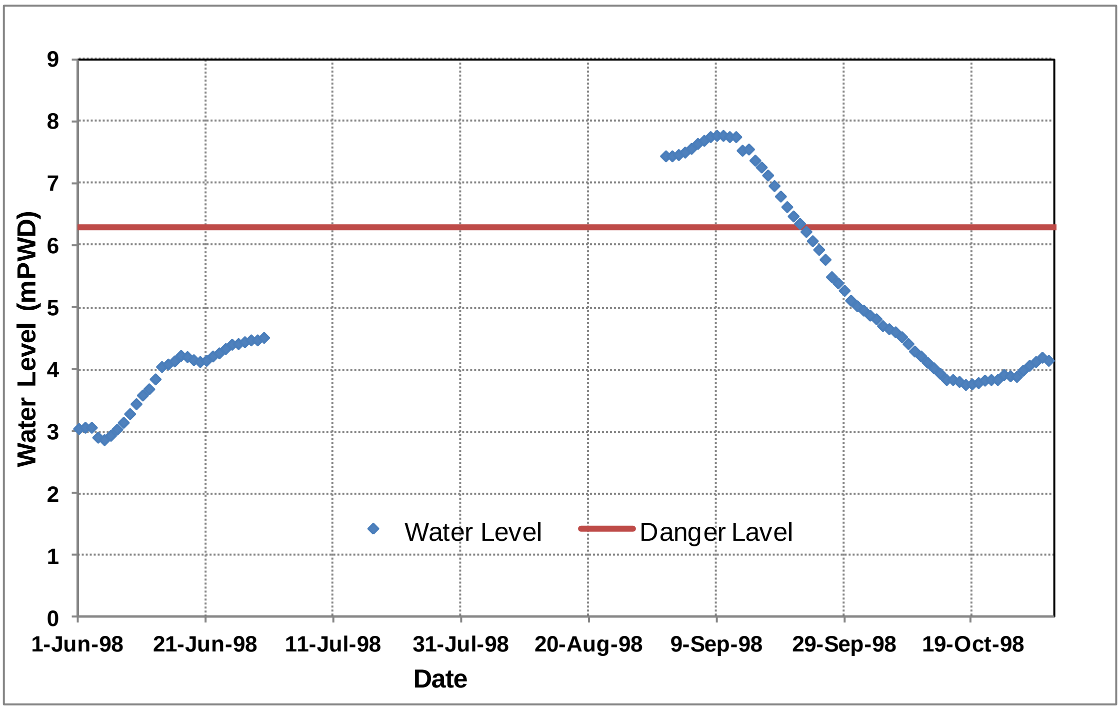

Figure A 32: Water level of the Dhaleswari River at Kalatia in comparison to its danger level in 1998

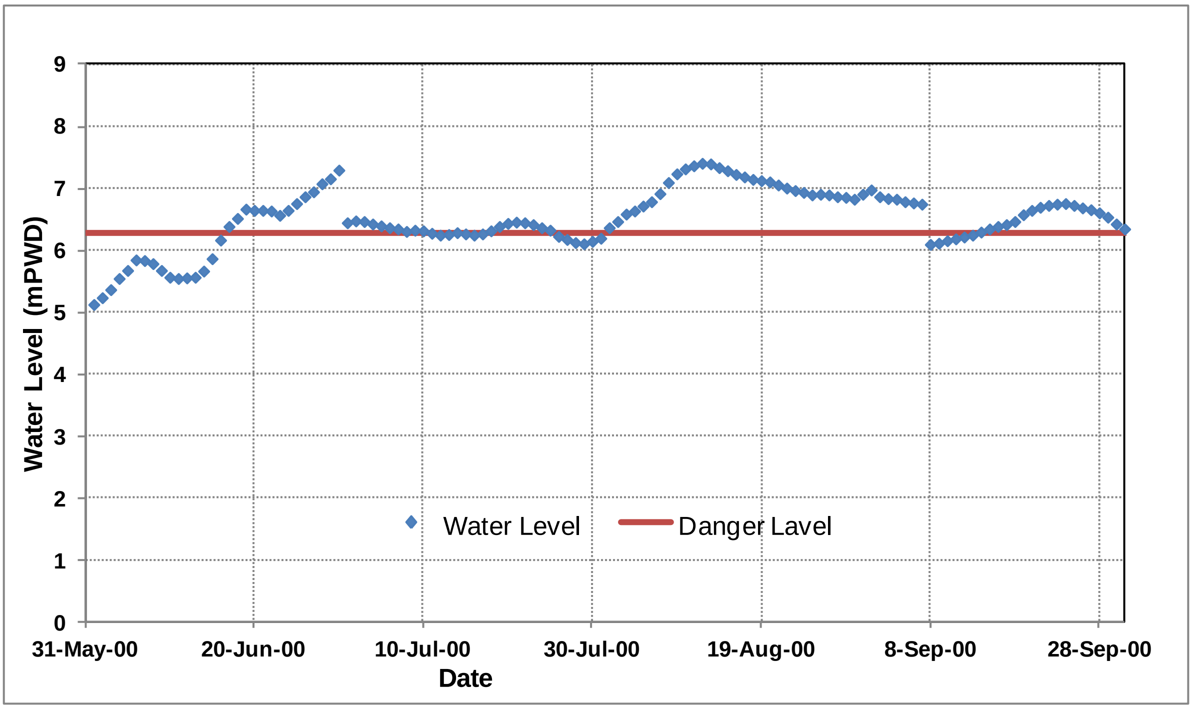

Figure A 33: Water level of the Dhaleswari River at Kalatia in comparison to its danger level in 2000