ASSESSMENT OF SHAFIQUE HAOR AND SONAMORAL HAOR SCHEMES AGAINST FLASH FLOOD IN GREATER SYLHET AREA

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ASSESSMENT OF SHAFIQUE HAOR AND SONAMORAL HAOR SCHEMES AGAINST FLASH FLOOD IN GREATER SYLHET AREA

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CERTIFICATE OF APPROVAL

We, hereby recommended that the M. Engg. research work presented by Rifat Jahan, Roll No. 0413162064 (P), Session: April 2013, entitled as **"Assessment of Shafique Haor and Sonamoral Haor Schemes against Flash Flood in Greater Sylhet Area"** has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Master of Engineering in Water Resources Engineering on 30th September, 2019.

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This is to certify that this project work entitled as **"Assessment of Shafique Haor and Sonamoral Haor Schemes against Flash Flood in Greater Sylhet Area"** is the outcome of research carried out by me under the supervision of Dr. Umme Kulsum Navera, Professor, Department of Water Resources Engineering, Bangladesh University of Engineering and Technology, Dhaka. I do hereby declare that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma from any other institution.

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LIST OF ABBREVIATION

BBS	Bangladesh Bureau of Statistics
BMD	Bangladesh Meteorological Department
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
DAE	Department of Agricultural Extension
DBHWD	Department of Bangladesh Haor and Wetland Development
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
FCDI	Flood Control, Drainage and Irrigation project
GEV	Generalized Extreme Value
GIS	Geographic Information System
ITC	International Training Centre
LANDSAT	Land Satellite
MDWL	Mean Daily Water level
M.Engg.	Master of Engineering
MSS	Multispectral Scanner System
NDWI	Normalized Difference Water Index
NIR	Near-Infrared
NWRD	National Water Resources Database
OLI	Operational Land Imager
RADARSAT	Radio Detection and Ranging Satellite
RS	Remote Sensing
SEP	Submersible Embankments Project
SLC	Scan Line Correction
SRDI	Soil Resources Development Institute
SWIR	Shortwave Infrared
TI	Thermal Infrared
TM	Thematic Mapper
USGS	United States Geological Survey
WARPO	Water Resources Planning Organization
WGS 84	World Geodetic System 1984

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ABSTRACT

Flash flooding is one of the most recurring natural disaster over the northeastern region of Bangladesh. Haors are important areas for Boro cultivation as almost 80% of haor areas are covered by Boro rice. The farmers usually plant Boro crops in the floodplain in December and harvest from April to the first week of May. The Boro crop largely damage when flash flood occurs early May. For better water management and to facilitate crop production, Bangladesh Water Development Board (BWDB) has implemented about 118 schemes in the haor area to mainly protect Boro crop with some other functions like, drainage, irrigation, full flood protection. So, it is of utmost importance to understand and evaluate the performance of pre and post scenario of the implemented schemes against the flash flood frequency and Boro crop production.

Therefore, a study has conducted to assessment the impact after implementation of the Flood Control, Drainage and Irrigation (FCDI) schemes against flash flood frequency and Boro crop production in greater Sylhet area. In this study, Shafique Haor scheme in Sylhet District and Sonamoral Haor scheme in Sunamganj District have been selected. To carry out the study, data of rainfall, discharge, water level, agricultural and Landsat satellite images have been collected from Bangladesh Meteorological Department (BMD), Bangladesh Water Development Board (BWDB), Center for Environmental and Geographic Information Services (CEGIS), Department of Extension (DAE) and United States Geological Survey (USGS) accordingly. In this study, hydrological and agricultural analyses have been carried out to assess the performance of Shafique Haor scheme and Sonamoral Haor scheme. Trend analysis, frequency analysis and Landsat satellite images analysis have been carried out under hydrological analysis. Under frequency analysis, Normal Distribution, Log-normal Distribution, Log-pearson type III and Gumbel's Distribution have been considered. Normalized Difference Water Index (NDWI) has been calculated from the Landsat satellite images. In case of agricultural analysis, cropping pattern, cropping intensity, crop damage and crop production has been calculated. Impact has been assessed and summarized on changes in flash flood frequency and Boro crop production of Shafique Haor scheme and Sonamoral Haor scheme. In this regard, baseline has been created for pre-scheme scenario and post-scheme scenario for the identified indicators. Later, impact has been assessed by subtracting or comparing pre-scheme scenario status from post-scheme scenario status.

It has been found that after implementation of the scheme interventions, risk of entrance of early flash floods reduced significantly. From the study, it has been also revealed that additional 5,466 ton and 1,327 ton crops have been produced in Shafique Haor scheme and Sonamoral Haor scheme accordingly during the post-scheme period. Therefore, Shafique Haor scheme and Sonamoral Haor scheme can be considered as complying with the objective to protect Boro crop from early flash floods and to facilitate crop production.

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Bangladesh possesses enormous area of wetlands including rivers, streams, haors, baors, beels, jheels, lake etc. Haors are characterized as bowl or saucer-shaped large tectonic depression, located in the North-Eastern region of Bangladesh (Ahmed, 2008). These haors collectively known as the Haor basin or Sylhet basin. It spreads over 47 upazilas under seven districts in North-Eastern Bangladesh namely, Sylhet, Sunamganj, Habiganj, Maulovi Bazar, Kishoreganj, Brahmanbaria and Netrokona (Figure 1.1) (Alam, 2010). Overall, the haor region covers an estimated area of 1.99 million hectare which accounts for approximately 13.5% of the country's total surface area (DBHWD, 2012a).

The haor basin covering about 6,000 km^2 in Sylhet Division, mostly in Sunamganj District in Bangladesh (Salauddin, 2010). According to Haor Master Plan volume-2 (2012), Sunamganj District has a total area of 367,000 ha, 95 numbers of haors and the haor area is 73% (Figure 1.2). Sylhet District has a total area of 349,000 ha, 105 numbers of haors and the haor area is 54% (Figure 1.3).

Flash flooding is one of the most recurring natural disaster over the North-Eastern part of Bangladesh. The flooding in the haor area is associated with the rainfall in the upstream catchment in India (Meghalaya, Barak and Tripura basins in India) and often occurs in a short notice. These rapid flooding with a high discharge and velocity are called flash flood. Flash floods spill onto low-lying floodplain lands inundating crops, damaging infrastructure by erosion and often causing loss of lives and property. It's severity depends on time and quantity of rainfall in the hill and drain out capacity of main rivers (Salauddin, 2010). Pressure of hilly flow plus rain fed water in the rivers reach to such a level to overflow or wash out the embankment/dams or banks of the rivers/canal and to enter into the haor. Almost 80% of the haors area is covered by Boro crop during January to May (Pre-monsoon), which produce 18% of the total rice production in Bangladesh (Huda, 2004). Farmers in haors area want to harvest the Boro crop before flash flood strike the region but it is a recurrent phenomenon by which farmers experience to lose their crops. So, the flash flood during April and May is the top ranked hazard that affects agriculture in haors area severely.

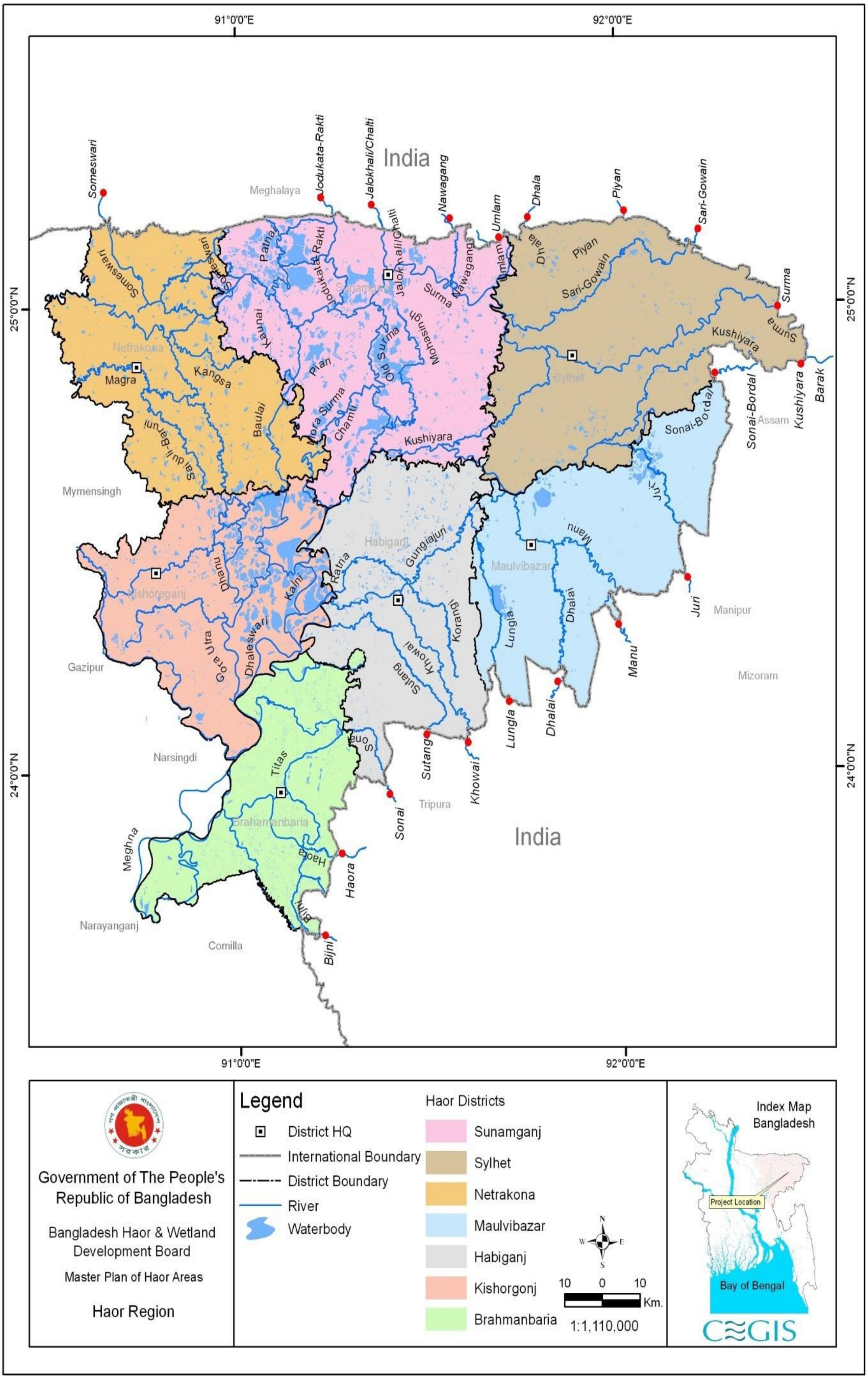

Figure 1.1: Haor districts of Bangladesh (Source: CEGIS, 2019)

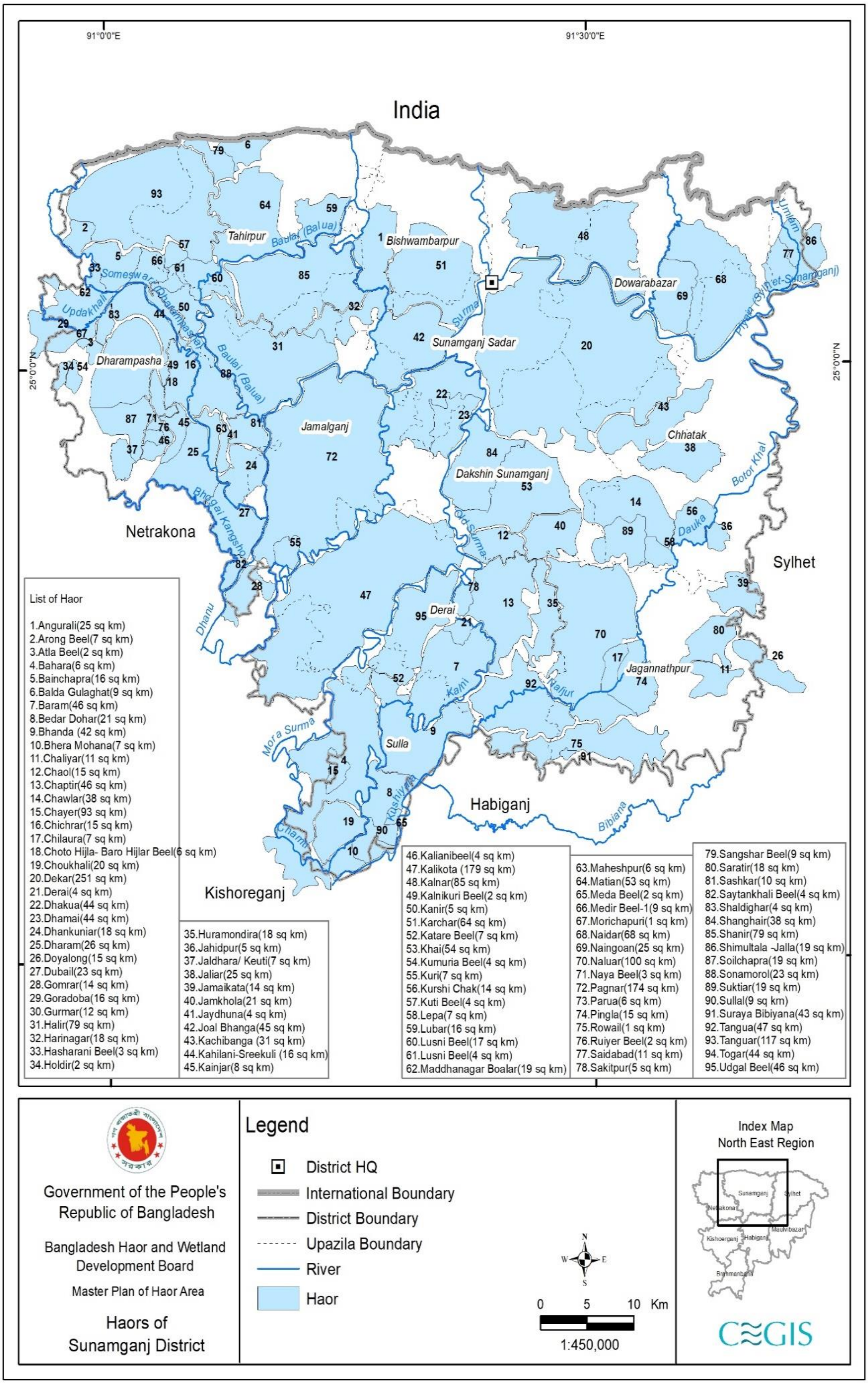

Figure 1.2: Haors of Sunamganj District of Northeast Region (Source: CEGIS, 2019)

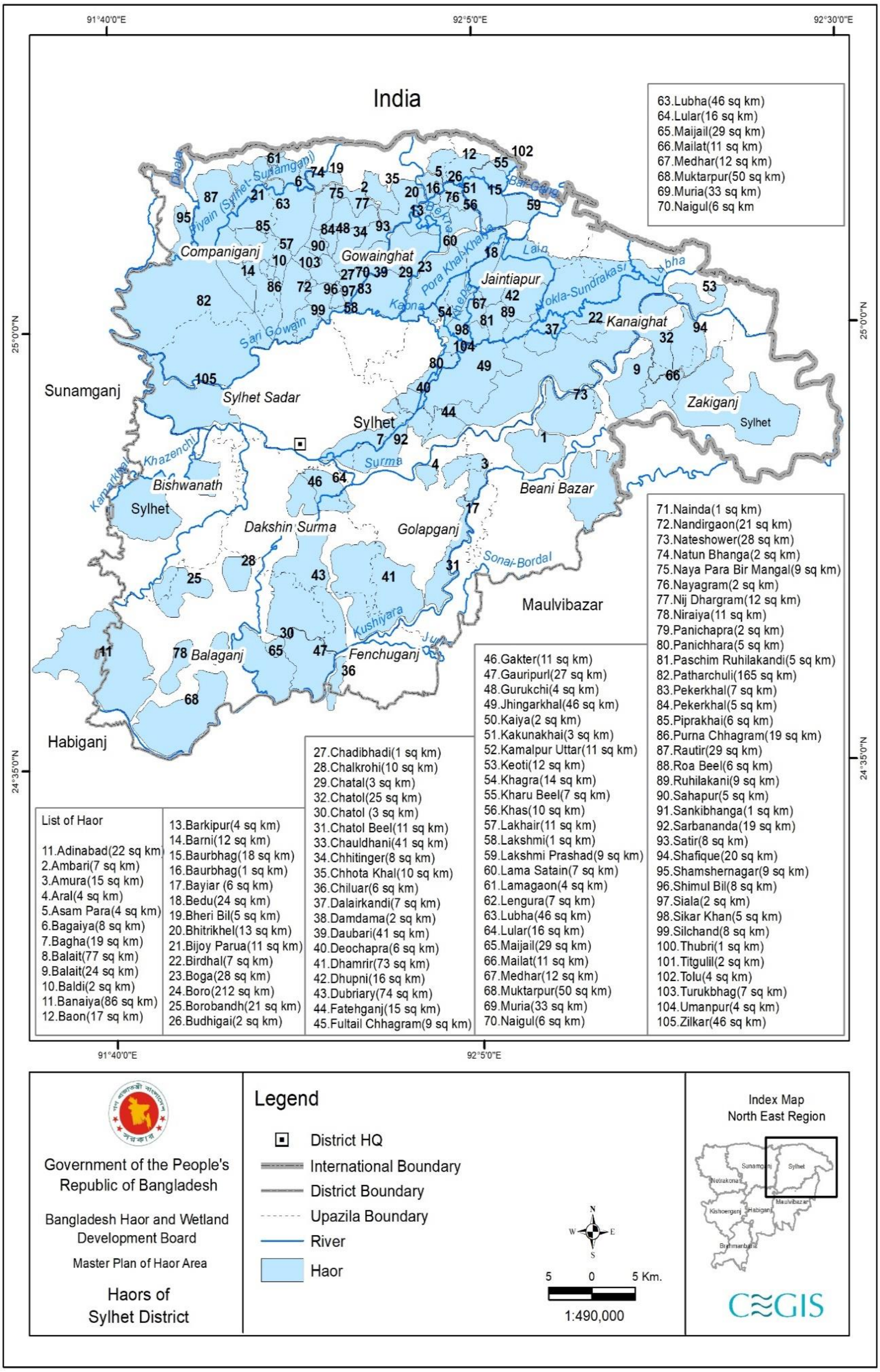

Figure 1.3: Haors of Sylhet District of Northeast Region (Source: CEGIS, 2019)

Recently, climate change is exacerbating the situation (Bhattacharya, 2012). Last several years in 1974, 1988, 1998, 2004 (UAI, 2005) and 2010 flood attacks severely in this region and damage of agricultural production (Alam, 2010). Thus, any disturbance (such as flash flooding) on the Boro crops production potentially impacts the staple food supply significantly for the people at local, regional, and national level. Therefore, several flood control schemes in the form of embankments and related water control measures, collectively known as **"**Flood Control and Drainage/Flood Control, Drainage and Irrigation (FCD/I)**"** projects, have been developed under the Bangladesh Flood Action Plan (FAP) (Ansary, 1997). These number of infrastructures built over the years to have benefited the local people and rice farmers. All these infrastructures have direct impact on the present state of haors and wetland eco-system.

1.2 Scope of the Study

Over the year, Bangladesh Water Development Board (BWDB) has implemented 118 Flood Control/Flood Control and Drainage/Flood Control, Drainage and Irrigation (FC/FCD/FCDI) schemes to protect crops from flash floods in haor area (DBHWD, 2012a). Submergible embankments, regulator or sluices, culverts, irrigation inlets and drainage outlets, fish pass, rubber dam have been constructed under these schemes in a view to facilitate boosting up of agricultural production, improvement of communication and saving life and properties from distress of flash floods and ensuring the sustainability of the environment. A total of approximately 0.29 million hectare cultivable land has been protected from flash flood by implementing 1826 km of submersible embankment (Arif, 2010). The submersible embankments in haor region were designed to delay the flash flood water entering into haors until May 15 with a 10-year return period level (Kaisar, 2016). The main objectives of these embankments was to give opportunity to the farmers to harvest Boro crop during pre-monsoon without any damage by flash flood. Water is allowed to enter inside the embankment immediately after harvesting the Boro through regulators located at strategic locations minimizing the head difference between inside and outside the embankment, thereby reducing the damage to the embankments when they are overtopped (Saleh, 2007).

A number of studies have shown that Submersible Embankments Projects (SEP) have achieved their desired objectives of protecting the Boro crop from pre-monsoon flood and increased the Boro production (Saleh, 2007). Nevertheless, schemes were implemented to protect from flash floods, recent massive Boro crop damage in 2004, 2010, 2016, and 2017 indicate that the facilities to save the crops are not sufficient (Mohammad, 2018). For example, the Department of Agriculture Extension (DAE) stated that the flash flood of April 2017 damaged nearly standing Boro paddy on about 114,000 hectares of land in four districts namely Sunamganj (57,289 hectares), Sylhet (34,379 hectares), Moulvibazar (10,277 hectares) and Habiganj (11,737 hectares) of Sylhet Division (Mohammed, 2017). This contrasting scenario has encouraged taking this study to assess pre-scheme and post-scheme scenario of haors to understand the scheme's effectiveness based on the hydrological and agricultural aspect. In addition, an assessment of the impacts of existing major interventions on flash flood and Boro crop production will help planners to take necessary steps for food security and aid in guidelines for further structural interventions in the future will facilitate the implementation of future development framework in haor region.

Among seven haor districts, Sunamganj has the maximum extent of haors and is a highly disaster prone area due to its geological location. The flash flood which is recurrent during April and May is the number one ranked hazard that affects agriculture in Sunamganj severely especially upazilas adjacent to the hilly area. Sonamoral Haor in Sunamganj District was a deeply flooded haor. The implementation period of Sonamoral Haor scheme was from 1985 to 1992 (DBHWD, 2017). On the other hand, Shafique Haor in Sylhet District was a flood plain haor and Shafique Haor scheme was one of the latest completed scheme in this district. The timeline for implementation of Shafique Haor scheme was from 1997 to 2006 (DBHWD, 2017). Based on the vulnerability of the areas and availability of data, Shafique Haor scheme and Sonamoral Haor scheme have been selected as the study areas. Therefore, in this study, an attempt has been made to assessment of Shafique Haor scheme and Sonamoral Haor scheme against flash flood in greater Sylhet area.

1.3 Objectives of the Study

The overall objective of the study is to assessment and compare the pre-scheme and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme. This assessment will be carried out based on the changes in flash flood frequency and Boro crop production which have occurred after the implementation of the schemes. The specific objectives of the study are:

1. To assess the changes in flash flood frequency (water level and discharge), rainfall distribution and Boro crop production (cropping pattern and production) in the study area.
2. To compare both the selected schemes based on the pre-scheme and post-scheme condition against flash flood frequency and Boro crop production.

The expected results of this research as follows:

This study will be focused on the changes in flash flood frequency and Boro crop production before and after the implementation of the schemes. It will also provide an understanding about the effectiveness of the structural and non-structural interventions in haors.

1.4 Organization of Thesis Work

The thesis has been organized under five chapters.

Chapter 1 describes the introductory aspects like background of the study, scope of the study, objectives of the study and how the thesis has been organized.

Chapter 2 describes the definition of wetland, wetlands of Bangladesh, characteristics of haor, examples of different types of wetlands in Bangladesh and the available literatures related to the past studies on haor in Bangladesh. This chapter also includes the studies on interventions in wetlands around the world and summary.

Chapter 3 represents theory and methodology of the study approach. This chapter includes related theories of this study. Detailed methodology of the hydrological analysis, Landsat image analysis and agricultural analysis, data collection and data analysis followed for this study and summary are also included in this chapter.

Chapter 4 represents the output of analysis and discussion about the results. This chapter includes results of the hydrological and agricultural analyses of the study. In this chapter, hydrological analysis includes frequency analysis, trend analysis and Landsat image analysis. This chapter also includes the cropping pattern and crop production analysis based on agriculture aspect and comparison of the pre-scheme and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme.

Chapter 5 includes two sections, one section is conclusions of the study and another one is recommendations for further study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

A number of studies have been conducted on wetlands in Bangladesh as well as all over the world. In this chapter, some of the pioneering works of previous national and international studies, publication, documents, reports and researches have been reviewed. These literatures can help to better understand and gain knowledge in hydrological trend analysis, frequency analysis, Landsat image analysis and agricultural analysis. By getting knowledge, the current study objectives have been fulfilled having proper conceptions. Brief description of the literatures has been reviewed is given in the following sections.

2.2 Definition of Wet Land

Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface of the land, or where the land is covered by shallow water (Davis, 1994).

According to the Bangladesh Water Act, 2013 wetlands are defined as "Wetland means any land where water remains at the level of surface or close to it and which inundates with shallow water from time to time, and where grows such plants that may usually grow and survive in marsh land" (DBHWD, 2016a).

Ramsar Convention (1971) defines wetlands as follows: Under the text of the Convention (Article 1.1), wetlands are defined as: "Wetlands are areas of marsh, fen, peat land, or water; whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Davis, 1994).

In addition, for the purpose of protecting coherent sites, the Article 2.1 provides that wetlands to be included in the Ramsar List of internationally important wetlands: "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six meters at low tide lying within the wetlands" (Davis, 1994). In addition, there are human-mad wetlands. It is also to be noted that lakes and rivers are understood to be covered by the Ramsar definition of wetland, in their entirety, regardless of their depth (Davis, 1994).

2.3 Wetlands of Bangladesh

The abundance of water and wetlands has always been the geographically and historical destiny of Bangladesh. More than two third of Bangladesh may be classified as wetland according to the definition enunciated in the Ramsar Convention (Saheed, 1984). The total area of wetlands in Bangladesh has been variously estimated to be seven and eight million hectares i.e. about 50% of the total land surface (Nishat, 1993). The wetland classification of Bangladesh is basically based on the Ramsar classification framework. In the context of Bangladesh, this wetland classification system is modified to better suit the unique characteristics of wetlands of Bangladesh. The wetlands of Bangladesh are primarily classified into four systems which are (DBHWD, 2016a):

(a) Inland Wetlands
(b) Marine/Coastal Wetlands
(c) Human-made Wetlands and
(d) Reversible Wetlands

Each system, except for Reversible wetlands is further classified into two classes, which are:

(a) Permanent
(b) Non-permanent

In Bangladesh, which lies in the floodplain of three great rivers, the Bengali language has several terms to differentiate between lakes, including haor, baor, beel and jheel. All four are types of similar freshwater wetlands. The line of difference among a haor, a baor and a beel is usually very thin.

Haors are bowl-shaped depressions of considerable aerial extent lying between natural levees of the rivers or high lands of the northeast region of Bangladesh. In most cases, haors have been formed as a result of peripheral faulting leading to the depression of the haor area. In the wet seasons, the haors are full of water, but during the dry seasons, these are dried up except for the beels.

Baor is an oxbow lake which is a dead section of a river created when the river changed course. A Baor normally is still part of the flood plain of the river to which inlets and outlets connect it.

Beels are shallow lakes, which form in the lowest parts of the haor; sometimes these are perennial but more often seasonal. The water surfaces are contiguous with the ground water table and that beels are sustained from ground water to a large extent. In Bangladesh, there are thousands of beels of different sizes. Beels are mainly fed by surface runoff water.

Lakes are large bodies of water that are surrounded by land and are not part of an ocean. Lakes are relatively still bodies of water when compared to a river where the water flows. Many lakes are artificial and are constructed for industrial or agricultural use, for hydro-electric power generation or domestic water supply, or for aesthetic, recreational purposes, or other activities.

Jheel a local term representing a reach of an old river channel bed. Usually it appears as an oxbow lake. Jheels are commonly seen in the southwestern Ganges deltaic parts of the country.

2.4 Characteristics of Haor

Haors with unique hydro-ecological characteristics are large bowl shaped floodplain depressions. The core haor area, alternatively referred to as the Haor basin or the Sylhet basin located in the north-eastern region of Bangladesh. Characteristics of haor region has been described in the following section.

2.4.1 Physical Settings

(a) Physiography

Mainly physiography of this area was classified based on the combination of the geological material in which particular kinds of soil have formed and the landscape on which they occur. Seven districts comprising the haor area are placed on the following eleven (11) physiographic units and subunits out of thirty-four (34), based on agro-ecological regions of Bangladesh prepared by Food and Agriculture Organization (FAO), shown in Figure 2.1. The units are (i) Northern and Eastern Piedmont Plains, (ii) Northern and Eastern Hills, (iii) Sylhet Basin, (iv) Eastern Surma-Kushiyara Floodplain, (v) Old Brahmaputra Floodplain, (vi) Young Brahmaputra and Jamuna Floodplain, (vii) Active Brahmaputra-Jamuna Floodplain, (viii) Old Meghna Estuarine Floodplain, (ix) Madhupur Tract, (x) Middle Meghna River Floodplain and (xi) Akhaura Terrace. Among these units, six major units are (a) Northern and Eastern Piedmont Plains (b Northern and Eastern Hills (c) Sylhet Basin, (d) Eastern Surma-Kushiyara Floodplain (e) Old Brahmaputra Floodplain and (f) Old Meghna Estuarine Floodplain (DBHWD, 2012b).

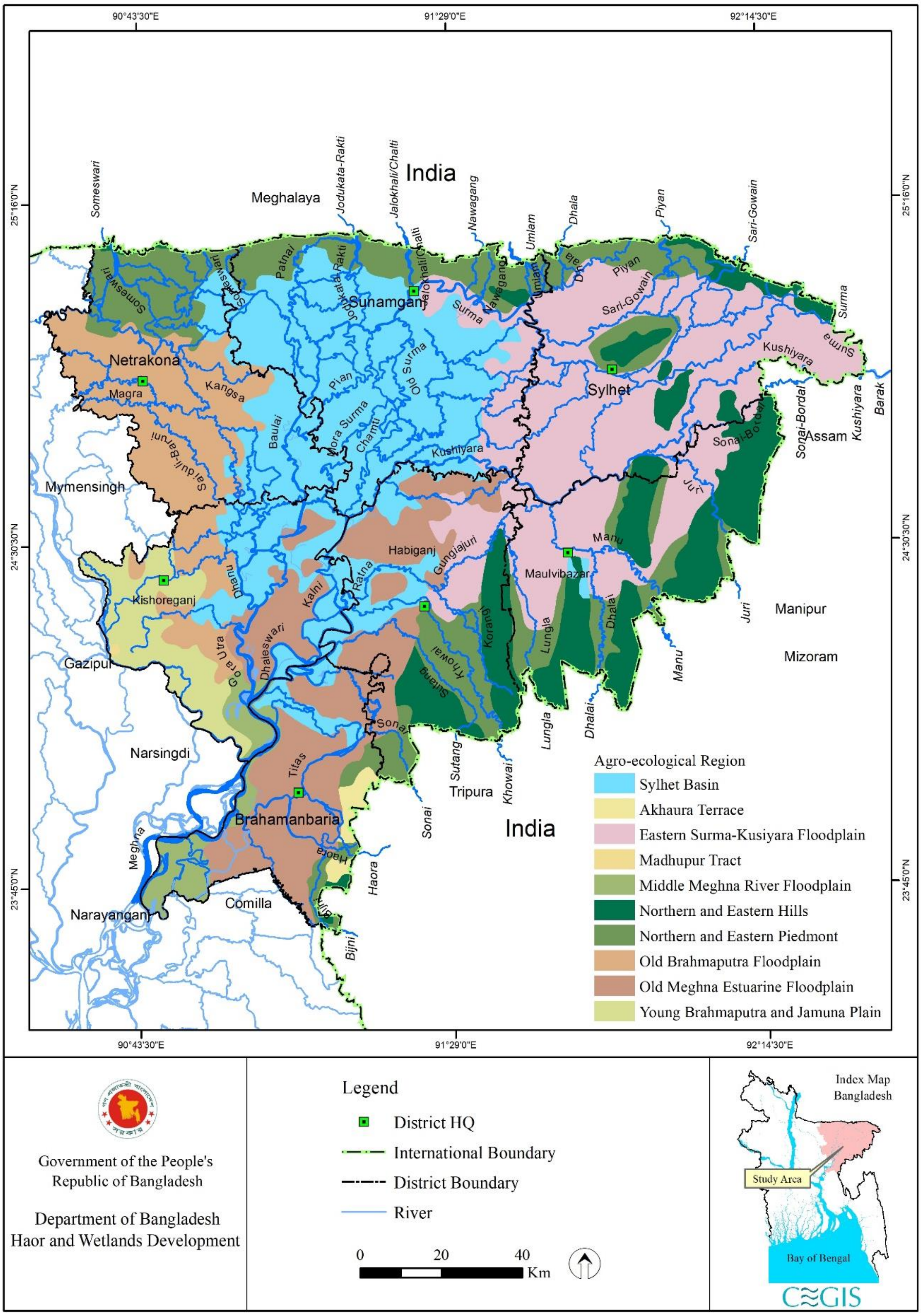

Figure 2.1: Physiography of the North East Region (Source: CEGIS, 2019)

2.4.2 Topography

The primary haor region formed through the eastern continuation of the central broad Indo-Gangetic plains. Evolution of the Indian sub-continent has been the result of a collision between the northward moving Indian plate and the Stationary Eurasian Plate since the Cretaceous times. Parts of this plate has further fractured and sunk below the sea-level during Oligocene period. The Bengal Basin started to take shape post this event and started filling up with sediment through a process of deltaic sedimentation, eventually turning into a slowly subsiding tectonic basin. The Bengal Basin of modern times is primarily located within Bangladesh, with small parts in the West Bengal.

(a) Digital Elevation Model (DEM)

The north-eastern haor region falls within the Bengal Basin engulfed by India on the north, east and southern borders. The Sylhet Trough is a sub-basin of the Bengal Basin and consists of 13-20 km thick alluvial and deltaic sediments underlain by much older gneiss and granite rocks (DBHWD, 2017). The basin is bounded by the Shillong Plateau in the north, the Indian Burmese ranges in the east and by the Indian Shield in the west. The north eastern haor region has been experiencing some profound subsidence in recent decades. The general topographical layout of the haor region is represented in Table 2.1 and has been derived from the digital elevation model (DEM) illustrated in Figure 2.2.

Table 2.1: Topography of the haor region

Elevation (m)	Area (km^2)	% Area
<= 1	4	0
1-5	6708	34
5-10	8948	46
10-50	3759	19
50-100	223	1
100-310	19	0

The Sylhet Basin has subsided 10-12 m in the last several hundred years with an annual subsidence rate of 21 mm which appears to be arrived at by using Morgan and McIntire's estimate of 10 m subsidence in 500 years (DBHWD, 2017). With an annual consideration of subsidence at 2-4 mm and a soil compaction rate of 1-2 mm/year, the actual subsidence rate of the Sylhet Basin might be approximately 3-6 mm/year (DBHWD, 2017). The southern and eastern parts of the Sylhet Basin are characterized by a series of north trending folds which have formed as a result of deformation from the Indo-Burmese ranges. The anticlines constitute the Tripura Hills along the southern border of the region.

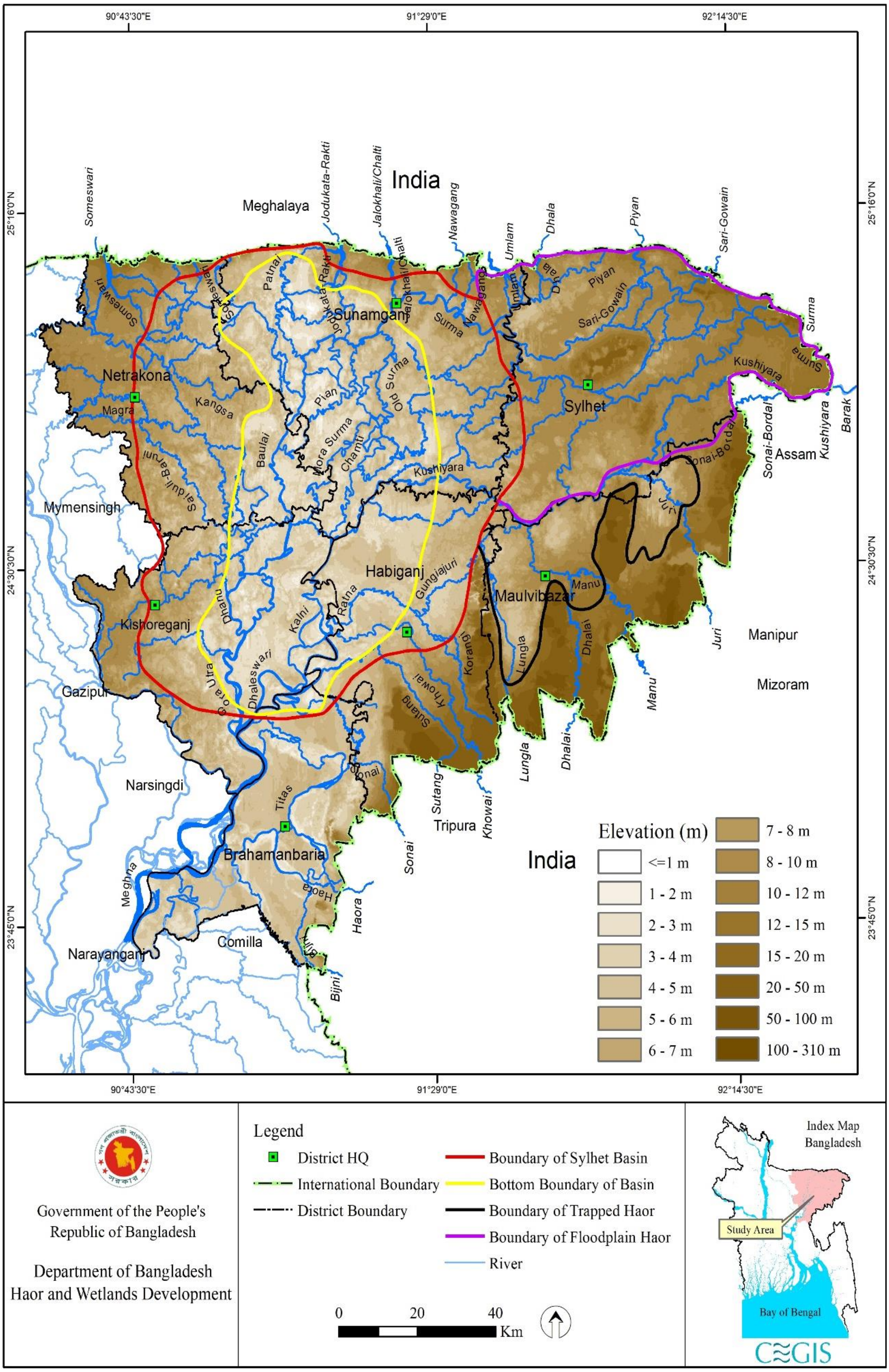

Figure 2.2: Illustration of Digital Elevation Model (DEM) for North-eastern Bangladesh (Source: CEGIS, 2019)

2.4.3 Climate in the Northeast Region

The Northeast Region is located entirely to the north of the Tropic of Cancer, hence its climate is characterized by sub-tropical monsoon. The monsoon results in intense regional and orographic rains caused by the interface of mist air masses coming from the Indian Ocean through the Bay of Bengal with a predominant northeastern direction and the steep and high hills located at the foothills in the states of Assam, Meghalaia and Tripura in India. The hills in Indian states experience very severe precipitation, causing very high flows in the major rivers draining through the Northeast Region of Bangladesh such as the Surma, Kushiyara, Manu, Khowai and Someswari. Some of the more intense precipitations in the world fall in this region where the average annual rainfall is around 12,000 mm (DBHWD, 2016b). As a result of the said unique climatic and physiographic settings of the upper Meghna area, the meteorology, hydrology, fluvial regimes and geomorphology are quite and distinct from other regions of Bangladesh.

The hydro-meteorological seasons of the Northeast Region are generally classified into:

(a) Pre-monsoon season extending from April to May,

(b) Monsoon season from June through September,

(c) Post-monsoon season from October to November and

(d) Dry season from December through March.

(a) Pre-monsoon Season

The pre-monsoon season occurs from April to May and is characterized by an increase in precipitation with rainfall ranging from nearly 490 mm in the southwest to around 1,290 mm in the northeast (DBHWD, 2016b). The intensification of rainfall during the pre-monsoon season increases the incidence of flash floods in the region, which can potentially damage the crops when the river flows overtop and inundate agriculture land during the harvest season, causing serious damage to farmers as well as the country.

(b) Monsoon Season

The southwest monsoon brings moist winds into the Northeast Region from the Bay of Bengal along a circular route over the Chittagong Region so that the winds actually approach the region from the southeast. Rainfall in the season is abundant and it is often referred to as “monsoon”, meaning rainy season. During the monsoon season, the entire Haor region goes underwater.

(c) Post-monsoon Season

The post-monsoon season happens during October and November. The rainfall is sporadic and ranges from near 170 mm in the southwest to about 320 mm in the northeast (DBHWD, 2016b). Figure 2.3 presents the average rainfall distribution throughout the Upper Meghna River Watershed.

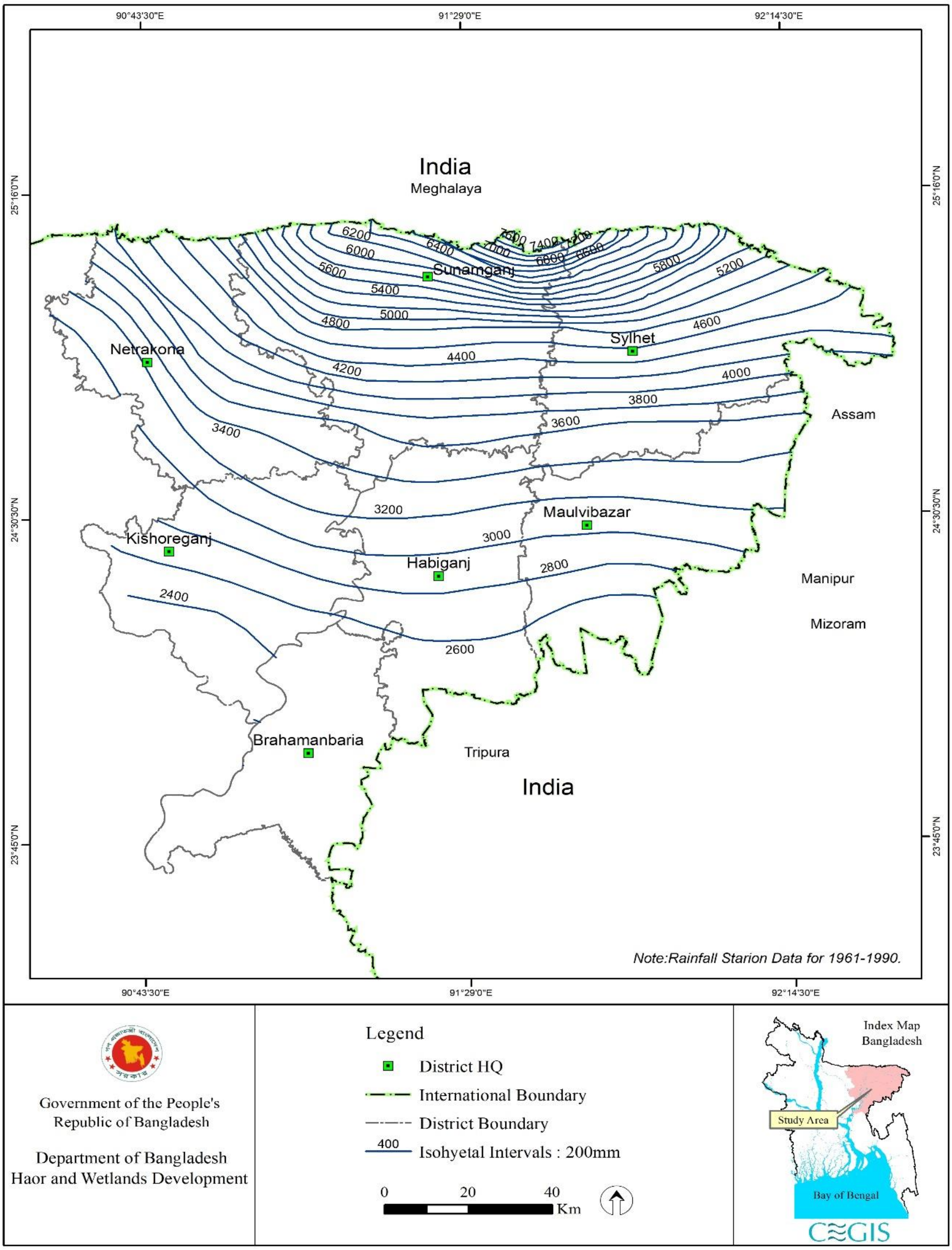

Figure 2.3: Isohyet graph in Upper Meghna River Basin (Source: CEGIS, 2019)

2.4.4 Flood

The most common problem that takes place in haor area is flood. Usually there are two types of floods in that area: flash flood and monsoon flood. Between these two types of flood flash flood is more concerning than the other as the damage caused to the crops by this flood is severe. The other, monsoon flood does not cause that much damage.

(a) Monsoon Flood

The monsoon flood is a seasonal flood that increases and decreases slowly and inundates a huge area during June to September. The monsoon flood is significant for this area as it is needed for the conservation of ecosystem, but it is not considerably vital since it occurs no damage to crops due to the absence of crop in the fields during this season.

(b) Flash Flood

Northeastern part of Bangladesh especially Sunamganj, Sylhet and Netrokona districts are located in one of the depressed portion of the country. Most of the rivers in these areas are originated from nearby hilly area of India. These rivers are extremely flashy that is characterized by sudden and wide variation in flow as a result of excessive rainfall. When heavy rainfall is occurred in the hilly region of India, water quickly moves towards the Haor area of Bangladesh through a number of rivers and Khals. This floodwater not only carries the water but also carry a huge amount of sediment originated mainly from hill.

Over the time this sediment has deposited on the rivers and canals bed and has reduced the conveyance capacity more or less all of the water resources system with n the Haor area. As a result, when flash flood due to sudden heavy rainfall creates pressure on the water resources system, water easily overtopped and creates breaching at several locations on the submersible embankment eventually water quickly enter into the haor. Most of the cases, flood water comes into the haor very early in the moonson and farmars do not get sufficient time to harvest their standing boro crops (Mosleh, 2017).

One of the functions of flash floodwater is to carry sediments, which are eroded from the hilly catchment area. During heavy rainfall in the hilly region, massive erosion is taken place on the exposed surface of the hill. If the high intensity rainfall is continued for certain period then courser sediment such as big sized stone, boulder etc starts to erode and move along the rivers. Finally, these sediments are deposited on the river bed, canals and agricultural land. During flash flood, sediment transport rates increase significantly of the rivers and hence major flood events make a disproportionate distribution of sediment and changes in channel size, shape and even location. Over the years, sediment has deposited mainly on the river bed and depressed portion of the haor. According to the local people, in some places about 4 to 5 meter sediment has deposited on the river bed, which not only created obstruction for water flow but also hampered the navigation system in the north east region (Alam, 2011).

Internal canals have lost their carrying capacity due deposition of sediment on the bed of beels and in some cases created drainage problem for the haor area. Due to deposition of sediment, beds of beels have raised which ultimately hampered the fisheries and agricultural activities as a result of scarcity of water in dry season Flash flood has another impact on the plan form of the rivers and canals in the north east haor area. Due to high magnitude flash flood, sometime severe erosion is occurred along the river bank causes not only a huge amount of national loss but also creates immense sufferings to the local people. Sand carpeting is another problem induced from flash flood. This problem is normally found in haor very adjacent to the hill such as Matian Haor, Angurali Haor, Karchar Haor and Kalner Haor under Sunamganj District (Alam, 2011).

2.4.5 River System

A large number of Transboundary Rivers enter into Bangladesh in the North East Region. Major parts of the catchment of these rivers are outside the country. The haor region lies in the Meghna basin which is 69,514 km^2 and 33% of this area fall within Bangladesh (DBHWD, 2017). The Meghna basin is drained ultimately into the Bay of Bengal through the Kalni- Kushiyara and Surma- Baulai system on average 159,087 million m^3/year of this flow, 56% is generated at the upstream of Bangladesh while 44% is generated within the country (DBHWD, 2017). Twenty-three transboundary rivers enter into Bangladesh in the North East Region. The major parts of the catchments of these river are outside the country (in India). In the haor area, three major transboundary river systems are the Meghalay, Barak and Tripura systems. Among them The Barak River (Indian River) feeds the Surma and the Kushiyara and consequently, it also contributes in the other two major systems, namely the Surma-Baulai and the Kalni-Kushiyara. These are the common border rivers between Bangladesh and India. The inflow (mainly pre-monsoon flow) from India into Bangladesh is the main cause of Flash Flood in the haor area. River network of haor region has been presented in Figure 2.4.

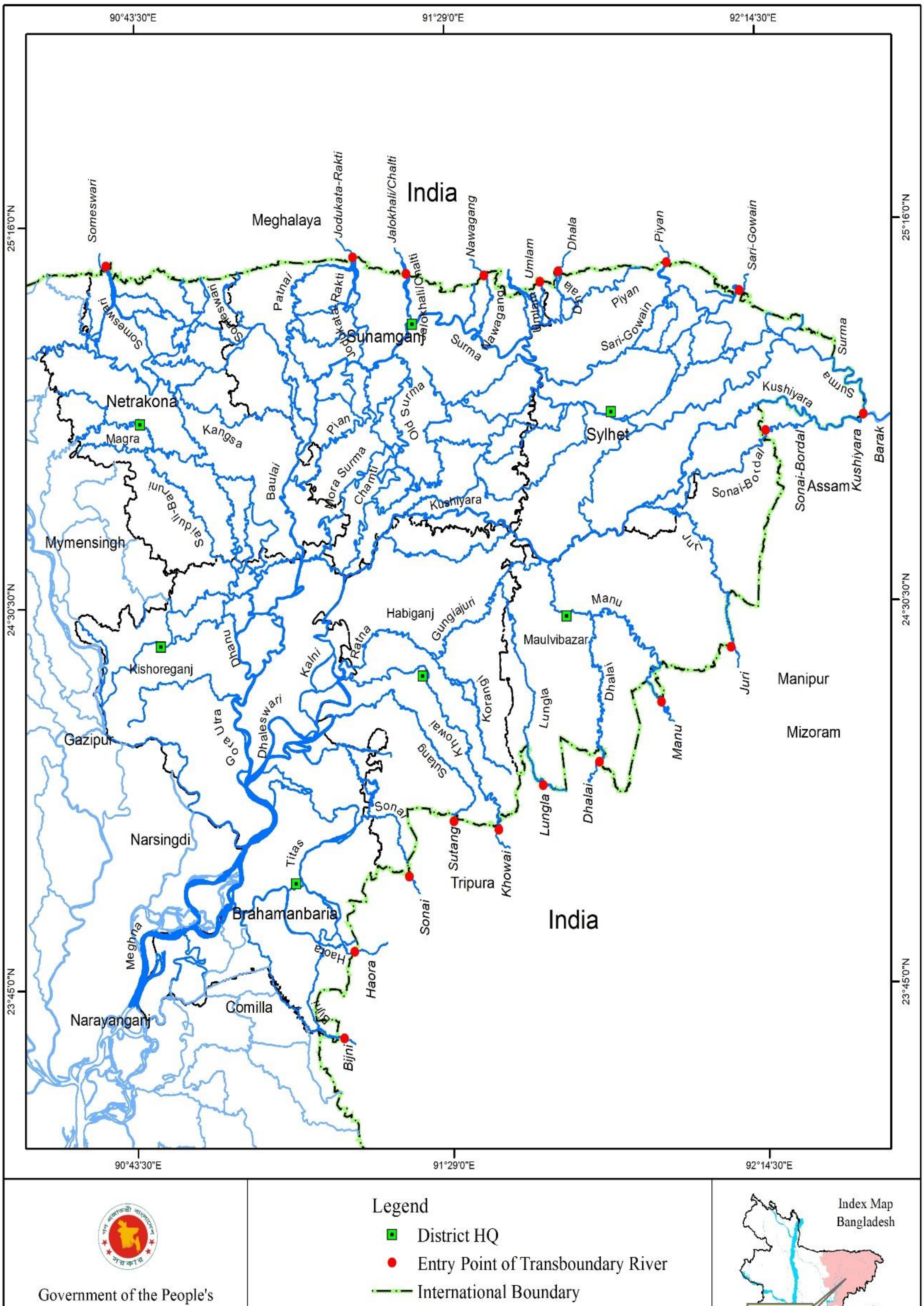

Figure 2.4: River network in the haor area (Source: CEGIS, 2019)

2.4.6 Environment and Vegetation of the Haor Area

Compared with other major natural forms of landscape, a wetland is young, dynamic and physically unstable. Due to continuous submergence, wetland habitat is characterized by anaerobic a conditions which inhibits normal plant growth apart from a group of plants known as hydrophytes are adapted to withstand these conditions. Only a few patches remain of the swamp forests that once dominated the area, featuring flood tolerant trees like Hijal (Barringtonia acutangula) and Koroch (Ponogamia pinnata). The Hijal or Hual, Korij or Koroch, Bhui Dumur (Ficus heterophyllus), Nol (Arundo donax), Khagra (Pharagmites karka), Ban Golap (Rosa involucratia) and Barun (Crataeva nurvala) are the main plant species found in the swamp forests. All of them are flood-tolerant species and can survive in the submerged condition for extended periods of time. However, among these hijal, tamal and koroj trees are of the greatest value to the people and the environment (Alam, 2011).

2.4.7 Boro Crops in Northeast Region

The farmers get ready to prepare the seedbed for their boro rice crop throughout the country in mid-November. The farmers of the haor areas are nothing exception to that regular activities. In fact, boro is the traditional crop of the Northeastern haor area. The haor areas are naturally hazardous compared to those of the other irrigated areas of the country. With the increased global warming syndrome, the haors are getting more hostile to offer a safe harvest. A boro crop in the haor area generally encounters the difficulties like a failure of timely crop establishment, cold injury in the reproductive stage of an early crop, flash flood damage at the premature to mature stage of a crop etc. The normal seeding time in the seedbed is early November for a long-duration variety like BRRI dhan 29 and mid to end-November for a short-duration variety like BRRI dhan 28. The seedbed preparation depends on the time of receding of flood water in the haor area. If the water recedes early i.e. in October, the farmers have to go for seedbed preparation in October. Obviously, they have to transplant their crop early too as their transplanting schedule is adjusted with the time of recession of water. Generally, the October seeded crop has to encounter cold shock at the reproductive phase in late February to early March to experience severe sterility as had in 2007. On the contrary, the late established (seedbed preparation in December) crop have the probability to encounter flash flood at the late growth stage of the crop. So farmers are facing problems for survival in the area.

2.5 Examples of Different Types of Wetlands in Bangladesh

Some examples of different types of wetlands in Bangladesh are given in the following sections.

2.5.1 Tanguar Haor

Tanguar Haor is one of the biggest wetland of Bangladesh. It is a beautiful natural sight of this country. Tanguar haor is lying in the Dharmapasha and Tahirpur upazilas of Sunamganj District in Bangladesh. Tanguar Haor is a unique wetland ecosystem of national importance and has come into international focus. The area of Tanguar Haor is about 100 km^2. Tanguar Haor is the source of livelihood for more than 40,000 people. In 1999 the Government of Bangladesh declared Tanguar Haor as an Ecologically Critical Area. With this declaration, the Government takes many steps to protect the haor. Tanguar Haor is called **"**Mother Fishery**"** of Bangladesh. More than 140 species of fresh water fish in the haor. She plays an important role in fish productions. This hoar also provides home of many birds. Every winter the haor is home to about 200 types of migratory birds. It is a mind blowing place for take a tour (Khan, 1994).

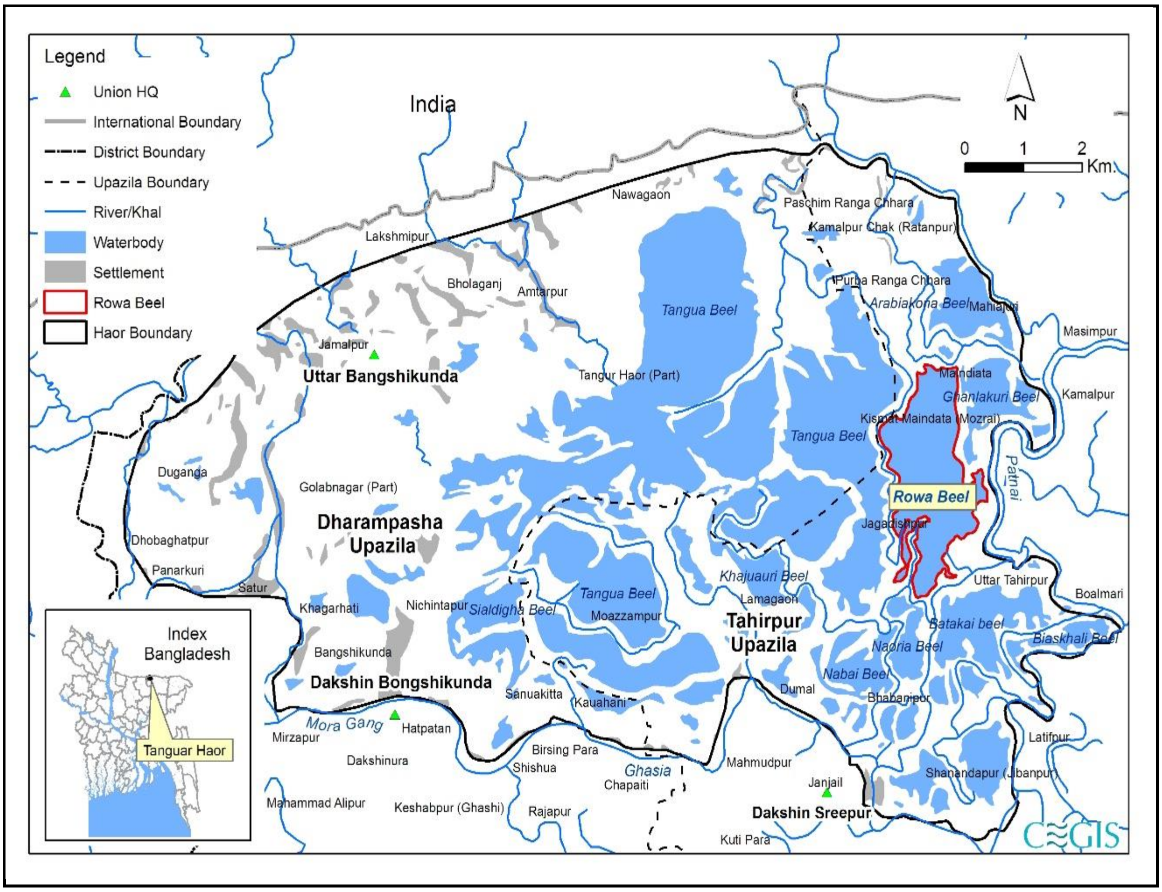

Figure 2.5: Location of Tanguar Haor, Sunamganj, Bangladesh (Source: CEGIS, 2019)

Figure 2.6: Tanguar Haor, Sunamganj, Bangladesh (Source: https: //www. flickr.com/ photos /shudipto/4037242273, 2019)

2.5.2 Hakaluki Haor

Hakaluki Haor is situated in the eastern part of Bangladesh adjacent to the Assam-Bangladesh border. Five upzillas comprise this haor's total area (Kulaura, Juri and Baralekha of Moulvibazar district, Golapganj and Fenchuganj of Sylhet district). It covers a large surface area of about 181.15 km^2. Around 40% of this land falls in the territory of Baralekha Upzilla. There are more than 238 small, medium and large interconnecting beels, some of which are perennial and others seasonal. During the dry season, approximately 4,4000 ha are being covered by the beel, but with the onset of the rains in the summer, the entire area floods to about four and half times of this size (18,383 ha) and remains under water for up to five months. During this period, all the beels are united as one large lake, or haor, making Hakaluki Haor the largest freshwater wetland in Bangladesh. The haor is mainly fed by the Juri/ Kantinala, Sonai/ Bordol, Damai. Fanai, and Kuiachara Rivers, out of which the Bordol/ Sonai, and Juuri/ Kantinala Rivers are originated in India (Banglapedia, 2015).

A total of 558 species of animal and birds have been identified here. Among these are the freshwater Turtle and Tortoises, Otters, Capped Langur, Pallas's Fish Eagle, dolphin, snakes etc. 417 species of birds have been spotted here among which 26 are totally threatened, 2 are vulnerable, and 10 are endangered and 14 critically endangered species (Banglapedia, 2015).

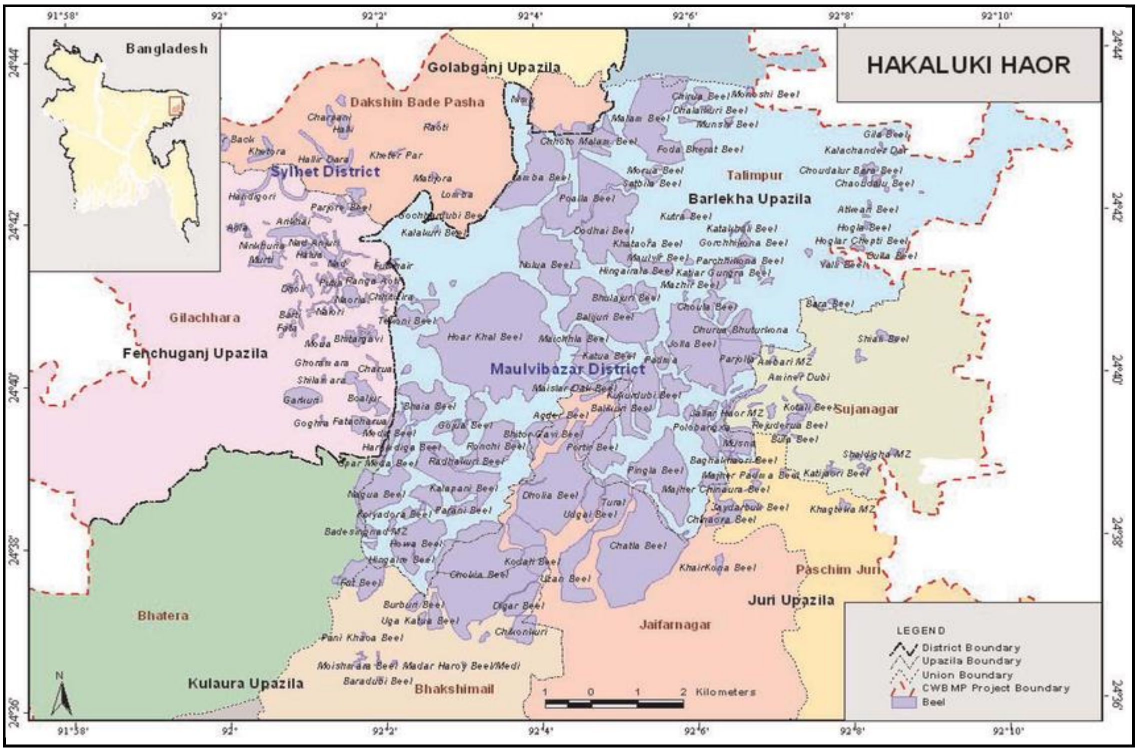

Figure 2.7: Location of Hakaluki Haor, Sylhet, Bangladesh (Source: DBHWD, 2012a)


Figure 2.8: Hakaluki Haor, Sylhet, Bangladesh (Source: https://www.flickr.com/search /?text=Hakaluki%20haor, 2019)

2.5.3 Chalan Beel

Chalan Beel is an extensive lowland area in the lower Atrai basin, and spreads across Singra and Gurudaspur upazilas of Natore, Chatmohar, Bhangura and Faridpur upazilas of Pabna District, and Ullahpara, Raiganj and Tarash upazilas of Sirajganj District. Chalan Beel is the largest Beel of the country and comprises a series of depressions interconnected by various channels to form more or less one continuous sheet of water in the rainy season when it covers an area of about 368 km^2 (Banglapedia, 2014).

Chalan Beel

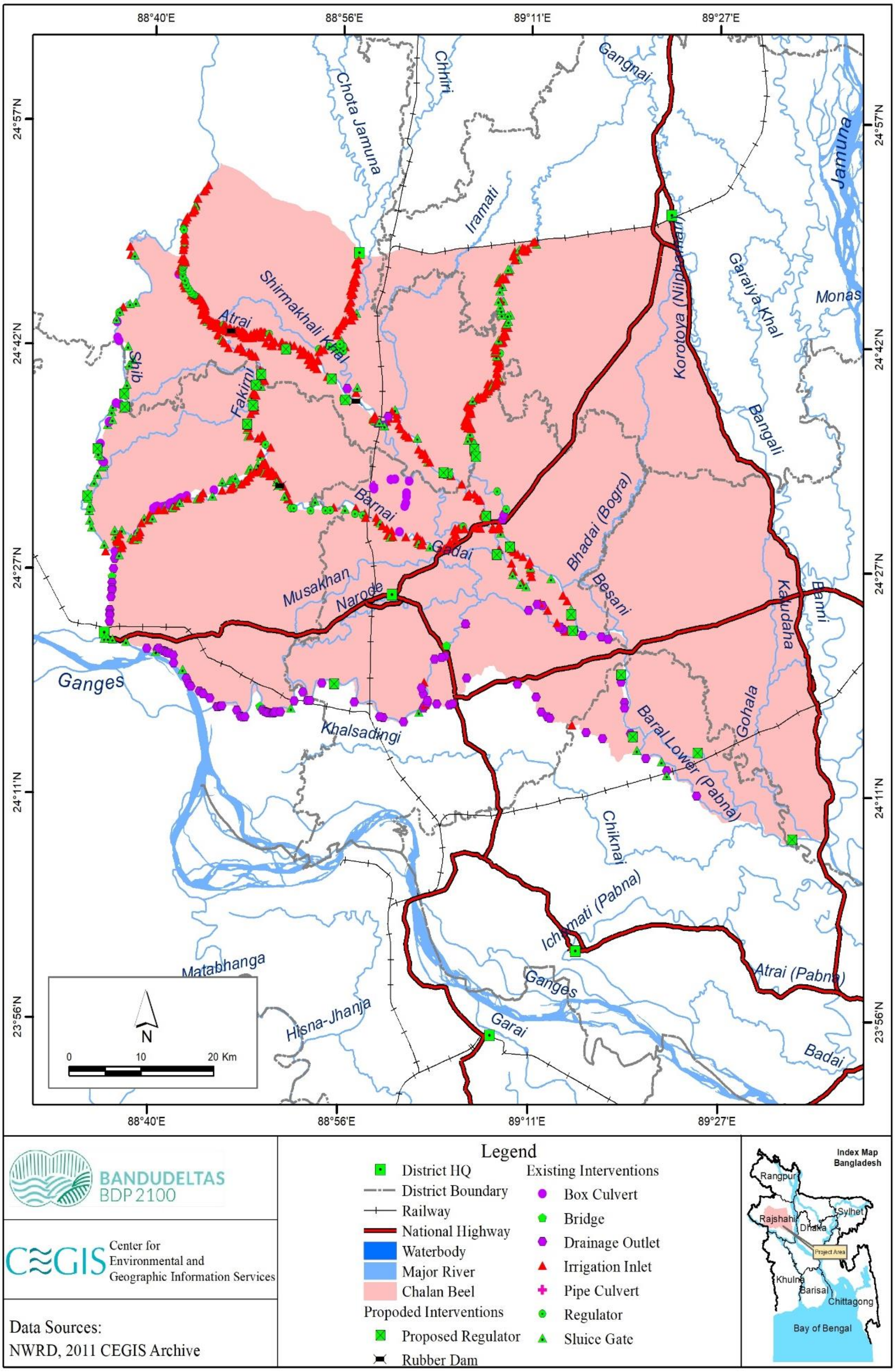

Figure 2.9: Location of Chalan Beel, Natore, Bangladesh (Source: CEGIS, 2019)

Figure 2.10: Chalan Beel, Natore, Bangladesh (Source: https://www.flickr.com/ search/?text=chalan%20beel, 2019)

2.5.4 Marjat Baor

The Marjat Baor is located at Chougacha, Jessore. The total surface area covered by the large Baor is 200 ha (Ahmed, 2017).

Figure 2.11: Marjat Baor, Chougacha, Jessore (Source: Ahmed, 2017)

2.5.5 Kaptai Lake

Kaptai Lake is the largest man-made lake in Bangladesh. It is located in the Kaptai Upazila under Rangamati District of Chittagong Division. The lake was created as a result of construction of the Kaptai Dam on the Karnaphuli River, as part of the Karnaphuli Hydro-Electric Project. The Kaptai Lake's average depth is 30m (100 ft) and maximum depth is 150m (490 ft) (Banglapedia, 2014).

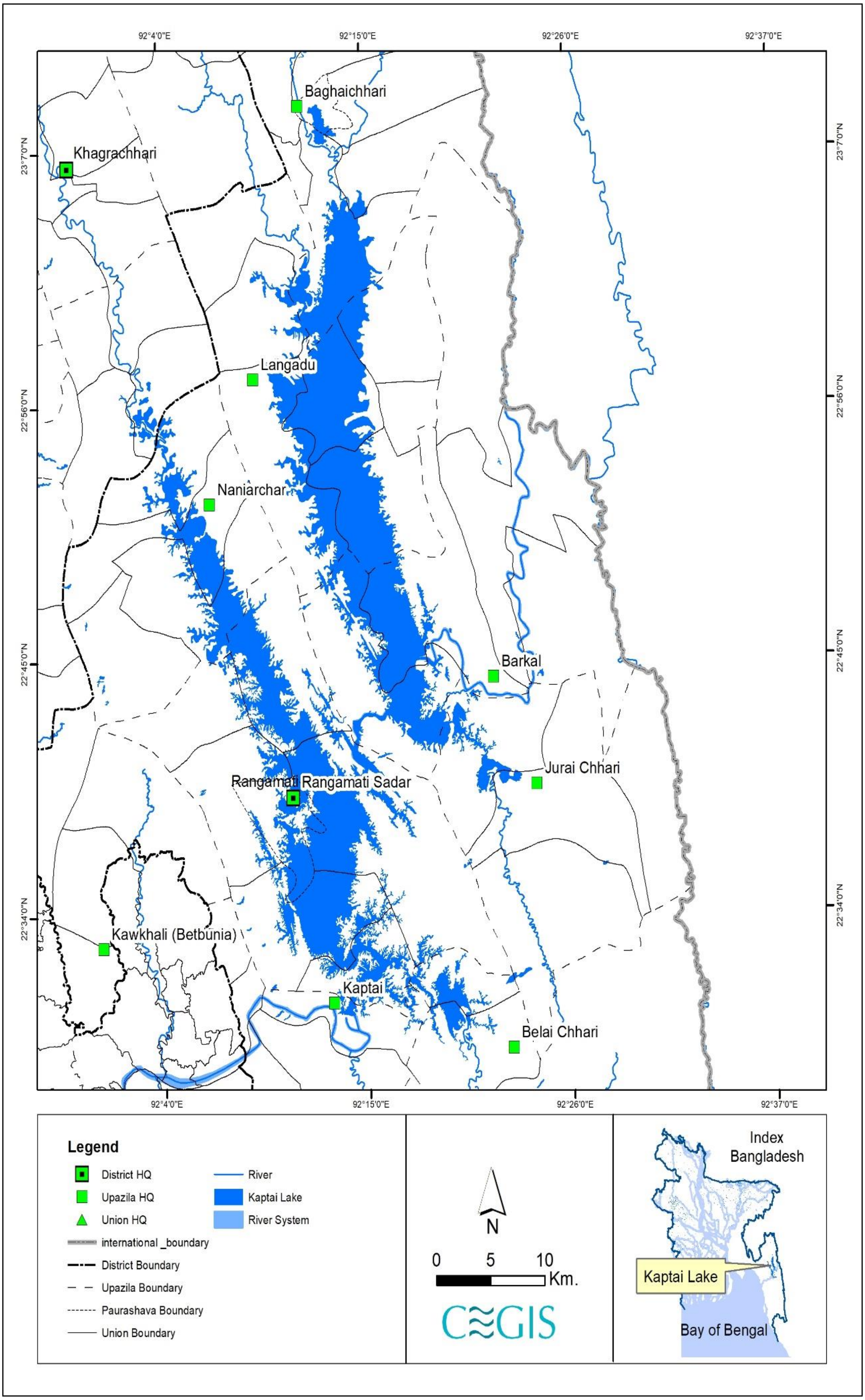

Figure 2.12: Location of Kaptai Lake, Rangamati, Bangladesh (Source: CEGIS, 2019)

2.6 Previous Studies on Haor in Bangladesh

Different literatures relevant to Haor i.e. national and international journals, conference papers, reports, thesis reports of previous relevant studies have been reviewed. Followings are the reviews of some of those studies.

Center for Environmental and Geographic Information Services (CEGIS) found that the Haor region had long been lagging behind mainstream of the national development, although the economic development of Bangladesh was moving steadily at a moderate pace. The future challenges in the context of climate change and variability are also a major concern for the sustainable development of the region. In that connection it had become imperative to formulate a Master Plan that nine aims at integrated development of Haor area considering the development potential. In DBHWD (2012a), the formulated 20-year Master Plan is a framework plan which will be implemented on the short, medium and long term basis. This **“**integrated development plan**”** spells out the means for optimising available resources of the area for future development of potentials by incorporating all relevant social and environmental considerations. Specifically, integrated development would comprise mainly flood management, environmental sustainability, production of crop, fisheries and livestock, expansion of education, settlement and health facilities, road communication, navigation, water supply and sanitation, industry, afforestation and generation of power and energy. The planned investment portfolios have been prepared for seventeen sectors namely Water Resources, Agriculture, Fisheries, Pearl Culture, Livestock, Forest, Education, Health, Transportation, Housing and Settlement, Water Supply and Sanitation, Industry, Energy and Power, Mineral Resources, Biodiversity and Wetland, Tourism and Social Services.

Saleh (2007) observed that Boro production had been fluctuated around 0.4 MMT till 1990 but there had been a rising trend afterward. Although the average annual growth rate was about 4.1%, the rate increased to 7.4% after 1990. They found that, even collectively the SEPs had achieved their desired objectives of protecting the Boro crops from pre-monsoon flood, especially after 1990. Both HYV Boro area and production have increased with the increase in SEP coverage. The SEPs did not have any impact on increasing the irrigation coverage, which is overwhelmingly based on surface water. They also found that pre-monsoon rainfall did not create any adverse internal flooding or drainage congestion, which could be detrimental to Boro production. It was suggested that considering SEPs's positive impact on the regional Boro production, adequate annual maintenance and periodic rehabilitation works should be carried out for the sustainability of these projects.

A study conducted by Khan (2012) in two upazilas in Kishoregonj District which are mainly haor region showed that the river flood does minimum damage where the flash flood is the main reason for crop damage, especially boro rice production. As shown the result of that study, almost 97% of the damage is done to boro rice production as flash flood water enters to the haors in the harvesting periods.

Mosleh (2017) studied to assess the loss of agricultural land cover due to flash flood occurred on April 2017. We have used **"**before**"** and **"**after**"** Landsat images extracted from USGS database to assess the change of land cover in Tanguar Haor basin. Our result shows that a considerable area of agricultural land has been submerged by this flash flood and eventually a significant amount of crop has been lost. Consequently, almost 60 thousand people are at risk to suffer from food insecurity along with scarcity of safe drinking water due to contamination of pathogenic water microbes from unhygienic sanitary condition. This study will help to visualize the loss of crop production that may play a significant role for ensuring food security in the haor basin of Bangladesh.

Alam (2010) conducted a study in the Haor areas of Bangladesh to assess the land utilization status, delineate the productivity and profitability of growing modern rice, evaluate the existing cropping patterns and assess the prospect of possible cropping patterns. They found that, there are about 1.26 million hectares of cultivated lands in seven Haor districts, of which 66% falls under haor area. Nearly 94 and 87% areas were devoted to MV Boro rice production. Both BRRI dhan 28 and 29 were being the widely adopted rice varieties. On an average, about 33% of the Haor areas were under mechanized irrigation. The cost of production for MV Boro was almost double than that of LV rice. The yield of MV Boro was 79% higher than that of LVs and the return from MVs was 82% higher. Rabi-Fallow-T. Aman, Vegetable-Aus-T. Aman and RabiB.Aman patterns were the potential cropping patterns in some selected areas and this could increase both cropping intensity and productivity in those areas. According to the farmer's assessment, lack of flood control dam and lack of short duration varieties etc. are the major hindrance to the adoption of potential cropping patterns. Construction of community harvest and threshing facilities and flood control devices could be the important public interventions for enhanced agricultural productivity in the haor areas.

Assessment of impact of submersible embankment project in Sonamoral Haor by Khan (2010) indicates that the project has been successful for Boro production. But standard of living of Haor based livelihood groups has not improved though Boro rice production has increased. The average Household Development Index (HHDI) has declined from 0.53 to 0.43 in post project condition. Agriculture landowners are the main beneficiaries of the submersible embankment project. The negative impacts of the project like reducing ecological resources (fish, aquatic plants) conflict among water users, restricting boat communication and controlling access to the natural resources has affect majority of target households. He recommended that submersible embankment project to prevent pre-monsoon flash flood in the Haor region should not be planed for single purpose of protecting Boro rice only. Project planning should also give attention to the improvement of standard of living of the community as emphasized in National Water Policy.

IWM (2006) observed that additional projects taken up in the Haor region will mean that the embankment heights would have to be raised further and would require regular reviewing with the addition of new projects. This also means that the higher the level of embankment the cost of implementation as well as the operation and maintainace will increase. This drawback does not end here; higher embankments will mean less stability and greater risk of failure during the pre-monsoon flood. Another important factor is that the dredging options have to be considered actively not only as a measure to reduce the embankment height but also to ensure smooth navigation in the dry period and early drainage of Haor area in post-monsoon period. Thus for sustainability and efficient management of the Haor projects both embankment raising and intelligent dredging options have to be considered together and not in an isolated way.

Kafi (2008) found that embankments and regulators restrict the free movement of fish from rivers to beels and haors and vice versa. Haor are inundated and linked to rivers during the monsoon but are isolated during the dry season. He observed that restricted fish free movement hampers migration of fish species that severely affects fish growth and breeding, which is sign of species declination. He also observed that with the construction of haor projects, floodplain have become gradually less. This has confined flood water as well as sediments within the river system. The confinement of rivers has

10 led to raise riverbeds, resulting in an increase in peak flood level. Increased inundation during monsoon brings more sediment into the floodplain, including beels, haors and khals. The habitat area available for fish is thus reduced during pre-monsoon and early monsoon period. He found that submersible embankment prohibits the early stage of flooding in order to save Boro crops, resulting in the accumulation of plant nutrients are not likely to dissolve properly by early flooding. That's why the shortage of nutrients is a possibility which would indicate decrease in fish species.

Mamun (2013) observed indiscriminate harvesting of mother fishes, use of agrochemicals, sedimentation on haor basin and habitat destruction were found as major causes of fisheries resources degradation in the study area. Most of the water quality parameters were found good which were within the standard level set by Government of Bangladesh for fisheries. However, they found EC and TDS were higher than the recommended level for fish production.

It was revealed from Salauddin (2011) that the existing scenarios of Haor area and change of patterns from 2000 to 2008 is significant. He observed that the Normalized Difference Vegetation Index (NDVI) values are minimums in 2000, 2002 and 2004 are about 0.34, 0.32 and 0.35 respectively whereas in 2003 and 2006 the NDVI values are maximum. It was found that the land cover in the Haor area had been changed significantly since 2000. Analysis revealed that vegetative cover area in 2008 had increased to about 8.35% compared to the 2000 vegetative cover area. He also observed that the access of livelihood groups to livelihood capital i.e. natural capital, physical capital, human capital, social capital and financial capital was changed from 2000 to 2008. The impacts of land cover changes to the livelihood groups of the haor area is positive trend except the natural capital.

The study of Uddin (2013) is Eco-Environmental Changes of Hail Haor Wetland Resources under Sylhet Basin of Bangladesh due to sedimentation: A GIS Approach. An attempt has been undertaken to the area covered by wetlands in the Hail Haor has been significantly reduced over the period from 1989 to 2003. According to GIS analysis using PAT (Polygon Attribute Tables) files, total Hail Haor area was about 10,000 ha in 1989. In 2003, the area of this water body was reduced and the area becomes 5,200 ha. In 2010, this water ecosystem also decreased significantly and the area of which becomes 2000 ha. The rate of reduction of the water body is alarming but in the dry season, the area of the

Hail Haor shrinks further which become 900 ha. The study also shows that considerable changes have occurred due to sedimentation and as a result depth and duration of inundation has changed. This change shows a positive impact on agricultural aspects enhancing emergence of new soil boundaries and serious negative impact on eco-environmental aspects.

In contrast, small scale flooding comes with plenty of benefits. It replenishes the groundwater and helps to sustain the agricultural industry. The sediments carried out by flood water make the land more fertile. Flood water avails considerable amount of water required by crops. In the southern part of the country, salts deposited on fields are being washed and removed by flood water. Hence, prevent the agriculture lands from becoming infertile. In a nutshell, the benefits of flooding are immense, but at times, floods become destructive when they are on the extreme (Hasan, 2015).

2.7 Studies on Interventions in Wetlands around the World

Embankment construction is an important structural measure to prevent vulnerability of flood in lower reaches of Ajay River. Taming of river has huge negative impact on floodplain as well as entire riparian environment. With the growing need for protecting people's properties, agricultural land and crop earthen embankment and flood control embankments is getting importance. Embankment breaching, an episodic process in fluvial dynamics, is affecting a wide range of physical, ecological and socio-economic issues in the fluvial environment. Ghosh (2015) has involved in this study with the enquiry of stability of the embankments, nature of breaching, extent of the sand incursion over the agricultural fields and micro-topographical changes brought into the lower reaches of the Ajay River basin.

Humans directly change the dynamics of the water cycle through dams constructed for water storage, and through water withdrawals for industrial, agricultural, or domestic purposes. Ingjerd (2014), analyses of climate change and direct human impacts on the terrestrial water cycle are presented and compared using a multimodal approach. Seven global hydrological models have been forced with multiple climate projections, and with and without taking into account impacts of human interventions such as dams and water withdrawals on the hydrological cycle. Model results are analyzed for different levels of global warming, allowing for analyses in line with temperature targets for climate change mitigation. The results indicate that direct human impacts on the water cycle in some regions, e.g., parts of Asia and in the western United States, are of the same order of magnitude, or even exceed impacts to be expected for moderate levels of global warming (+2 K). Despite some spread in model projections, irrigation water consumption is generally projected to increase with higher global mean temperatures. Irrigation water scarcity is particularly large in parts of southern and eastern Asia, and is expected to become even larger in the future.

Coastal wetland degradation and loss caused by intensive human activities, such as land reclamation and embankment, is a serious environmental problem. Xiaoli (2014) studied the succession of soil and vegetation in a coastal wetland dominated by Chinese tamarisk (Tamarix chinensis) community after the construction of a seawall. When the intertidal wetland became supratidal wetland, soil salinity firstly decreased and the gradient from sea to land became weaker. Next, the area of vegetation and plant species diversity increased, and the phenomenon of plant zonation disappeared. They reasoned that the rooted cause of soil and vegetation succession was the change in hydrological environment. Moreover, a Drivers-Pressures-State-Impacts-Response (DPSIR) model was used to analyze the relationship between human activities and coastal wetland. Using this model, they presented the potential problems that might arise in this wetland and predicted that vegetation flourishing was only a short term phenomenon but wetland degradation was the final consequences due to excessive exploitation of groundwater. At last, they proposed a few of operable measures as responses to these potential problems from the perspective of coastal management.

Matthew (2015), Water Control Structures (WCSs) restrict hydrological connectivity in salt marshes and thereby impede nekton movement within the greater habitat mosaic. Transient fishery species, which spawn outside salt marshes and must get past these barriers to reach spawning areas or salt-marsh nurseries, are especially vulnerable to these structures. Water control structures incorporating slots (narrow vertical openings spanning most of the water column) are thought to improve nekton passage; however, few studies have directly examined nekton passage through Water Control Structures (WCSs) slots. Dual-frequency identification sonar (DIDSON) acoustic imaging was used monthly (April–September 2010) on diurnal flood tides to examine nekton movement through 15-cm-wide slots at two identical WCSs located in Louisiana tidal marsh channels. Nekton behavior was compared between these WCSs and a nearby natural salt-marsh creek. Examination of 12 h of subsampled acoustic data revealed large concentrations of salt-marsh nekton at the WCSs (n D 2,970 individuals total), but passage rates through the slots were low (10% of total observed individuals migrated via the slots). Most migrating fish were observed leaving the managed area and swimming against a flood tide. The mean size of migrating individuals (»25 cm TL) did not differ in relation to swimming direction (going into versus exiting the managed marsh) and was similar to that reported from other studies examining similar slot widths. Nekton formed congregations in the WCS channel, but no congregations were observed in the natural salt-marsh creek, even though nekton species composition and sizes were similar among sites. The WCSs in our study appear to function as ecological hot spots, where large individuals may encounter enhanced foraging opportunities but also fishing mortality and where smaller individuals may experience greater predation rates.

2.8 Summary

Several studies have been carried out till to date on different types of works on Haor in Bangladesh as well as over the world which focus mainly livelihood of haor people. Very few studies have been done on the assessment of pre-scheme and post-scheme condition. Thus why it has been selected to assessment the performance of Shafique Haor scheme and Sonamoral Haor scheme based on the comparison of pre-scheme and post-scheme condition. On the basis of background of the study and the literature review, the main focus of my study is to assess the hydrological and agricultural changes of the selected Shafique Haor scheme and Sonamoral Haor scheme.

CHAPTER 3

THEORY AND METHODOLOGY

3.1 General

A detailed description on the theory and methodology to achieve the objectives of the study has been described in this chapter. Data is the main element of any study. Proper observation and long-term prediction depend on data availability. With limited data any type of prediction will be error full. It is also important to check its consistency and accuracy.

3.2 Theory of Frequency Analysis

In this study, several theories regarding hydrological, Landsat image and agricultural analyses have been discussed. In this study, theory of frequency analysis under hydrological analysis has been discussed. Theory of Remote Sensing (RS) and Global Information System (GIS) under Landsat image analyses and theory related crop production under agricultural analyses have been also included in this section.

3.2.1 Frequency Analysis

Frequency of a hydrologic event, such as the annual peak flow is the annual peak flow is the probability that a value will be equaled or exceeded in any year. This is more appropriately called the exceedance probability, P (F). The reciprocal of the exceedance probability is the return period T in years, i.e. T = 1/ P (F). The length of record should be sufficient to justify extrapolating the relationship. For example, it might be reasonable to estimate a 50-year flood on the basis of a 30-year record, but to estimate a 100-year flood on the basis of a 10-year record would normally be absurd (Neill, 1973). Viessman (1996) noted that as a general rule, frequency analysis is cautioned when working with shorter records and estimating frequencies of hydrologic events greater than twice the record length.

Frequency analysis can be conducted in two ways: one is the analytical approach and the other is the graphical technique in which flood magnitudes are usually plotted against probability of exceedance. Here, in the following sections, procedures are given for rainfall frequency analysis; the similar procedures can also be followed for water level frequency analysis and discharge frequency analysis.

3.2.2 Analytical Frequency Analysis

Analytical frequency analysis is based on fitting theoretical probability distributions to given data. Numerous distributions have been suggested on the basis of their ability to **"**fit**"** the plotted data from streams (Linsley, 1988). The Log-Pearson Type III (LP3) has been adopted for use in the United States federal agencies for flood analysis. The first asymptotic distribution of extreme values (EV1), commonly called Gumbel method has been widely used and is recommended in the United Kingdom.

(a) Extreme Value Distribution

Distributions of the extreme values selected from sets of samples of any probability distribution converge to any one of three forms of Extreme Value Distributions, called Type I, II, and III, respectively, when the number of selected extreme values is large. The three limiting forms are special cases of a single distribution called Generalized Extreme Value (GEV) Distribution (Chow, 1988). The cumulative distribution function for the GEV is

$$F(x) = \exp\left[-\left(1-\kappa\frac{x-u}{\alpha}\right)^{1/\kappa}\right] \tag{3.1}$$

Where k, u, and α are parameters to be determined. For EVI Distribution x is unbounded, while for EVII, x is bounded from below, and for EVIII, x is bounded from above. The EVI and EVII Distributions are also known as the Gumbel and Frechet Distributions, respectively.

The Extreme Value Type I (EVI) cumulative distribution function is

$$F(x) = \exp\left[-\exp\left(-\frac{x-u}{\alpha}\right)\right] \qquad -\propto \le x \le \propto \tag{3.2}$$

The parameters are estimated by

$$\alpha = \frac{\sqrt{6}}{\pi}s \quad \text{and} \quad u = \bar{x} - 0.5772\alpha \tag{3.3}$$

Equation (3.2) can be expressed as

$$F(x) = e^{-e^{-y}} \tag{3.4}$$

Where y is the reduced variate defined as

$$y = \frac{x - u}{\alpha} \tag{3.5}$$

Solving for y:

$$y = -\ln\left[\ln\left(\frac{1}{F(x)}\right)\right] \tag{3.6}$$

Noting that the probability of occurrence of an event $x \geq x_T$ is the inverse of its return period T, we can write

$$\frac{1}{T} = P(x \geq x_T) = 1 - P(x \leq x_T) = 1 - F(x_T)$$

$$So, F(x_T) = 1 - \frac{1}{T}$$

And substituting for $F\,(x_T)$ into Equation (3.6)

$$y_T = -\ln\left[\ln\left(\frac{T}{T-1}\right)\right] \tag{3.7}$$

For a given return period x_T is related to y_T by Equation (3.5), or

$$x_T = u + \alpha y_T \tag{3.8}$$

3.2.3 Frequency Analysis by Using Frequency Factors

Calculating the magnitudes of extreme events by the method outlined in the above example requires that the probability distribution function be invertible, that is, given a value of T or $F(x_T) = 1 - \frac{1}{T}$, the corresponding value of x_T can be determined. Some probability distribution functions are not readily invertible, like the Normal and Pearson Type III Distributions. Thus an alternative method based on frequency factor is used for calculating the magnitudes of extreme events. Chow (1951) has shown that most frequency functions can be generalized to

$$x_T = \bar{x} + K_T s \qquad (3.9)$$

where x_T is a flood of specified probability or return period *T*, $\bar{x}$ is the mean of the flood series, s is the standard deviation of the series; and K_T is the frequency factor and is a function of return period and type of probability distribution, as well as coefficient of skewness for skewed distributions, such as LP3.

In the event that the variable analyzed is $y = \log x$, for example as in Lognormal and LP3 Distributions, the same method is applied to the statistics for the logarithms of data using $y_T = \bar{y} + K_T s_y$, and the required value of x_T is found taking antilog of y_T.

Chow (1951) proposed the frequency factor as in Equation (3.9), and it is applicable to many probability distributions used in hydrologic frequency analysis. The K-T relationship can be expressed in mathematical terms or by a table.

(a) Normal Distribution

From Equation (3.9) the frequency factor can be expressed as

$$K_T = \frac{x_T - \bar{x}}{s} = z \qquad (3.10)$$

Thus, for Normal Distribution K_T is the same as the standard normal variable z. The value of z and hence K_T cumulative probability of the standard normal distribution table.

(b) Lognormal Distribution

The recommended procedure for use of the Lognormal Distribution is to convert the data series to logarithms and compute:

(1) $y_i = \log x_i$

(2) Compute the mean, $\bar{y}$ and standard deviation s_y

(3) Compute $y_T = \bar{y} + K_T s_y$

$$K_T = \frac{y_T - \bar{y}}{s_y} = z$$

(4) Finally, compute $x_T = anti\log y_T$

(c) Log-Pearson Type III (LP3) Distribution

The recommended procedure for use of the LP3 Distribution is to convert the data series to logarithms and compute:

(1) $y_i = \log x_i$

(2) Compute the mean, $\bar{y}$ and standard deviation s_y

(3) Compute coefficient of skewness

$$C_s = \frac{n\sum(y_i - \bar{y})^3}{(n-1)(n-2)s_y^{\,3}}$$

(4) Compute $y_T = \bar{y} + K_T s_y$ (3.11)

Where K_T is taken from table of values of the frequency factors for the LP3 Distribution for various values of return period and coefficient of skewness, Cs.

When Cs =0, the frequency factor is equal to the standard normal variable z.

(5) Finally, compute $x_T = anti\log y_T$

(d) Extreme Value I (EVI) Distribution

Chow (1951) derived the following expression for frequency factor for the EVI Distribution

$$K_T = \frac{\sqrt{6}}{\pi}\left[0.5772 + \ln\left\{\ln\left(\frac{T}{T-1}\right)\right\}\right] \tag{3.12}$$

When $x_T = \mu$, Equation (3.9) (in population term) gives $K_T = 0$ and Equation (3.12) gives T=2.33 years. This is the return period of the mean of the EVI Distribution.

The reliability of results of frequency analysis depends on how well the assumed probabilities model applies to a given set of hydrologic data. This can be done by calculating confidence limits which are upper and lower boundary values of the confidence interval.

3.3 Remote Sensing (RS) and Global Information System (GIS)

Geo-informatics is a science and technology of gathering, analyzing, interpreting, and disseminating geographical information. It encompasses a broad range of disciplines and technologies including landscape ecology, remote sensing (RS), spatial statistics, geographical information systems (GIS) and global positioning systems (GPS) (Haque, 2017). RS and GIS together has become very important in monitoring vegetation, water feature extraction, environmental preservation, detecting land cover and land uses and so on (Aggarwal, 2004). The collection of remotely sensed data facilitates the synoptic analyses of Earth - system function, patterning and change at local, regional and global scales over time; such data also provide an important link between intensive, localized ecological research and regional, national and international conservation and management of biological diversity (Wilkie, 1996).

According to Colwell (1983), Remote Sensing (RS) includes all methods of obtaining pictures or other forms of electromagnetic records of Earth's surface from a distance, and the treatment and processing of the picture data. Remote Sensing then in the widest sense is concerned with detecting and recording electromagnetic radiation from the target areas in the field of view of the sensor instrument. This radiation may have originated directly from separate components of the target area, it may be solar energy reflected from them; or it may be reflections of energy transmitted to the target area from the sensor itself (Patra, 2010).

According to Campell (1996), Remote Sensing (RS) is the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface.

International Training Centre (ITC), Holland defined Geographical Information Systems (GIS) as a computerized system that facilitates the phases of data entry, data analysis and data presentation especially in cases when we are dealing with geo referenced data (Patra, 2010).

According to Burrough (1998), Geographical Information Systems (GIS) as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purpose.

Figure 3.1: Remote Sensing & GIS integration (Source: http://www.jalasri.kces, 2019)

3.3.1 Principles of Remote Sensing Systems

The principles of remote sensing are based primarily on the properties of the electromagnetic spectrum and the geometry of airborne or satellite platforms relative to their targets. Remote sensors are the instruments which detect various objects on the earth's surface by measuring electromagnetic energy reflected or emitted from them.

The sensors are mounted on the platforms discussed above. Different sensors record different wavelengths bands of electromagnetic energy coming from the earth's surface (Patra, 2010).

3.3.2 Primary Components of Remote Sensing

Primary components of remote sensing are as follows:

- Electromagnetic energy is emitted from a source.
- This energy interacts with particles in the atmosphere.
- Energy interacts with surface objects.
- Energy is detected and recorded by the sensor.
- Data are displayed digitally for visual and numerical interpretation on a computer (Aggarwal, 2004).

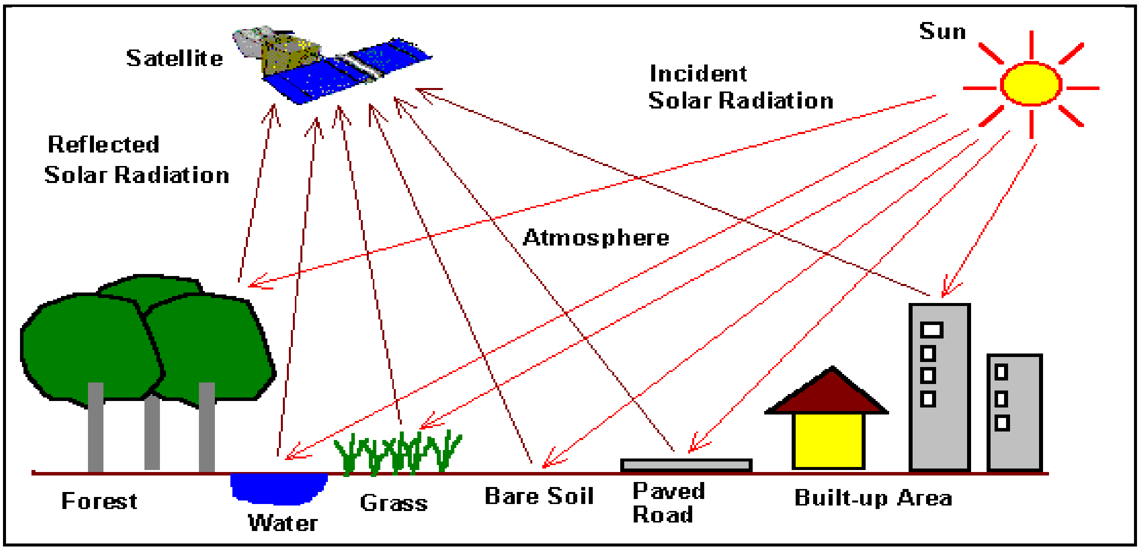

Figure 3.2: The satellite remote sensing process (Source: Aggarwal, 2004)

3.3.3 Types of Remote Sensing

(a) Based on Source of Energy

Remote sensing can be either passive or active. Active systems have their own source of energy (such as RADAR) whereas the passive systems depend upon external source of illumination (such as SUN) or self-emission for remote sensing (Aggarwal, 2004).

Passive Sensors: Remote sensing systems, which measure this naturally available energy, are called passive sensors. This can only take place when the sun is illuminating the earth. There is no reflected energy available from the sun at night. Solar energy and radiant heat are examples of passive energy sources (Daptardar, 2013).

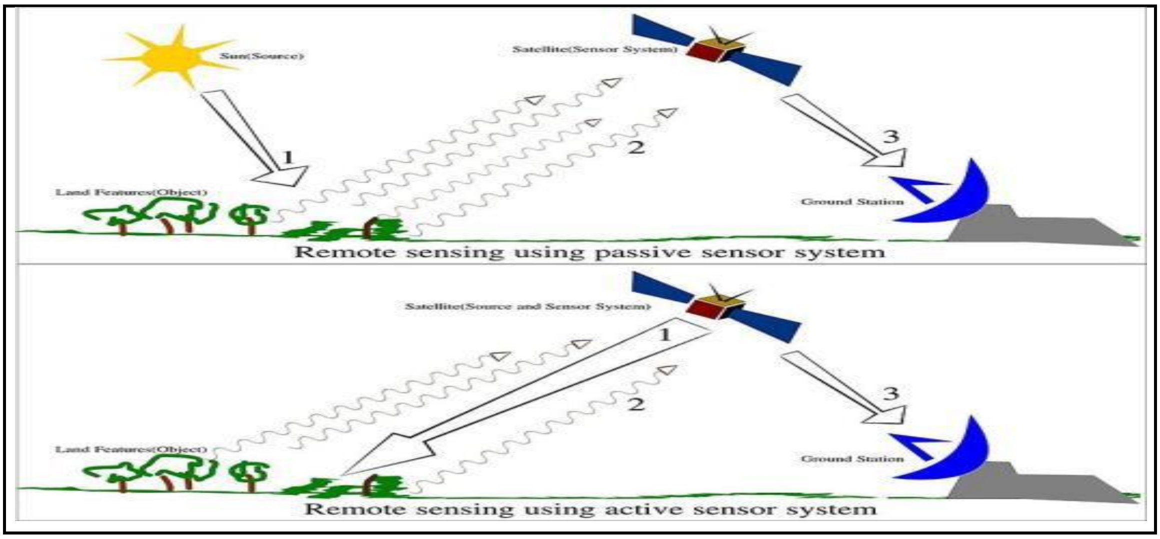

Figure 3.3: Passive and Active Sensor System (Source: https://en.wikipedia. org/wiki/ Remote _sensing, 2019)

Active Sensors: Remote sensing systems, which provide their own source of energy for illumination, are known as active sensors. These sensors have the advantage of obtaining data any time of day or season. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speeds and direction of an object (Kerle, 2004).

(b) Based on Range of Electromagnetic Spectrum

Optical Remote Sensing: The optical remote sensing devices operate in the visible, near infrared, middle infrared and short wave infrared portion of the electromagnetic spectrum. These devices are sensitive to the wavelengths ranging from 300 nm to 3000 nm. Most of the remote sensors record the EMR in this range, e.g., bands of IRS P6 LISS IV sensor are in optical range of EMR (Kerle, 2004).

Thermal Remote Sensing: The sensors, which operate in thermal range of electromagnetic spectrum record, the energy emitted from the earth features in the wavelength range of 3000 nm to 5000 nm and 8000 nm to 14000 nm. The previous range is related to high temperature phenomenon like forest fire and later with the general earth features having lower temperatures. Hence thermal remote sensing is very useful for fire detection and thermal pollution. e.g., the last five bands of ASTER and band 6 of Landsat ETM+ operates in thermal range (Daptardar, 2013).

Microwave Remote Sensing: A microwave remote sensor records the backscattered microwaves in the wavelength range of 1 mm to 1 m of electromagnetic spectrum. Most of the microwave sensors are active sensors, having their own sources of energy, e.g., RADARSAT. These sensors have edge over other type of sensors, as these are independent of weather and solar radiations (Patra, 2010).

3.3.4 Application of Geographic Information System (GIS)

According to Centre for Spatial Database Management and Solutions (CSDMS), Geographic Information System (GIS) is a computer based tool for mapping and analyzing things that exist and events that happen one earth. It is a system designed to capture, store, manipulate, analyze, manage, and present all types of spatial or geographical data (Patra, 2010). GIS user expects support from the system to enter geo referenced data to analyze it in various ways and to produce output (maps and other) from the data. GIS draws on concepts and ideas from many different disciplines, such as cartography, cognitive science, computer science, engineering, environmental sciences, geodesy, landscape architecture, law, photogrammetry, public policy, remote sensing, statistics and surveying. So, it involves not only the study of the fundamental issues arising from the creation, handling, storage and use of geographic information, but it also examines the impacts of GIS on individuals and society and the influences of society on GIS (Campbell, 1996). In this study Arc Map 10.2.2 has been used for mapping.

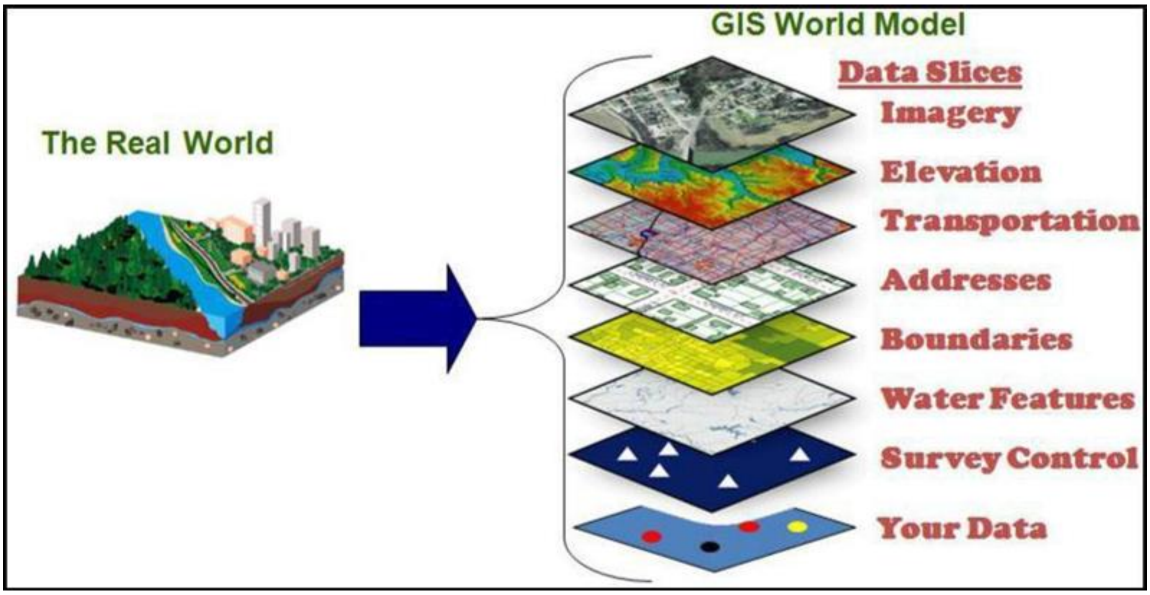

Figure 3.4: GIS World Model (Source:http://grindgis.com/what-is-gis/what-is-gis-definition, 2019)

3.3.5 Components of Geographic Information System (GIS)

According to Tveito, 2002 Geographic Information System (GIS) is a technology system, not just one particular component. GIS is composed of:

1) Data: Both Spatial and Attribute Data are used.
2) Software: Data is entered into GIS Software which provides a user interface and data functionality.
3) GIS Professional: Software is accessed by GIS Professionals.
4) Hardware: Increasingly become more mobile, this is where the GIS Software resides.
5) Organization: Their need for data which drives the entire process.
6) Output: Analysis. Reports. Tracking. Decision Making. Planning and Work Flow Management.

Figure 3.5: Components of GIS (Source: Tveito, 2002)

3.3.6 Working Principle of Geographic Information System (GIS)

According to Maroju 2007, five-step process applying Geographic Information System (GIS) to any problem that requires a geographic decision.

1) Asking: What is the problem being try to solve or analyze and where is it located? Framing the question will help to decide what to analyze and how to present the results to the audience.

2) Acquiring: Next finding the data to complete the project. The type of data and the geographic scope of project helping direct for methods of collecting data and conducting the analysis.

3) Examining: Knowing for certain data is appropriate for the Study after thoroughly examining. This includes how the data is organized, how accurate it is and where the data came from.

4) Analyzing: Geographic analysis is the core strength of GIS. Depending on project, there are many different analysis methods to choose from GIS modeling tools make it relatively easy to make these changes and create new output.

5) Acting: The analysis results can be shared through reports, maps, tables and charts and delivered in printed format or digitally over a network or on the web.

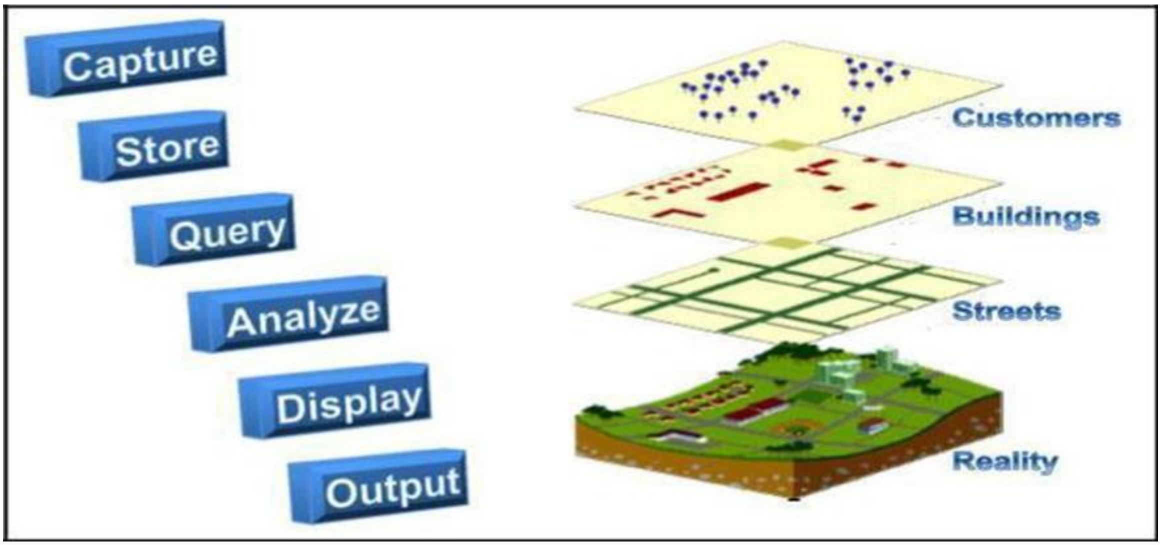

Figure 3.6: GIS working Process (Source: Aggarwal, 2004)

3.4 Agricultural Analysis

3.4.1 Cropping Pattern

Cropping pattern means yearly sequence and spatial arrangement of crops and fallow in a given area. The crop-growing period is divided into two main seasons, Kharif and Rabi. Crops (such as rice, jute, maize, millets, etc) which are grown during the Kharif season are called Kharif crops and those (such as wheat, mustard, chickpea, lentil etc) grown during the Rabi season are called Rabi crops. The Kharif season extends from May through October, while the Rabi seasons starts from November and continues up to April.

In addition to these two main seasons, another transition season called Pre-kharif has been identified. This season starts from March-April and ends in May-June. Cropping pattern is the proportion of area under various crops at a point of as it changes over space and time or it indicated the yearly sequence and spatial arrangements of crops and follows in an area.

Pre-monsoon and monsoon growing season. Cropping season linked to monsoon between March-October, often divided into kharif-1 (March-June) and kharif-2 (July-October). Dry agricultural crop growing season; mainly used for the cool winter season between November and February.

3.4.2 Net Cultivate Area

This is the land area actually cropping during the census/ survey year regardless of number of crops grown plus current fallow. It includes areas under temporary and permanent crops and also current fallow.

3.4.3 Cropping Intensity

Cropping intensity/intensity of cropping (CI) is the ratio between total cropped area in a year and actual net cultivate area expressed in percentage as:

$$\text{Cropping Intensity (CI)} = \frac{\text{Total Cropped Area}}{\text{Net Cropped Area}} \times 100$$

3.4.4 Crop Yield

In agriculture, crop yield (also known as agricultural output) refers to both the measure of the yield of a crop per unit area of land cultivation, and the seed generation of the plant itself. Normal yield is an agricultural term referring to the average historic yield established for a particular farm or area. It is also used to describe average yields. Normal production would be the normal crop acreage planted multiplied by the normal yield.

3.4.5 Crop Production

The crop production group evaluates agricultural practices and systems concerning crop yield, profit, environmental and ecological consequences with the goal of identifying best practices for local and international growers to produce more with less. Crop production has been estimated using the formula:

Total crop production = (Damage free area × Normal yield) + (Damaged area × Damaged yield)

3.4.6 Crop Damage

Crop damage is any reduction in the quantity and /or quality of yield that results from injury. The crop damage (production loss) has been calculated using the formula:

Crop production loss = (Total cropped area × Normal yield) - (Damaged area × Damaged yield) + (Damage free area × Normal yield).

3.4.7 Land Type

Land type is a system of classifying cultivated land based on the seasonal inundation depth of normal flooding. According to Soil Resource Development Institute (SOLARIS-SRDI, 2006), five land types (High land, Medium Highland, Medium Lowland, Lowland and Very Lowland) have been classified in terms of depth of flooding on agriculture land in Table 3.1.

Table 3.1: Land types classification

Land Type	Flooding depth (cm)	Flooding characteristics
High land (F_0)	0-30	Non-flooded to intermittent
Medium Highland (F_1)	30-90	Seasonal
Medium Low Land (F_2)	90-80	Seasonal
Low land (F_3)	180-300	Seasonal, but remains wet in early dry season
Very Lowland (F_4)	>300	Seasonal, but remains wet in most of the dry season

3.5 Methodology of the Study

Though there are different types of statistical distribution in frequency analysis, four types of distribution have been considered in this study. These are Extreme Value I Distribution, Log-pearson type III, Normal Distribution and Log-normal Distribution. For performing those distribution, frequency analysis has been done. Trend analysis of rainfall, water level and discharge has been carried out for the annual year, pre-monsoon, monsoon, post-monsoon and dry season. Hydrographs of rainfall, water level and discharge have been also drawn in this study. Then the correlation among the results of trend analysis of rainfall, water level and discharge have been also drawn for pre-scheme and post-scheme condition.

The software ArcMap 10.2.2 has been used for analyzing the Landsat images. First, the necessary Landsat images of the study area have been downloaded from the United States Geological Survey (USGS) website. The downloaded images then processed using ArcGIS. The processing starts with the atmospheric correction for the calculation of radiance and then the reflectance has been calculated. Finally, Normalized Difference Water Index (NDWI), one of the satellite-derived indices, has been calculated for the detection of change of study area with course of time. Finally, maps showing the Normalized Difference Water Index (NDWI) values have been prepared.

In order to observe the change of Boro crop production, all data related to land resources and agriculture resources has been collected from secondary sources. Then, crop production has been estimated using the crop production formula for pre-scheme and post scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme.

Finally, assessment of Shafique Haor scheme and Sonamoral Haor scheme has been carried out based on flash flood frequency and Boro crop production. Impact assessment has been done by comparing the “Post-scheme scenario” of selected indicator with the status of the same indicator under the “Pre-scheme scenario”.

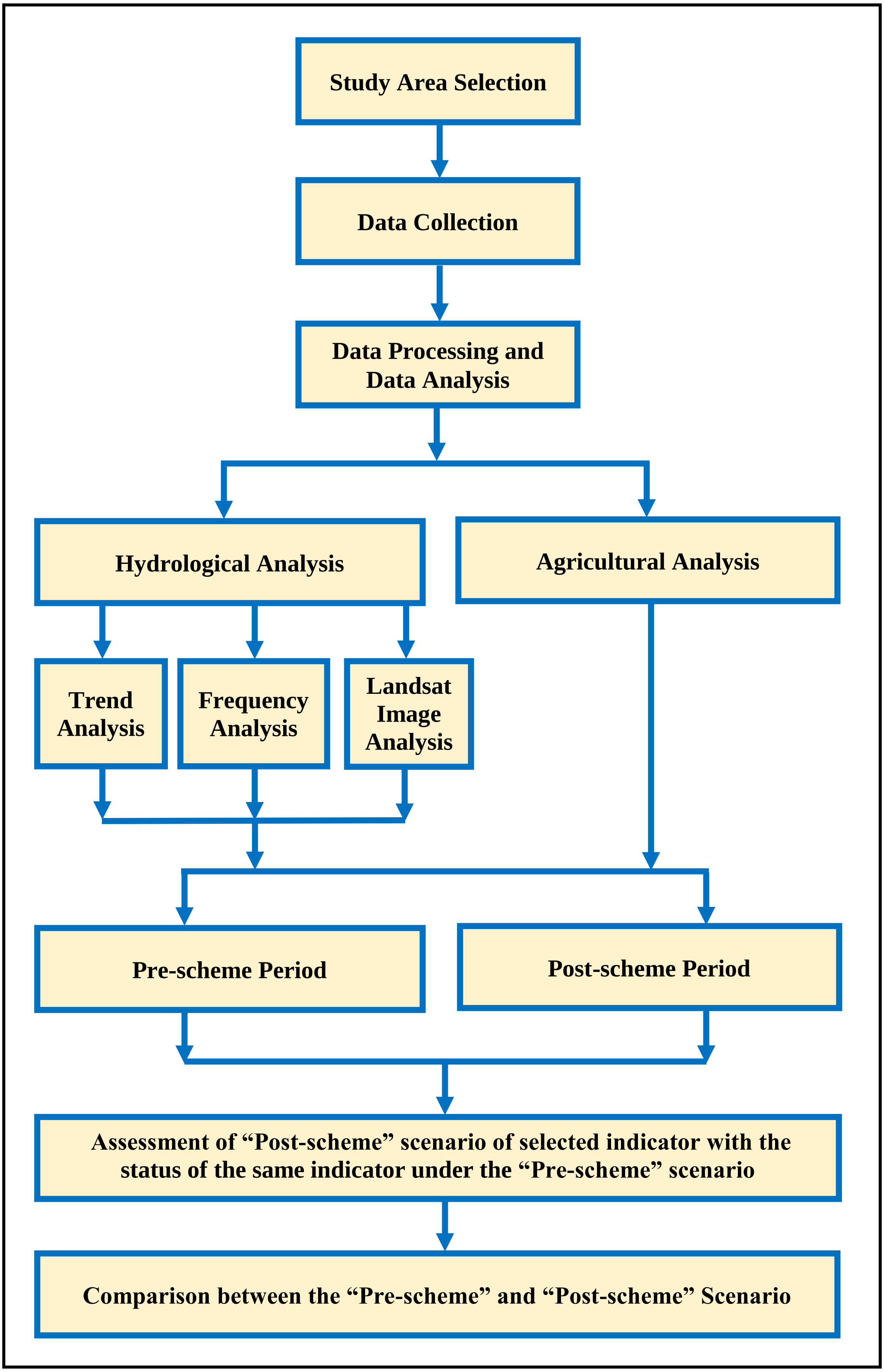

Figure 3.7: Flow chart of the methodology for the study

3.5.1 Description of Study Area

(a) Shafique Haor Scheme

Location of Shafique Haor Scheme:

Shafique Haor scheme is located in the eastern side of the Kanaighat Upazila headquarter spreading over two upazilas namely Kanaighat and Zakigonj under Sylhet District with Chatal Haor on the southwestern part of the scheme.

The Surma River passes through the north side of the scheme while the Kushyara River passes along the southern side of the scheme. There is submersible flood embankment along the right bank of the Surma River and protects the land and resources of the scheme stakeholders. Most of the settlements are in the northeast and northwestern side of the scheme. Land level slopes is down from northeastern side to the southwestern side.

Gross area of the Shafique Haor scheme is about 2,380 ha and net cultivable area is about 2,140 ha (DBHWD, 2017). Construction works of Shafique Haor scheme started in 1997 and the scheme completed in 2006 (DBHWD, 2017). Population of this haor has been estimated to be around 19,000 (CEGIS, 2006).

Water Resource System:

Water river system of the Shafique Haor consists of two important rivers namely Surma and Kushiyara, khals, road side ditch and a number of seasonal and perennial beels spreading over the haor area. Both of the important rivers pass outside the scheme area and control the river hydrology. Surma River originated from Lubha River at Charipara and traveled along the northwestern to northeastern side of the haor. At Amalshid mouza (Bara Takuri union) in Zakigonj upazila, Surma River has confluence with Kushiyara River and Kushiyara River traveled along the northern side of the scheme area. The important khals in the Shafique Haor scheme area are, Eidgha khal, Hatir khal, Kholakuri khal and Dhonabagha khal.

Haors and Beels:

There are two haors under the Shafique Haor scheme namely: Shafique Haor and Chatal Haor. Another important part of the water resource system in the haor area are the beels. In this scheme area, there are more than six beels of different size such as Manikuri Beel, Matijura Beel, Choa Beel and Chatal Beel. Most of which are located in the southeast and southwestern low lying area in the haor (CEGIS, 2006).

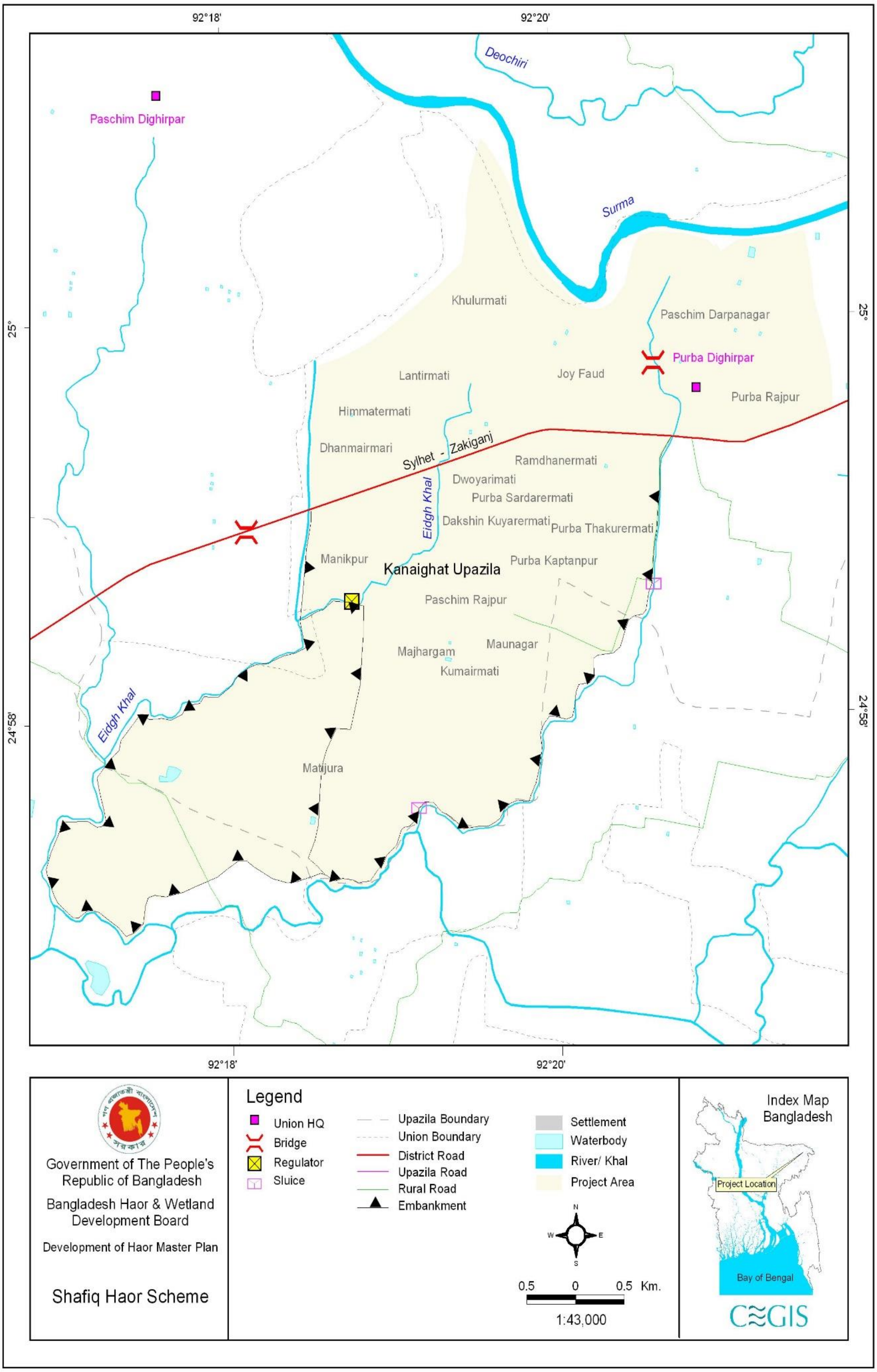

Figure 3.8: Location of the Shafique Haor shceme (Source: CEGIS, 2006)

Flooding Condition:

Flash flood is a common problem in this haor. The upstream runoff comes from excessive rainfall in India. Inadequate water holding capacity of the rivers and floodwater pressure of Surma and Kushyira are the main reason of flooding. Floodwater in the Shafique Haor enters through either the Surma River or the Kushiyara River. More damage occurs when floodwater enters from both the rivers at the same time. Floodwater enters through southwestern side from Kushiyara River into Chatal Haor first. Getting the Chatel Haor over flooded, water enters into the haor by overtopping and breaching the embankment.

Flood water of the Surma River enters into the haor from the north direction. Relatively more flood water enters into the haor from Kushiyara River than that of Surma River. Flash flood inundate the low lying area very rapidly and the people do not get the chance to harvest their standing crop in the agricultural land. Flash flood enters into the haor around the 4th or 5th of the Bangla month Baisak and inundates the haor within 2-3 days. The flood inundation area is about 75% of the total haor area. When the floodwater from both the rivers enter at a time then the inundation goes up to 90% of the areas (CEGIS, 2006).

Rainfall:

The rainfall data of Sylhet BMD station for the period from 1988 to 2018 have been analyzed with a view to appreciate the present rainfall scenario of the study area. This is the nearest station of Bangladesh Meteorological Department from the Shafique Haor scheme. The monthly maximum, minimum and average rainfall are shown in Figure 3.9.

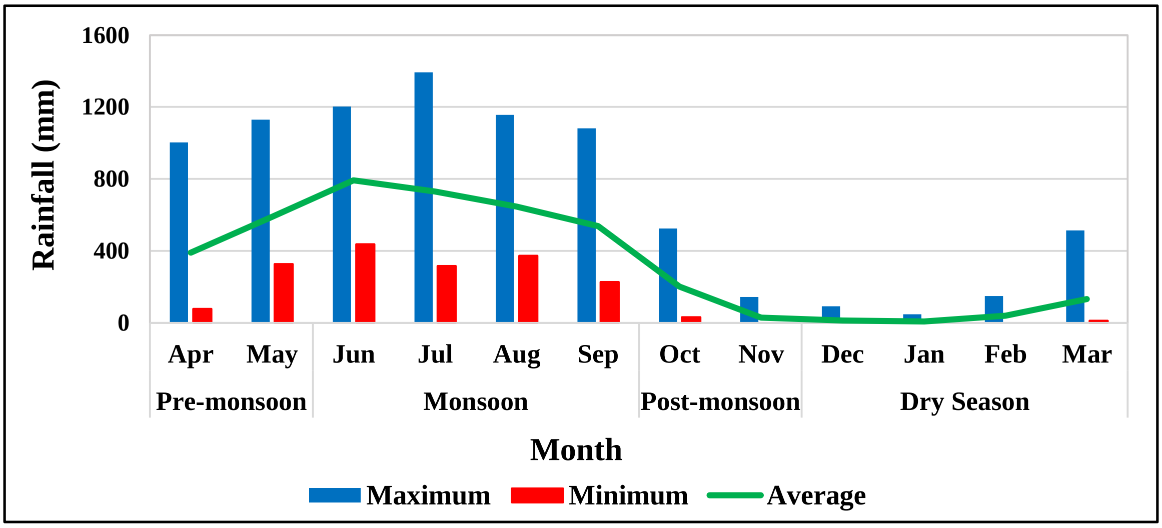

Figure 3.9: Monthly maximum, minimum and average rainfall of Sylhet BMD station during 1988 -2018

The Figure 3.9 shows significant rainfall during the months of April to September. On the other hand, there is very insignificant rainfall during the period of November to February. Average rainfall is found as highest in June (793 mm) whereas the maximum rainfall ever recorded in the area is 1394 mm in the month of July, 2004.

Temperature:

The temperature data of Sylhet BMD station for the period from 1988-2017 has been collected and analyzed. This is the nearest station of Bangladesh Meteorological Department from the Shafique Haor scheme.

It has been observed that the maximum temperature in the study area varies from 29ºC to 35ºC while the minimum varies within the range of 12ºC and 24ºC. The temperature rises during March to October and falls during December to February. The monthly maximum and minimum temperature are shown in Figure 3.10.

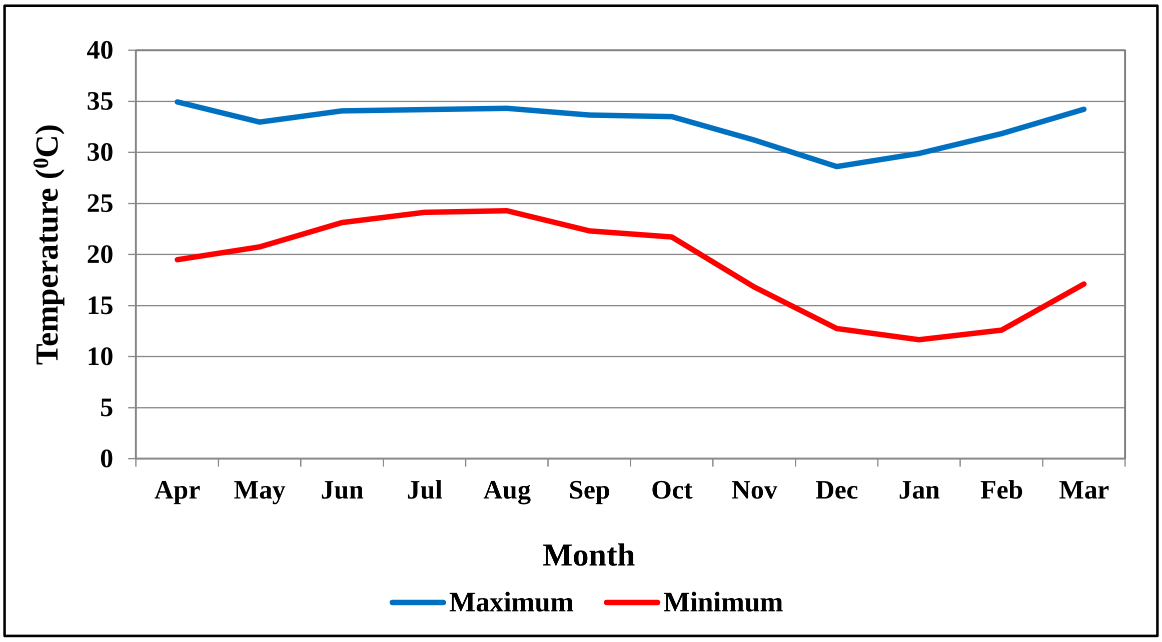

Figure 3.10: Monthly maximum and minimum temperature of Sylhet BMD station during 1988 -2017

Relative Humidity (RH):

The relative humidity data of Sylhet BMD station has been collected for the period 1988-2017 and analyzed. This is the nearest station of Bangladesh Meteorological Department from the Shafique Haor scheme. It shows that the maximum monthly humidity is 93% while the monthly minimum relative humidity is 60%. The monthly maximum, minimum and average relative Humidity (RH) are presented in Figure 3.11.

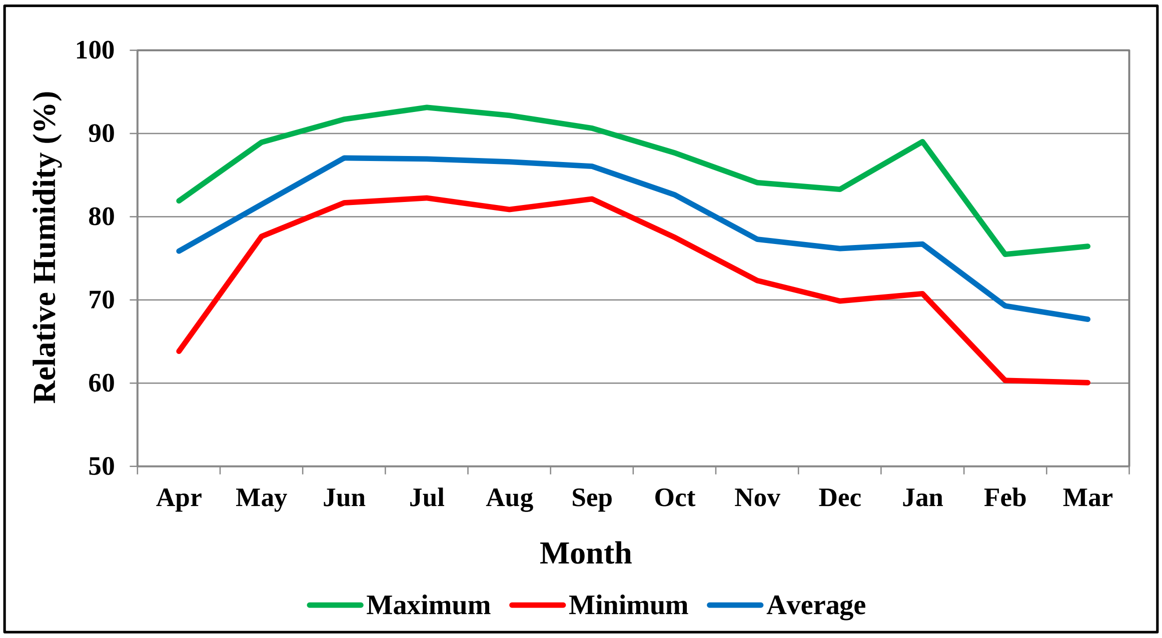

Figure 3.11: Monthly Relative Humidity of Sylhet BMD station during 1988 -2017

Wind Speed:

The wind speed data for the period from 1988 to 2017 has been collected and analyzed from Sylhet BMD station. This is the nearest station of Bangladesh Meteorological Department from the Shafique Haor scheme. The maximum recorded wind speed is found to be 83.34 Km/h which occurred in May, 1997. Most high winds (Speed >=60 Km/h) were observed during the months of March, April, May, June, and October. The wind speed during different time period has been shown in Figure 3.12.

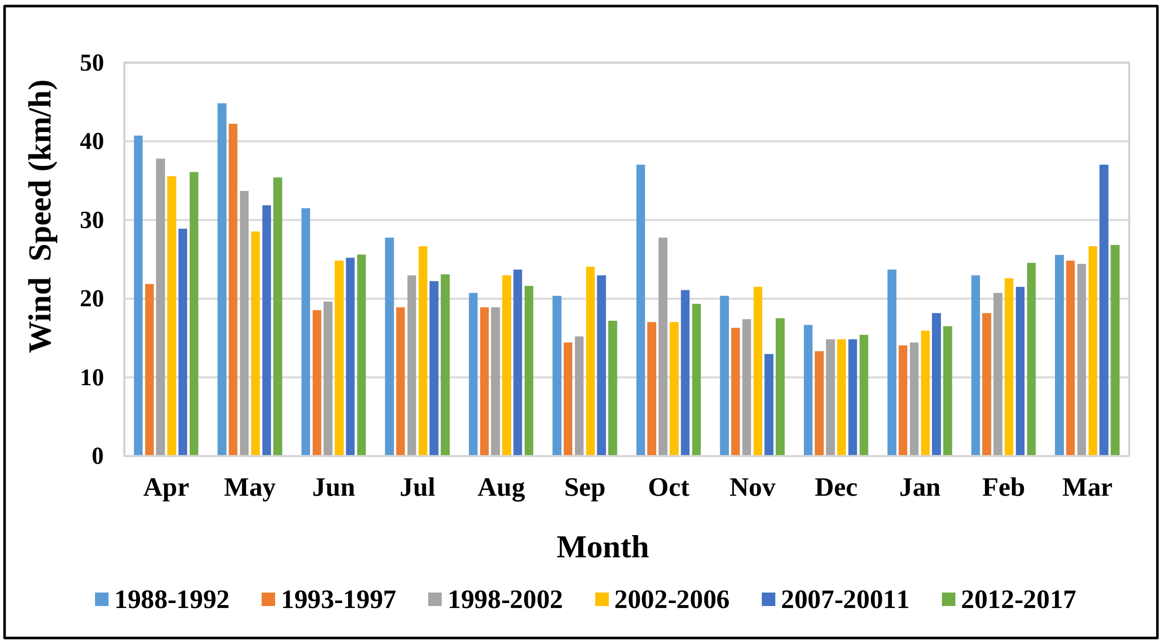

Figure 3.12: Monthly wind speed distribution of Sylhet BMD station during 1988 -2017

Sun-shine Hour:

The analysis of sunshine hours for the last 30 years (1988-2017) shows that the average monthly sunshine hours varies from 1.7 to 6.3 hours/day of Sylhet BMD station. This is the nearest station of Bangladesh Meteorological Department from the Shafique Haor scheme. The maximum sunshine hours of 9.8 hrs/day was recorded in May in 1998. The average and maximum monthly sunshine hours are shown in Figure 3.13.

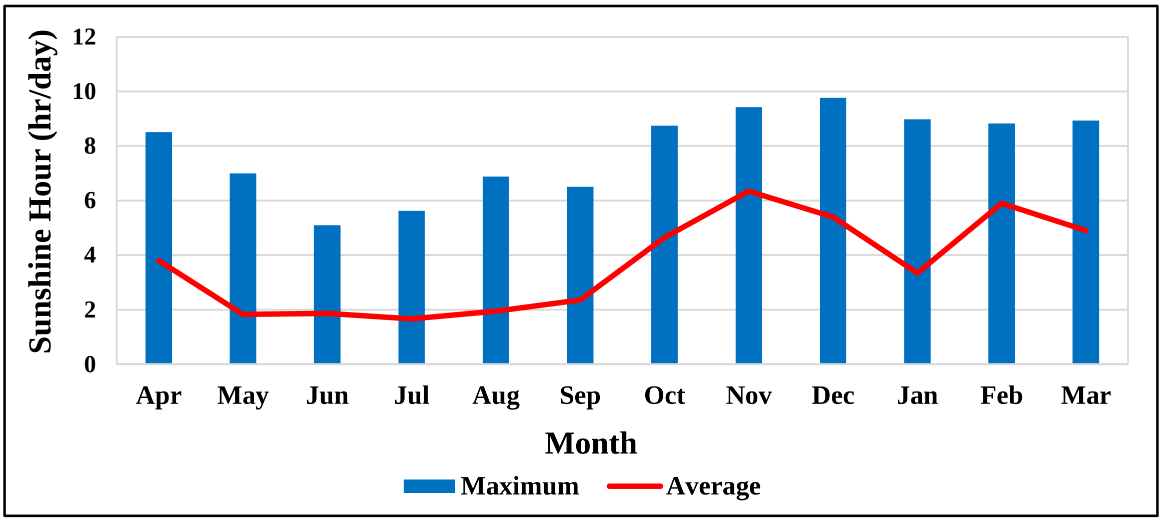

Figure 3.13: Monthly sunshine hour at Sylhet BMD Station (1988-2017)

Drainage Condition:

In Shafique Haor scheme, floodwater mainly drains out through Hatir khal regulator into Chatal Haor, which is located in the southwestern side of the Haor. Chowa Beel pipe sluice and Shuter Khal pipe sluice are the most important routes for draining floodwater, which are located in the southeastern part of the scheme. In addition, drainage also take place through a) Sada Khal; b) Boura Khal and c) Napiter Khal. There are some low-lying areas where drainage congestion creates problem for agricultural activities. Roughly 25% area suffers water logging (CEGIS, 2006). This water logging is due to improper drainage and excessive sedimentation in the linked canals. It is reported that the regulators function well but even then water logging remains due to non-excavation of the canals.

Hydrological Region (HR):

WARPO has delineated eight hydrological regions of Bangladesh, based on appropriate natural features namely Northwest (NW), North Central (NC), Northeast (NE), Southeast (SE), Southcentral (SC), Southwest (SW), Eastern Hills (EH) and Main Rivers and Estuaries (RE). Shafique Haor scheme has fallen under Northeast (NE) hydrological region.

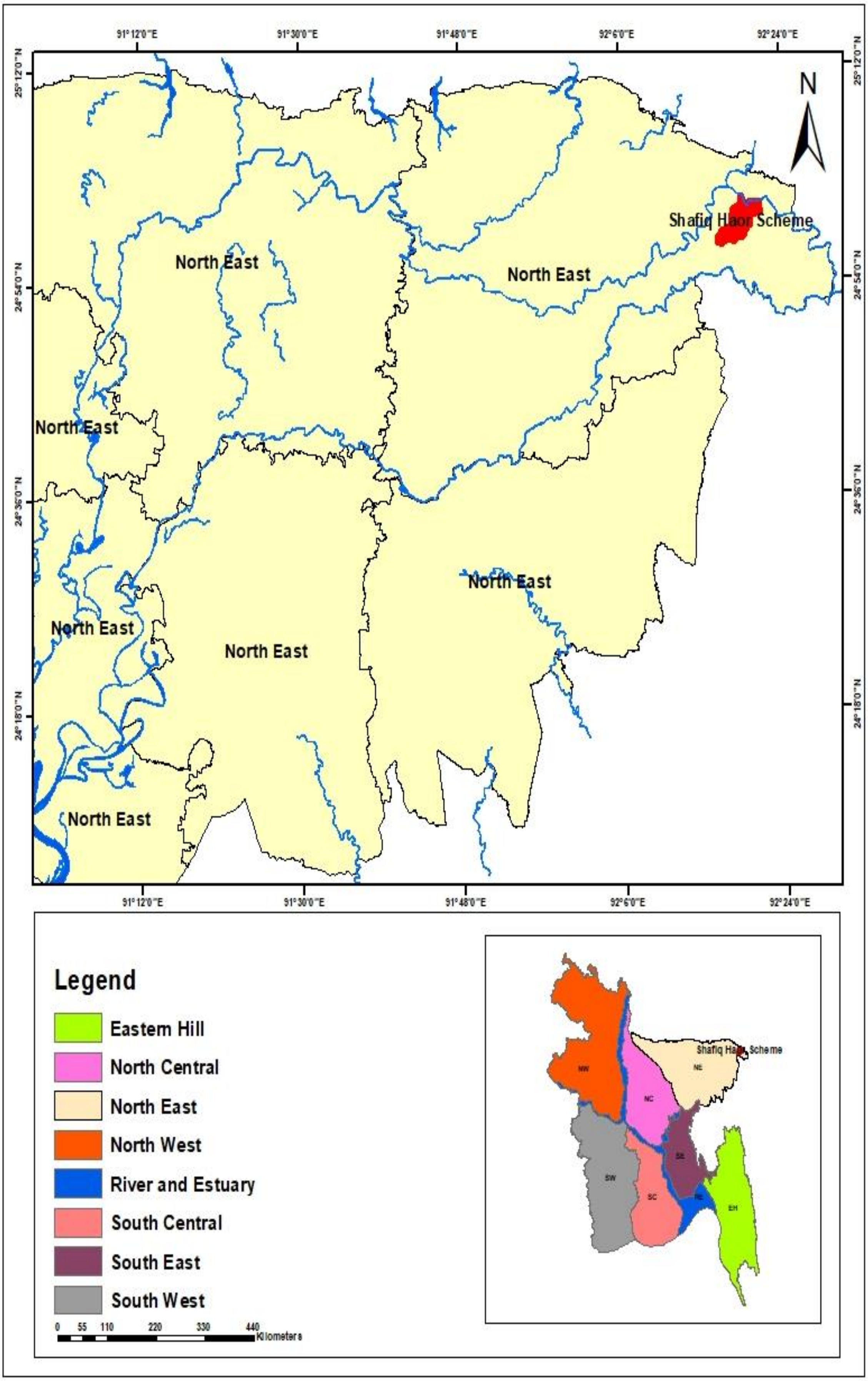

Figure 3.14: Location of hydrological region of Shafique Haor scheme

Agro-Ecological Zone (AEZ):

The Shafiq Haor scheme has fallen under Agroecological region 20: Eastern Surma-Kushiara Floodplain (AEZ-20) (BARC, 2012). This region occupies the relatively higher parts of the Surma-Kushiyara Floodplain formed on sediments of the rivers draining into the Meghna catchment area from the hills. The area is mainly smooth, broad ridges and basins.

This area is occupied by grey, heavy silty clay loams on the ridges and clays in the basins. Non-calcareous Grey Floodplain soils are the only General Soil Type. Organic matter content of the soil is low to medium. Soil reaction ranges from very strongly acidic to neutral. Levels of CEC and Zn are medium. The status of N and P is very low to low and K and B are low to medium. Some physic-chemical properties of the soils of AEZ-20 are given below.

Table 3.2: Some physic-chemical properties of soils of Eastern Surma-Kushiara floodplain (AEZ-20)

Major Land Type	Soil p^H	Soil OM	Nutrients status							
			N	P	K	S	Ca	Mg	Zn	B
Medium highland (25%)	4.4-7.1	L-M	VL-L	VL-L	L-M	L-M	M-O	M-O	M	L-M
Medium highland (20%)	4.7-6.1	L-M	VL-L	VL-L	L-M	L-M	M-O	M-O	M	L-M
Lowland (36%)	4.2-7.7	L-M	VL-L	VL-L	L-M	L-M	M-O	M-O	M	L-M

Notation: OM=Organic matter; VL=Very low; L=Low; M=Medium; O=Optimum.

Natural Resources:

Stone is the only natural resource of Kanaighat upazila. Government revenue increases substantially from Lobhachara stone quarry. The **“**Kanthalbari Swamp Hill**”**, which means hill existence in inundated low-lying area, is located at Kanthalbari village under Razaganj union in Kanaighat upazila in Sylhet district. The Kanthalbari Swamp Hill shows its beauty during rainy season. Hill in the haor is the main attraction of the venue, as there is no such venue in any other part of the country so far. At least 30 separate small hills are seen at Kanthalbari as well as in the haor. The distance of the hills from each other is very little and the middle places of the hills are plane-land. The middle places remain inundated at seven to eight months.

Status of the Structures of Shafique Haor Scheme:

The status of the structures of Shafique Haor scheme (CEGIS, 2006) are described in below Table 3.3

Table 3.3: Status of the structures of Shafique Haor scheme

Sl No	Structures of Shafique Haor scheme	Condition of the structures
1	Submersible embankment from Matijura to Sylhet Zakiganj road near Julyir bridge (western side of the Shafique Haor).	One major public cut near Hatir khal regulator which cause both flooding problems as well as hamper the retention of water for irrigation during dry seasons. There are 5/6 breaches located near the following mouzas: a) Matijura; b) Nayamati.The height of the overall submersible embankment along with the specified locations remained as low.
2	Submersible embankment from Matijura to Sylhet Zakiganj road near Sharak bazaar. (Eastern side of the Shafique Haor)	One major public cut near Chowa beel regulator and 8 breaches are located near the following mouzas: a) Matijura; b) Mathargram, and c) Captanpur. The height of overall submersible embankment along with the specified locations remained as low.
3	Internal submersible embankment at Noyamati mouza	One major breach near Noyamati mouza. - The height of the overall submersible embankment is low.
4	Hatir khal regulator (2-vent).	The regulator is functioning but the overall physical condition of the regulator is not sustainable. Some components of the regular has been stolen. The water discharge capacity/drainage of the regulator is not enough. Therefore, the drainage period remains extended. Connecting canal of this regulator has been silted up.
5	Shuter khal pipe sluice.	Newly constructed and remaining in good condition. The height of the attached embankment is low.
6	Chowa beel pipe sluice.	The structure is newly constructed. Physical condition of the pipe sluice is good.

Structural Components of Shafique Haor Scheme:

The scheme has been implemented during the period 1997- 2006 (DBHWD, 2017). Total embankment of the Shafique Haor scheme is 23 km. The major physical elements of the Shafique Haor scheme has been mentioned in Table 3.4.

Table 3.4: Data Inventory of Shafique Haor scheme

Scheme Name:		Shafique Haor scheme		Division:		Sunamganj O&M Division					
Project Type:		FCD		Project Area:		2380 Hectare		Beneficial Area:		2140 Hectare	
Project Started:		1997		Project Ended:		2006		Embankment Length:		23 Kilometer	
Sl No	Structure Type	Latitude	Longitude	No. of Vents	Barrel Length (m)	Height (m)	Width (m)	Dia (m)	Sill/Bed	Soffit	Deck
1	Box Culvert	24.9912	92.3422	1	9.750	2.740	3.050	-	12.71	15.45	15.72
2	Bridge	24.9909	92.3505	-	-	4.150	1.700	-	12.45	16.60	17.49
3	Bridge	24.9929	92.3570	-	-	5.570	3.800	-	11.29	16.86	17.76
4	Box Culvert	24.9936	92.3586	1	4.050	3.300	2.950	-	11.62	14.92	15.25
5	Box Culvert	24.9974	92.3591	1	7.300	2.670	3.050	-	12.62	15.29	15.59
6	Pipe Culvert	25.0072	92.3483	-	10.000	-	-	1.000	14.92	-	-
7	Pipe Culvert	25.0056	92.3290	-	1.250	-	-	1.000	15.07	-	-
8	Box Culvert	25.0077	92.3235	1	3.650	1.000	1.220	-	14.42	15.42	15.57
9	Pipe Culvert	25.0007	92.3163	-	3.700	-	-	0.650	14.48	-	-
10	Pipe Culvert	24.9999	92.3157	-	5.500	-	-	0.650	14.32	-	-
11	Pipe Culvert	24.9980	92.3127	-	3.800	-	-	0.600	13.49	-	-
12	Box Culvert	24.9910	92.3106	-	4.200	2.050	1.900	-	12.82	14.87	15.09
13	Box Culvert	24.9871	92.3105	1	4.200	3.170	2.900	-	11.87	15.04	15.27
14	Bridge	24.9919	92.3291	-	-	4.440	16.600	-	11.99	16.43	17.32
15	Bridge	24.9897	92.3204	-	-	4.510	15.300	-	11.49	16.00	16.81
16	Sluice Gate	24.9779	92.3095	2	5.450	1.080	1.250	-	9.98	11.06	-

(b) Sonamoral Haor Scheme

Location of Sonamoral Haor Scheme:

The Sonamoral Haor scheme is situated about 8.5 km South-West of Jamalganj Upazila and about 9.5 km North-East of Dharmapasha Upazila headquarter in Sunamgnj District. There are two unions in this Haor areas: Uttar Sukhair-Rajapur -90 % and Joysree -10 %. Most of the portion of the irregular shaped Sonamoral Haor is located in Jamalganj Upazila and the remaining western part is located in the Dharmapasha Upazila under Sunamganj District. Several haor projects such as Gurmar and Halir haor in the North, Pagner Haor in the East and Joydhona, Dhankunia and Chandra Sonarthal Haor in the South side. Topographically northwestern corner of the Sonamoral Haor is relatively highly elevated area and southern part of this haor is relatively low. The topographical variation inside the scheme area ranges from 0.42 m+PWD to 5.16 m+PWD with a major depression in the South- Eastern side of the scheme. The total scheme area is 3,275 ha and the net benefited area is 3,160 ha (SSISP, 1990). Construction works of Sonamoral Haor scheme started in 1985 and completed in 1992 (DBHWD, 2017). Population of this haor has been estimated to be about 33,000 (CEGIS, 2006).

Water Resources System:

Water resources system of the Sonamoral Haor scheme is composed of a number of rivers, khals and beels located in and around the scheme. The scheme is bounded by Bauli River on the North-East, Someswari River on the West, Konai River on the south and Surma River on the East side. There are four main khals in haor area: a) Jordar Khal; b) Kukurmarar Khal; c) Doarar Khal and d) Daulatpur Khal. There are some sub-khal a) Patharkandi-Bagbari; b) Harjalhali- Sukhiar Bazar and c) Protappur-Verirpar khals.

Haors and Beels:

There are three haors under the Sonamoral Haor scheme namely: Sonamorol Haor, Maheshpur Haor and Sashkar Haor. Within the Sonamoral Haor scheme area, there are a number of beels, which are connected to the bounding rivers of Bauli, Dorchari and Surma through various khals, of which the most important is the Juddail and Kharashjan Khal. The beels are Chata Beel, Katailjan Beel, Chaittainya Beel, Baro Beel, Bausi Beel, Fera gang (ox-bo lake) Beel, Filainya Beel, Baon bora Beel, Karchar Beel, Shasanka Beel and others beel (small size).

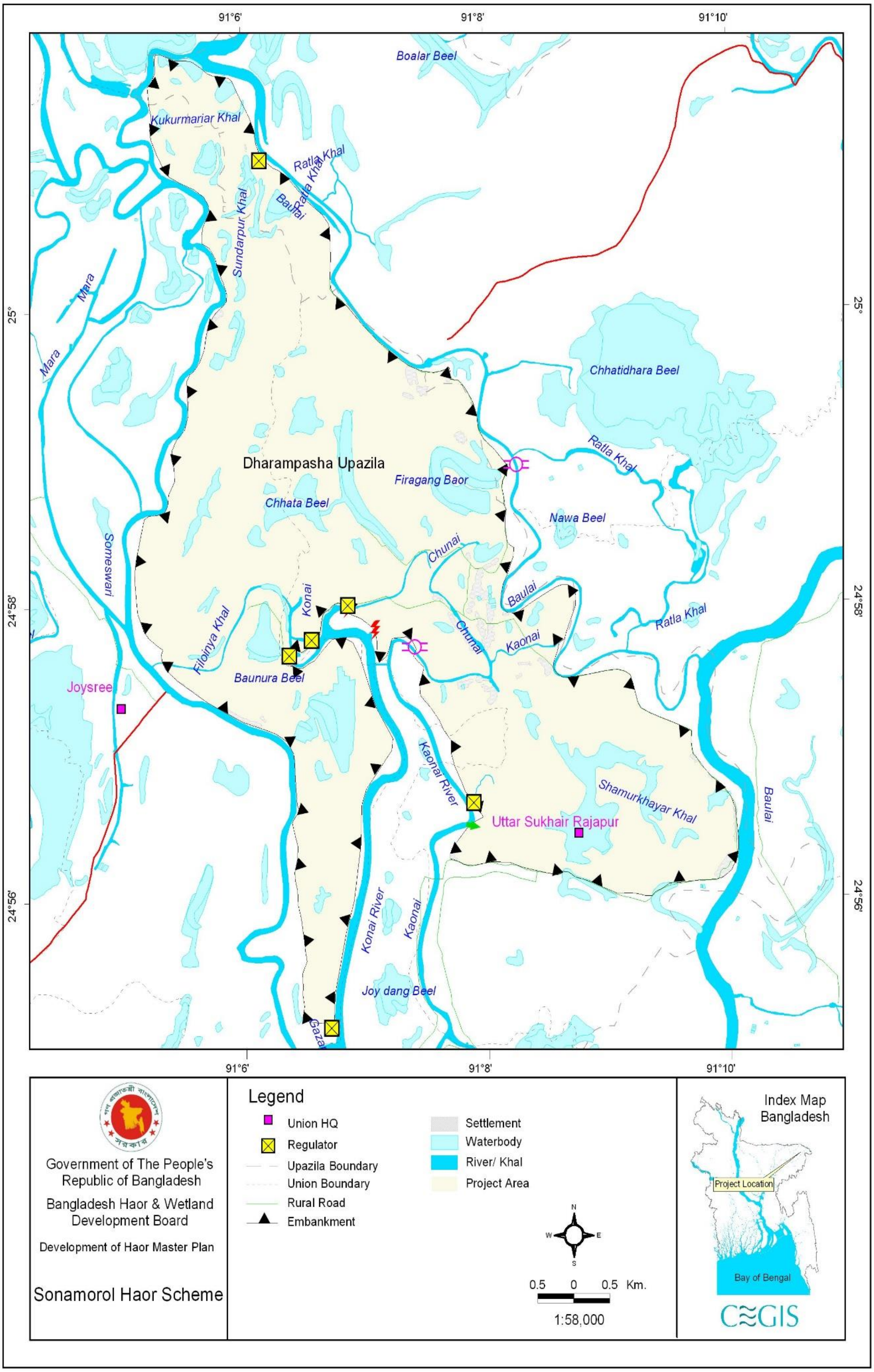

Figure 3.15: Location of the Sonamoral Haor shceme (Source: CEGIS, 2006)

Flooding Condition:

The location of Sunamganj and its topography made it extremely prone to be effected by early rain in bordering Indian Hilly State that fetches heavy downpour of rainwater. This area faces pre-monsoon flashflood almost every year due to huge volume of water coming in from the Surma River through different connected rivers surrounding the project area. In the early monsoon, when excessive floodwater accumulates in the Surma River, it creates backwater on the Baulai River, Someswari River and Konai River. This backwater as well as the water coming from upstream jointly raises the water level above the embankment resulting in overtopping and breaching of the embankment at several locations through which water easily enters into the haor.

Flood water normally entered into the haor area within the time range from 15th April to 20th April (SSISP, 1990). Water starts overtopping the submersed embankment into this haor area from the northern part of the project area when flash flood occurs. Local rainfall also creates flood in the haor, but it does not exceed one fourth of the total area. The entire haor inundates within few days when heavy rainfall occurred in the neighboring hilly area. The rivers, which are responsible for the flash flood and their distribution, are Baulai River (controls 40%) and Someswari River (controls 60%). During the monsoon, Sonamoral Haor is flooded to depth ranging from 1.5 to 6.0 meters (Shawinigan, 1992).

Drainage Condition:

Drainage network of the study area comprises of a number of khals, beels and river in and around the project area. Land level slopes down from north to south, which favors drainage towards Someswari and konai rivers. Water from low-lying beels is mainly drained out by Juddail and Kharashjan Khal through regulators constructed on the respective khals. Both the regulators are now working properly. In addition to the above-mentioned regulators, water also drains out through a number of locations where embankment is cut by the public and breached by floodwater. In the lowest part and the beels of the study area, water normally drains out within the first week of December. But the there is a tendency of delay in water drain out due to drainage congestion. If the haor drain out with in first week of December then it will be good for farmers to transplant Boro in the field. About 25% area of Haor suffer drainage congestion problem (Khan, 2010).

The rivers those controls drainage are: Baulai River; Kalapani River; Somesswari River, Surma River and all internal and external canals are already silted up to an extent. Water logging is becoming a challenging issue of the study area.

Agro-Ecological Zone (AEZ):

Thirty agro-ecological zones (AEZ) and 88 sub-zones have been identified by adding successive layers of information on the physical environment which are relevant for land use and assessing agricultural potential. The Sonamoral Haor scheme falls in only one AEZ namely Sylhet Basin (AEZ-21) (BARC, 2012). The region occupies the lower western side of Surma-Kusiyara Floodplain. The area is mainly smooth broad basins with narrow rims of higher land along the rivers. Soils of the area are grey silty clay loams and clay loam in the higher parts that dry out seasonally and grey clays in the wet basins. Non calcareous Grey Floodplain soils and Acid Basin Clays are the major components of the general soil types. The soils have medium level of organic matter and soil reaction is mainly slightly acidic in top soil. Fertility level is medium to high with very low to low N and P contents.

Table 3.5: Some physic-chemical properties of soils of Sylhet Basin (AEZ-21)

Major Land Type	Soil p^H	Soil OM	Nutrients status							
			N	P	K	S	Ca	Mg	Zn	B
Medium Lowland (19%)	4.7-5.9	L-M	VL-L	VL-L	L-M	M-O	M-O	M-O	M-O	M-O
Lowland (43%)	4.8-6.1	M	VL-L	VL-L	M-O	M-O	M-O	M-O	M-O	M-O
Very Lowland (32%)	4.9-6.2	M	VL-L	VL-L	M-O	M-O	M-O	M-O	M-O	M-O

Notation: OM=Organic matter; VL=Very low; L=Low; M=Medium; O=Optimum.

Hydrological Region :

WARPO has delineated eight hydrological regions of Bangladesh, based on appropriate natural features namely Northwest (NW), North Central (NC), Northeast (NE), Southeast (SE), Southcentral (SC), Southwest (SW), Eastern Hills (EH) and Main Rivers and Estuaries (RE). Sonamoral Haor scheme has fallen under Northeast (NE) hydrological region. The figure of hydrological region of Shafique Haor scheme has been presented in Figure 3.16

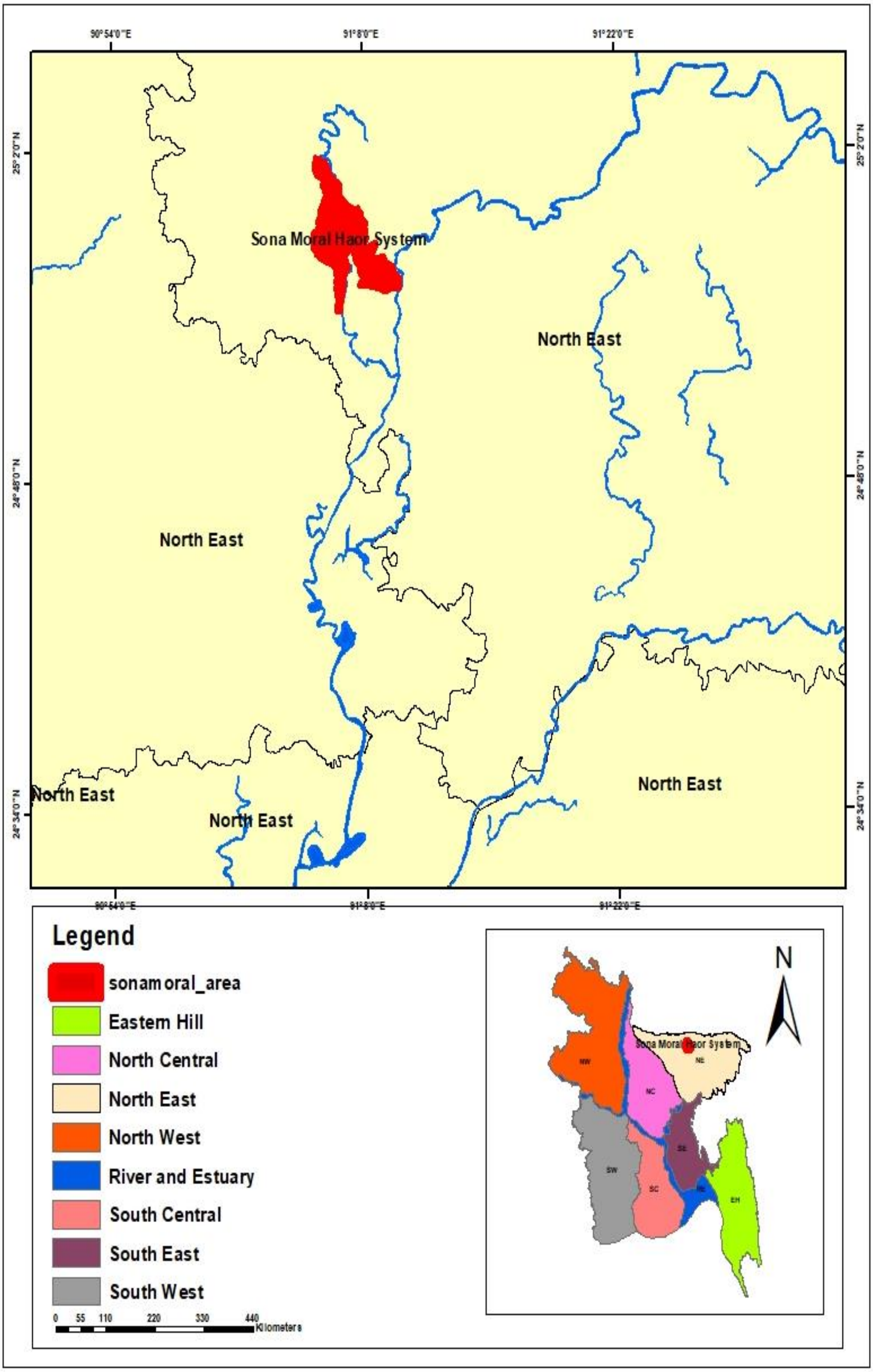

Figure 3.16: Location of hydrological region of Sonamoral Haor scheme

Climate Condition:

Meteorological condition (Rainfall, Temperature, Relative Humidity, Wind Speed and Sunshine) of the Sonamoral Haor scheme and Shafique Haor scheme are same. As Sylhet BMD station is the nearest station for both the schemes. The meteorological analysis of the mentioned years of Sylhet BMD station and its graphical presentation has been incorporated in Figure 3.9 to Figure 3.13.

Natural Resources:

The haors are considered as the most productive wetland resources of Bangladesh and Dharmapasha Upazila and Jamalganj Upazila are covered with several of them. The haor basin supports a large variety of wetland biodiversity and works as a natural reservoir as it plays a key role in basin water resources management and development by regulating water flows of the Meghna river system. Also, Tanguar haor is noted sanctuary of both permanent and migratory birds. With the recession of floodwater, a large variety of small fishes, oysters, water snails and bivalves, and pasture spread over the surface attracting a large number of migratory birds. These birds use this area as temporary resting and roosting ground before moving elsewhere.

The Swamp forests, which were once dominant with the flood tolerant tree species like hijal (Barringtonia acutangula) and Koroch (Pongamia pinnata), have been reduced to a few small patches. In the past century or so, when the population pressure was less, most of the rimlands of the haors remained as cultivable wetland and were used for extensive grazing during the dry season. As the population increased, boro cultivation expanded onto these marginal lands leading to a large area being drained.

Thus, the very existences of these wetlands are now threatened. The area is enriched with various aquatic biodiversity along with 140 species of fish. About 8,000 migratory wild birds visit the area annually (Salauddin, 2010).

Strucutral Components of Sonamoral Haor Scheme:

The scheme has been implemented during the period 1985 -1992 (DBHWD, 2017) under the financial support of Asian Development Bank (ADB). Total length of the embankment is 50 kilometers. The major physical elements of the Sonamoral Haor scheme has been mentioned in Table 3.6.

Table 3.6: Data Inventory of Sonamoral Haor scheme

Scheme Name:	Sonamoral Haor scheme	Division:	Sunamganj O&M Division		
Project Type:	FCD	Project Area:	3275Hectare	Beneficial Area:	3160 Hectare
Project Started:	1985	Project Completed:	1992	Embankment Length:	50 Kilometer

Sl No.	Structure Type	Latitude	Longitude	No. of Vents	Barrel Length (m)	Height (m)	Width (m)	Dia (m)	Sill/Bed	Soffit	Deck
1	Regulator	24.9198	91.1087	2	7.260	6.190	1.500	-	0.55	6.74	7.13
2	Pipe Culvert	24.9293	91.1105	-	13.000	-	-	0.470	4.20	4.67	-
3	Pipe Culvert	24.9449	91.1131	-	11.600	-	-	0.470	3.05	3.52	-
4	Sluice Gate	24.9476	91.1141	3	3.730	1.670	1.370		2.35	4.02	4.57
5	Pipe Culvert	24.9528	91.1174	-	9.450	-	-	0.470	0.13	5.01	-
6	Regulator	24.9638	91.1063	3	7.450	-	1.500		1.26	6.22	6.56
7	Pipe Culvert	24.9628	91.1205	-	22.200	6.090	-	0.910	0.00	2.17	-
8	Pipe Culvert	24.9526	91.1252	-	-	-	-	-	-	-	-
9	Pipe Culvert	24.9526	91.1274	-	-	-	-	-	-	-	-
10	Regulator	24.9452	91.1285	2	7.300	4.970	1.500		1.21	6.18	6.55
11	Pipe Culvert	25.0153	91.0895	-	14.600	-	-	0.430	4.65	5.08	-
12	Pipe Culvert	25.0198	91.0850	-	-	-	-	-	-	-	-
13	Pipe Culvert	25.0246	91.0845	-	13.500	-	-	0.420	2.14	2.56	-
14	Box Culvert	24.9597	91.1499	1	6.000	1.210	1.900	-	4.78	5.99	6.13
15	Sluice Gate	25.0179	91.0996	1	6.000	1.480	3.000	-	0.23	1.71	6.84

Status of the structures of Sonamoral Haor Scheme:

The status of the structures of Sonamoral Haor scheme (CEGIS, 2006) are described in below Table 3.7

Table 3.7: Status of the structures of Sonamoral Haor scheme

Sl. No	Structures of Sonamoal Haor scheme	Condition of the structures
1	Submersible embankment from Bhadgaonbade mouza to Islampur mouza (Southern side of Sonamoral Haor beside the Konai river locally called "kalagang")	There are 5/ 6 breaches are located near the following villages: a) Jurdhar; b) Doarar; c) Islampur; and d) Binadpur. The height of this section of the submersible embankment is low. Flash flood enters into this haor from the Dhankunia haor due to this low height of the submersible embankment.
2	Submersible embankment from Islampur mouza to Sundarpur mouza (Eastern side of Sonamoral Haor beside the Boulai River and partly beside the Shurma River).	There are 4/5 major breaches are located near the following villages: a) Shukhair Nij; b) Noagaon; c) Jarakona ; d) Sundarpur (locally known as Koyra). The height of this section of the submersible embankment is low. Flash flood enters from the Boulai River both through the breaches mentioned above and also through over topping several sections of the submersible embankment. This is also caused by the siltation on the Boulai River. Wave erosion cause damages to this section of the submersible embankment as well.
3	Daulatpur Regulator (2- vent)	Physical condition of the regulator is good and functional. Link canal has been silted up.
4	Submersible embankment from Sundarpur mouza to Bhadgaonbade mouza (Western side of Sonamoral Haor)	There are 4-5 minor breaches are located near the following villages: a) Najarpur; b) Haripur; c) Joysree; d) Bhadgaon Bade. The height of overall submersible embankment along with the specified locations remained low. Flood waters entrance from Shomeshwari River. Wave erosion cause damages to this section of the submersible embankment as well.
5	Jurdhar Regulator (3-vent)	Physical condition of the regulator is poor and nonfunctional. Link canal has been silted up. Attached embankment has a breach near the regulator. Some components (e.g. key, handle etc.) of the regulator has been stolen.
6	Doarar Regulator (2-vent)	Physical condition of the regulator is poor and nonfunctional. Linked canal has been silted up. Attached embankment has a breach in the southern side of the regulator.
7	Kukurmara Regulator (2-vent)	This regulator is functioning with a poor physical condition. Linked canal has been silted up.

3.5.2 Data Collection

For the present assessment study, different types of data have been obtained from different sources. The type of data can be listed as follows:

(a) Rainfall data;

(b) Discharge data;

(c) Water level data;

(d) Landsat image data and

(e) Agricultural data.

(a) Rainfall Data Collection

Data on meteorological parameter as rainfall of the Sylhet BMD station has been collected from the NWRD-CEGIS archive of 1956 to 2017. This is National Water Resources Database (NWRD) of Water Resources Planning Organization (WARPO) archived in Center for Environmental and Geographic Information Services (CEGIS). Rainfall data of 2018 was also collected from Bangladesh Meteorological Department (BMD) of the Sylhet BMD station. This is the nearest Bangladesh Meteorological Department (BMD) station from both the Shafique Haor scheme and Sonamoral Haor scheme and represents the regional rainfall condition of the study area. Information about the rainfall data used in this study has been presented in Table 3.8.

Table 3.8: Rainfall data for the Shafique Haor scheme and Sonamoral Haor scheme

Scheme Name	Station ID	Station Name	Year
Shafique Haor scheme	10705	Sylhet	1956-2018
Sonamoral Haor scheme			

(b) Discharge Data Collection

The time series of discharge data from 1969 to 2018 of the Surma-Meghna River and from 1988 to 2018 of Jadukata River has been collected for the Shafique Haor scheme and Sonamoral Haor scheme accordingly. Bangladesh Water Development Board (BWDB) measures daily discharge data. In this study three non-tidal gauge stations of BWDB such as Kanairghat (ID 266) for Shafique Haor scheme and Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) for Sonamoral Haor scheme have been counted for discharge data collection. Discharge data have been collected from Bangladesh Water Development Board (BWDB). Information about the discharge data used in this study is presented in Table 3.9.

Table 3.9: Discharge data for the Shafique Haor scheme and Sonamoral Haor scheme

Scheme Name	Station ID	Station Name	Year
Shafique Haor scheme	266	Kanairghat	1969-2018
Sonamoral Haor scheme	131	Saktiarkhola	1988-1992
	131.5	Laurergarh Saktiarkhola	1993-2018

(c) Water Level Data Collection

Mean Daily Water Level (MDWL) has been collected in daily basis by Bangladesh Water Development Board (BWDB). There are several stations where water level data is measured. In this study three non-tidal gauge stations of BWDB such as Kanairghat (ID 266) for Shafique Haor scheme and Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) for Sonamoral Haor scheme have been counted for water level data collection.

These water level data have been collected from NWRD-CEGIS archive. This is National Water Resources Database (NWRD) of Water Resources Planning Organization (WARPO) archived in Center for Environmental and Geographic Information Services (CEGIS). Information about the time series data of water level used in this study has been presented in Table 3.10.

Table 3.10: Water level data for Shafique Haor scheme and Sonamoral Haor scheme

Scheme Name	Station ID	Station Name	Year
Shafique Haor scheme	266	Kanairghat	1952-2018
Sonamoral Haor scheme	131	Saktiarkhola	1964-1992
	131.5	Laurergarh Saktiarkhola	1993-2018

(d) Landsat Image Data Collection

Landsat images have been downloaded from the Landsat Archive of United States Geological Survey (USGS) and the website address is Earth Explorer (http://earthexplorer.usgs.gov/) where Landsat imagery is available from the archive, free for registered users. There are no restrictions on Landsat data downloaded from the USGS; it can be used or redistributed as desired. Downloaded imagery is composed of a .tiff file for each Landsat band and an MTL.txt file which contains metadata information. Images are already georeferenced in WGS 84 datum (Yunus, 2005). Different Landsat and their information about sensor and spatial resolutions of the Shafique Haor scheme and Sonamoral Haor scheme have been presented in following Table 3.11 and Table 3.12 accordingly.

Table 3.11: Different Landsat and their information for Shafique Haor scheme

Year	Month	Satellite	Sensor	Resolution (meters)
1990	April	Landsat 5	Thematic Mapper (TM)	30*30
	August	Landsat 5	Thematic Mapper (TM)	30*30
	October	Landsat 5	Thematic Mapper (TM)	30*30
1996	April	Landsat 5	Thematic Mapper (TM)	30*30
	September	Landsat 5	Thematic Mapper (TM)	30*30
	October	Landsat 5	Thematic Mapper (TM)	30*30
2008	May	Landsat 5	Thematic Mapper (TM)	30*30
	September	Landsat 5	Thematic Mapper (TM)	30*30
	October	Landsat 5	Thematic Mapper (TM)	30*30
2017	May	Landsat 8	Operational Land Imager (OLI)	30*30
	September	Landsat 7	Enhanced Thematic Mapper Plus (ETM +)	30*30
	October	Landsat 8	Operational Land Imager (OLI)	30*30
2018	May	Landsat 7	Enhanced Thematic Mapper Plus (ETM +)	30*30
	September	Landsat 7	Enhanced Thematic Mapper Plus (ETM +)	30*30
	October	Landsat 7	Enhanced Thematic Mapper Plus (ETM +)	30*30

Table 3.12: Different Landsat and their information for Sonamoral Haor scheme

Year	Month	Satellite	Sensor	Resolution (meters)
1978	April	Landsat 3	Multispectral Scanner System (MSS)	60*60
	November	Landsat 2	Multispectral Scanner System (MSS)	60*60
1979	September	Landsat 2	Multispectral Scanner System (MSS)	60*60
2010	April	Landsat 5	Thematic Mapper (TM)	30*30
	August	Landsat 5	Thematic Mapper (TM)	30*30
	October	Landsat 5	Thematic Mapper (TM)	30*30
2017	May	Landsat 8	Operational Land Imager (OLI)	30*30
	June	Landsat 8	Operational Land Imager (OLI)	30*30
	October	Landsat 8	Operational Land Imager (OLI)	30*30
2018	May	Landsat 8	Operational Land Imager (OLI)	30*30
	September	Landsat 8	Operational Land Imager (OLI)	30*30
	October	Landsat 8	Operational Land Imager (OLI)	30*30

(e) Agricultural Data Collection

The Agro-ecological Region of the study area has been identified from secondary sources such as "Agro-ecological Regions of Bangladesh" prepared by FAO, United Nations (1988) and Fertilizer Recommendation Guide, BARC (2012). Data on land use, land type have been collected using SOLARIS tool. This tool was developed by CEGIS for SRDI (Soil Resources Development Institute). This is National Water Resources Database (NWRD) of Water Resources Planning Organization (WARPO) archived in CEGIS. Secondary data of cropping patterns, crop variety, crop yield and crop damage under agricultural analysis have been collected from the concerned Upazila Agricultural Offices of Department of Agriculture Extension (DAE), Bangladesh Bureau of Statistics (BBS) and Yearbook of Agricultural Statistics.

3.5.3 Data Processing and Data Analysis

The collected secondary data were in a complex format which was not suitable for analysis. The dataset has been checked for quality and consistency and processed using Microsoft Office Excel application. Also, data has been brought into a common format for analysis.

(a) Trend Analysis

Trend is the pattern of the values of a climatic variable with time. The time series data has been analyzed for trend. Trend analysis has been done using linear regression in a spreadsheet program and presented with different graphs with a suitable format. From the slopes of the linear trend line, the regional variation of the trend of different climatic parameters can be observed. A negative slope indicates a decreasing trend, and a positive slope indicates an increasing trend in rainfall magnitude where the higher numerical value indicates a greater change in trend and vice versa.

Linear regression is used to test for linear temporal trends. Ordinary least squares regression is used to fit the "best" straight line. A positive slope indicates an increasing trend and a negative slope a decreasing trend. The linear correlation coefficient r, which is the correlation coefficient between the observed and calculated concentrations, provides information about the direction and strength of the linear trend. A positive value of r indicates an increasing linear trend and a negative value indicates a decreasing linear trend. The trend is "strong" if the absolute value of r (which ranges from -1 to 1) is near to one (ITRC, 2013).

A regression line models concentrations for a certain period of time (based on the availability of measured data). This method does not consider the uncertainty of the regression fit that arises from the variability of the data around the calculated regression line. So, if it is assumed that the regression line is valid for future monitoring, this approach would underestimate the actual time required to achieve a criterion. More reliable estimates can be achieved when the dataset values fall nearly on the calculated regression line than values that scatter much about the regression line.

(b) Application of Probability Distribution Functions

Rainfall data, water level data and discharge data have been used for probability distribution after performing the trend analysis. Gumbel's Distribution, Log-Pearson type III Distribution, Log-normal Distribution and Normal Distribution have been performed using the formulas described as equations 3.1 - 3.12 in Microsoft Excel spreadsheets. Return period has been estimated using the four probability distribution functions for the rainfall data, water level data and discharge data parameters.

(c) Landsat Image Analysis

Band Reflectance Calculation:

Radiance calculation: Radiance is calculated from the Landsat imagery using the following equation:

$L\lambda$ = (Gain) × (Digital Number) + (Bias)

Where, Gain and Bias values are obtained from the MTL file provided with the data set.

Reflectance calculation: Once the radiation is calculated by the above equation then reflectance is calculated by the following equation:

$$\text{Reflectance, } = \frac{\pi L_\lambda d^2}{(Esun * \sin\theta_E)} \qquad (3.13)$$

Where,

E_{sun} = Mean exoatmospheric solar irradiance;

θE= Sun Elevation;

$\theta°= (\theta * \pi)/180$ rad;

d = Earth sun distance provided in the MTL file. (Chander, 2009).

Table 3.13: Values of Effective Exo-Atmo spheric Solar Irradiance (Esun) for Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+)

Band	Landsat 7 ETM+	Landsat 5 TM	Landsat 4 TM	Landsat 8 OLI
1	1970	1958	1958	-
2	1842	1827	1826	2067
3	1547	1551	1554	1893
4	1044	1036	1033	1603
5	225.7	214.9	214.7	972.6
6	-	-	-	245.0
7	82.06	80.65	80.70	79.72
8	1369	-	-	-
9	-	-	-	399.7

(Source: https://landsat.usgs.gov, 2019)

Table 3.14: Values of Effective Exo-Atmospheric Solar Irradiance (Esun) for Landsat Scanner (MSS)

Band	L5 MSS	L4 MSS	L3 MSS	L2 MSS	L1 MSS
Green	1768	1766	1775	1795	1791
Red	1528	1525	1508	1507	1537
Near Infrared-1	1227	1235	1263	1263	1274
Near Infrared-2	828.1	839.5	868.9	864.4	846.3

(Source: https://landsat.usgs.gov, 2019)

Calculation of Normalized Difference Water Index (NDWI):

Normalized Difference Water Index (NDWI) may refer to one of at least two remote sensing-derived indexes related to liquid water: One is used to monitor changes in water content of leaves, using Near-Infrared (NIR) and short-wave infrared (SWIR) wavelengths, proposed by Gao in 1996. Another index is used to monitor changes related to water content in water bodies, using Green and Near-Infrared (NIR) wavelengths, defined by Feeters in 1996.

$$\text{NDWI} = \frac{\rho\text{Green} - \rho\text{NIR}}{\rho\text{Green} + \rho\text{NIR}} \tag{3.14}$$

Normalized Difference Water Index (NDWI) is calculated using the Landsat satellites images where the water feature has positive value. The images are consisting of different spectral bands with specific spatial resolution. The spectral band information for different Landsat satellites has been given Table 3.15.

Table 3.15: The band designations for the Landsat satellite

Satellite name	Bands	Wavelength (micrometers)	Resolution (meters)
Landsat 1-3 Multispectral Scanner System (MSS)	Band 4- Green	0.5-0.6	60
	Band 5-Red	0.6-0.7	60
	Band 6-Near Infrared	0.7-0.8	60
	Band 7-Near Infrared	0.8-1.1	60
Landsat 4-5 Multispectral Scanner System (MSS)	Band 1- Green	0.5-0.6	60
	Band 2-Red	0.6-0.7	60
	Band 3-Near Infrared	0.7-0.8	60
	Band 4-Near Infrared	0.8-1.1	60
Landsat 4-5 Thematic Mapper (TM)	Band 1-Blue	0.45-0.52	30
	Band 2- Green	0.52-0.60	30
	Band 3- Red	0.63-0.69	30
	Band 4- Near Infrared (NIR)	0.76-0.90	30
	Band 5-Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6- Thermal	10.40-12..50	120*(30)
	Band 7- Shortwave Infrared (SWIR) 2	2.08-2.35	30
Landsat 7 Enhanced Thematic Mapper Plus (ETM+)	Band 1-Blue	0.45-0.52	30
	Band 2- Green	0.52-0.60	30
	Band 3- Red	0.63-0.69	30
	Band 4- Near Infrared (NIR)	0.76-0.90	30
	Band 5-Shortwave Infrared (SWIR) 1	1.55-1.75	30
	Band 6- Thermal	10.40-12..50	120*(30)
	Band 7- Shortwave Infrared (SWIR) 2	2.08-2.35	30
	Band 8 Panchromatic	0.52-0.90	15
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)	Band 1-Coastal aerosol	0.43-0.45	30
	Band 2- Blue	0.45-0.51	30
	Band 3- Green	0.53-0.59	30
	Band 4- Red	0.64-0.67	30
	Band 5-Near Infrared (NIR)	0.85-0.88	30
	Band 6- SWIR 1	1.57-1.65	30
	Band 7- SWIR 2	2.11-2.29	30
	Band 8-Panchromatic	0.50-0.68	15
	Band 9- Cirrus	1.36-1.38	30
	Band 10- Thermal Infrared (TIRS) 1	10.60-11.19	100*(30)
	Band 11- Thermal Infrared (TIRS) 2	11.50-12.51	100*(30)

(Source: https://landsat.usgs.gov, 2019)

The analysis of the Landsat images has been done according to the following steps:

1) Band - Green and Band - NIR images are loaded in ArcGIS.
2) The images reclassified with unique values and the zero value is classified as No Data value.
3) The radiance was then calculated using Raster Calculator field.
4) Then the reflectance has been calculated in Raster Calculator field using equation (3.13).
5) The reflectance has been corrected for negative value.
6) The Normalized Difference Water Index (NDWI) has been calculated then using equation (3.14).
7) Shafique Haor scheme and Sonamoral Haor scheme were then clipped by Raster Clip.
8) Then raster file has been reclassified and the water feature has been presented by the positive value.
9) The area has been calculated by the classified pixel number multiplying by the spatial resolution.

(d) Agricultural Analysis

The average yield value (ton/ha) of different crops in the Shafique Haor scheme and Sonamoral Haor scheme area has been calculated based on the information of cropping patterns and cropping intensity collected from Upazila Agriculture Extension office and Yearbook of Agricultural Statistics. Then total crop production has been estimated.

Crop damage due to natural calamities and climate change induced by factor (Flash flood, drainage congestion, water logging, and scarcity of irrigation water as well as drought etc.) data has been collected from the officials of the Department of Agricultural Extension (DAE) office. After calculation the crop production then crop damage (production loss) has also been estimated.

(e) Assessment of Schemes

Assessment of selected schemes has been carried out based on flash flood frequency and Boro crop production. Comparison of pre-scheme and post-scheme period of the Shafique Haor scheme and Sonamoral Haor scheme has been also carried out.

3.6 Summery

In this chapter, relevant equations are included to take care of the theoretical part and procedures are included in the methodology part. For the better understanding of this assessment study, both parts such as theory and methodology are important. Theory of frequency analysis, Landsat image analysis and agricultural analysis have been described. On the other hand, methodology part describes description of study area; data collection including rainfall data, water level data, discharge data, Landsat image data, agricultural data; hydrological analysis which includes trend analysis and frequency analysis. Landsat image data analysis which includes Normalized Difference Water Index (NDWI) calculation and agricultural analysis which includes crop production calculation and crop damage calculation.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

In this section, results of various hydrological analyses, Landsat satellite images analyses and agricultural analyses have been shown and discussed for the assessment of Shafique Haor scheme and Sonamoral Haor scheme. The result of hydrological analyses, especially trend analysis of hydrological data shows that rainfall, discharge and water level are increasing with the passing of time. Trend analysis for both annual and seasonal variation has been carried out. Correlation among the results of trend analysis of cumulative annual rainfall, maximum annual discharge and maximum annual water level has been also carried out. Representative rainfall hyetograph, discharge hydrograph and water level hydrograph have been also drawn. In this section, frequency analysis of rainfall, discharge and water level has been also carried out for the selected return period. Frequency analysis includes various methods such as Normal Distribution, Log-normal Distribution, Log-pearson type III and Gumble's Distribution for maximum rainfall, discharge and water level. Normalized Difference Water Index (NDWI), one of the satellite-derived indices, has been calculated for the detection of change of surface water in Shafique Haor scheme and Sonamoral Haor scheme. The water areas vary in year to year. The result of agricultural analyses also indicates that Boro crop production has been increased significantly. The study has been conducted according to the procedures explained in the theory and methodology section.

4.2 Trend Analysis

The long-term climatic and hydrological change related to changes in rainfall patterns, discharge and water level is most likely to increase the frequency of flash floods in northeastern region. Trend analysis of rainfall, discharge and water level for Shafique Haor scheme and Sonamoral Haor scheme has been conducted to inspect the change of these variables.

4.2.1 Trend Analysis of Rainfall

The time series of rainfall data has been collected from the NWRD-CEGIS archive and Bangladesh Meteorological Department (BMD). Sylhet (ID 10705) BMD station is the nearest rainfall station from the Shafique Haor scheme and Sonamoral Haor scheme for the collection of available rainfall data of 1956-2018. Figure 4.1 and Figure 4.2 shows the location of rainfall BMD station for Shafique Haor scheme and Sonamoral Haor scheme accordingly.

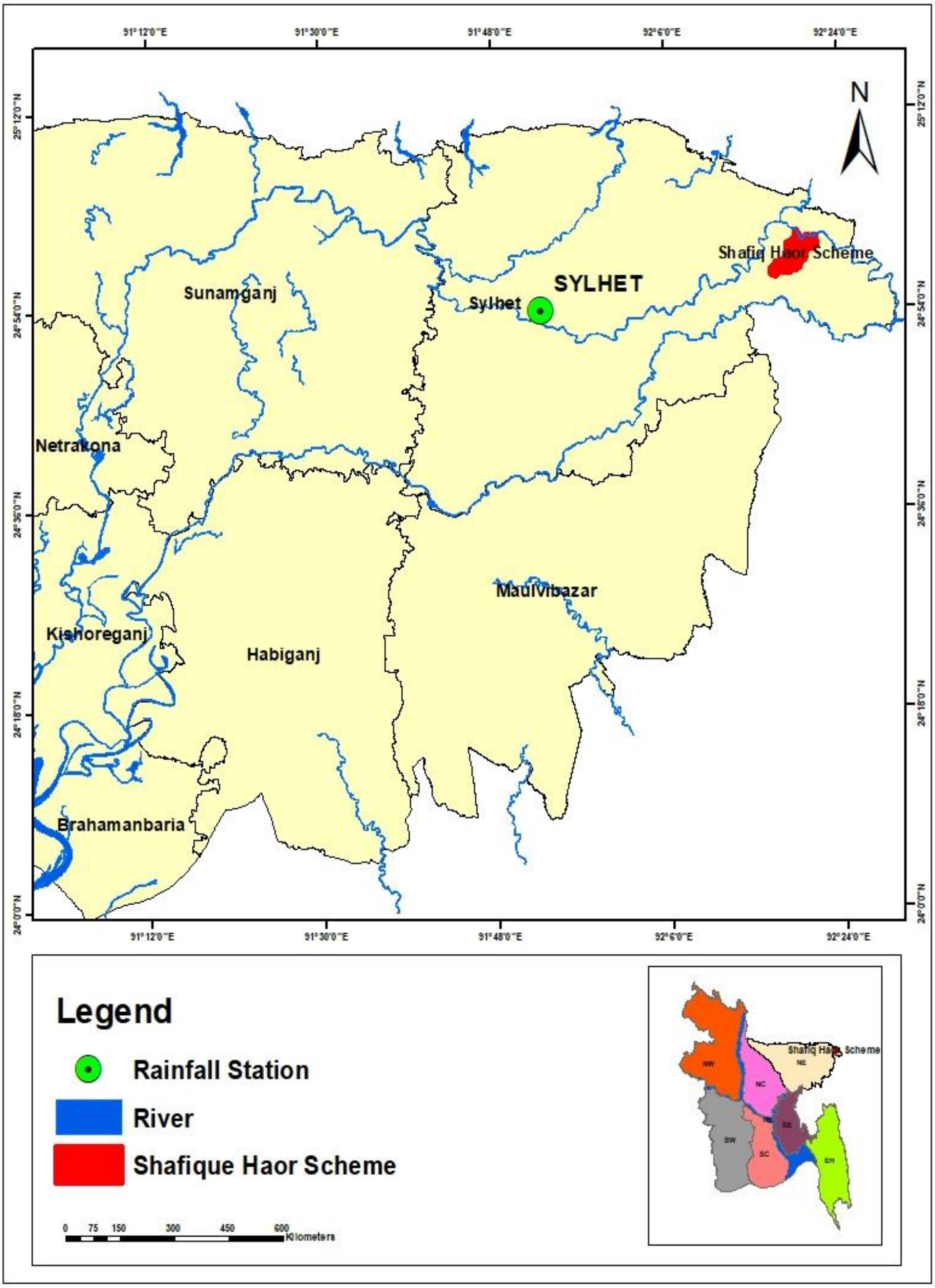

Figure 4.1: Location of Sylhet (ID 10705) BMD rainfall station from Shafique Haor scheme

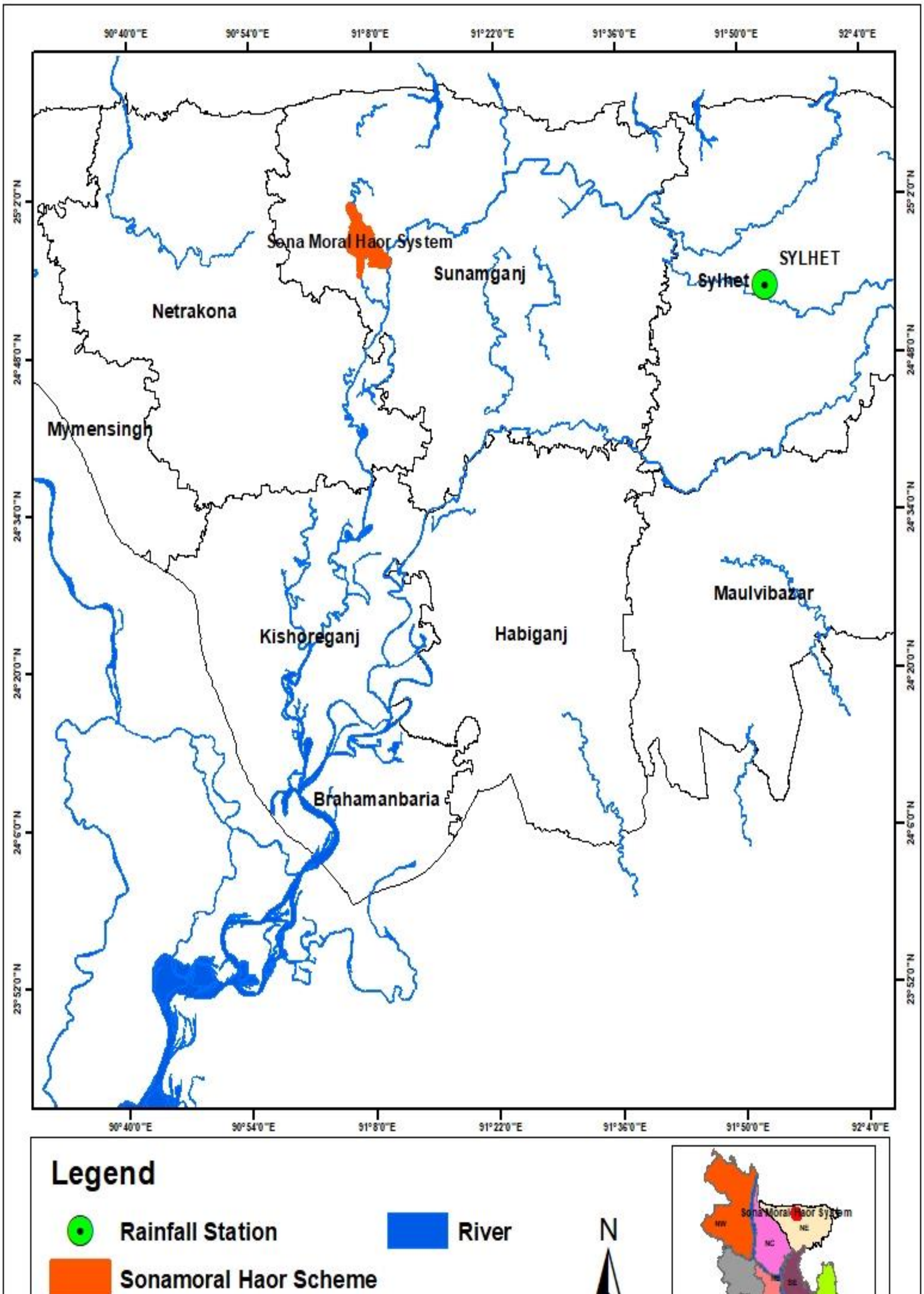

Figure 4.2: Location of Sylhet (ID 10705) BMD rainfall station from Sonamoral Haor scheme

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Cumulative annual rainfall data of Shafique Haor scheme has been collected from Sylhet (ID 10705) BMD rainfall station. Available rainfall data from 1956 to 1996 and 2007-2018 has been collected to conduct the trend analysis for pre-scheme and post-scheme scenario accordingly. Trend analysis of rainfall during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out for the both scenarios. The figures have been presented on the following pages.

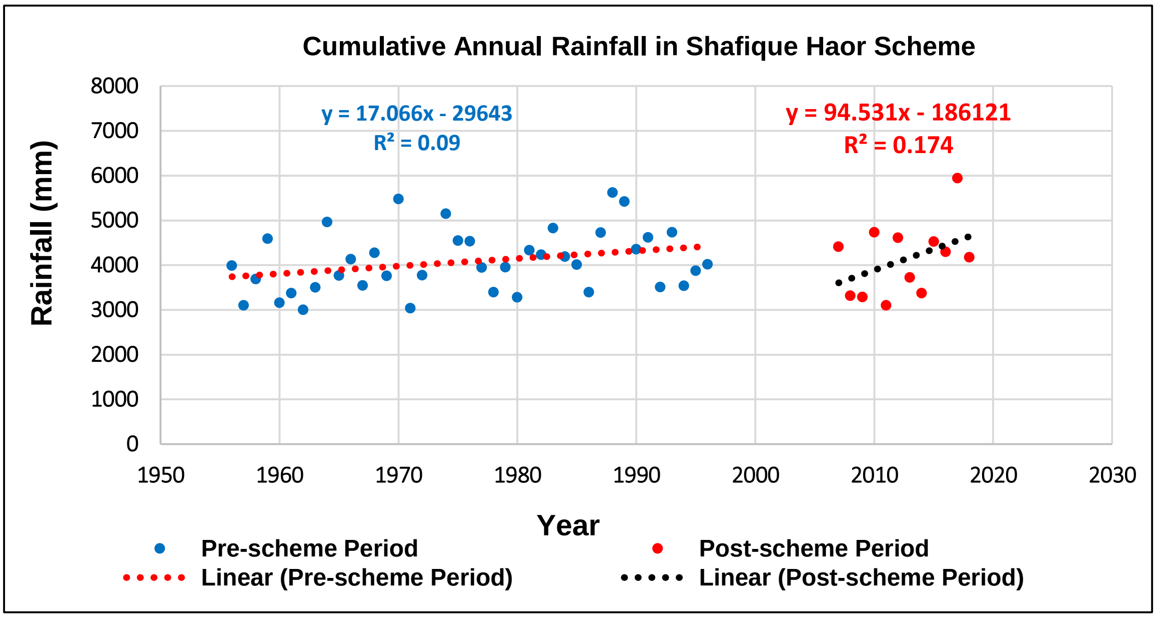

Figure 4.3: Cumulative annual rainfall during pre-scheme period (1956-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

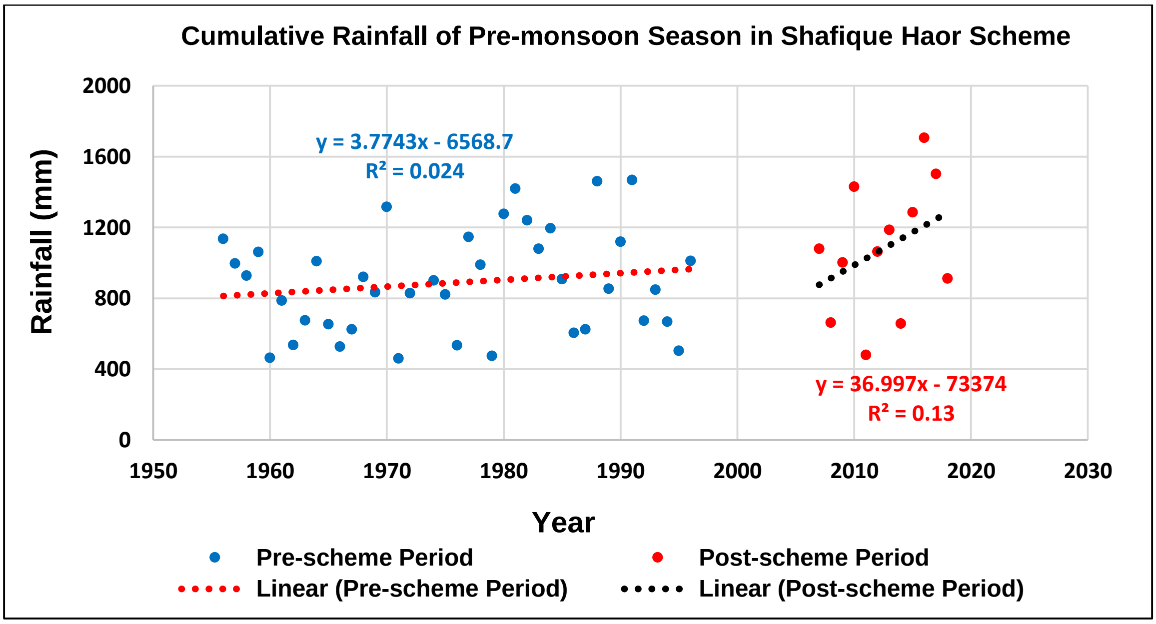

Figure 4.4: Cumulative rainfall of pre-monsoon season during pre-scheme period (1956-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

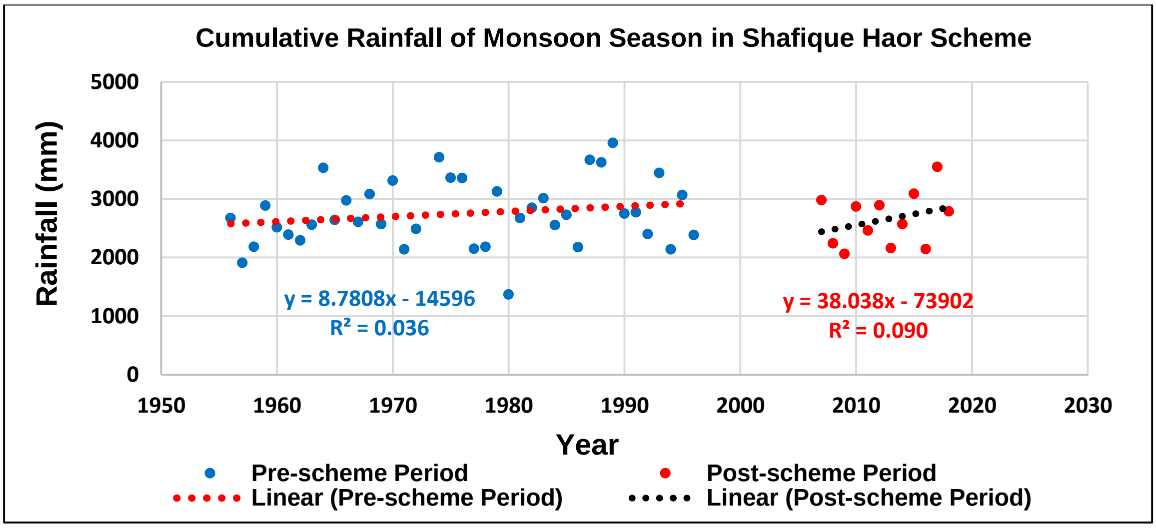

Figure 4.5: Cumulative rainfall of monsoon season during pre-scheme period (1956-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

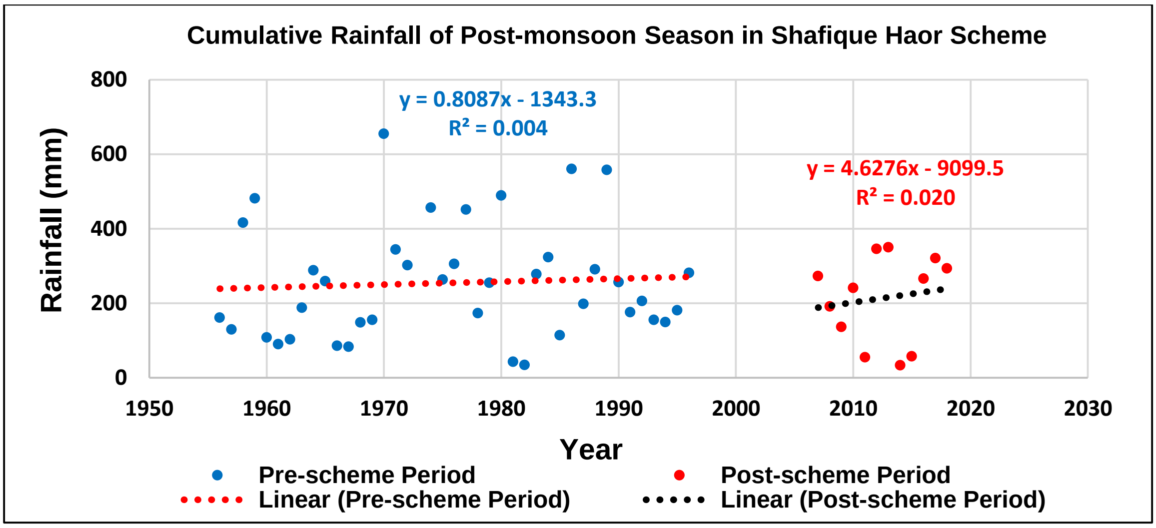

Figure 4.6: Cumulative rainfall of post-monsoon season during pre-scheme period (1956-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

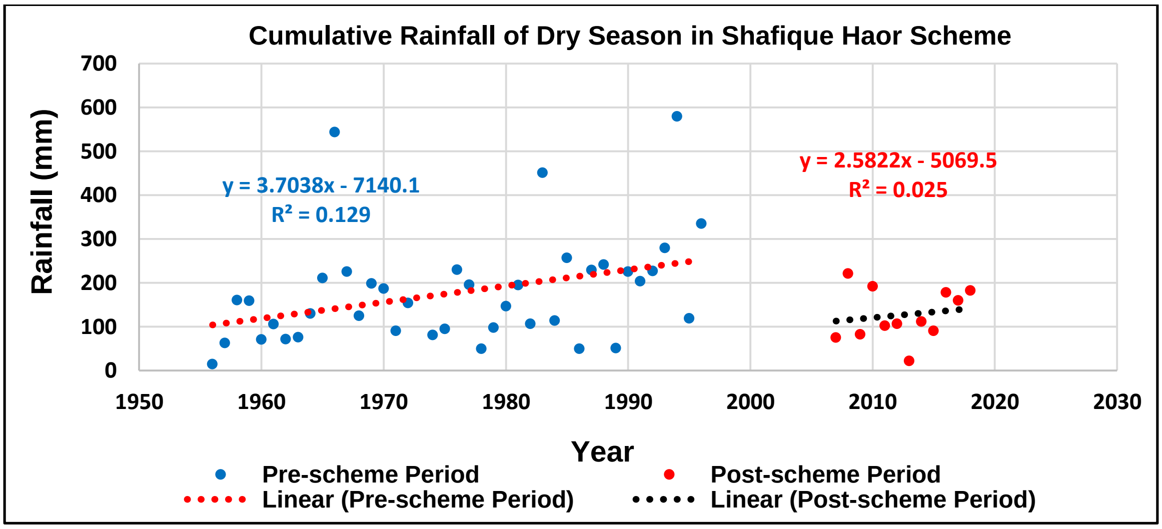

Figure 4.7: Cumulative rainfall of dry season during pre-scheme period (1956-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

From the trend analysis of cumulative annual rainfall at Sylhet (ID 10705) BMD station, it is evident that annual rainfall is gradually increasing with time. The R^2 value is 0.09 (Figure 4.3) for 1956-1996 which means poorly correlated with time. Cumulative annual rainfall for 2007-2018 is also gradually increasing with time and the R^2 value is 0.174 (Figure 4.3). It means moderate relationship between cumulative annual rainfall and time.

For pre-monsoon season, it is evident that cumulative rainfall is gradually increasing with time and it's R^2 value is 0.024 (Figure 4.4) for 1956-1996. It means cumulative rainfall is poorly correlated with time. For 2007-2018, it is evident that cumulative rainfall is gradually increasing with time as R^2 value is 0.13 (Figure 4.4). It means moderate relationship between cumulative rainfall of pre-monsoon season and time.

For monsoon season, it is evident that only for 1956-1996, cumulative rainfall is neither decreasing nor increasing with time. Cumulative rainfall of monsoon season is poorly correlated with time as $R^2 = 0.036$ (Figure 4.5). The R^2 value for 2007-2018 is 0.090 (Figure 4.5). It means cumulative rainfall of monsoon season is gradually increasing and poorly correlated with time for 2007-2018.

For post-monsoon season, it is evident that only for 1956-1996, cumulative rainfall is neither decreasing nor increasing with time. Cumulative rainfall of post-monsoon season is poorly correlated with time as $R^2 = 0.004$ (Figure 4.6). Cumulative rainfall of post-monsoon season for 2007-2018 is poorly correlated with time as $R^2 = 0.020$ (Figure 4.6) and is gradually increasing with time.

For dry season, it is evident that only for 1956-1996, cumulative rainfall is increasing with time and R^2 value is 0.129 (Figure 4.7). It means moderate relationship between cumulative rainfall of dry season and time. In case of dry season for 2007-2018, cumulative rainfall is gradually increasing with time and R^2 value is 0.025 (Figure 4.7). It means cumulative rainfall of dry season is poorly correlated with time.

Hyetograph of Shafique Haor Scheme:

In addition, hyetograph of annual maximum rainfall has been drawn for Sylhet (ID 10705) BMD station. The hyetograph shows that the rainfall changes over time. From the Figure 4.8, it has been observed that peak heights of the hyetograph are during the month of May to September for the period of 1956-1996. The hyetograph for pre-scheme period of Shafique Haor scheme has given below:

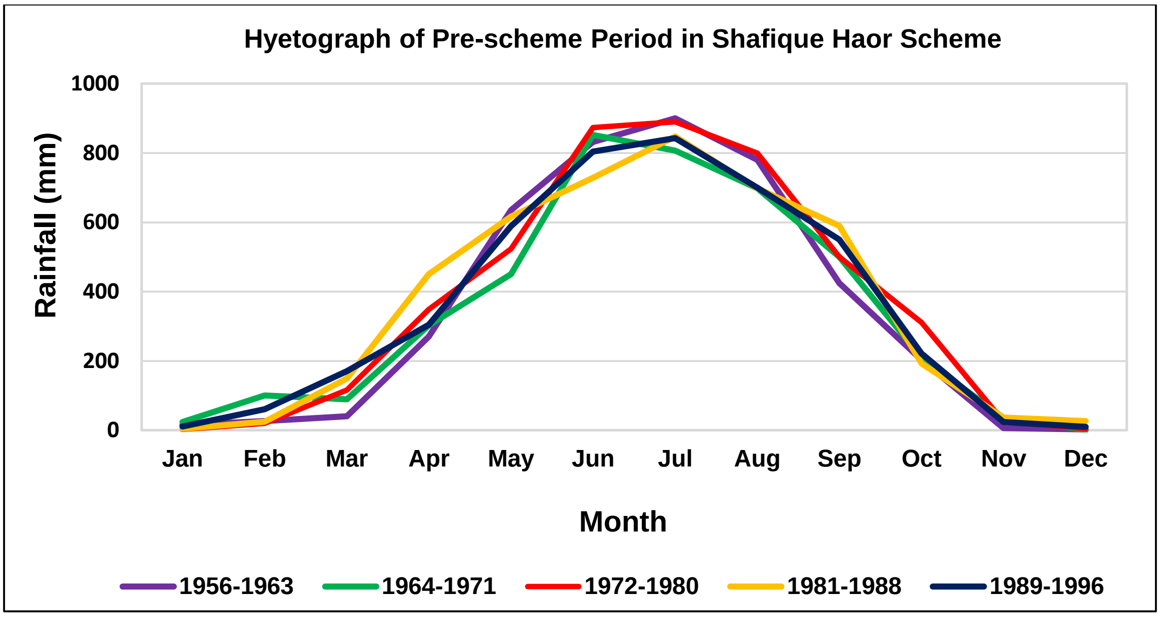

Figure 4.8: Hyetograph of annual maximum rainfall during pre-scheme period in Shafique Haor scheme

Hyetograph of annual maximum rainfall has been also drawn for Sylhet (ID 10705) BMD station. The hyetograph shows that the rainfall changes over time. From the Figure 4.9, it has been observed that peak heights of the hyetograph are during the month of May to September for the period of 2007-2018. The hyetograph for post-scheme period of Shafique Haor scheme has given below:

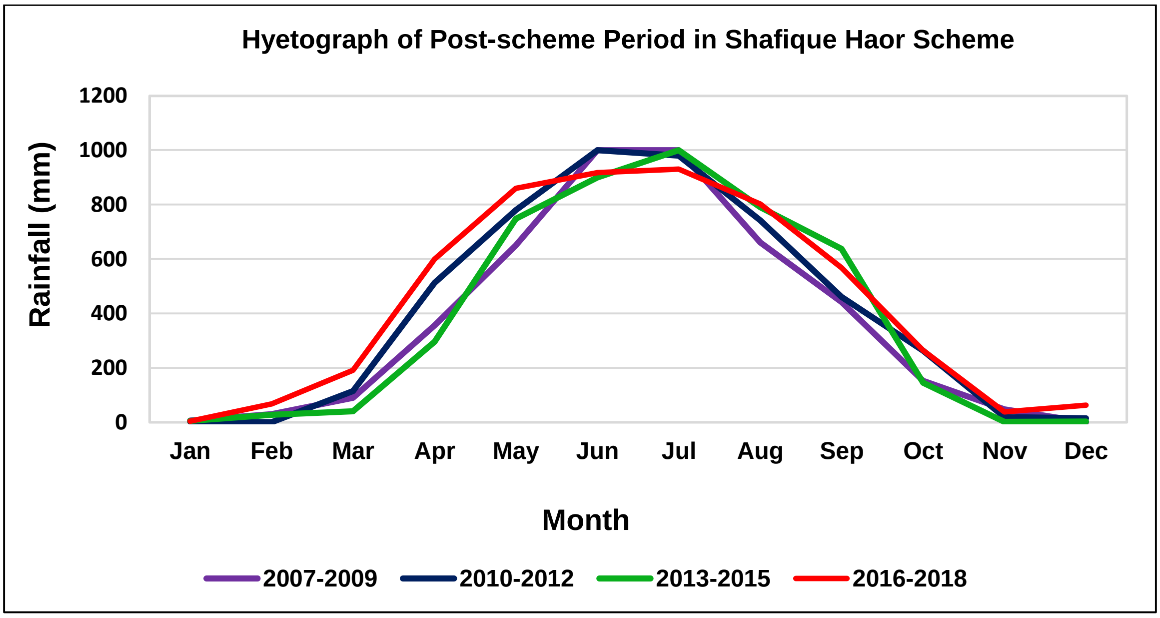

Figure 4.9: Hyetograph of annual maximum rainfall during post-scheme period in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Cumulative annual rainfall data of Sonamoral Haor scheme has been collected from Sylhet (ID 10705) BMD rainfall station. Available rainfall data from1956-1984 and 1993-2018 has been collected to conduct the trend analysis for pre-scheme and post-scheme scenario accordingly. Trend analysis of rainfall during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out for the both scenarios. The figures have been presented on the following pages.

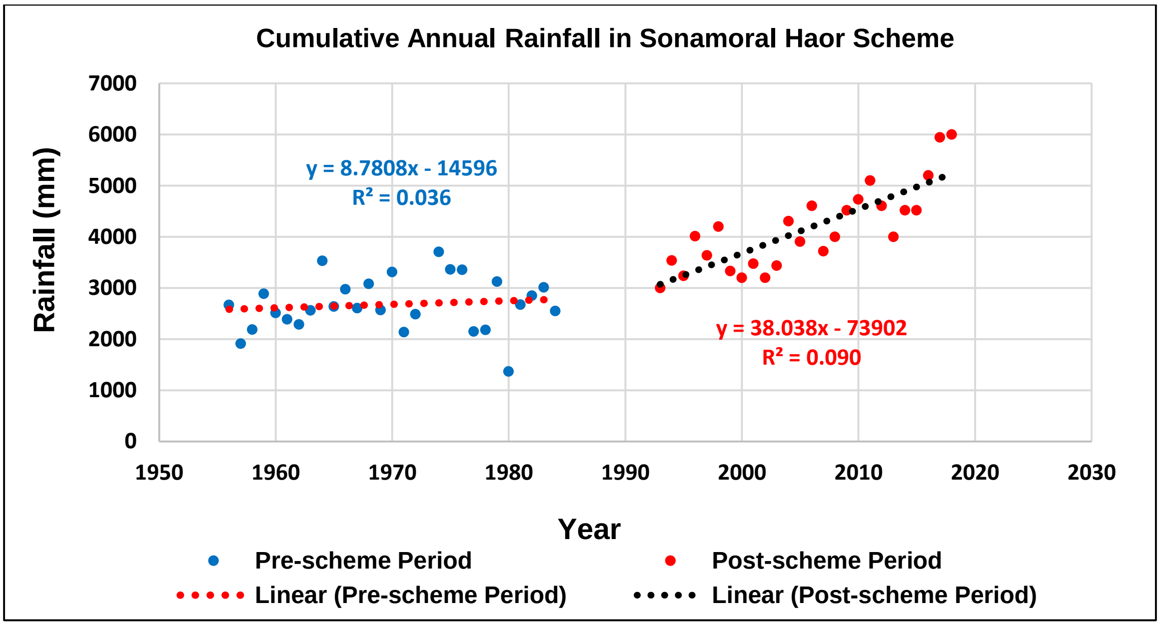

Figure 4.10: Cumulative annual rainfall during pre-scheme period (1956-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

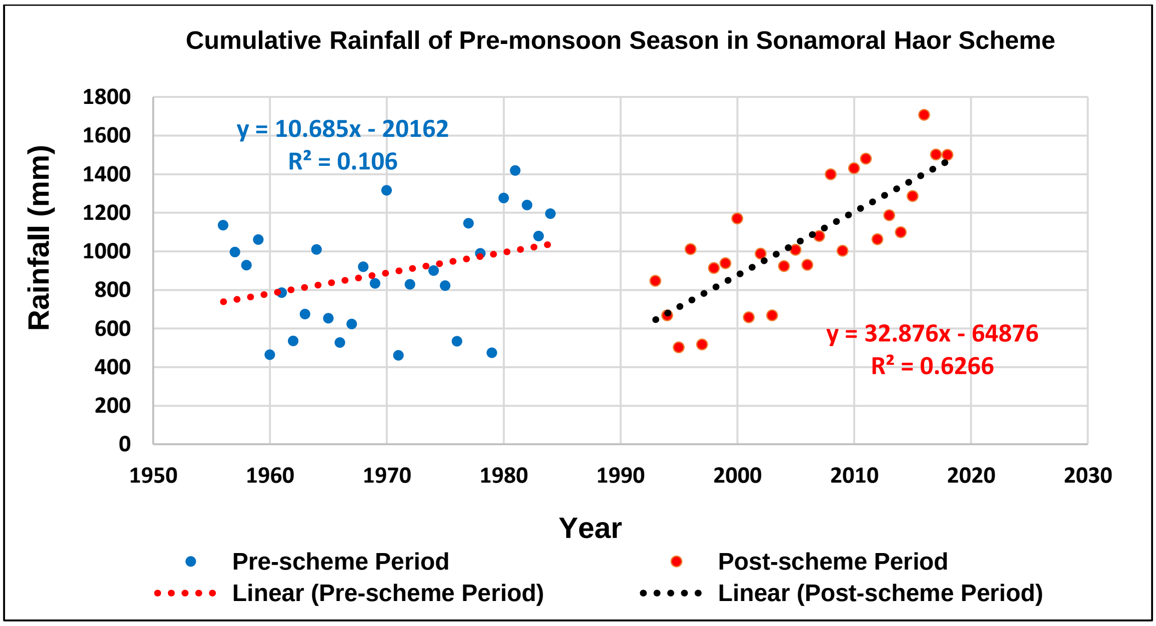

Figure 4.11: Cumulative rainfall of pre-monsoon season during pre-scheme period (1956-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

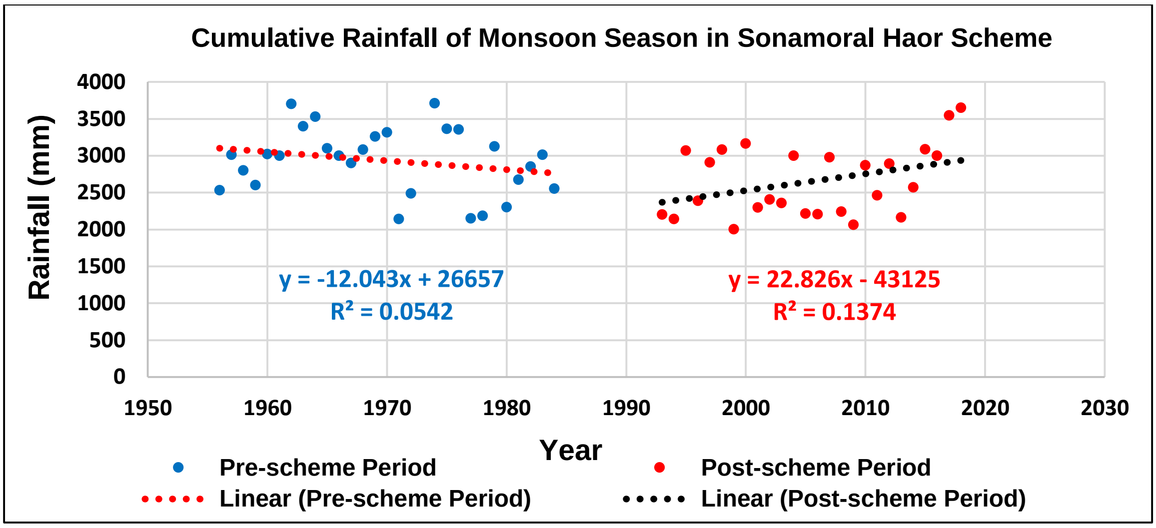

Figure 4.12: Cumulative rainfall of monsoon season during pre-scheme period (1956-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

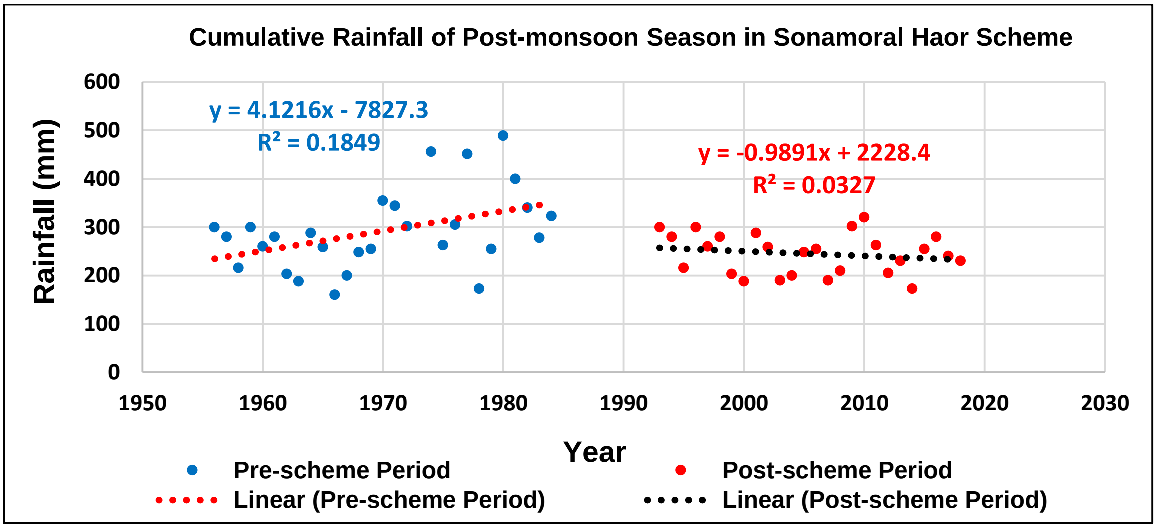

Figure 4.13: Cumulative rainfall of post-monsoon season during pre-scheme period (1956-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

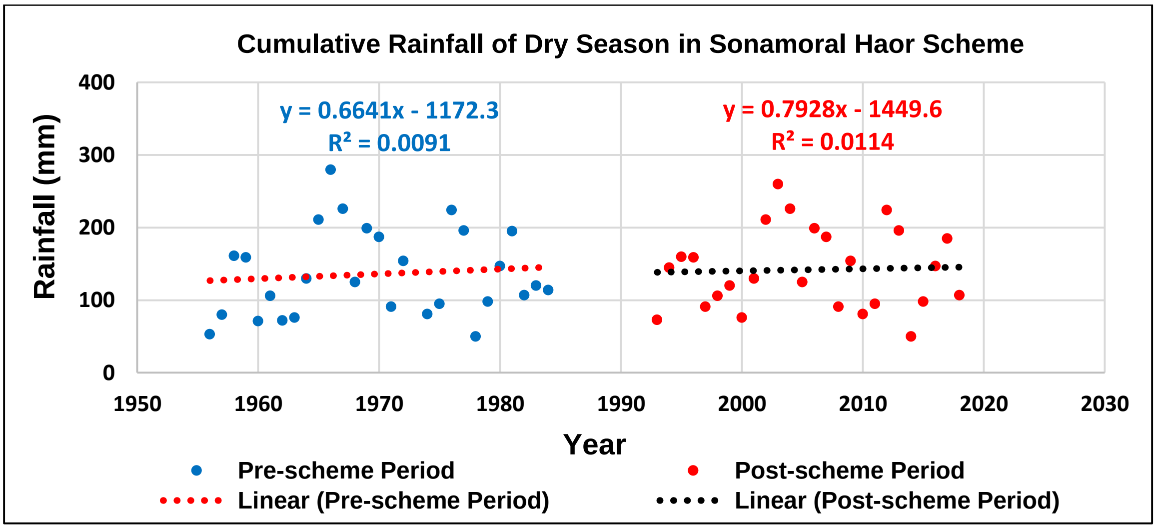

Figure 4.14: Cumulative rainfall of dry season during pre-scheme period (1956-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

From the trend analysis of cumulative annual rainfall at Sylhet (ID 10705) BMD station, it is evident that cumulative annual rainfall is gradually increasing with time and its R^2 value is 0.036 (Figure 4.10) for 1956-1984. It means cumulative annual rainfall is poorly correlated with time. Cumulative annual rainfall for 1993-2018 is increasing with time and it's R^2 value is 0.090 (Figure 4.10). It means poor relationship between cumulative annual rainfall and time.

For pre-monsoon season, it is evident that only for 1956-1984, cumulative rainfall is increasing with time and it's R^2 value is 0.106 (Figure 4.11). It means moderate relationship between cumulative rainfall of pre-monsoon season and time. For 1993-2018, it is evident that cumulative rainfall is increasing with time as R^2 value is 0.6266 (Figure 4.11). It means moderate relationship between cumulative rainfall of pre-monsoon season and time.

For monsoon season, it is evident that only for 1956-1984, cumulative rainfall is decreasing with time and it's R^2 value is 0.0542 (Figure 4.12). It means poorly relationship between cumulative rainfall of monsoon season and time. The R^2 value for 1993-2018 is 0.1374 (Figure 4.12). It means cumulative rainfall is gradually increasing and moderate relationship between cumulative rainfall of monsoon season and time.

For post-monsoon season, it is evident that only for 1956-1984, cumulative rainfall is increasing with time as it's R^2 value is 0.1849 (Figure 4.13). It means moderate relationship between cumulative rainfall of monsoon season and time. Cumulative rainfall of post-monsoon season for 1993-2018 is poorly correlated with time as $R^2 = 0.0327$ (Figure 4.13) and is decreasing with time.

For dry season, it is evident that only for 1956-1984, cumulative rainfall is neither decreasing nor increasing with time. Cumulative rainfall of dry season is poorly correlated with time as $R^2 = 0.0091$ (Figure 4.14). In case of dry season for 1993-2018, cumulative rainfall is neither increasing nor decreasing with time and R^2 value is 0.0114 (Figure 4.14). It means cumulative rainfall of dry season is poorly correlated with time.

Hyetograph of Sonamoral Haor Scheme:

In addition, hyetograph of annual maximum rainfall has been drawn for Sylhet (ID 10705) BMD station. The hyetograph shows that the rainfall changes over time. From the Figure 4.15, it has been observed that peak heights of the hyetograph are during the month of May to September for the period of 1956-1984. The hyetograph for pre-scheme period of Sonamoral Haor scheme has given below:

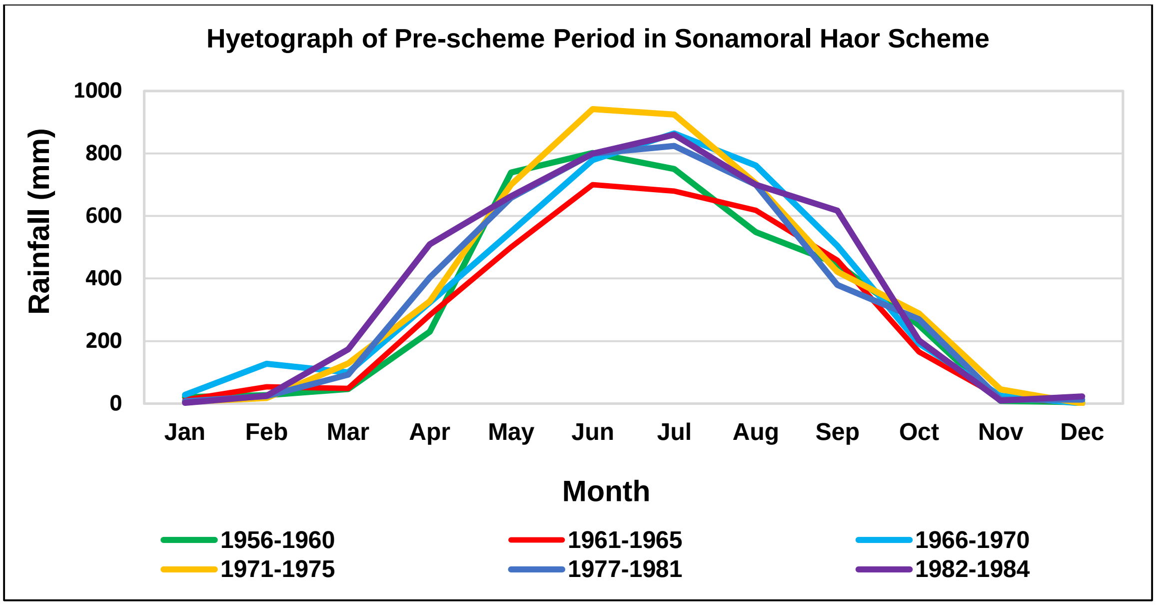

Figure 4.15: Hyetograph of annual maximum rainfall during pre-scheme period in Sonamoral Haor scheme

Hyetograph of annual maximum rainfall has been also drawn for Sylhet (ID 10705) BMD station for the year of 1993-2018. The hyetograph shows that the rainfall changes over time. From the Figure 4.16, it has been observed that peak heights of the hyetograph are during the month of May to September for the period of 1993-2018. The hyetograph for post-scheme period of Sonamoral Haor scheme has given below:

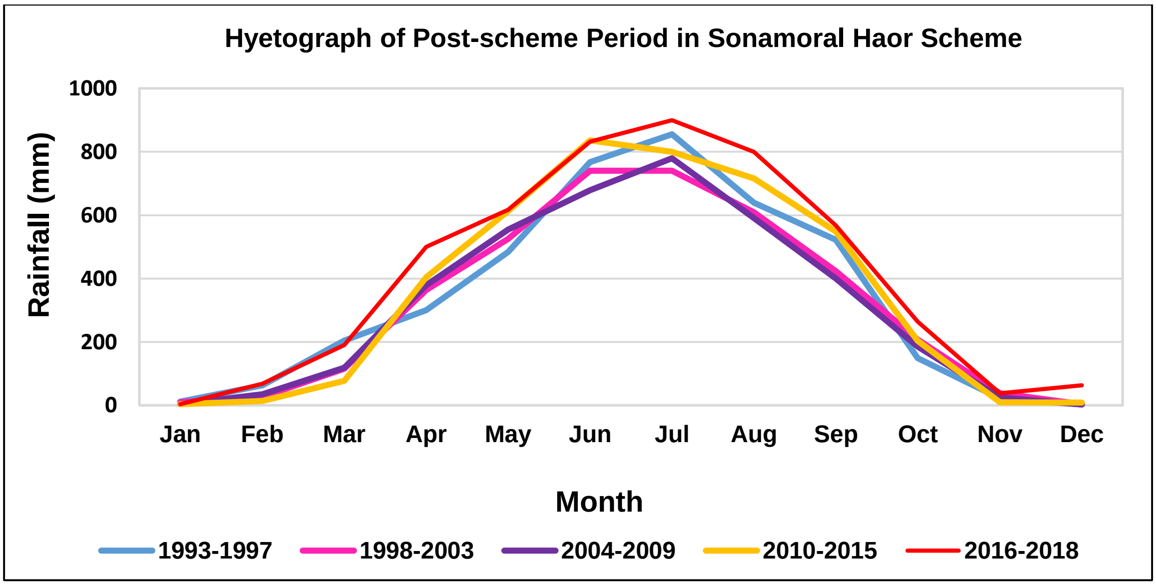

Figure 4.16: Hyetograph of annual maximum rainfall during post-scheme period in Sonamoral Haor scheme

4.2.2 Trend Analysis of Discharge

The time series of discharge data has been collected from Bangladesh Water Development Board (BWDB). Kanairghat (ID 266) BWDB station is the nearest discharge station from the Shafique Haor scheme for the collection of available discharge data of 1969-2018. Figure 4.17 shows the location of discharge BWDB station for Shafique Haor scheme.

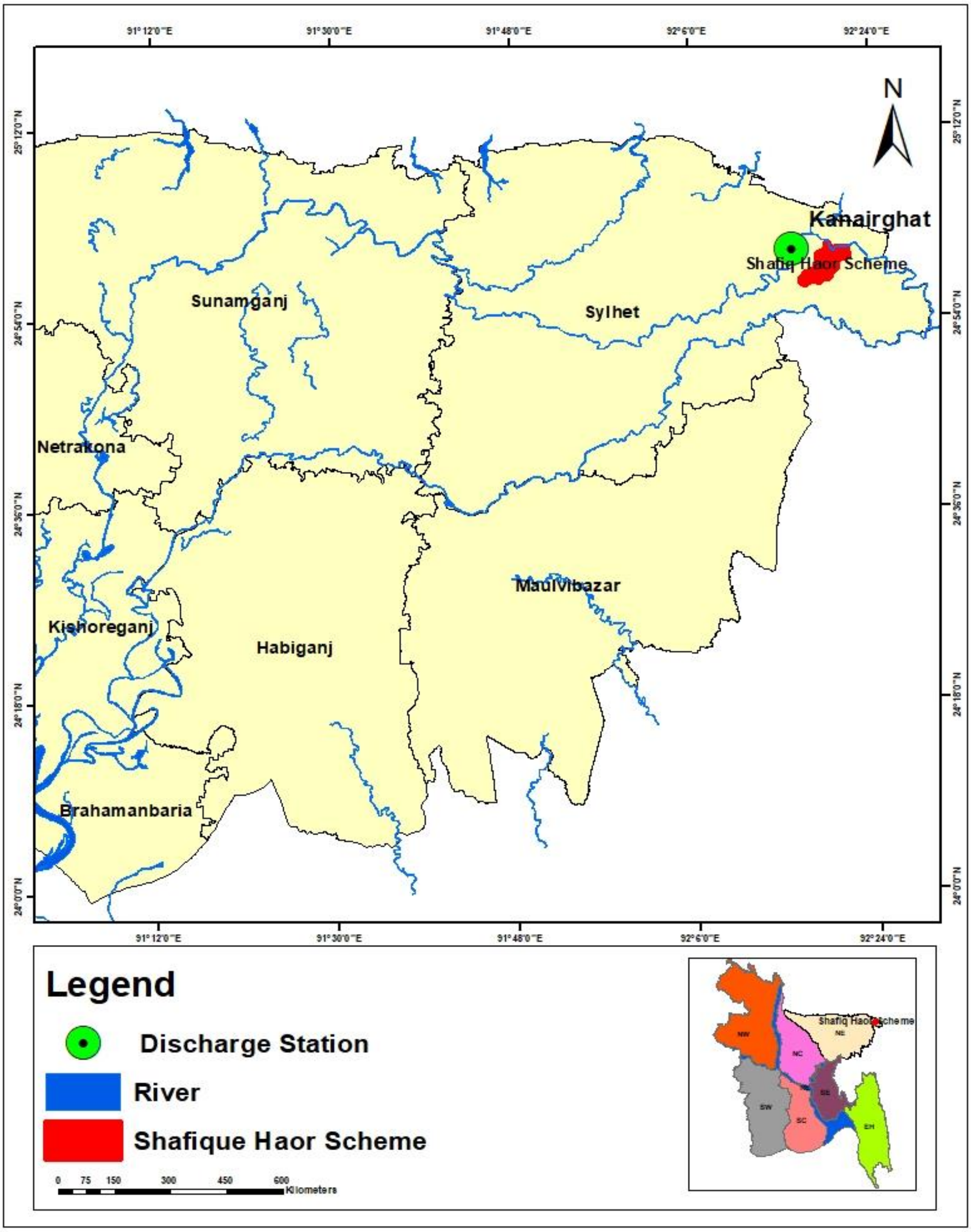

Figure 4.17: Location of Kanairghat (ID 266) BWDB discharge station from Shafique Haor scheme

Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB stations are the nearest discharge stations from the Sonamoral Haor scheme. These stations have been selected for collection of available discharge data of 1988-1992 and 1993-2018 accordingly. Figure 4.18 shows the location of discharge BWDB stations for Sonamoral Haor scheme.

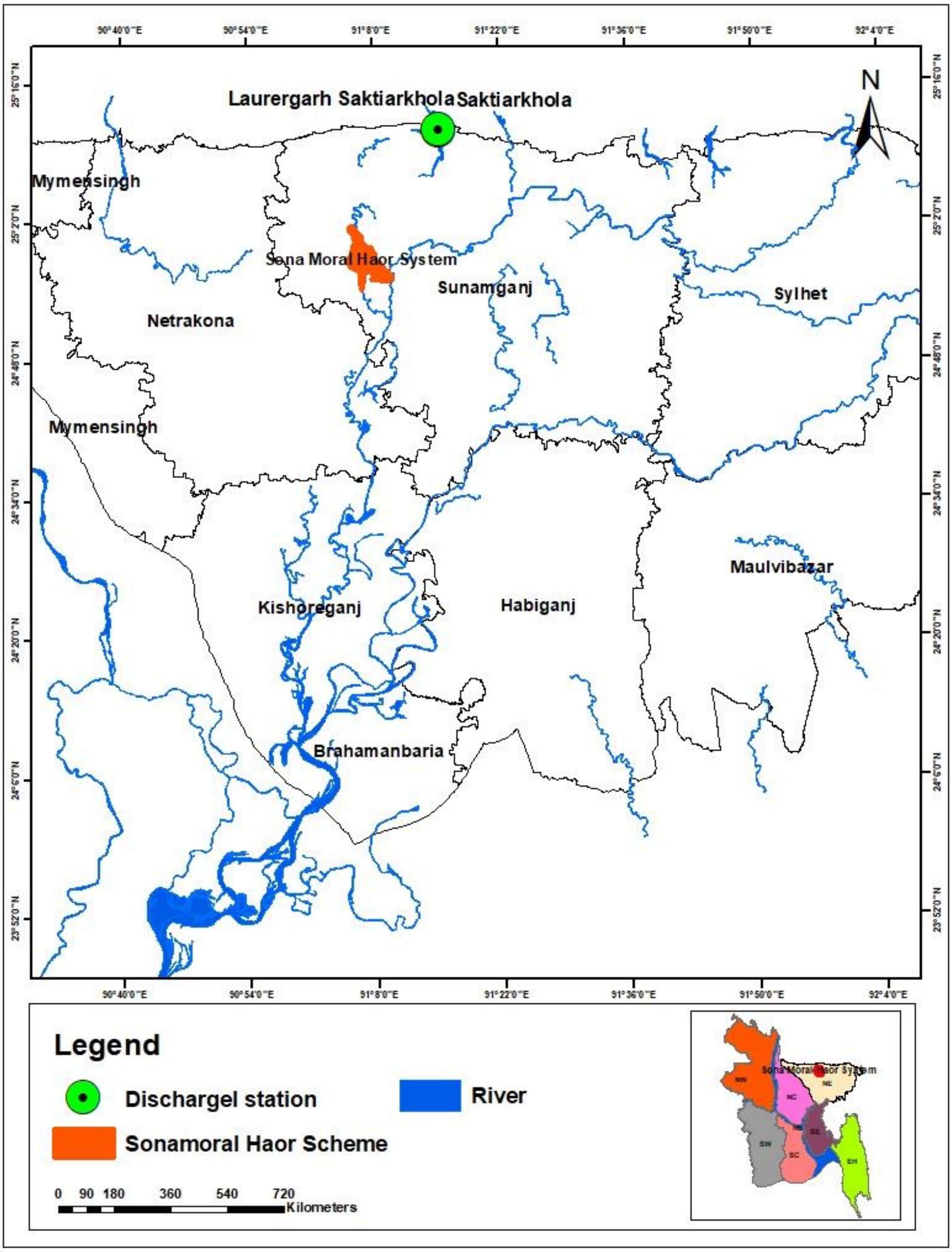

Figure 4.18: Location of Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB discharge stations from Sonamoral Haor scheme

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Average discharge data of Shafique Haor scheme has been collected from Kanairghat (ID 266) BWDB discharge station. Available discharge data from 1969-1996 and 2007-2018 has been collected to conduct the trend analysis for pre-scheme and post-scheme scenario accordingly. Trend analysis of discharge during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out for the both scenarios. The figures have been presented on the following pages.

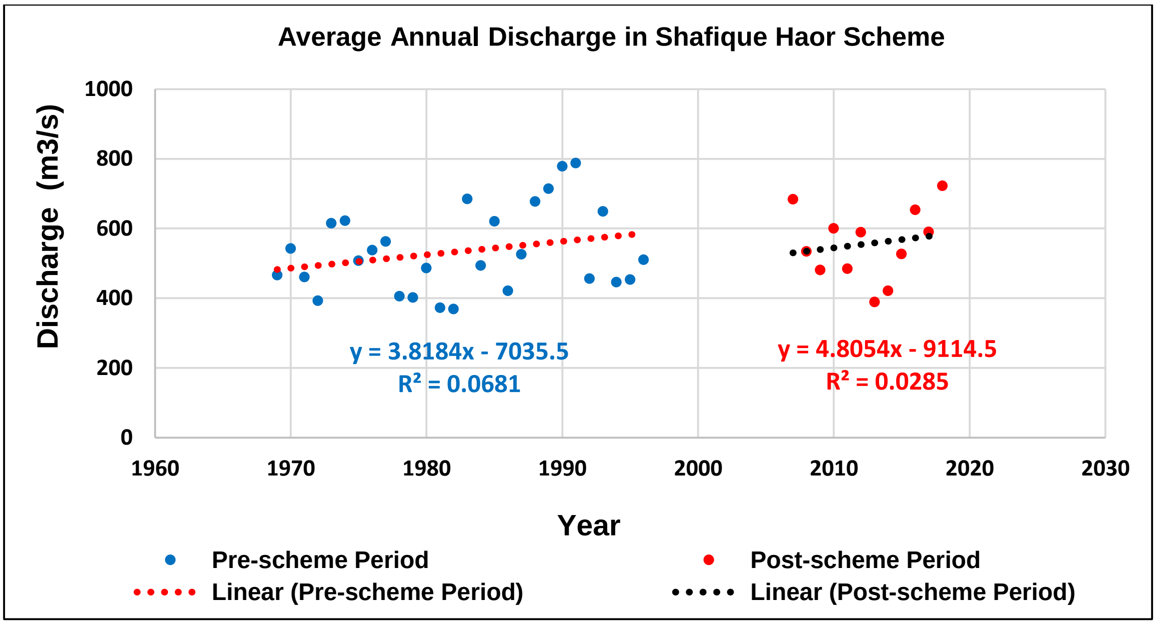

Figure 4.19: Average annual discharge during pre-scheme period (1969-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

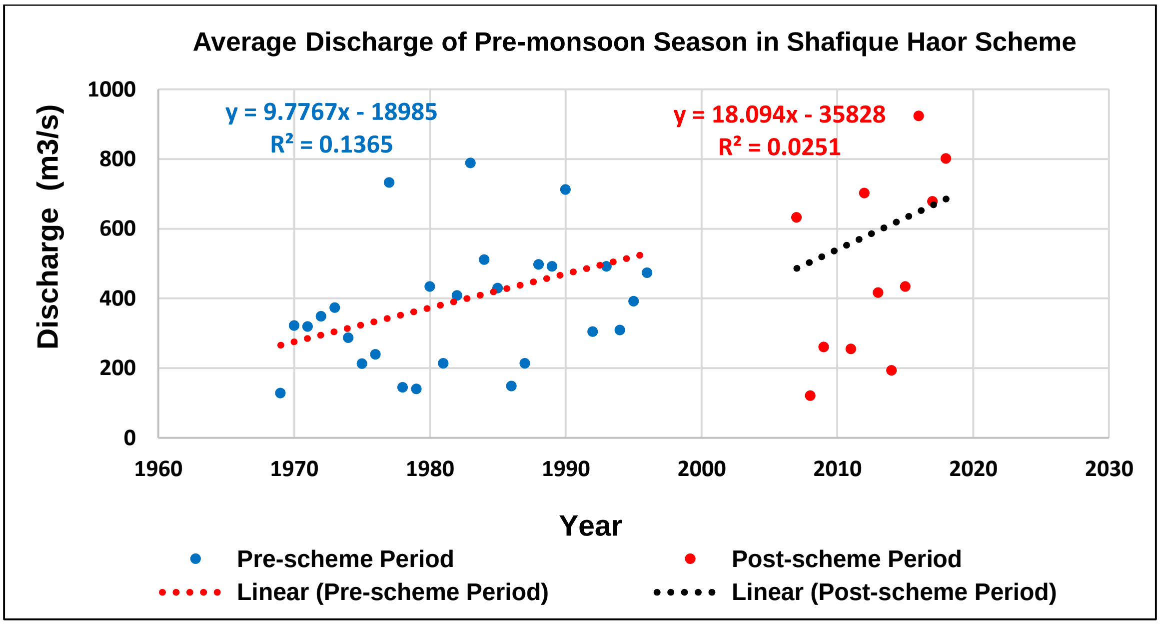

Figure 4.20: Average discharge of pre-monsoon season during pre-scheme period (1969-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

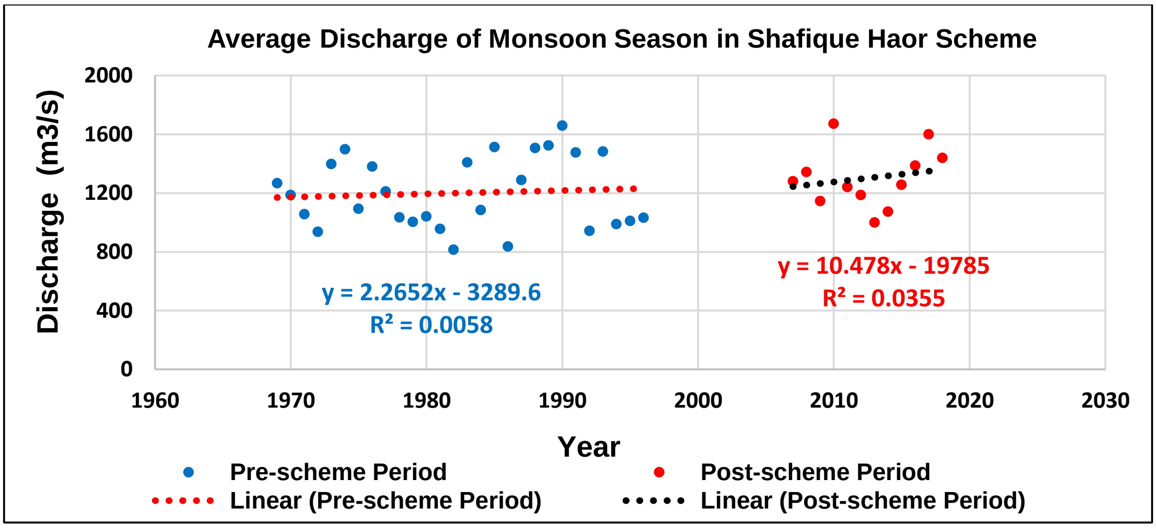

Figure 4.21: Average discharge of monsoon season during pre-scheme period (1969-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

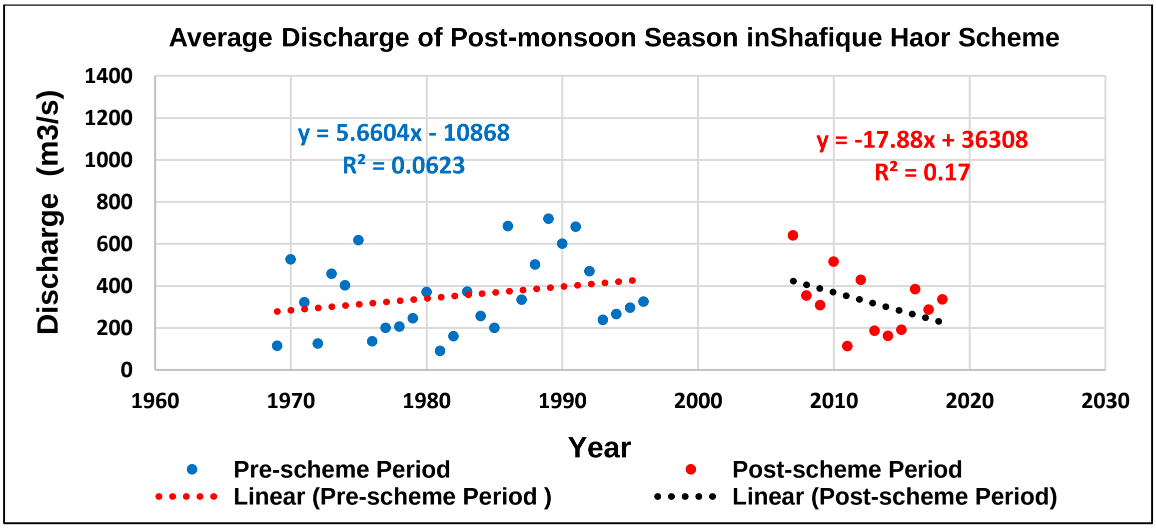

Figure 4.22: Average discharge of post-monsoon season during pre-scheme period (1969-1996) and post-scheme period (2007-2018) of Shafique Haor scheme

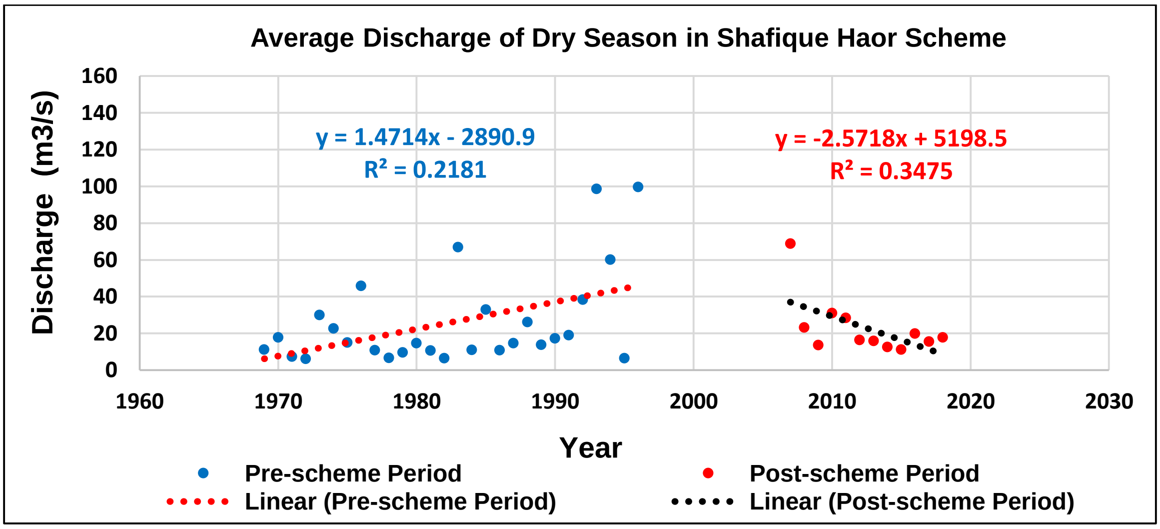

Figure 4.23: Average discharge of dry season during pre-scheme period (1969-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

From the annual trend analysis of average discharge at Kanairghat (ID 266) BWDB station, it is evident that annual discharge is increasing with time and it's R^2 value is 0.0681 (Figure 4.19) for 1969-1996. It means annual average discharge is poorly correlated with time. For 2007-2018, cumulative annual discharge is gradually increasing with time also and the R^2 value is 0.0285 (Figure 4.19). It means average discharge is poorly correlated with time.

For pre-monsoon season, it is evident that only for 1969-1996, average discharge is increasing with time and R^2 value is 0.1365 (Figure 4.20). It means moderate relationship between average discharge of pre-monsoon season and time. For 2007-2018, it is evident that average discharge of pre-monsoon is increasing with time as R^2 value is 0.0251 (Figure 4.20). It means average discharge of pre-monsoon season is poorly correlated with time.

For monsoon season, it is evident that only for 1969-1996, average discharge is neither decreasing nor increasing with time. Average discharge of monsoon season is poorly correlated with time as $R^2 = 0.0058$ (Figure 4.21). The R^2 value for 2007-2018 is 0.0355 (Figure 4.21). It means average discharge of monsoon season is gradually increasing and poorly correlated with time for 2007-2018.

For post-monsoon season, it is evident that only for 1969-1996, average discharge is gradually increasing with time and its R^2 value is 0.0623 (Figure 4.22). It means poorly correlated with time. The average discharge for 2007-2018 is decreasing with time. The R^2 value is 0.17 (Figure 4.22). It means moderate relationship between average discharge of post-monsoon season and time.

For dry season, it is evident that only for 1969-1996, average discharge is increasing with time and R^2 value is 0.2181 (Figure 4.23). It means moderate relationship between average discharge of dry season and time. In case of dry season for 2007-2018, average discharge is decreasing with time and R^2 value is 0.3475 (Figure 4.23). It means moderate relationship between average discharge of dry season and time.

Hydrograph of Shafique Haor Scheme:

In addition, hydrograph of annual maximum discharge has been drawn for Kanairghat (ID 266) BWDB station. The hydrograph shows that the discharge changes over time. From the Figure 4.24, it has been observed that peak heights of the hydrograph are during the month of June to September for the period of 1969-1996.

The hydrograph for pre-scheme period of Shafique Haor scheme has given below:

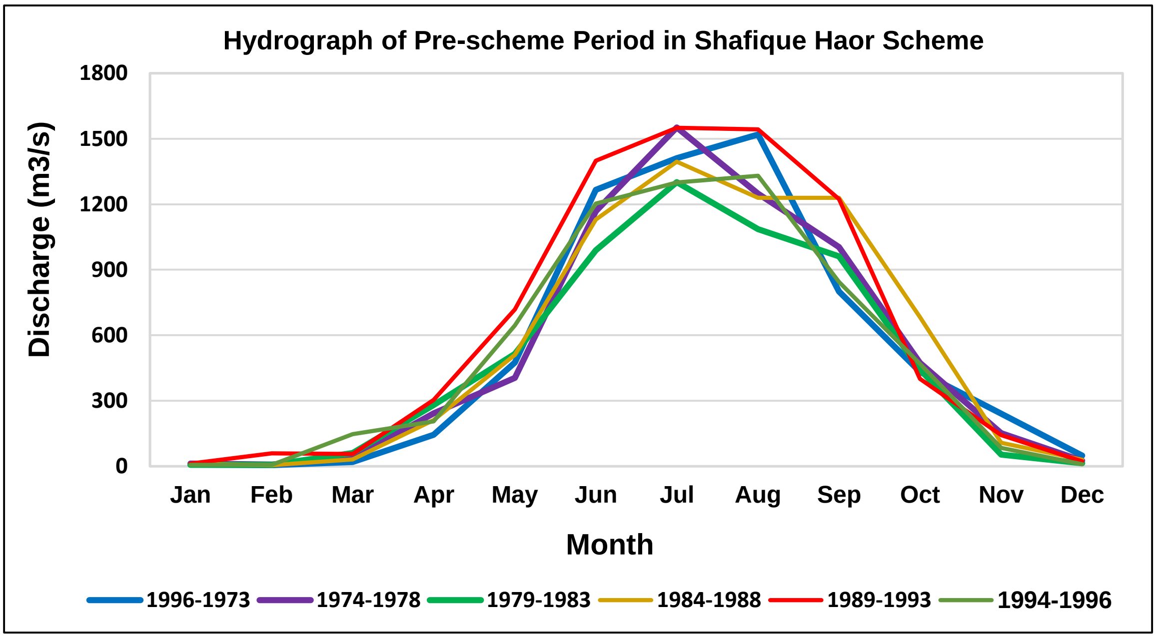

Figure 4.24: Hydrograph of annual maximum discharge during pre-scheme period in Shafique Haor scheme

Hydrograph of annual maximum discharge has been drawn for Kanairghat (ID 266) BWDB station. The hydrograph shows that the discharge changes over time. From the Figure 4.25, it has been observed that peak heights of the hydrographs are during the month of May to September for the period of 2007-2018. The hydrograph for post-scheme period of Shafique Haor scheme has given below:

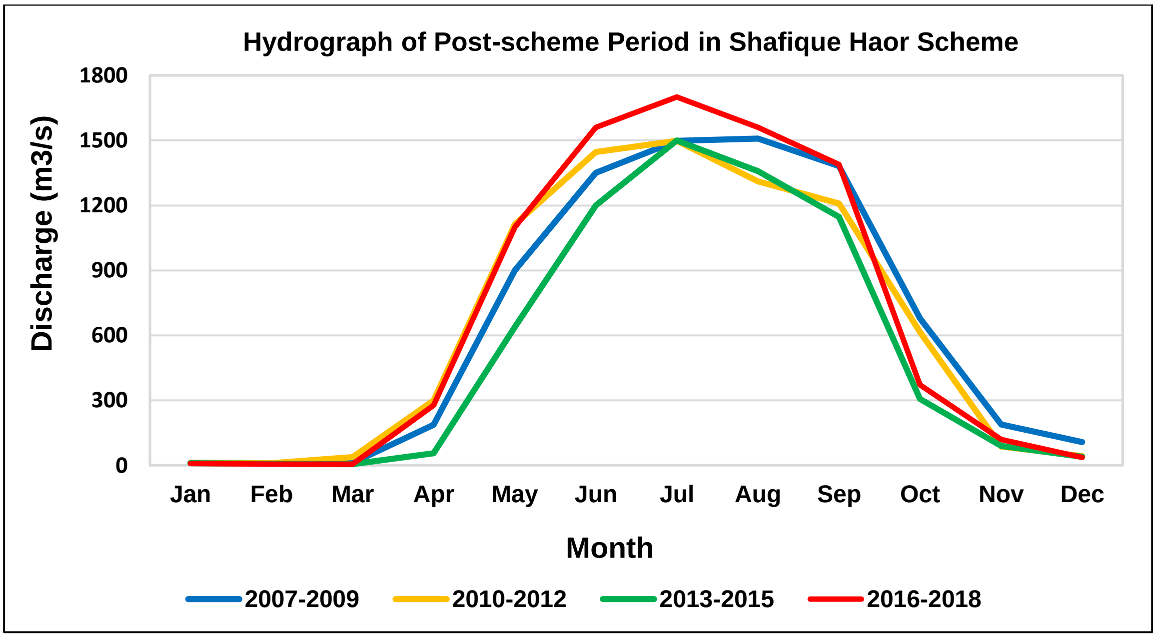

Figure 4.25: Hydrograph of annual maximum discharge during post-scheme period in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

The nearest discharge station of Bangladesh Water Development Board (BWDB) are Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5). There is no available discharge data of Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) before the year of 1988. As a result, there is no available discharge data for Sonamoaral Haor scheme for the pre-scheme period as the Sonamoral Haor Schem stared 1985. For the unavailability of data for the pre-scheme period, trend analysis of discharge has not been carried out.

Average discharge data of Sonamoral Haor scheme has been collected from Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB discharge stations. Available discharge data from 1993-2018 has been collected to conduct the trend analysis for post-scheme scenario. Trend analysis of discharge during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out. The figures have been presented on the following pages.

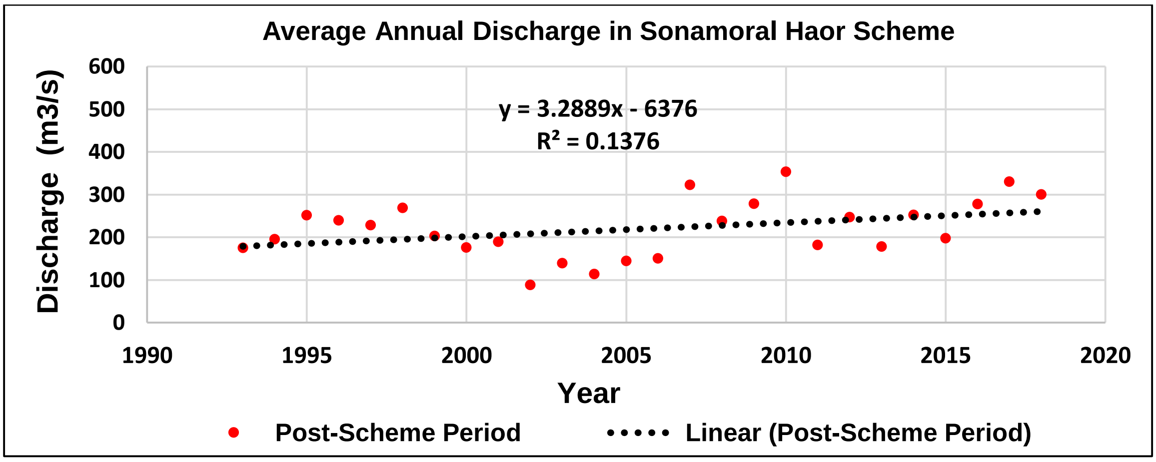

Figure 4.26: Average annual discharge during post-scheme period (1993-2018) in Sonamoral Haor scheme

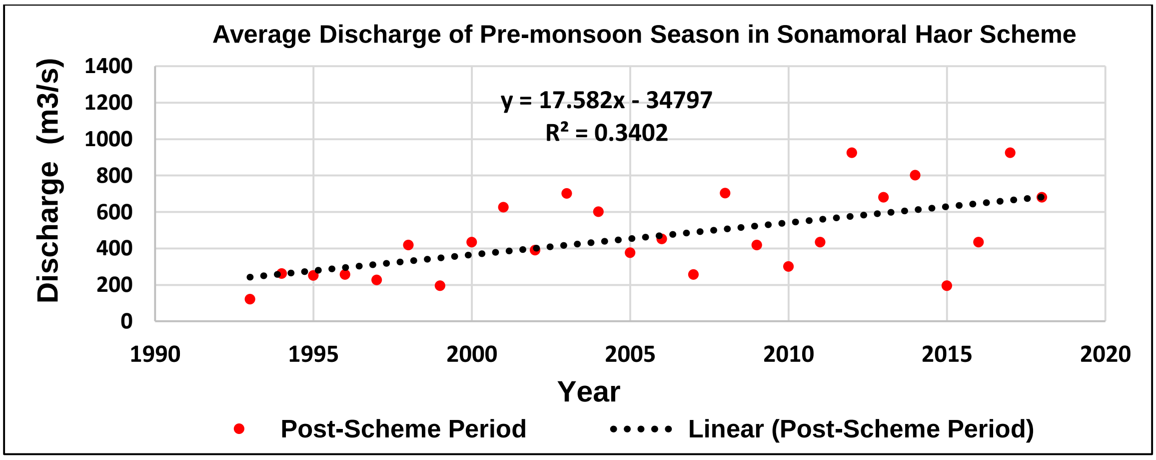

Figure 4.27: Average discharge of pre-monsoon season during post-scheme period (1993-2018) in Sonamoral Haor scheme

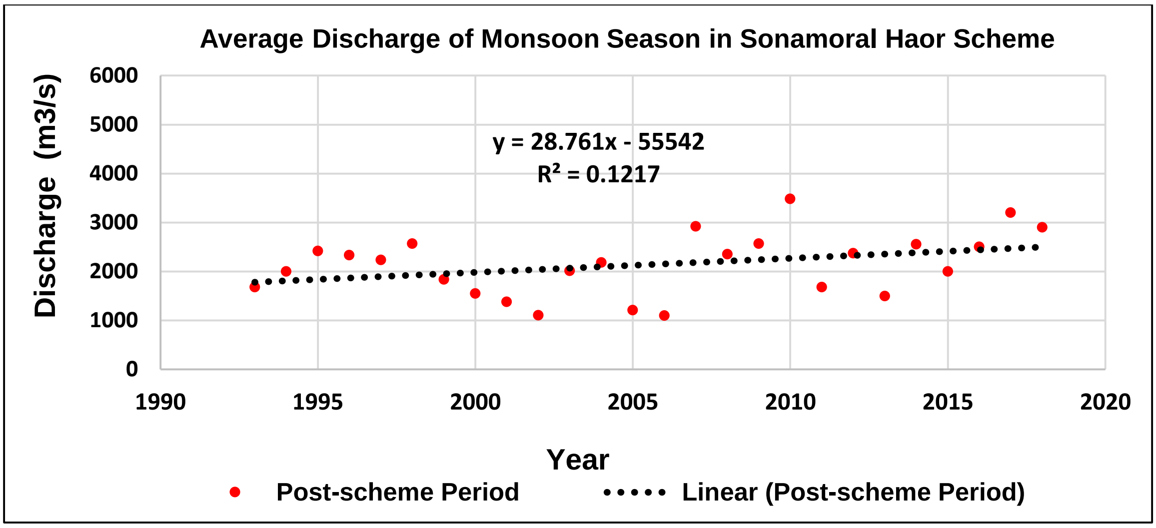

Figure 4.28: Average discharge of monsoon season during post-scheme period (1993-2018) in Sonamoral Haor scheme

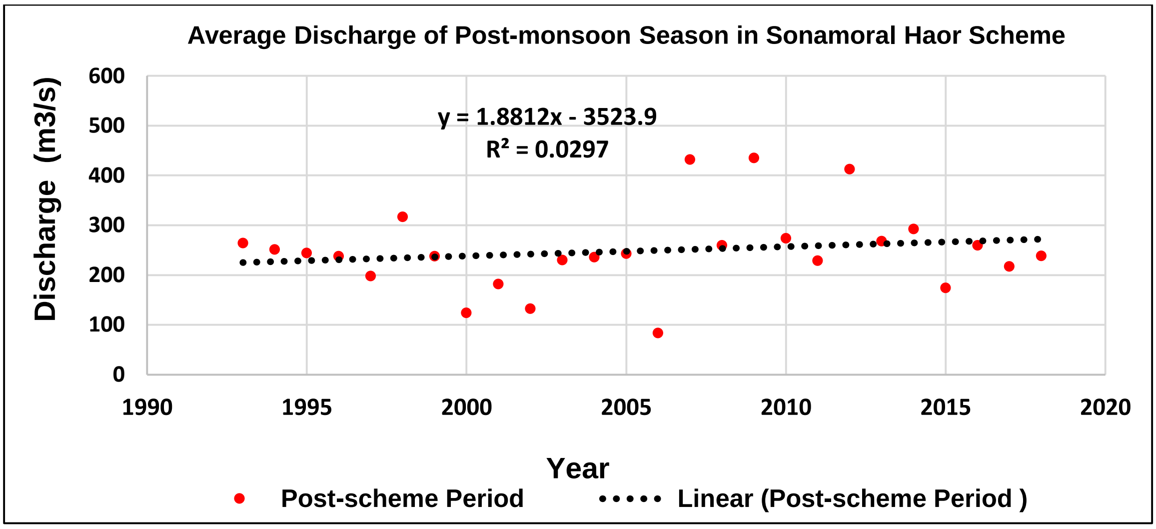

Figure 4.29: Average discharge of post-monsoon season during post-scheme period (1993-2018) in Sonamoral Haor scheme

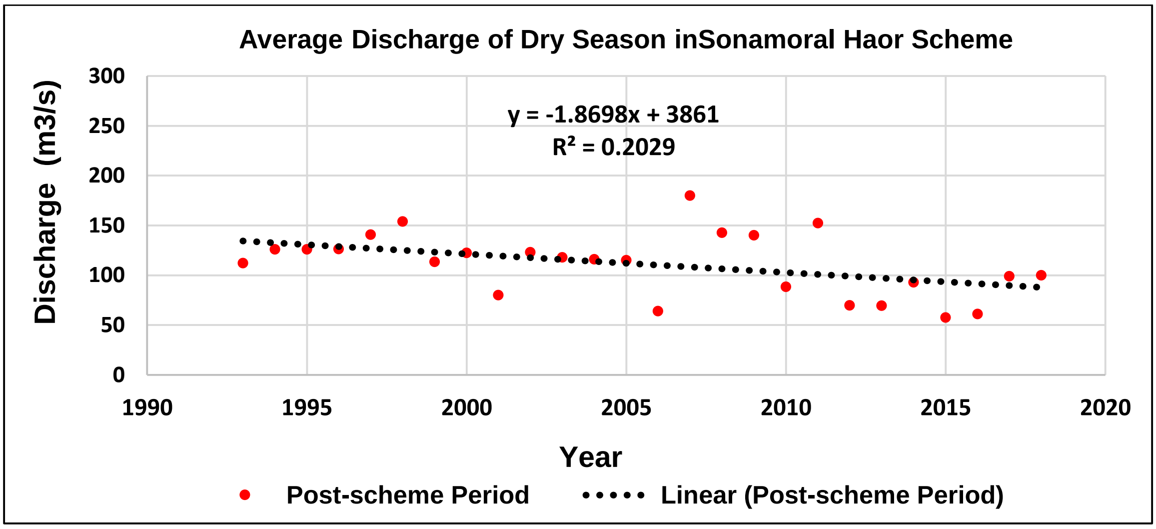

Figure 4.30: Average discharge of dry season during post-scheme period (1993-2018) in Sonamoral Haor scheme

From the annual trend analysis of average discharge with time at Saktiarkhola (ID131) and Laurergarh Saktiarkhola (ID 131.5) BWDB station, it is evident that average annual discharge is gradually increasing with time and the R^2 value is 0.1376 (Figure 4.26) for 1993-2018. It means moderately correlated with time.

For pre-monsoon season, it is evident that only for 1993-2018, average discharge is increasing with time and R^2 value is 0.3402 (Figure 4.27). It means moderately correlated with time.

For monsoon season, it is evident that only for 1993-2018, average discharge is gradually increasing with time and it's R^2 value is 0.1217 (Figure 4.28). It means moderately correlated with time.

For post-monsoon season, it is evident that only for 1993-2018, average discharge is gradually increasing with time and it's R^2 value is 0.0297 (Figure 4.29). It means average discharge is poorly correlated with time.

For dry season, it is evident that only for 1993-2018, average discharge is gradually decreasing with time and the R^2 value is 0.2029 (Figure 4.30). It means moderately correlated with time.

Hydrograph of Sonamoral Haor Scheme:

The starting period of implementation the Sonamoral Haor scheme was 1985. There is no available discharge data of Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) before the year of 1988. So, there is no available discharge data for the pre-scheme period of Sonamoral Haor scheme. As a result, hydrograph of annual maximum discharge has not been drawn for the pre-scheme period of Sonamoral Haor scheme.

In addition, hydrograph of annual maximum discharge has been drawn for Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB station for the year of 1993-2018. The hyetograph shows that the discharge changes over time.

From the Figure 4.31, it has been observed that peak heights of the hydrograph are during the month of June to September for the period of 1993-2018. The hydrograph for post-scheme period of Sonamoral Haor scheme has given below:

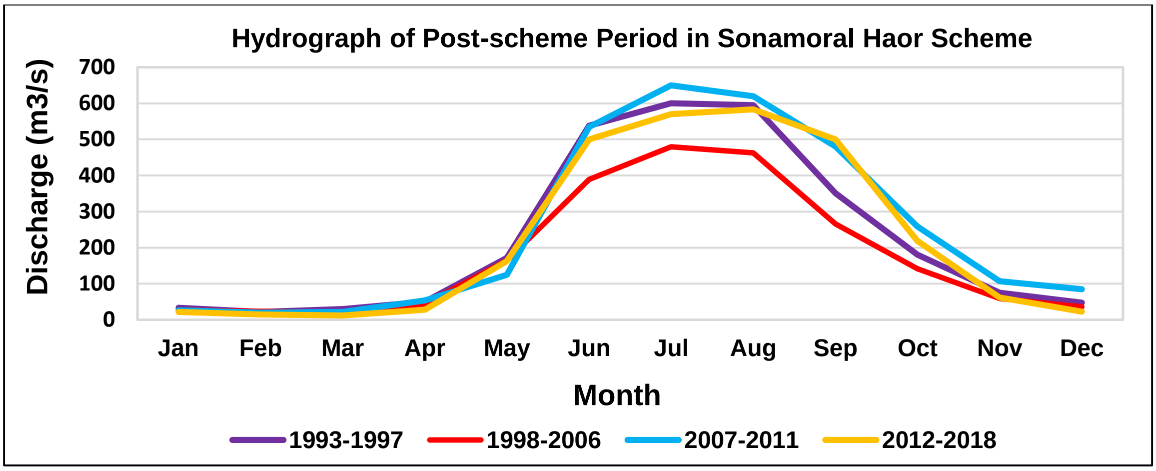

Figure 4.31: Hydrograph of annual maximum discharge during post-scheme period in Sonamoral Haor scheme

4.2.3 Trend Analysis of Water Level

The time series of water level data has been collected from the NWRD-CEGIS archive. Kanairghat (ID 266) BWDB station is the nearest rainfall station from the Shafique Haor scheme for the collection of available water level data of 1952-2018. Figure 4.32 shows the location of water level BWDB station for Shafique Haor scheme.

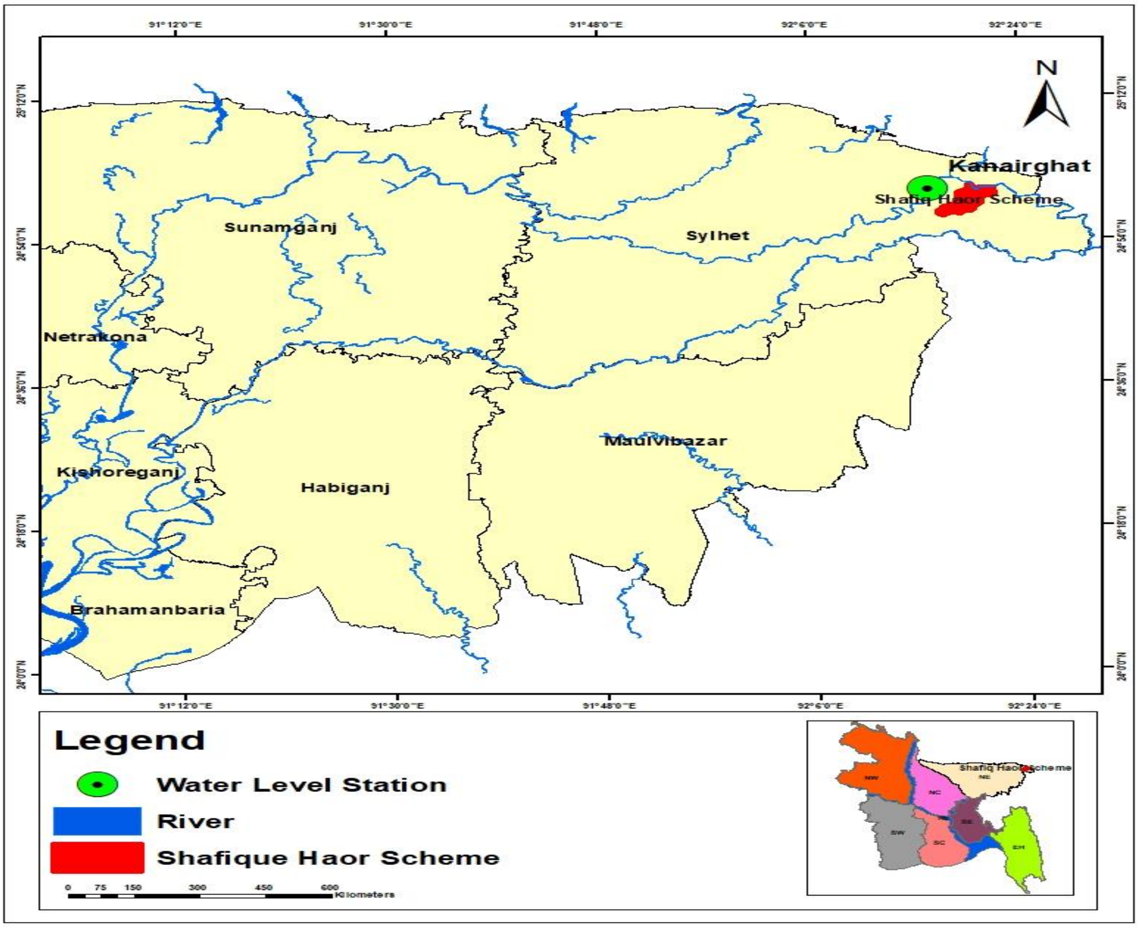

Figure 4.32: Location of Kanairghat (ID 266) BWDB water level station from Shafique Haor scheme

Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB stations are the nearest water level stations from the Sonamoral Haor scheme. These stations have been selected for collection of available water level data of 1964-1992 and 1993-2018 accordingly. Figure 4.33 shows the location of discharge BWDB stations for Sonamoral Haor scheme.

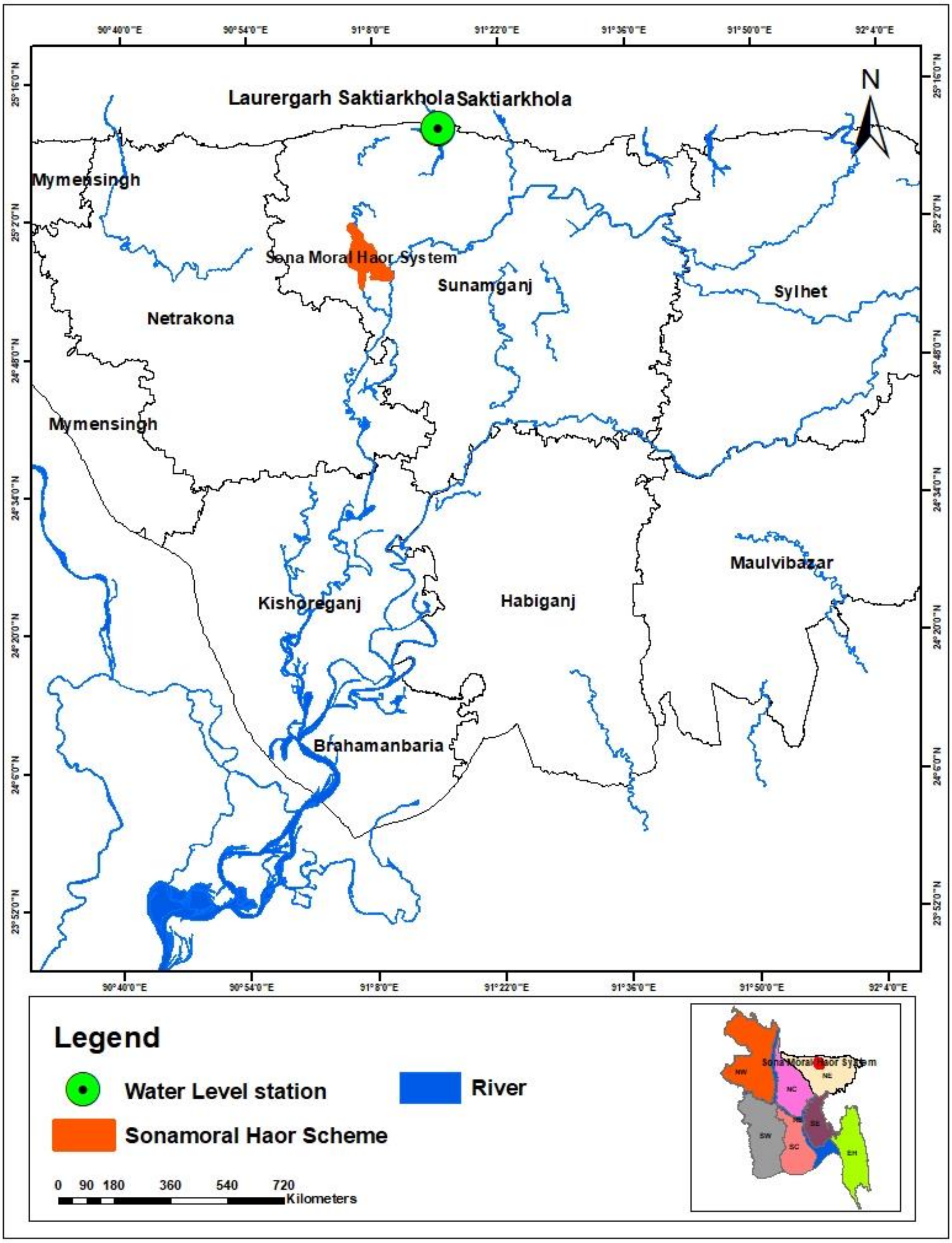

Figure 4.33: Location of Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB water level stations from Sonamoral Haor scheme

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Average water level data of Shafique Haor scheme has been collected from Kanairghat (ID 266) BWDB water level station. Available water level data from 1952-1996 and 2007-2018 has been collected to conduct the trend analysis for pre-scheme and post-scheme scenario accordingly. Trend analysis of water level during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out for the both scenarios. The figures have been presented on the following pages.

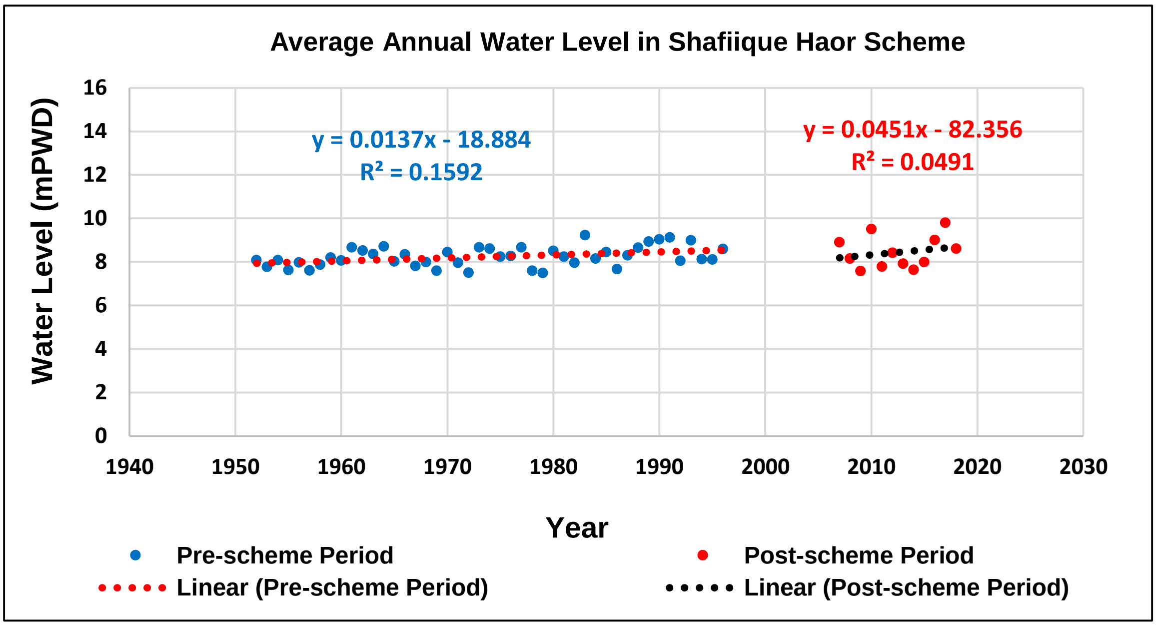

Figure 4.34: Average annual water level during pre-scheme period (1952-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

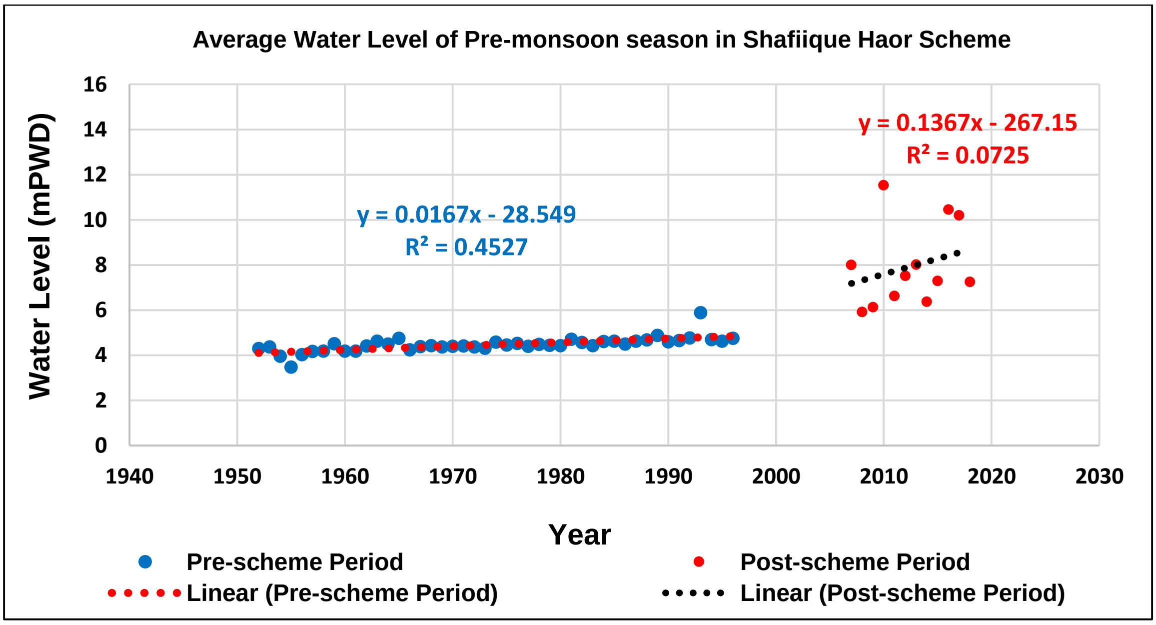

Figure 4.35: Average water level of pre-monsoon season during pre-scheme period (1952-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

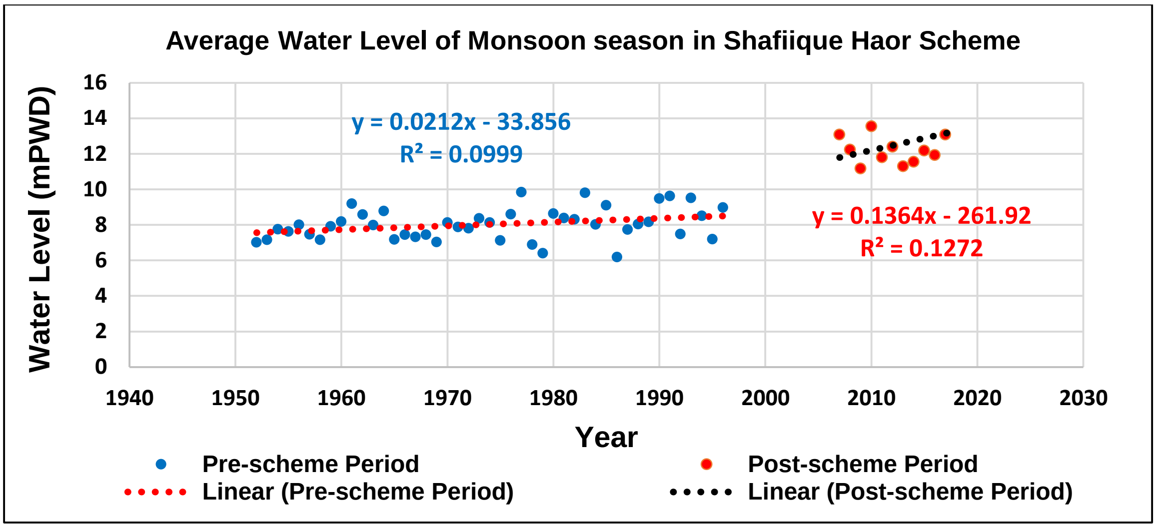

Figure 4.36: Average water level of monsoon season during pre-scheme period (1952-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

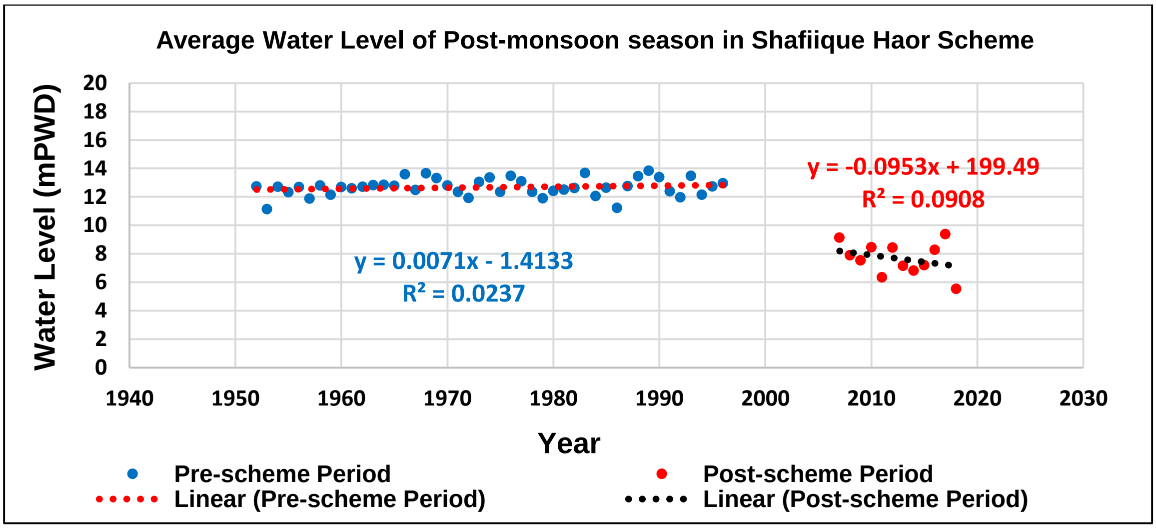

Figure 4.37: Average water level of post-monsoon season during pre-scheme period (1952-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

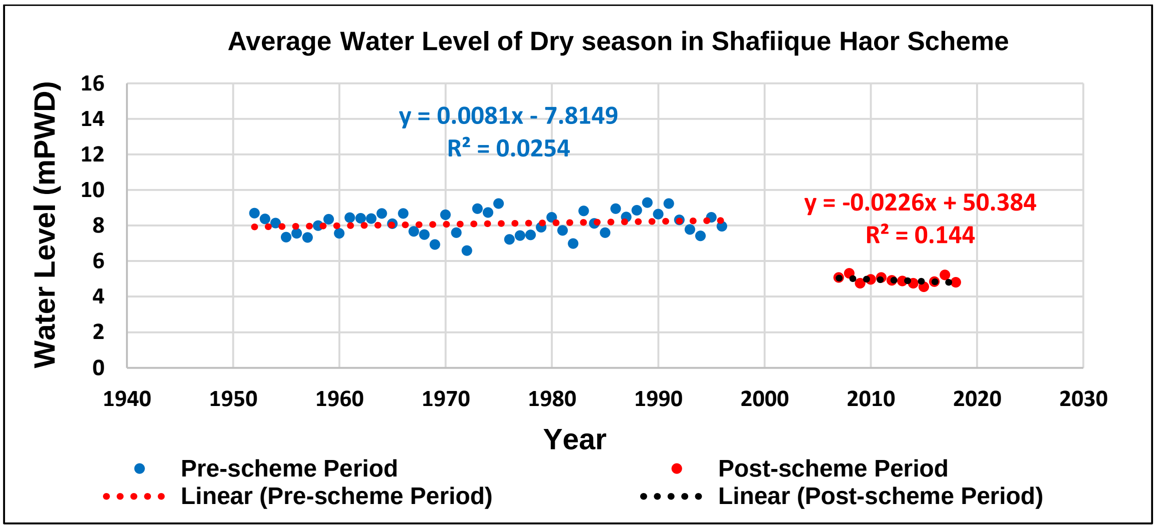

Figure 4.38: Average water level of dry season during pre-scheme period (1952-1996) and post-scheme period (2007-2018) in Shafique Haor scheme

From the annual trend analysis of average water level at Kanairghat (ID 266) BWDB station, it is evident that annual water level is neither decreasing nor increasing with time. There is moderate relationship between average annual water level and time as R^2 = 0.1592 (Figure 4.34) for 1952-1996. Average annual water level for 2007-2018 is gradually increasing with time and R^2 value is 0.0491 (Figure 4.34). It means annual average water level is poorly correlated with time.

For pre-monsoon season, it is evident that only for 1952-1996, average water level is gradually increasing with time and R^2 value is 0.4527 (Figure 4.35) which means moderate relationship between average water level of pre-monsoon season and time. For 2007-2018, it is evident that average water level is increasing with time as R^2 value is 0.0725 (Figure 4.35) which means poorly correlated with time.

For monsoon season, it is evident that only for 1952-1996, average water level is gradually increasing with time. Average water level of monsoon season is poorly correlated with time as R^2 = 0.0999 (Figure 4.36). The water level is increasing and the R^2 value for 2007-2018 is 0.1272 (Figure 4.36). It means moderate relationship between average water level of monsoon season and time.

For post-monsoon season, it is evident that only for 1952-1996, average water level is neither decreasing nor increasing with time and its R^2 value is 0.0237 (Figure 4.37) which means poorly correlated with time. Average water level of post-monsoon season for 2007-2018 is poorly correlated with time as R^2 =0.0908 (Figure 4.37) and is decreasing with time.

For dry season, it is evident that only for 1952-1996, average water level is neither decreasing nor increasing with time and R^2 value is 0.0254 (Figure 4.38). It means poorly correlated with time. In case of dry season for 2007-2018, average water level is decreasing with time and R^2 value is 0.144 (Figure 4.38). It means moderate relationship between average water level of dry season and time.

Hydrograph of Shafique Haor Scheme:

In addition, hydrograph of annual maximum water level has been drawn for Kanairghat (ID 266) BWDB water level station. The hydrograph shows that the water level changes over time. From Figure 4.39, it has been observed that peak heights of the hydrograph are during the month of May to September for the period of 1952-1996.

The hydrograph for pre-scheme period of Shafique Haor scheme has given below:

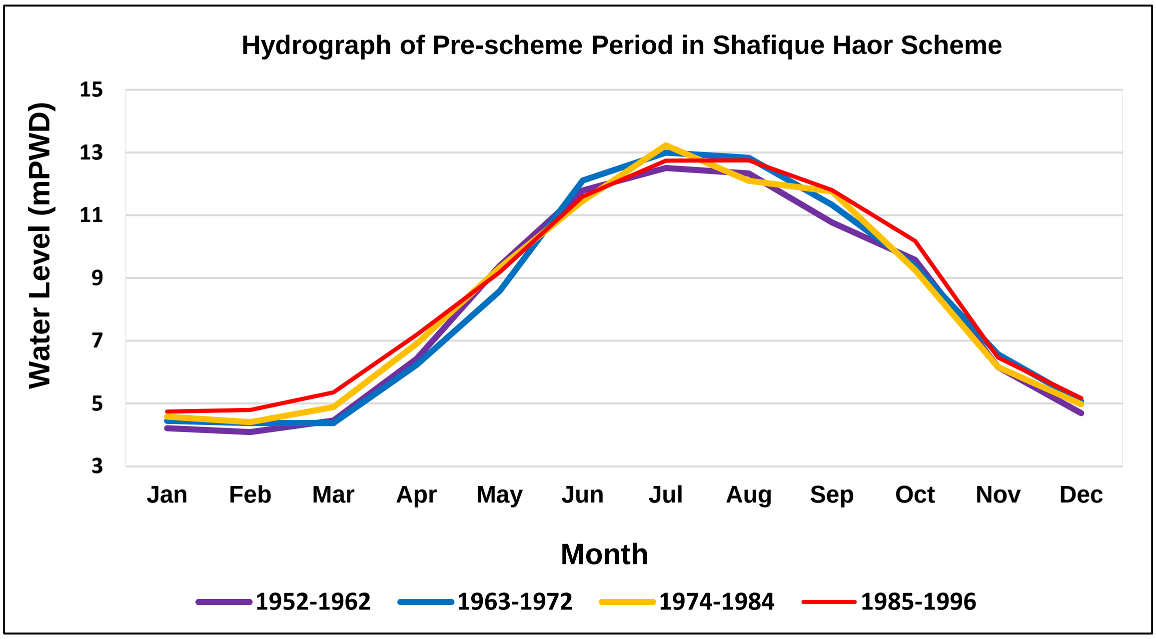

Figure 4.39: Hydrograph of annual maximum water level during pre-scheme period for Shafique Haor scheme

Hydrograph of annual maximum water level has been also drawn for Kanairghat (ID 266) BWDB water level station. The hydrograph shows that the water level changes over time. From the Figure 4.40, it has been observed that peak heights of the hydrograph are during the month of May to September for the period of 2007-2018. The hydrograph for post-scheme period of Shafique Haor scheme has given below:

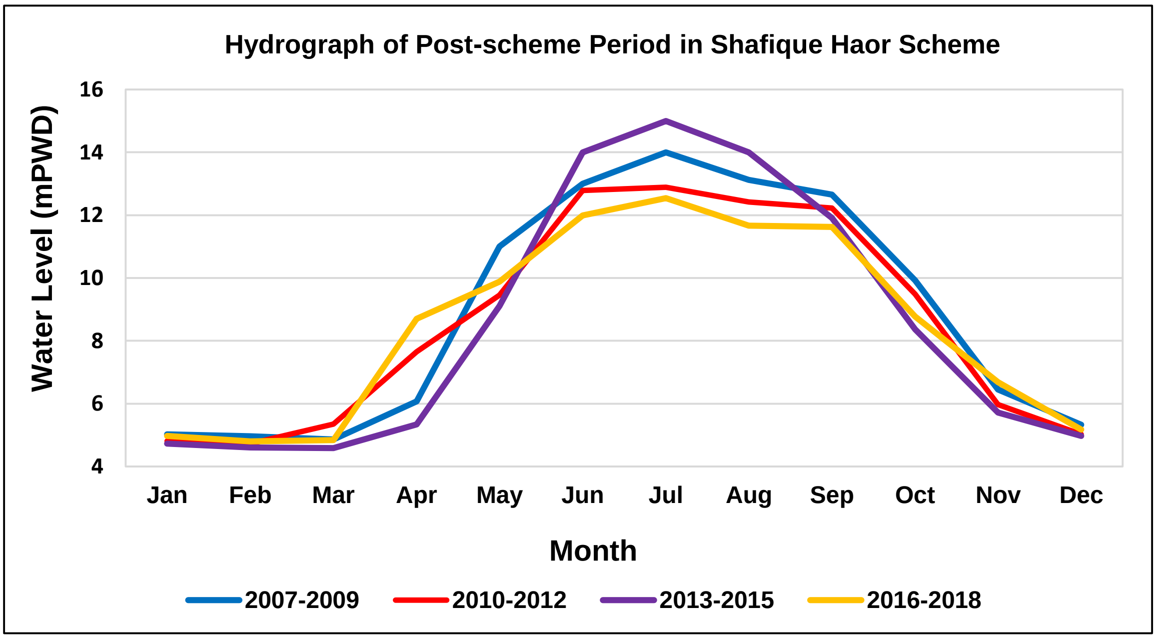

Figure 4.40: Hydrograph of annual maximum water level during post-scheme period in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Average water level data of Sonamoral Haor scheme has been collected from Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB water level stations. Available water level data from 1964-1984 and 1993-2018 has been collected to conduct the trend analysis for pre-scheme and post-scheme scenario. Trend analysis of water level during pre-monsoon season, monsoon season, post-monsoon season and dry season has also been carried out. The figures have been presented on the following pages.

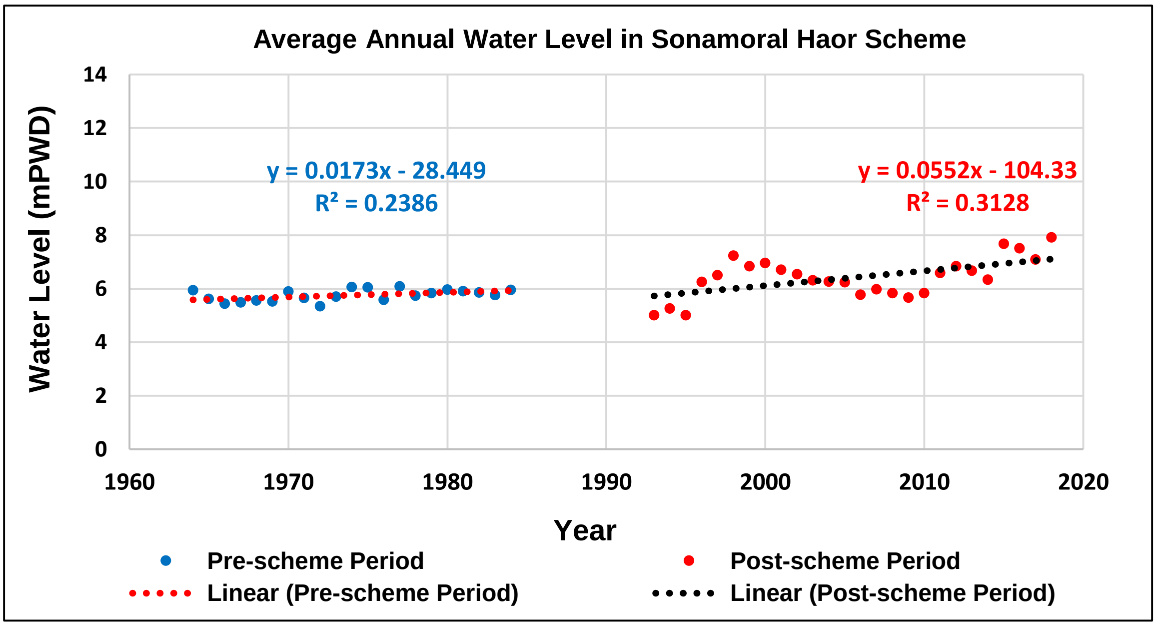

Figure 4.41: Average annual water level during pre-scheme period (1964-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

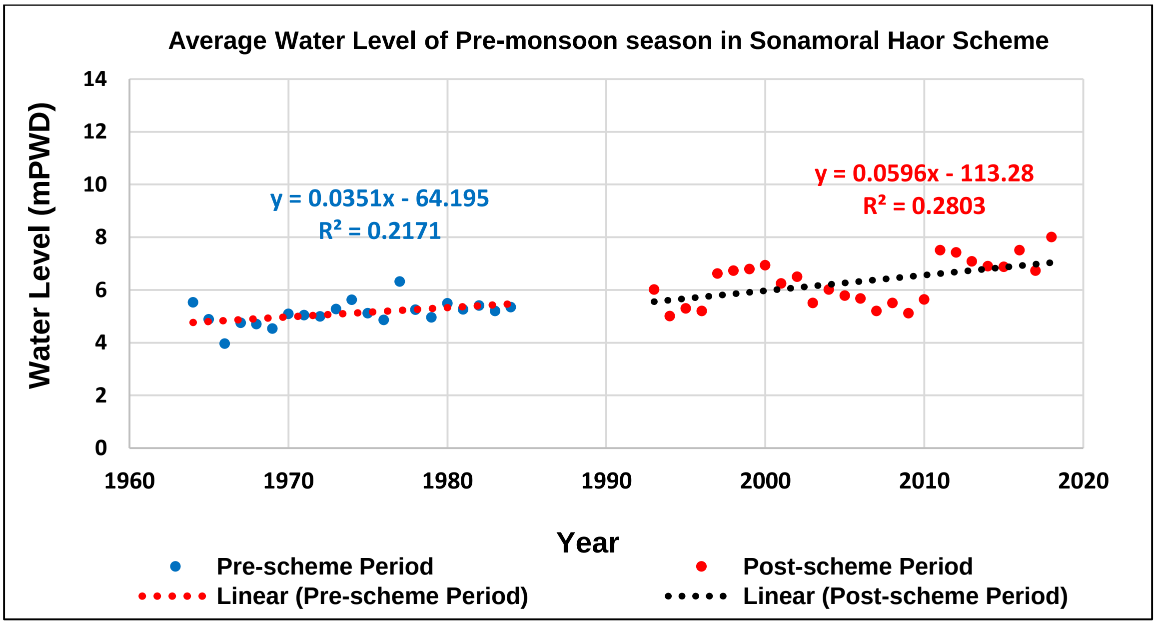

Figure 4.42: Average water level of pre-monsoon season during pre-scheme period (1964-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

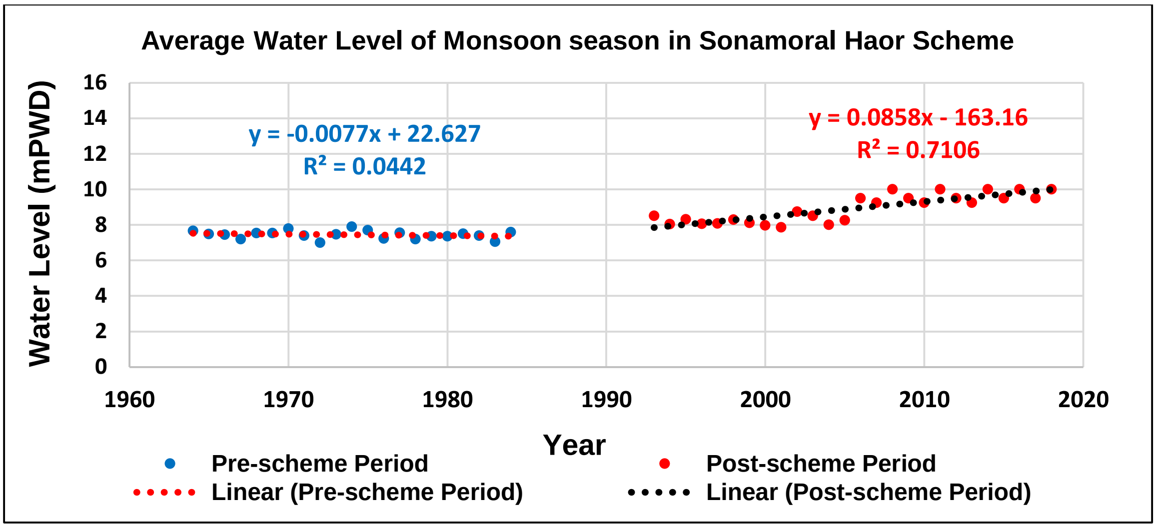

Figure 4.43: Average water level of monsoon season during pre-scheme period (1964-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

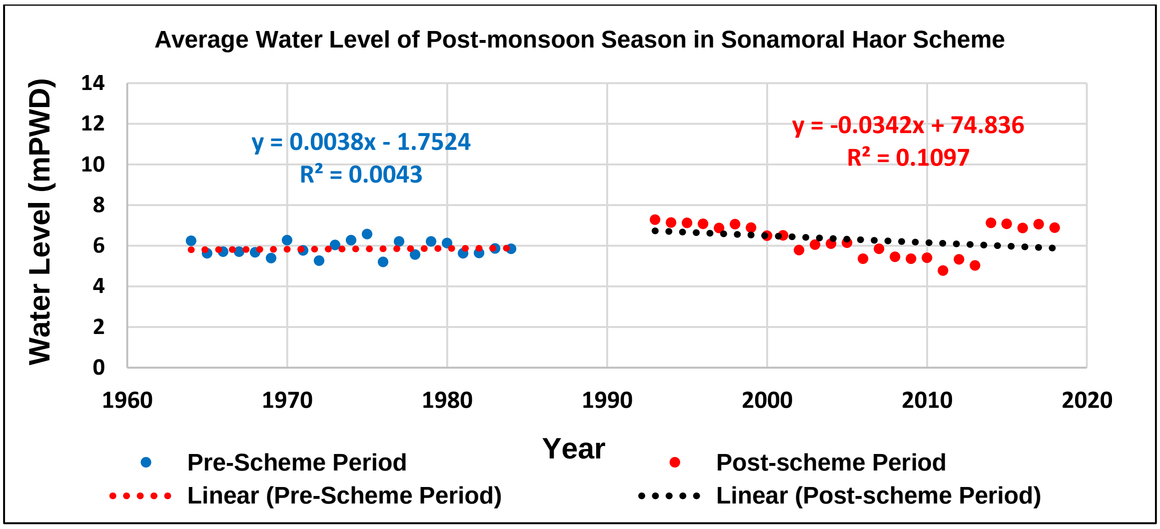

Figure 4.44: Average water level of post-monsoon season during pre-scheme period (1964-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

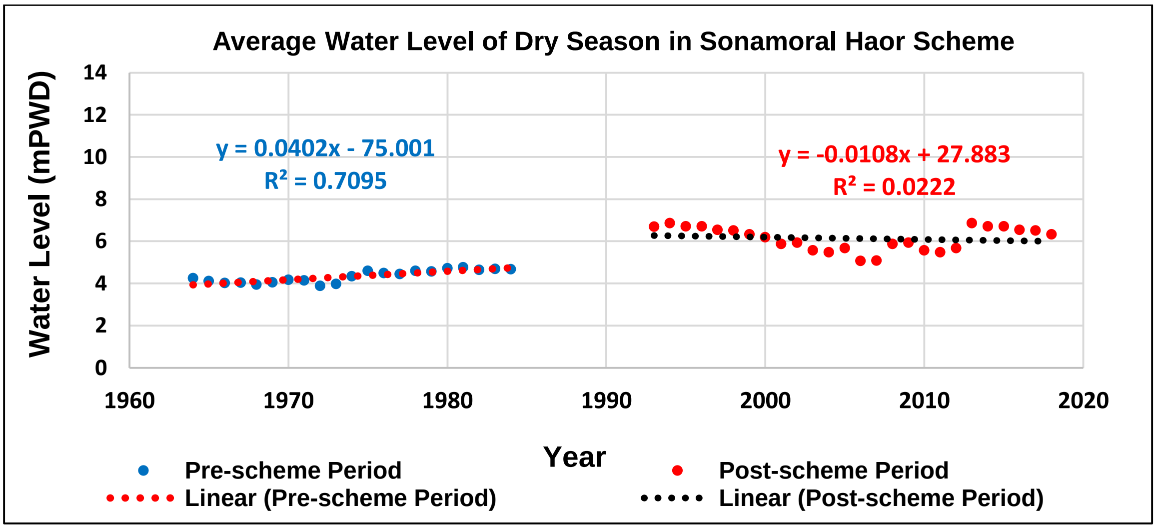

Figure 4.45: Average water level of dry season during pre-scheme period (1964-1984) and post-scheme period (1993-2018) in Sonamoral Haor scheme

From the annual trend analysis of average water level at Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB stations, it is evident that average annual water level is neither decreasing nor increasing with time. There is moderate relationship between average annual water level and time as $R^2 = 0.2386$ (Figure 4.41) for 1964-1984. Average annual water level for 1993-2018 is increasing with time and the R^2 value is 0.3128 (Figure 4.41). It means there is moderate relationship with time.

For pre-monsoon season, it is evident that only for 1964-1984, average water level is gradually increasing with time and R^2 value is 0.2171 (Figure 4.42). It means moderate relationship between average water level of pre-monsoon season and time. The water level is increasing and the R^2 value for 1993-2018 is 0.2803 (Figure 4.42). It means moderate relationship between average water level of pre-monsoon season and time.

For monsoon season, it is evident that only for 1964-1984, average water level is neither decreasing nor increasing with time. Average water level of monsoon season is poorly correlated with time as $R^2 = 0.0442$ (Figure 4.43). The water level is increasing and the R^2 value for 1993-2018 is 0.7106 (Figure 4.43). It means moderate relationship between average water level of monsoon season and time.

For post-monsoon season, it is evident that only for 1964-1984, average water level is neither decreasing nor increasing with time and its R^2 value is 0.0043 (Figure 4.44) which means poorly correlated with time. Average water level of post-monsoon season for 1993-2018 is decreasing with time and it's R^2 value is 0.1097 (Figure 4.44). It means moderate relationship between average water level of monsoon season and time.

For dry season, it is evident that only for 1964-1984, average water level is gradually increasing with time and R^2 value is 0.7095 (Figure 4.45). It means moderate relationship between average water level of dry season and time. In case of dry season for 1993-2018, average water level is decreasing with time and the R^2 value is 0.0222 (Figure 4.45). It means poor relationship with time.

Hydrograph of Sonamoral Haor Scheme:

In addition, hydrograph of annual maximum water level has been drawn for Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB water level stations. The hydrograph shows that the water level changes over time. From the Figure 4.46, it has been observed that peak heights of the hydrograph are during the month of May to September for the period of 1964-1984. The hydrograph for pre-scheme period of Sonamoral Haor scheme has given below:

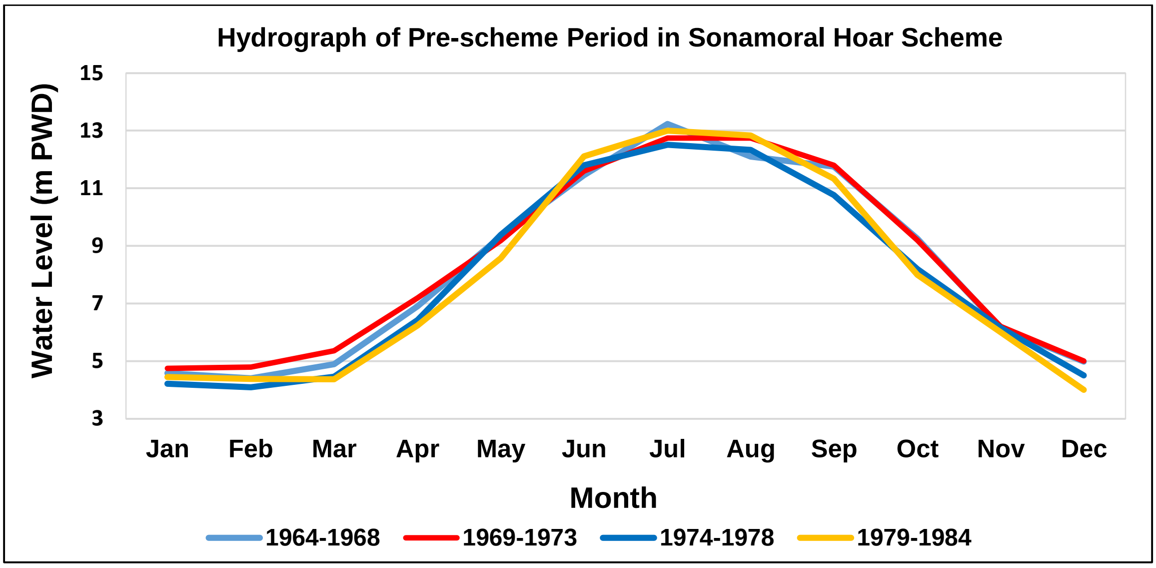

Figure 4.46: Hydrograph of annual maximum water level during pre-scheme period in Sonamoral Haor scheme

Hydrograph of annual maximum water level has been also drawn for Saktiarkhola (ID 131) and Laurergarh Saktiarkhola (ID 131.5) BWDB water level stations. The hydrograph shows that the water level changes over time. From the Figure 4.47, it has been observed that peak heights of the hydrograph are during the month of May to September for the period of 1993-2018. The hydrograph for post-scheme period of Sonamoral Haor scheme has given below:

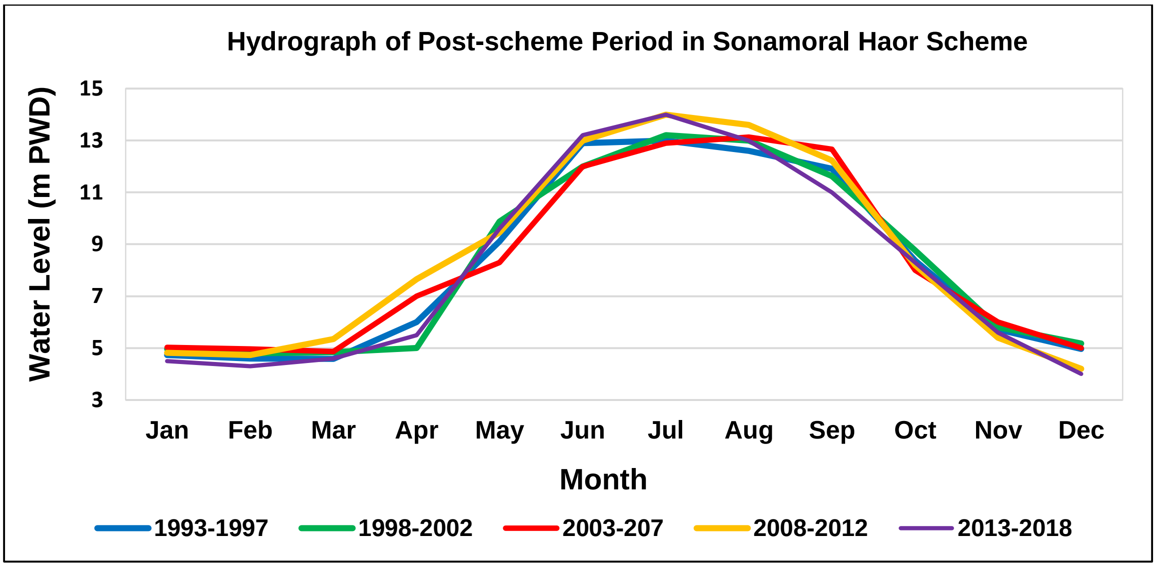

Figure 4.47: Hydrograph of annual maximum water level during post-scheme period in Sonamoral Haor scheme

4.2.4 Correlation among Rainfall, Discharge and Water Level

A correlation analysis has been carried out to explore the connection among rainfall, discharge and water level in Shafique Haor scheme and Sonamoral Haor scheme.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

The correlation analysis shows that rainfall quantity determined water discharge and water level. Correlation among rainfall, discharge and water level has been drawn in Figure 4.48 for the pre-scheme period and post-scheme period of Shafique Haor scheme. It has been plotted cumulative rainfall of monsoon season against annual maximum discharge and annual maximum water level data. From the figure, it has been observed that in 1970 and 1980, there is a drop of rainfall trend line and water level trend line for pre-scheme period. In case of post-scheme period, it has been also observed from Figure 4.48 that in 2012 and 2015, there is a peak in case of rainfall trend line and at the same time of discharge trend line.

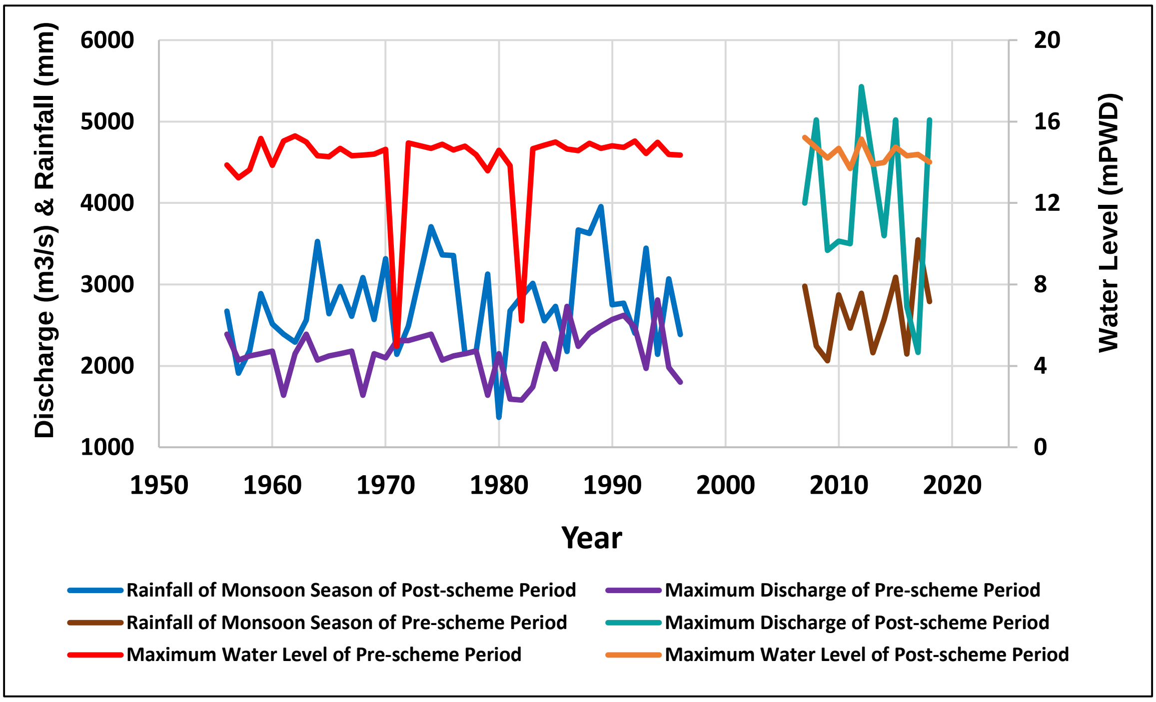

Figure 4.48: Correlation among cumulative rainfall, maximum discharge and maximum water level in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

River discharge and water level are strongly correlated with rainfall at the annual scale and for most of the months. Correlation among rainfall, discharge and water level has been drawn in Figure 4:49 for the pre-scheme period and post-scheme period of Sonamoral Haor scheme. It has been plotted cumulative rainfall of monsoon season against annual maximum discharge and annual maximum water level data. From the Figure 4.49, it has been observed that in 1964 and 1984, there is a drop in case of rainfall trend line and at the same time of water level trend line for pre-scheme period. In case of post-scheme period, it has been also observed that there is a peak in case of rainfall trend line and at the same time of water level trend line in 2001 and there is a drop in case of rainfall trend line and at the same time of water level trend line in 2008.

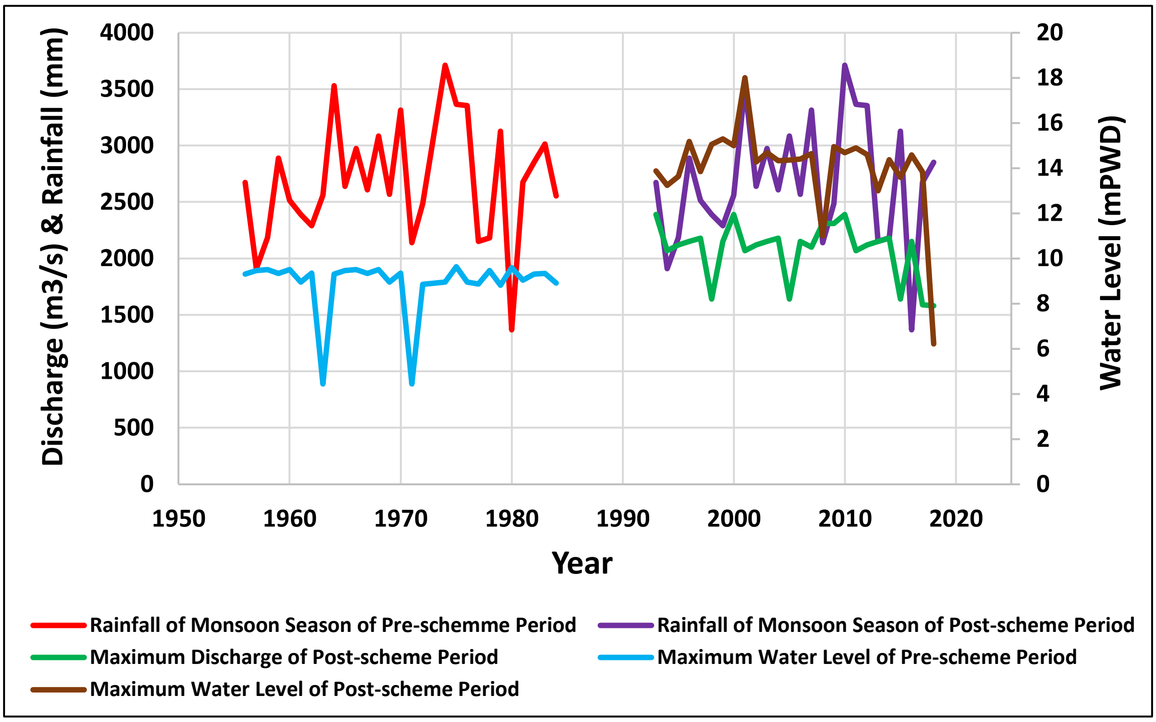

Figure 4.49: Correlation among cumulative rainfall, maximum discharge and maximum water level in Sonamoral Haor scheme

4.2.5 Assessment of the Change of Meteorological and Hydrological Parameter

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Meteorological and hydrological change have been observed by trend analysis and by drawn hyetograph and hydrograph. From the analysis, it has been observed that the rainfall, discharge and water level are gradually increasing with the course of time due to climate change impact in Shafique Haor scheme. The trend analysis of annual and seasonal rainfall for the period of pre-scheme and post-scheme could reveal that annual rainfall, rainfall during pre-monsoon season and dry season is gradually increasing. Whereas rainfall during monsoon season and post-monsoon season is neither decreasing nor increasing for the pre-scheme period and gradually increasing for post-scheme period.

The trend analysis of annual and seasonal discharge for the period of pre-scheme and post-scheme could reveal that annual discharge and discharge during pre-monsoon season is gradually increasing. Whereas discharge during monsoon season is neither decreasing nor increasing for pre-scheme period and is gradually increasing for post-scheme period. Average discharge is increasing for pre-scheme and decreasing for post-scheme period for both post monsoon season and dry season.

The trend analysis of annual and seasonal water level could reveal that annual water level is neither decreasing nor increasing for the period of pre-scheme period and gradually increasing for the period of post-scheme period. Water level during pre-monsoon season and monsoon season is gradually increasing and increasing for the pre-scheme period and post-scheme period accordingly. For post-monsoon season and dry season, average water level is neither decreasing nor increasing for pre-scheme period and is decreasing for post-scheme period. In case of dry season,

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Trend analysis has been carried out to figure out trend of meteorological and hydrological factors for Sonamoral Haor scheme. The trend analysis of annual and seasonal rainfall for the period of pre-scheme and post-scheme could reveal that annual rainfall and rainfall during pre-monsoon season is increasing. Whereas rainfall during monsoon season rainfall is decreasing in pre-scheme period and gradually increasing in post-scheme period. For post-monsoon season, rainfall is increasing in pre-scheme period whereas it is decreasing in post-scheme period. For dry season, rainfall is neither decreasing nor increasing in both pre-scheme period and post-scheme period.

The trend analysis of annual and seasonal discharge for the post-scheme period could reveal that annual discharge, discharge during pre-monsoon season, monsoon season and post-monsoon season is gradually increasing. Whereas rainfall during dry season is decreasing for post-scheme period.

The trend analysis of annual and seasonal water level for the period of pre-scheme and post-scheme could reveal that annual discharge is neither decreasing nor increasing for the period of pre-scheme period and increasing for post-scheme period. For pre-monsoon season, water level is gradually increasing for pre-scheme period and increasing for post-scheme period. For monsoon season, average water level is neither decreasing nor increasing for pre-scheme period and increasing for post-scheme period. For post-monsoon season, average water level is neither decreasing nor increasing for pre-scheme period and water level is decreasing for post-scheme period. For dry season, water level is increasing and for pre-scheme period and water level is decreasing for post-scheme period.

4.3 Frequency Analysis

Frequency analysis of extremes is one of the most common and earliest applications of statistics within hydrology. Frequency analysis of rainfall, discharge and water level has been carried out to inspect the frequency of flash flood in Shafique Haor scheme and Sonamoral Haor scheme.

4.3.1 Frequency Analysis of Rainfall

Frequency analysis of rainfall data for pre-scheme and post-scheme scenario has been described in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Rainfall data has been estimated for 2, 5, 10, 20 and 50 years return period for Shafiq Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble's Distribution. After the frequency analysis, probability curves of rainfall have been plotted for the pre-scheme period and post-scheme period in Figure 4.50 and Figure 4.51 accordingly.

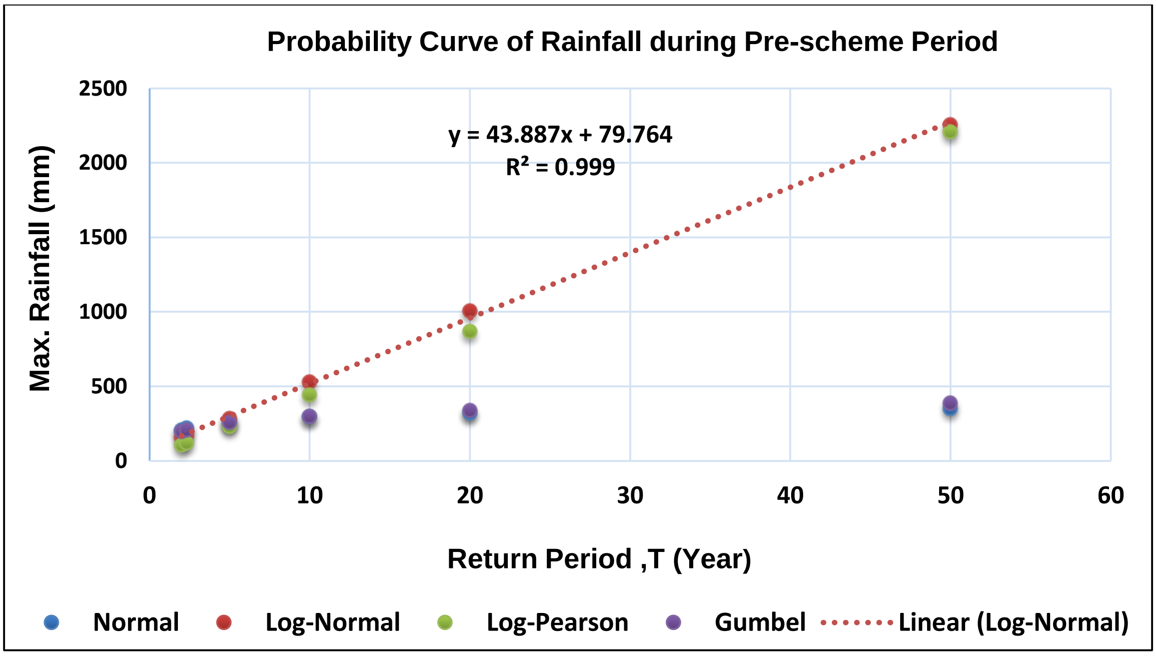

Figure 4.50: Probability curve for maximum rainfall value during the pre-scheme period in Shafique Haor scheme

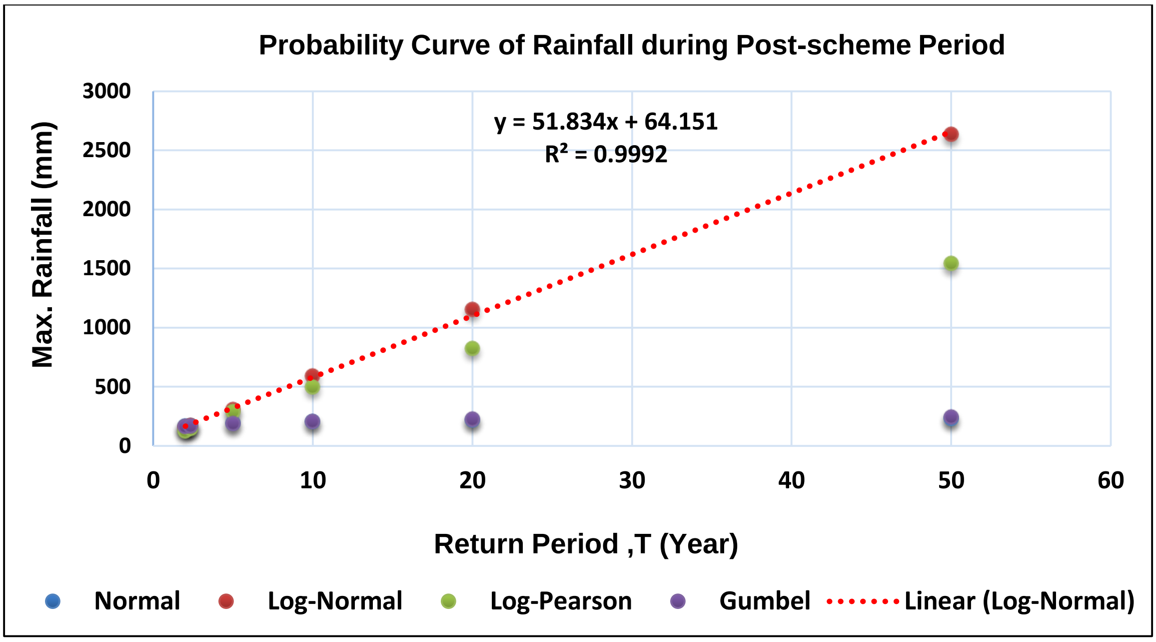

Figure 4.51: Probability curve for maximum rainfall value during the post-scheme period in Shafique Haor scheme

Corresponding tables showing the result of frequency analysis of rainfall data for pre-scheme period and post-scheme period in Table 4.1 and Table 4.2 accordingly. From the frequency analysis, it has been observed that the values of rainfall are increasing for both the period of Shafique Haor scheme for the selected return period.

Table 4.1: Statistical analysis for maximum rainfall during pre-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	207	265	295	320	349
Log-Normal	157	285	529	1006	2255
Log-Pearson type III	105	232	442	868	2207
Gumbel	196	257	297	336	386

Table 4.2: Statistical analysis for maximum rainfall during post-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	169	194	207	217	229
Log-Normal	158	306	592	1153	2636
Log-Pearson type III	125	291	499	824	1543
Gumbel	164	190	207	224	245

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Rainfall data has been estimated for 2, 5, 10, 20 and 50 years return period for Sonamoral Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble’s Distribution.

After the frequency analysis, probability curves of rainfall have been plotted for the pre-scheme period and post-scheme period in Figure 4.52 and Figure 4.53 accordingly.

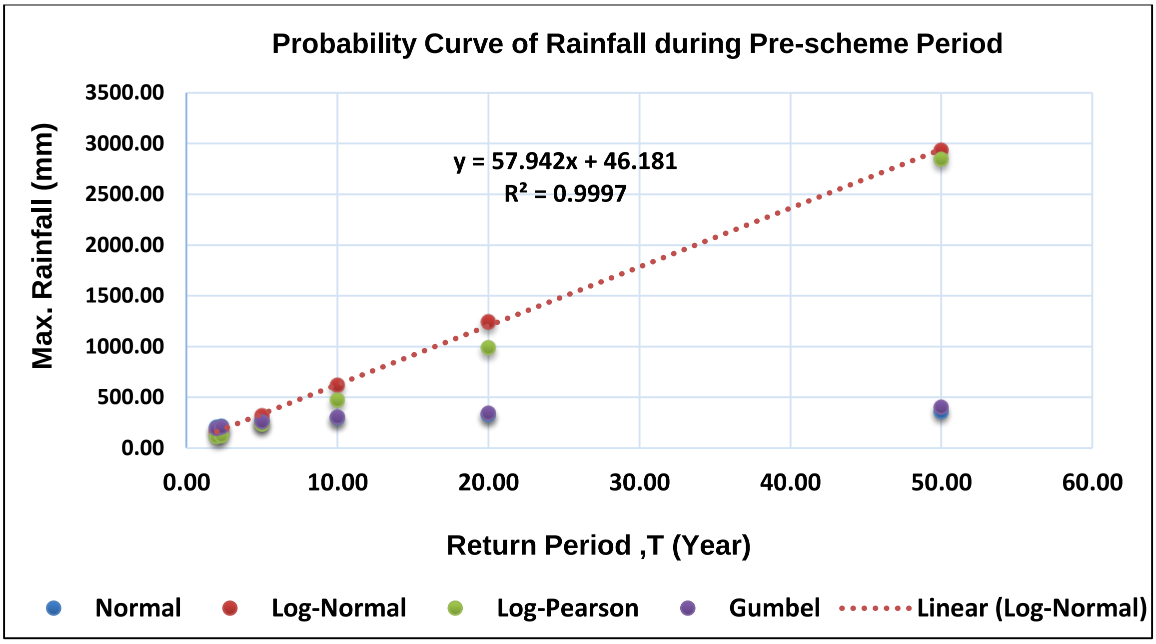

Figure 4.52: Probability curve for maximum rainfall value during the pre-scheme period in Sonamoral Haor scheme

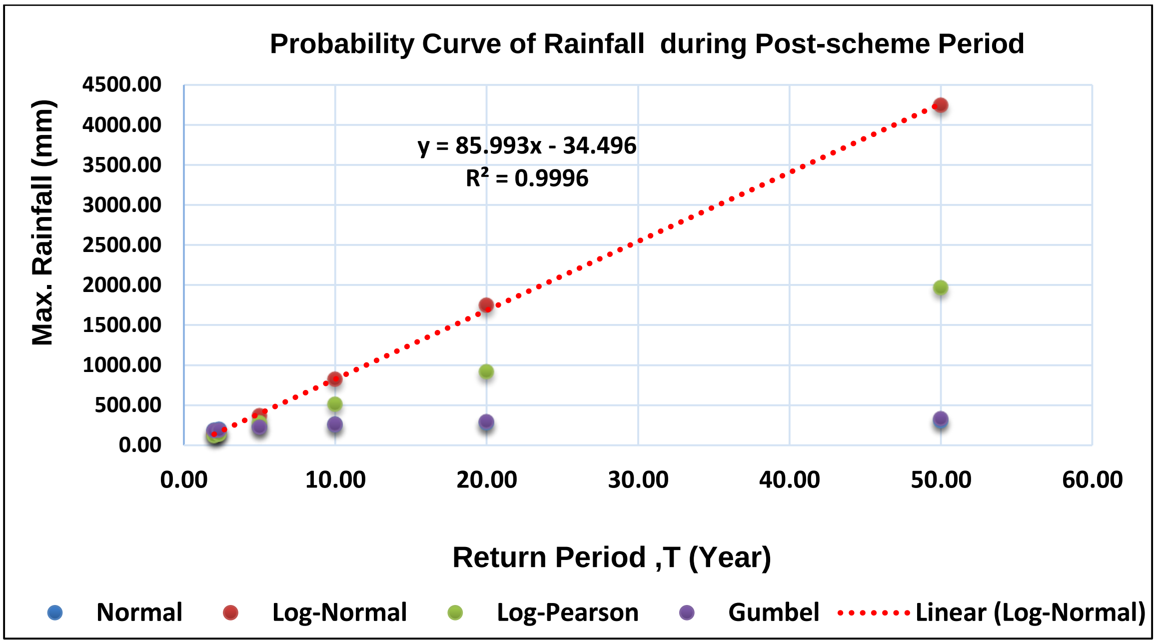

Figure 4.53: Probability curve for maximum rainfall value during the post-scheme period in Sonamoral Haor scheme

Corresponding tables showing the result of frequency analysis of rainfall data for pre-scheme period and post-scheme period in Table 4.3 and Table 4.4 accordingly. From the frequency analysis, it has been observed that the values of rainfall are increasing for both the period of Sonamoral Haor scheme for the selected return period.

Table 4.3: Statistical analysis for maximum rainfall during pre-scheme period of Sonamoral Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	203	267	300	327	358
Log-Normal	165	316	621	1240	2932
Log-Pearson type III	109	236	469	987	2847
Gumbel	191	257	301	344	398

Table 4.4:Statistical analysis for maximum rainfall during post-scheme period of Sonamoral Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	188	235	260	280	303
Log-Normal	139	366	822	1744	4246
Log-Pearson type III	118	280	511	918	1967
Gumbel	179	228	261	292	333

4.3.2 Frequency Analysis of Discharge

Frequency analysis of discharge data for pre-scheme and post-scheme scenario has been described in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Rainfall data has been estimated for 2, 5, 10, 20 and 50 years return period for Shafiq Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble's Distribution. After the frequency analysis, probability curves of discharge have been plotted for the pre-scheme period and post-scheme period in Figure 4.54 and Figure 4.55 accordingly.

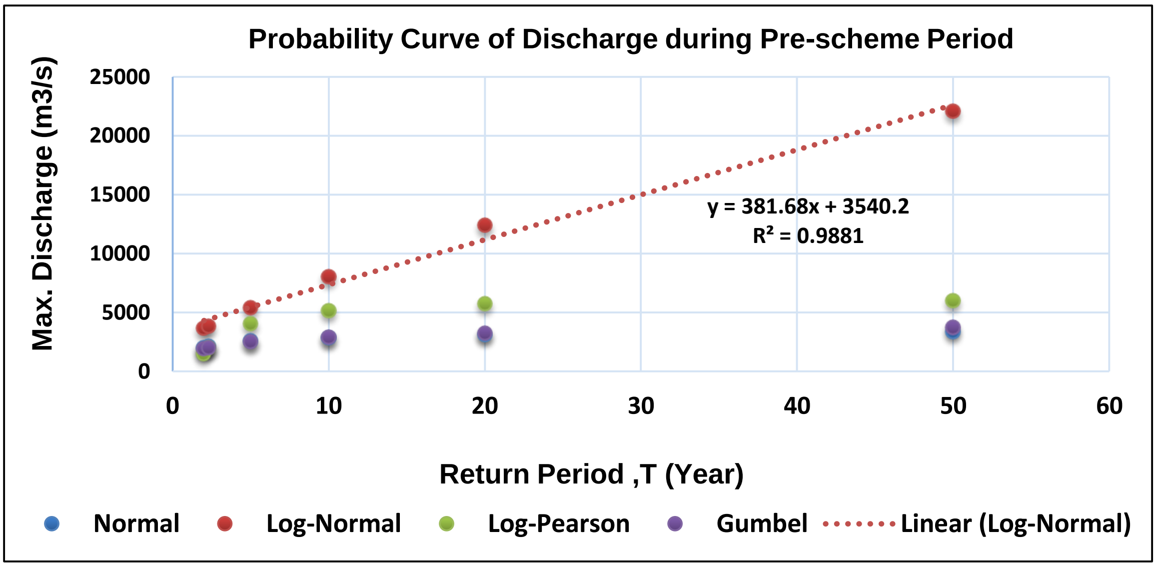

Figure 4.54: Probability curve for maximum discharge value during the pre-scheme period in Shafique Haor scheme

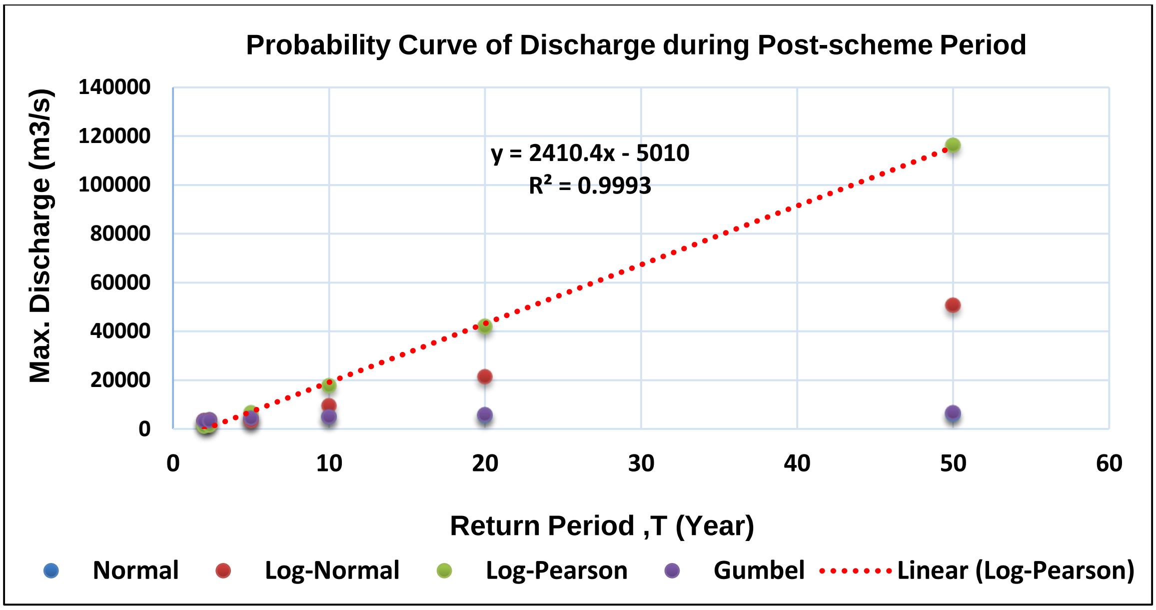

Figure 4.55: Probability curve for maximum discharge value during the post-scheme period in Shafique Haor scheme

Corresponding tables showing the result of frequency analysis of discharge data for pre-scheme period and post-scheme period in Table 4.5 and Table 4.6 accordingly. From the frequency analysis, it has been observed that the values of discharge are increasing for both the period of Shafique Haor scheme for the selected return period.

Table 4.5:Statistical analysis for maximum discharge during pre-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	2016	2565	2853	3090	3357
Log-Normal	3643	5389	8022	12380	22069
Log-Pearson type III	1494	4024	5145	5714	5989
Gumbel	1909	2486	2868	3234	3708

Table 4.6:Statistical analysis for maximum discharge during post-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	3398	4463	5021	5481	5999
Log-Normal	3269	3283	9603	21346	50634
Log-Pearson type III	1131	6551	17732	42037	116197
Gumbel	3190	4309	5050	5761	6681

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Discharge data has been estimated for 2, 5, 10, 20 and 50 years return period for Sonamoral Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble's Distribution.

Probability curve has not been plotted for the pre-scheme period as there is no available discharge data for Sonamoaral Haor scheme. After the frequency analysis, probability curve has been plotted only for the post-scheme period in Figure 4.56.

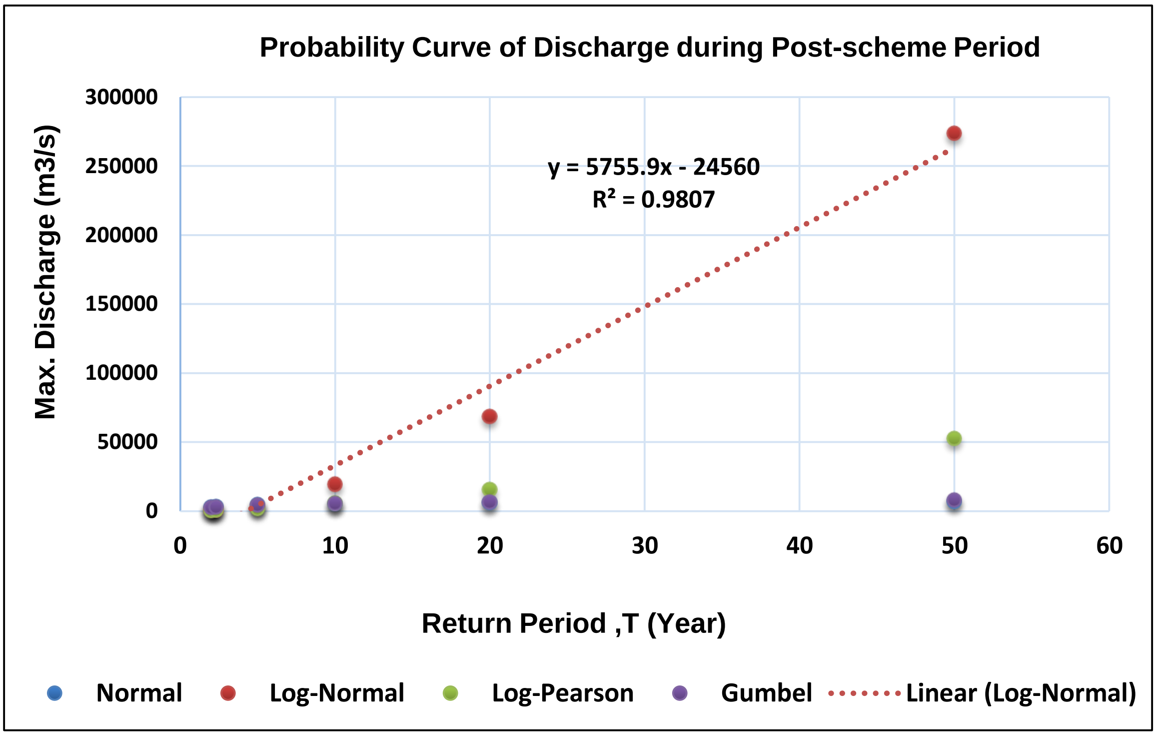

Figure 4.56: Probability curve for maximum discharge value for the post-scheme period in Sonamoral Haor scheme

Corresponding tables showing the result of frequency analysis of discharge data for post-scheme period in Table 4.7. From the frequency analysis, it has been observed that the values of discharge are increasing for post-scheme period of Sonamoral Haor scheme for the selected return period.

Table 4.7: Statistical analysis for maximum discharge during post-scheme period of Sonamoral Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	2955	45856	5439	6143	6936
Log-Normal	920	3511	19420	68562	273709
Log-Pearson type III	393	2032	5823	15476	52626
Gumbel	2637	4350	5483	6571	7979

4.3.3 Frequency Analysis of Water Level

Frequency analysis of discharge data for pre-scheme and post-scheme scenario has been described in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Water level data has been estimated for 2, 5, 10, 20 and 50 years return period for Shafique Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble's Distribution. After the frequency analysis, probability curves of water level have been plotted for the pre-scheme period and post-scheme period in Figure 4.57 and Figure 4.58 accordingly.

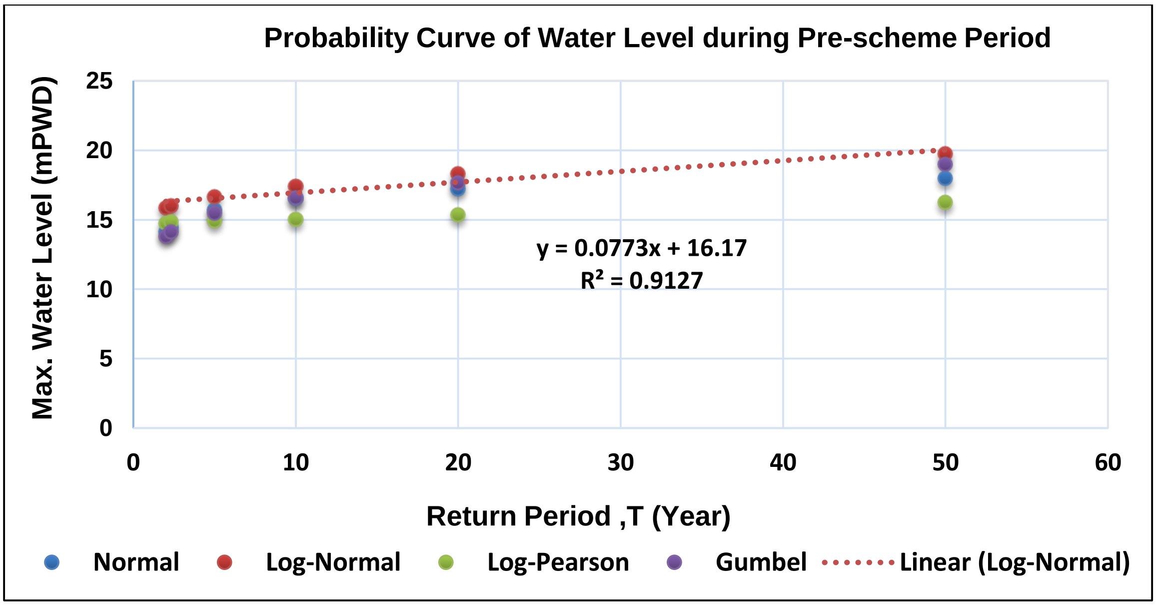

Figure 4.57: Probability curve for maximum water level value during the pre-scheme period in Shafique Haor scheme

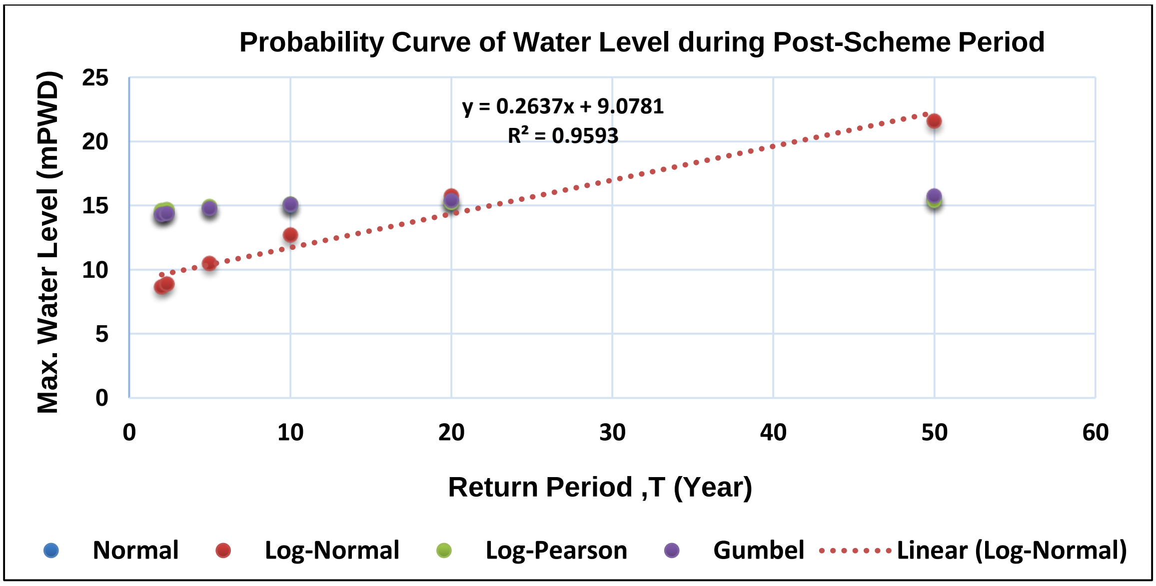

Figure 4.58: Probability curve for maximum water level value during the post-scheme period in Shafique Haor scheme

Corresponding tables showing the result of frequency analysis of water level data for pre-scheme period and post-scheme period in Table 4.8 and Table 4.9 accordingly. From the frequency analysis, it has been observed that the values of water level are increasing for both the period of Shafique Haor scheme for the selected return period.

Table 4.8: Statistical analysis for maximum water level during pre-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	14	16	17	17	18
Log-Normal	16	17	17	18	20
Log-Pearson type III	15	15	15	15	16
Gumbel	14	16	17	18	19

Table 4.9: Statistical analysis for maximum water level during post-scheme period of Shafique Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	14	15	15	15	15
Log-Normal	9.0	10	13	16	22
Log-Pearson type III	15	15	15	15	15
Gumbel EV1	14	15	15	15	16

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Water level data has been estimated for 2, 5, 10, 20 and 50 years return period for Shafique Haor scheme using Normal, Log-normal, Log-pearson type III and Gumble's Distribution. After the frequency analysis, probability curves of water level have been plotted for the pre-scheme period and post-scheme period in Figure 4.59 and Figure 4.60 accordingly.

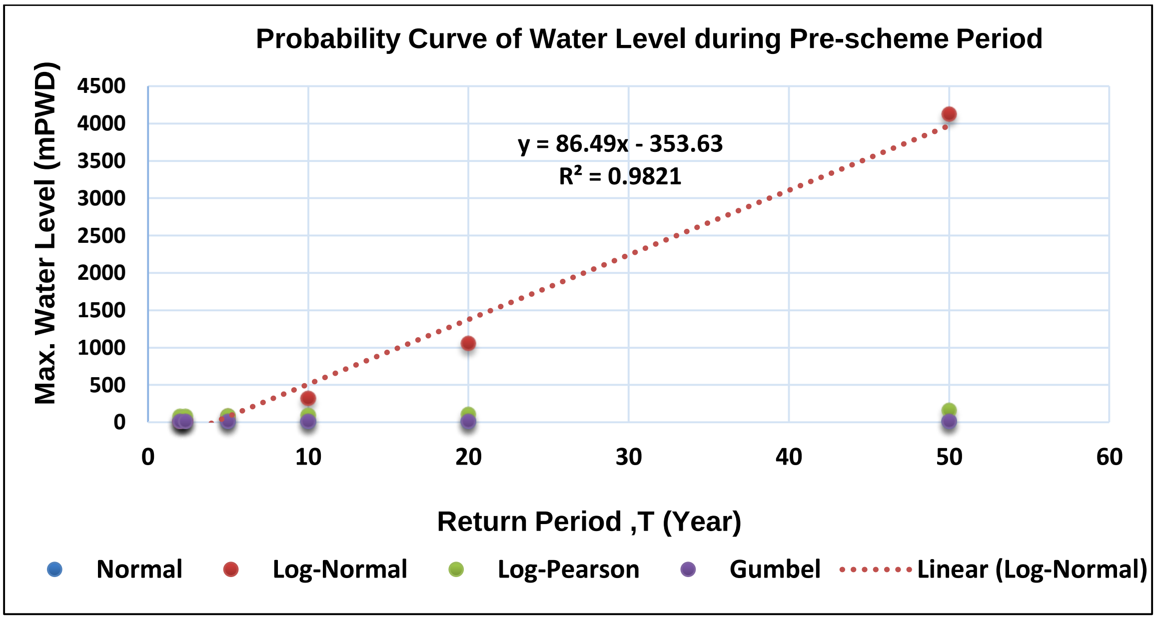

Figure 4.59: Probability curve for maximum water level value during the pre-scheme period in Sonamoral Haor scheme

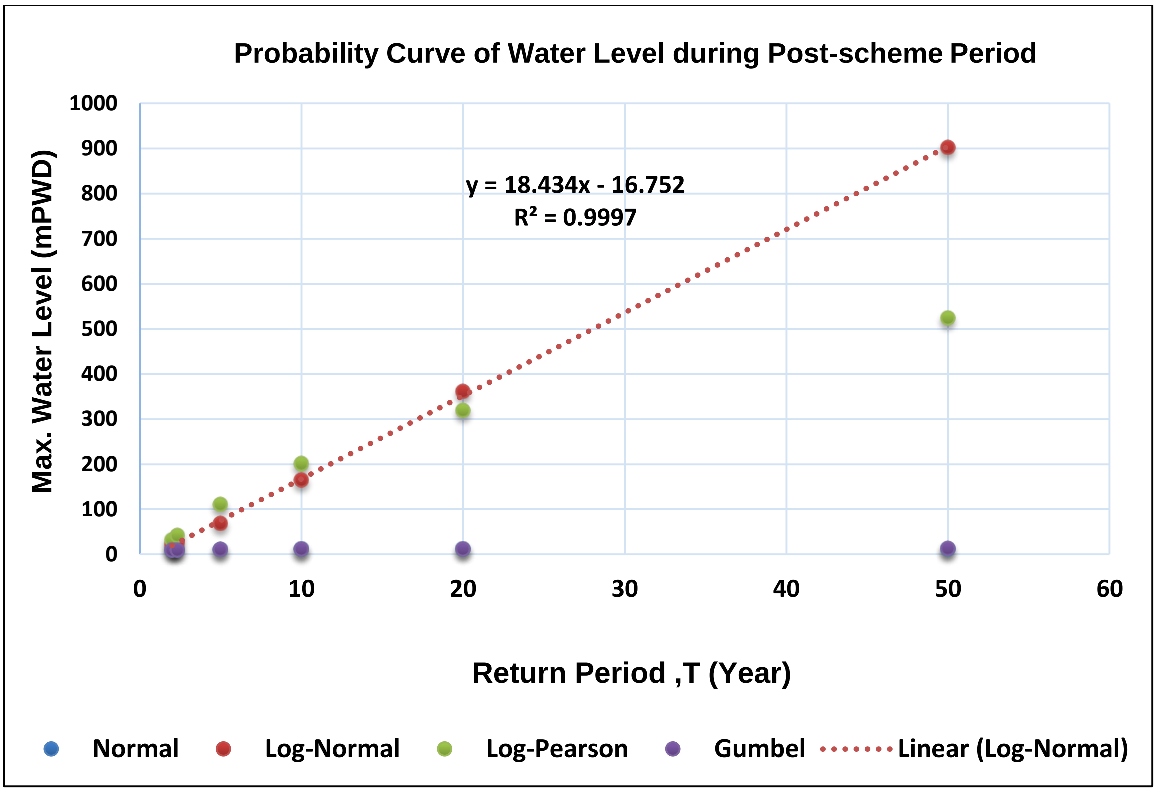

Figure 4.60: Probability curve for maximum water level value during the post-scheme period in Sonamoral Haor scheme

Corresponding tables showing the result of frequency analysis of water level data for pre-scheme period and post-scheme period in Table 4.10 and Table 4.11 accordingly. From the frequency analysis, it has been observed that the values of water level are increasing for both the period of Sonamoral Haor scheme for the selected return period.

Table 4.10: Statistical analysis for maximum water level during pre-scheme period of Sonamoral Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	9.0	10	10	11	11
Log-Normal	14	80	318	1052	4123
Log-Pearson type III	76	87	90	105	158
Gumbel	9.0	10	10	11	12

Table 4.11: Statistical analysis for maximum water level during post-scheme period of Sonamoral Haor scheme

Distribution	Years				
	2.00	5.00	10.00	20.00	50.00
Normal	10	11	12	12	13
Log-Normal	22	69	165	361	902
Log-Pearson type III	32	111	201	320	525
Gumbel	10	11	12	12	13

4.4 Landsat Image Analysis

Several image processing techniques have been introduced in recent decades for the extraction of water features from satellite data. The Normalized Difference Water Index (NDWI) was developed for the extraction of water features from Landsat imagery. It is the most widely used water indices. In this study, Landsat satellite images has been analyzed using the calculation of Normalized Difference Water Index (NDWI). Normalized Difference Water Index (NDWI) has been calculated to detect the change of water area for different years and spatial changes. Maps showing the Normalized Difference Water Index (NDWI) values have been prepared during the period of pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November) of Shafique Haor scheme and Sonamoral Haor scheme. The images have been downloaded from different Landsat satellites and the results has been organized accordingly for pre-scheme and post-scheme scenario. The higher water area observed in the month of June to October in image which might be presence of surface water by rain. These images are not Scan Line Corrected (SLC) images. For this reason, the missing values have been classified as **"**No Data**"** value and then the Normalized Difference Water Index (NDWI) is calculated. Normalized Water Index Difference (NDWI) has been conducted according to the procedures explained in the theory and methodology section.

4.4.1 Assessment of Water Area for Different Year

Normalized Difference Water Index (NDWI) is a remote sensing derived index for detecting the water area change. The pre-scheme scenario and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme has been described accordingly in the following section.

(a) Pre-scheme Scenario of Shafique Haor Scheme

After the calculation of Normalized Difference Water Index (NDWI), map has been prepared for every image of different years. Figure 4.61 and Figure 4.62 displays the output generated from the analysis of 1990 to 1996 Landsat imagery during pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Landsat imageries downloaded from Landsat 5. For the Normalized Difference Water Index (NDWI) analysis, Green and NIR images has been used. Green color represents land area and blue color represents water surface. The images have a spatial resolution of 30 m. The figures has been presented on the following pages.

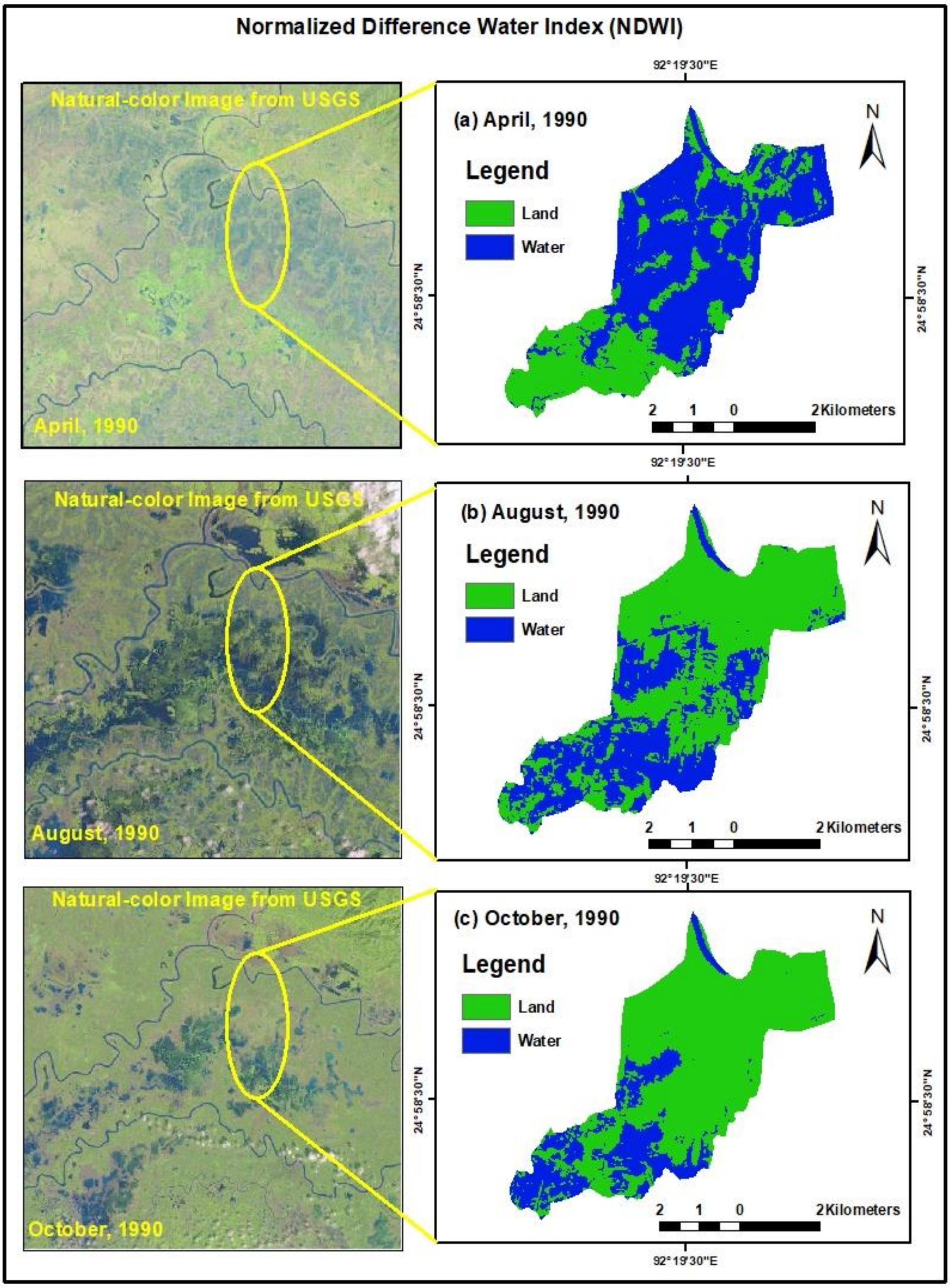

Figure 4.61: Water surface area detection map of Shafique Haor scheme for the year 1990 (a) April, (b) August and (c) October

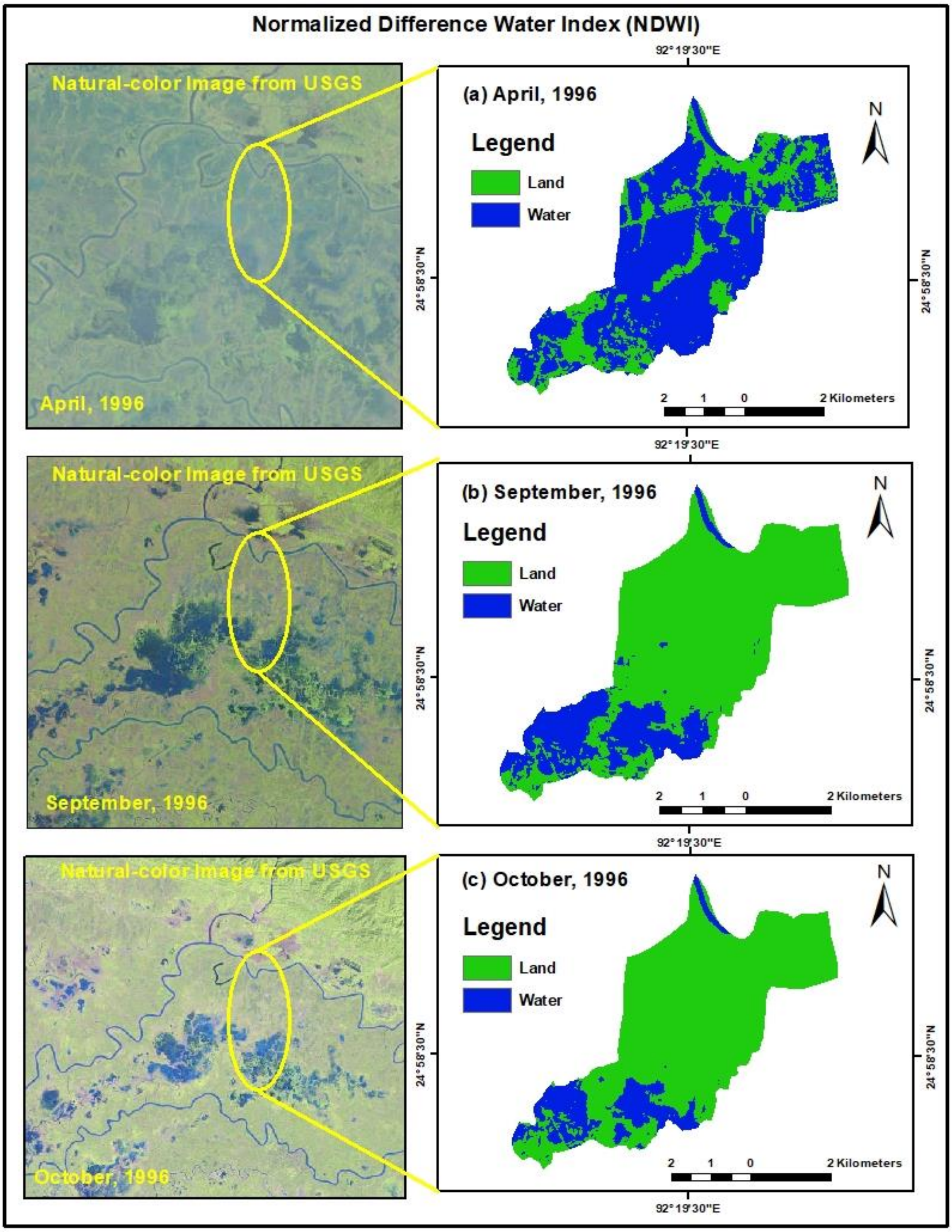

Figure 4.62: Water surface area detection map of Shafique Haor scheme for the year 1996 (a) April, (b) September and (c) October

From the analysis it has been observed that flash floods in the Shafique Haor scheme occurred in mid-April before construction of submergible embankment. The flash floods mainly flows through the Surma and Kushiyara rivers due to heavy rainfall in the upstream region. Floodwater enters in the Shafique Haor scheme during pre-monsoon period. In the pre-monsoon period, about 63-70% of scheme area got inundated and water stayed for about 3-4 months.

The flooding of Shafique Haor scheme also depends on the flooding of Chatal Haor situated on the southwestern part of the scheme. Floodwater enters through southwestern side from Kushiyara River into Chatal Haor first. Getting the Chatal Haor over flooded, water enters into the Shafique Haor scheme by overtopping. Flood water of the Surma River enters into the haor from the north direction. Relatively more flood water enters into the haor from Kushiyara River than that of Surma River. Flash flood inundate the low lying area very rapidly and the people do not get the chance to harvest their standing crop in the agricultural land.

From the Figure 4.61 and Figure 4.62, it has been observed that the land area of Shafique Haor scheme from the year 1990 to 1996 has been inundated and maximum area went under water during the month of pre-monsoon and monsoon season accordingly.

For the year 1990, the water area was 15.1 km^2 in April, 8.7 km^2 in August and 5.5 km^2 in October. For the year 1996, the water area was 5.2 km^2 in September and 3.5 km^2 in October and in April, the water cover area was 16.8 km^2 which is 3.23 times of water area in September and 4.8 times of water area in October. The ratio of land and water 5.8 is highest in pre-scheme period in October, 1996. Results from the images of Landsat 5 from the year 1990 to 1996 are presented in the Table 4.12.

Table 4.12: Shafique Haor scheme area derived from Landsat 5 images for the year 1990 to 1996

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
1990	April	15.1	62.5	9.1	37.5	0.6
	August	8.7	35.8	15.5	64	1.8
	October	5.5	22.6	18.7	77.4	3.4
1996	April	16.8	69.8	7.3	30.2	0.4
	September	5.2	21.5	18.9	78.5	3.6
	October	3.5	14.6	20.6	85.4	5.8

Figure 4.63 shows that the water area for different year's corresponding to the month. From the Figure 4.63, it has been observed that the flash flood occurred in April for both the year of 1990 and 1996. The inundated area simultaneously change its pattern.

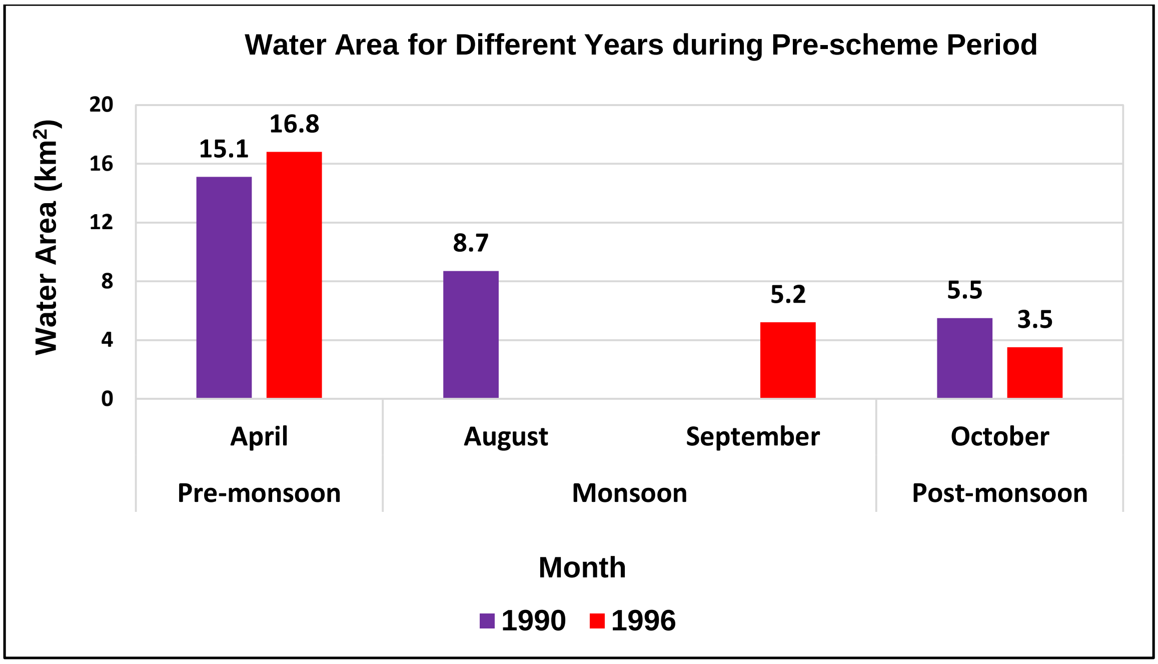

Figure 4.63: Water area for different years of pre-scheme period in Shafique Haor scheme

(b) Post-scheme Scenario of Shafique Haor Scheme

After the calculation of Normalized Difference Water Index (NDWI), map has been prepared for every image of different years. Figure 4.64 to Figure 4.66 displays the output generated from the analysis of 2008 to 2018 Landsat imagery during pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Landsat imageries downloaded from Landsat 5, Landsat 7 and Landsat 8. For the Normalized Difference Water Index (NDWI) analysis, Green and NIR images has been used. Green color represents land area and blue color represents water surface. The images have a spatial resolution of 30 m. The figures has been presented on the following pages.

From the analysis it has been observed that flash floods in the Shafique Haor scheme occurred in May after construction of submergible embankment. After implementation of the submersible embankment, entrance of flash floods into Shafique Haor scheme got delayed by almost one to two week. Local farmers get the chance to harvest their standing crop in the agricultural land. Thereafter, the flash floods overtop and breaching the submersible embankment in May and inundates the entire haor. In the post-monsoon period, about 26%-67% of scheme area got inundated and water stayed for about 3-4 months. Major public cuts near Hatir khal regulator and near Chowa beel regulator causes flooding problems in this scheme area. The height of overall submersible embankment remained as low and 8 breaches are located at Matijura; Mathargram, Nayamati and Captanpur mouzas which also causes flash flood problems in Shafique Haor scheme. However, the flash flood sometimes comes early due to excessive rainfall in the upper catchment like it happened in 2004, 2017and 2019.

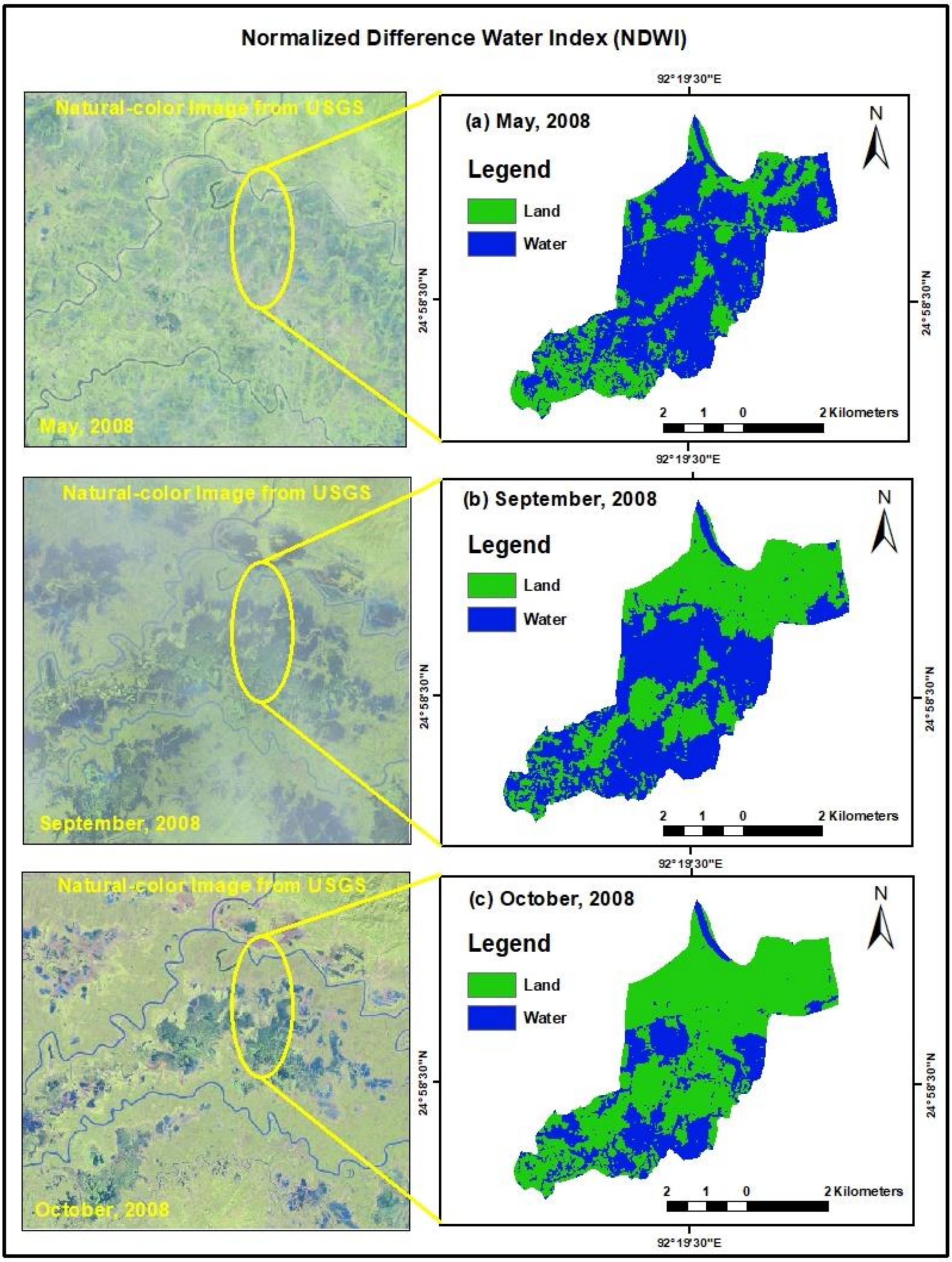

Figure 4.64: Water surface area detection map of Shafique Haor scheme for the year 2008 (a) May, (b) September and (c) October

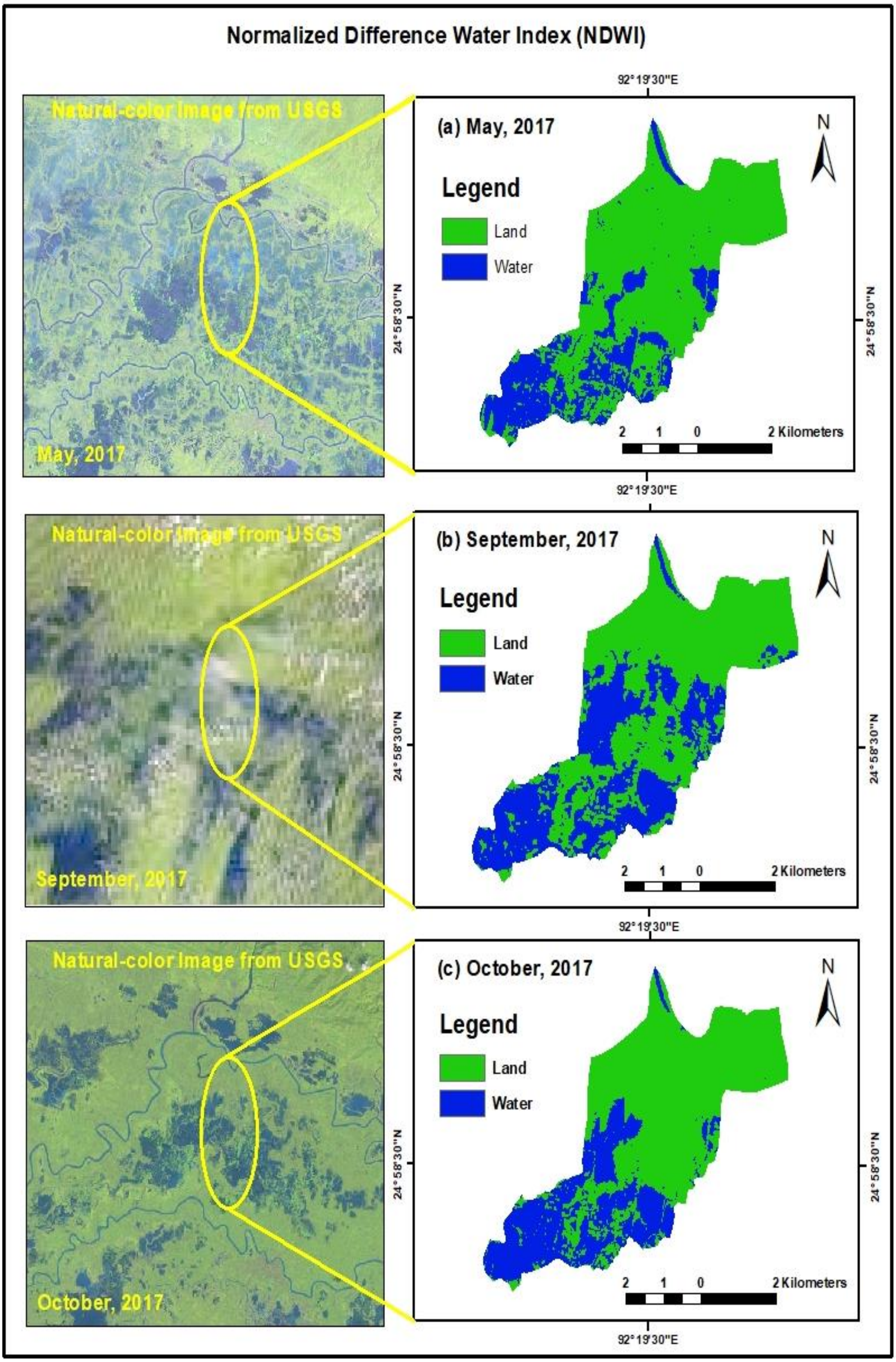

Figure 4.65: Water surface area detection map of Shafique Haor scheme for the year 2017 (a) May, (b) September and (c) October

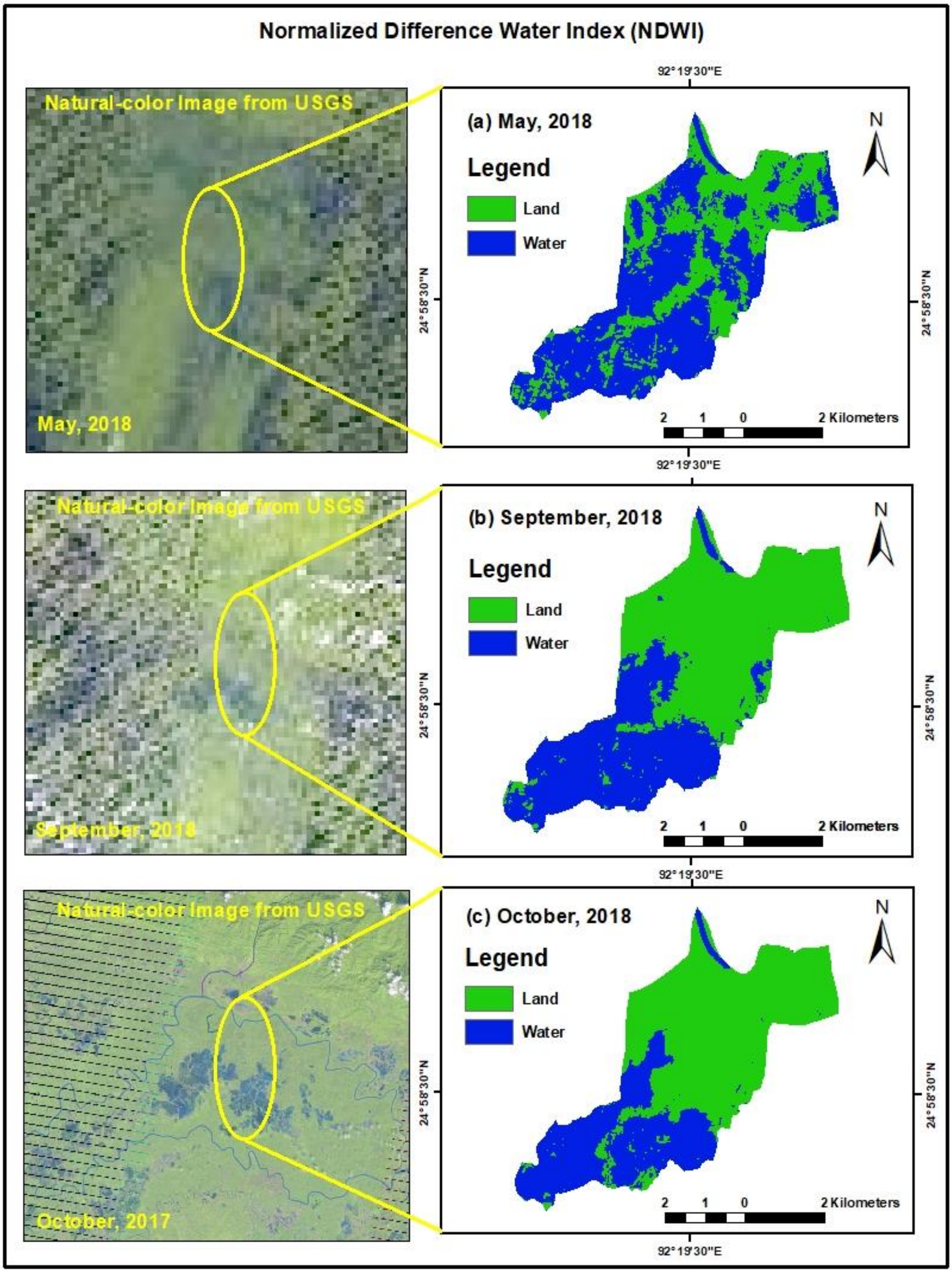

Figure 4.66: Water surface area detection map of Shafique Haor scheme for the year 2018 (a) May, (b) September and (c) October

From the Figure 4.64 to Figure 4.66, it has been observed that land area of Shafique Haor scheme from the year 2008 to 2018 has been inundated and maximum area went under water during the month of pre-monsoon and monsoon season accordingly.

For the year 2008, water area was 16.1 km^2 in May, 12.2 km^2 in September and 6.7 km^2 in October. For the year 2017, the water area was 6.2 km^2 in May, 9.2 km^2 in September and 7.8 km^2 in October. For the year 2018, the water area was 9.9 km^2 in September and 8.4 km^2 in October and in May, the water cover area is 14.6 km^2 which is 1.47 times of water area in September and 1.74 times of water area in October. The ratio of land and water 2.9 is highest in post-scheme period in May, 2017. Results from the images of Landsat 5, Landsat 7 and Landsat 8 from the year 2008 to 2018 are presented in the Table 4.13.

Table 4.13: Shafique Haor scheme area derived from Landsat 5, Landsat 7 and Landsat 8 images for the year 2008 to 2018

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2008	May	16.1	66.9	8.0	33.1	0.5
	September	12.2	50.7	11.9	49.3	1.0
	October	6.7	27.6	17.5	72.4	2.6
2017	May	6.2	25.8	17.9	74.2	2.9
	September	9.2	38.3	14.9	61.7	1.6
	October	7.8	32.2	16.4	67.8	2.1
2018	May	14.6	29.9	9.5	70.1	2.3
	September	9.9	41.0	14.2	59.0	1.4
	October	8.4	34.9	15.7	65.1	1.9

Figure 4.67 shows that the water area for different year's corresponding to the month. From the Figure 4.67, it has been observed that the flash flood occurred in May for the year of 2008, 2017 and 2018. The inundated area simultaneously change its pattern.

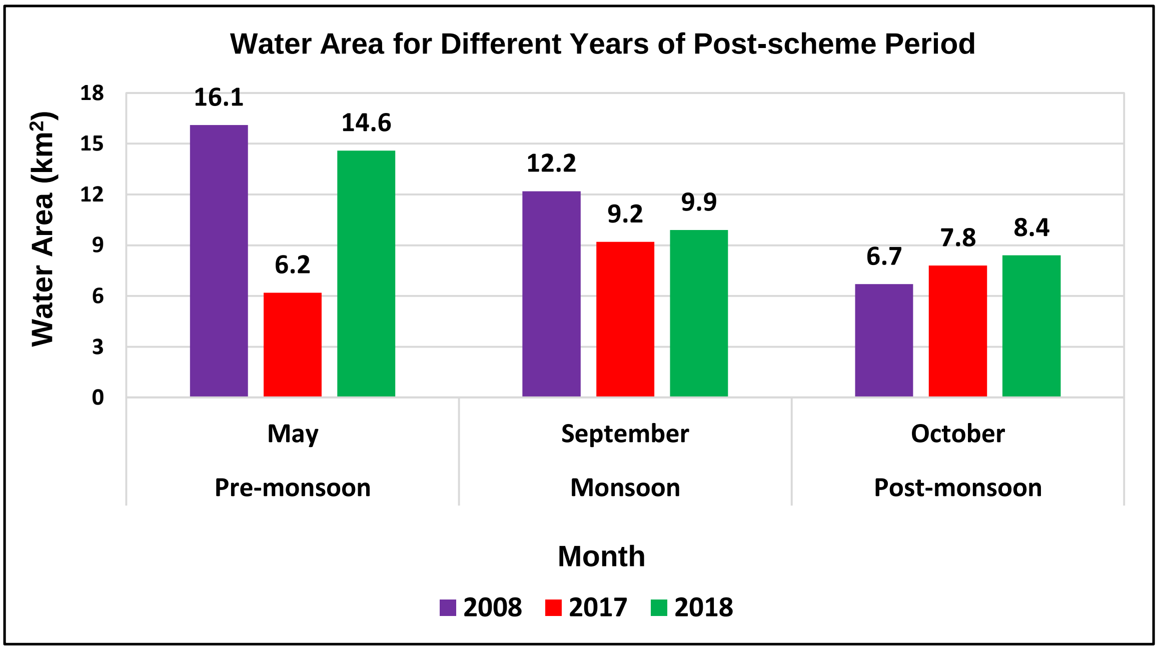

Figure 4.67: Water area for different years of post-scheme period in Shafique Haor scheme

(c) Pre-scheme Scenario of Sonamoral Haor Scheme

After the calculation of Normalized Difference Water Index (NDWI), map has been prepared for every image of different years. Figure 4.68 and Figure 4.69 displays the output generated from the analysis of 1978 to 1979 Landsat imagery during pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Landsat imageries downloaded from Landsat 2 and Landsat 3. There is no available images of Sonamoral Haor scheme during pre-scheme period. For the Normalized Difference Water Index (NDWI) analysis, Green and NIR images has been used. Green color represents land area and blue color represents water surface. The images have a spatial resolution of 60 m. The figures has been presented on the following pages.

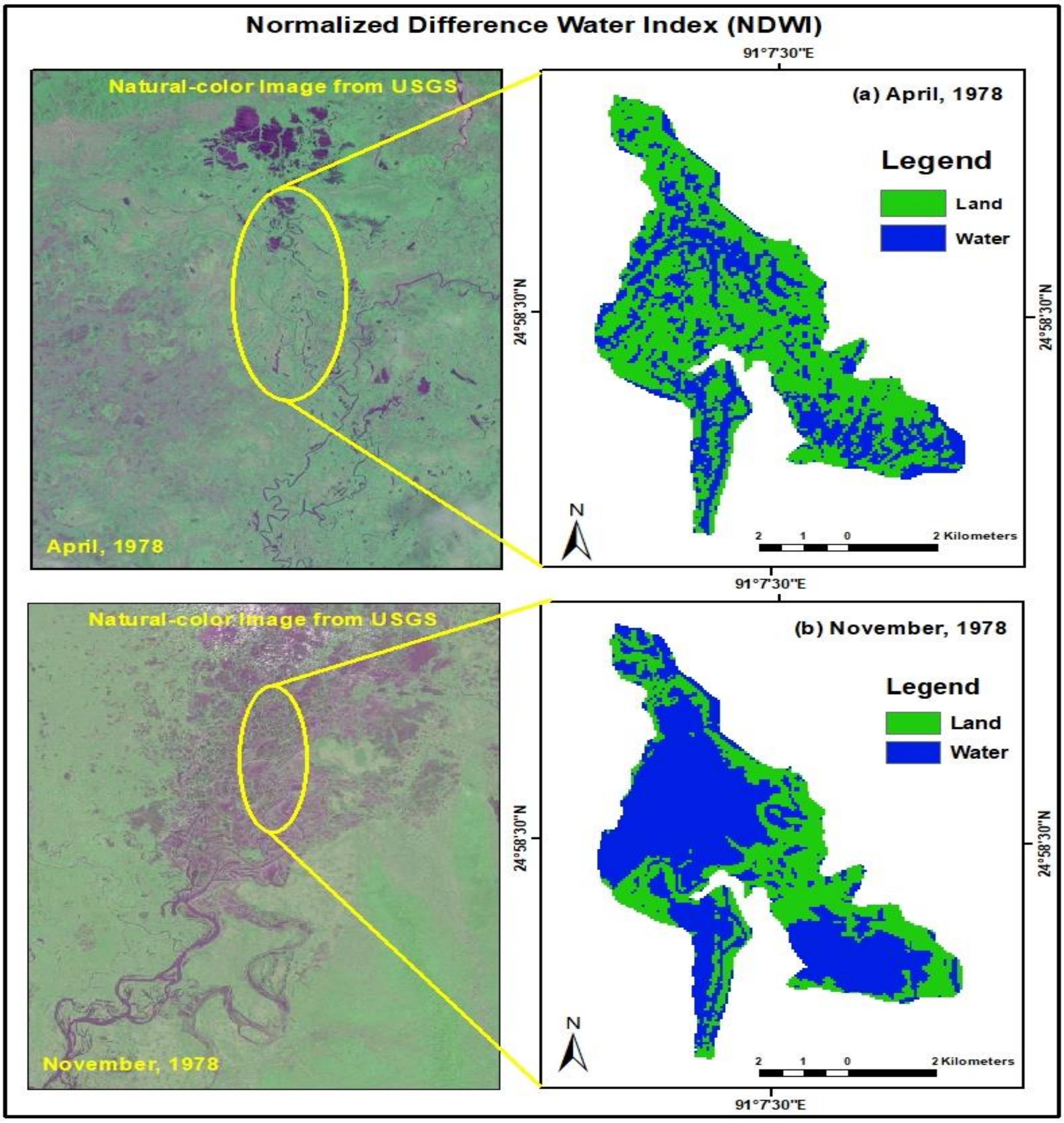

Figure 4.68: Water surface area detection map of Sonamoral Haor scheme for the year 1978 (a) April and (b) November

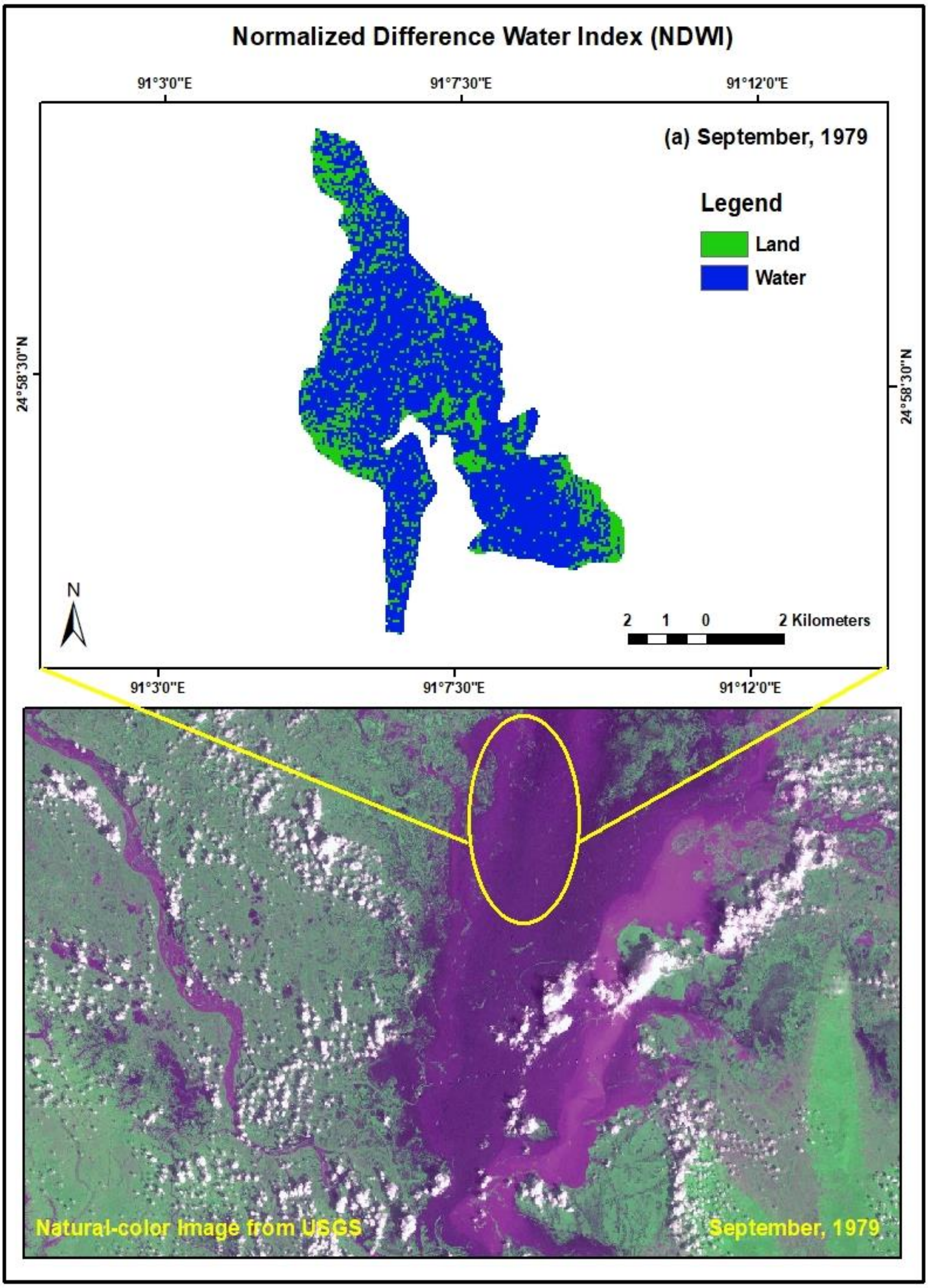

Figure 4.69: Water surface area detection map of Sonamoral Haor scheme for the year 1979 (a) September

From the analysis it has been observed that flash floods in the Sonamoral Haor scheme occurred in mid-April before construction of submergible embankment. All most every year, crops are damaged due to early flash flood. The flash floods mainly flows through different rivers due to heavy rainfall in the upstream region. Floodwater enters in the Sonamoral Haor scheme during pre-monsoon period. Flood water mainly enters in the Sonamoral Haor scheme by Bauli River on the North-East, Someswari River on the West, Konai River on the south and Surma River on the East side. In the pre-monsoon period, about 36% of scheme area got inundated and water stayed for about 3-4 months. This backwater as well as the water coming from upstream of the river jointly creates tremendous pressure on the embankment, resulting in overtopping and breaching of the embankment at several locations through which water easily enter into the haor. There are no available images for monsoon period in 1978.

From the Figure 4.68 and Figure 4.69, it has been observed that land area of Sonamoral Haor scheme from the year 1978 to 1979 has been inundated and maximum area went under water during the month of pre-monsoon and monsoon season accordingly. Figure 4.69 shows only image for monsoon period of 1979 as there are no available images during pre-monsoon and post-monsoon season in Sonamoral Haor scheme for the pre-scheme period. The image of monsoon season of 1979 has been taken to compare the changes with pre-monsoon and post-monsoon season of 1978 for better understanding of the water area change in different seasons during the pre-scheme period.

For the year 1978, the water area was 13.8 km^2 in April and 23.8 km^2 in November. For the year 1979, the water area was 28.6 km^2 in September. There is no available image of monsoon season in 1978 and no available image of pre-monsoon and post-monsoon season in 1979. The ratio of land and water 1.8 is highest in pre-scheme period in April, 1978. Results from the images of Landsat 2 and Landsat 3 from the year 1978 to 1979 has been presented in the Table 4.14.

Table 4.14: Sonamoral Haor scheme area derived from Landsat 2 and Landsat 3 images for the year 1978 to 1979

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
1978	April	13.8	36.2	24.3	63.8	1.8
	November	23.8	62.5	14.3	37.5	0.6
1979	September	28.6	75.2	9.5	24.8	0.3

Figure 4.70 shows that the water area for different year’s corresponding to the month. From the Figure 4.70, it has been observed that the flash flood occurred in April for the year of 1978 in Sonamoral Haor scheme. The inundated area simultaneously change its pattern.

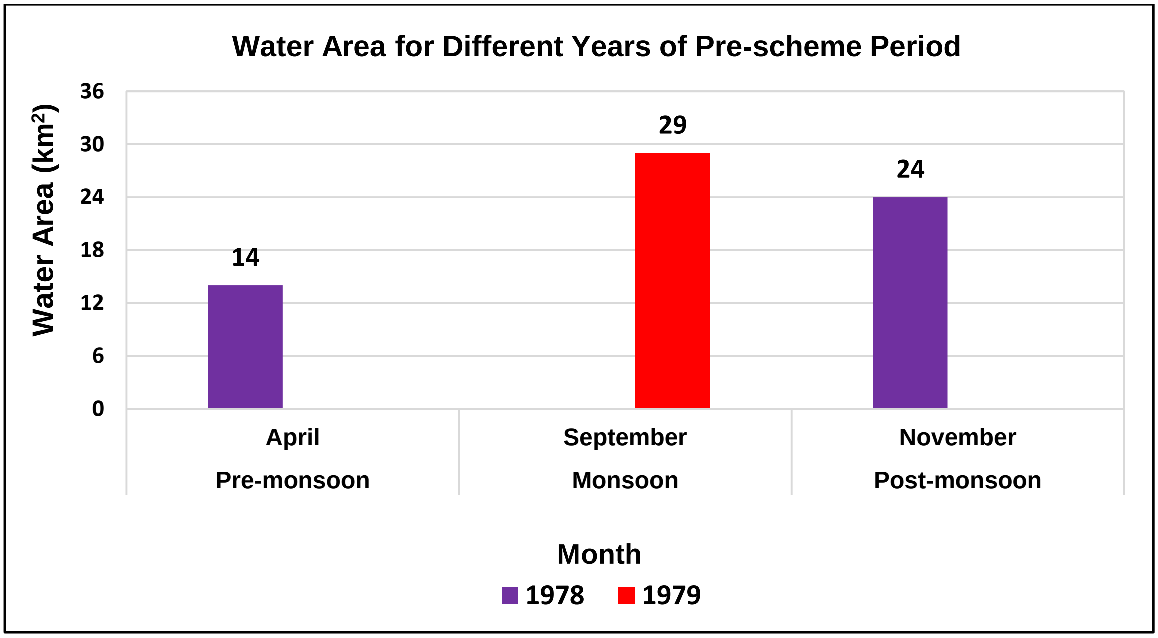

Figure 4.70: Water area for different years of pre-scheme period in Sonamoral Haor scheme

(d) Post-scheme Scenario of Sonamoral Haor Scheme

After the calculation of Normalized Difference Water Index (NDWI), map has been prepared for every image of different years. Figure 4.71 to Figure 4.73 displays the output generated from the analysis of 2010 to 2018 Landsat imagery during pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Landsat imageries downloaded from Landsat 5 and Landsat 8. For the Normalized Difference Water Index (NDWI) analysis, Green and NIR images has been used. Green color represents land area and blue color represents water surface. The images have a spatial resolution of 30 m. The figures has been presented on the following pages.

From the analysis it has been observed that flash floods in the Sonamoral Haor scheme occurred in May after construction of submergible embankment. After implementation of the submersible embankment, entrance of flash floods into Sonamoral Haor scheme supposed to inundate one or two weeks later. Local farmers get the chance to harvest their standing crop in the agricultural land. Thereafter, the flash floods overtop and breaching the submersible embankment in last week of April and May and inundates the entire haor. In the post-monsoon period, about 30-40% of scheme area got inundated in 2010 and 2018. But about 93% of scheme area got inundated in 2017. However, the flash flood sometimes comes early due to excessive rainfall in the upper catchment like it happened in 2004, 2017and 2019. Flash flood enters into this haor from the Dhankunia Haor due to this low height of the submersible embankment and several major breaches which are located near the following villages of Shukhair Nij, Noagaon, Jarakona, Sundarpur (locally known as Koyra), Jurdhar, Doarar, Islampur, Binadpur, Najarpur, Haripur, Joysree and Bhadgaon Bade which also causes flash flood problems in Sonamoral Haor scheme. Wave erosion cause damages to this submersible embankment and the siltation on the Boulai River cause flash flood in Sonamoral Haor scheme as well.

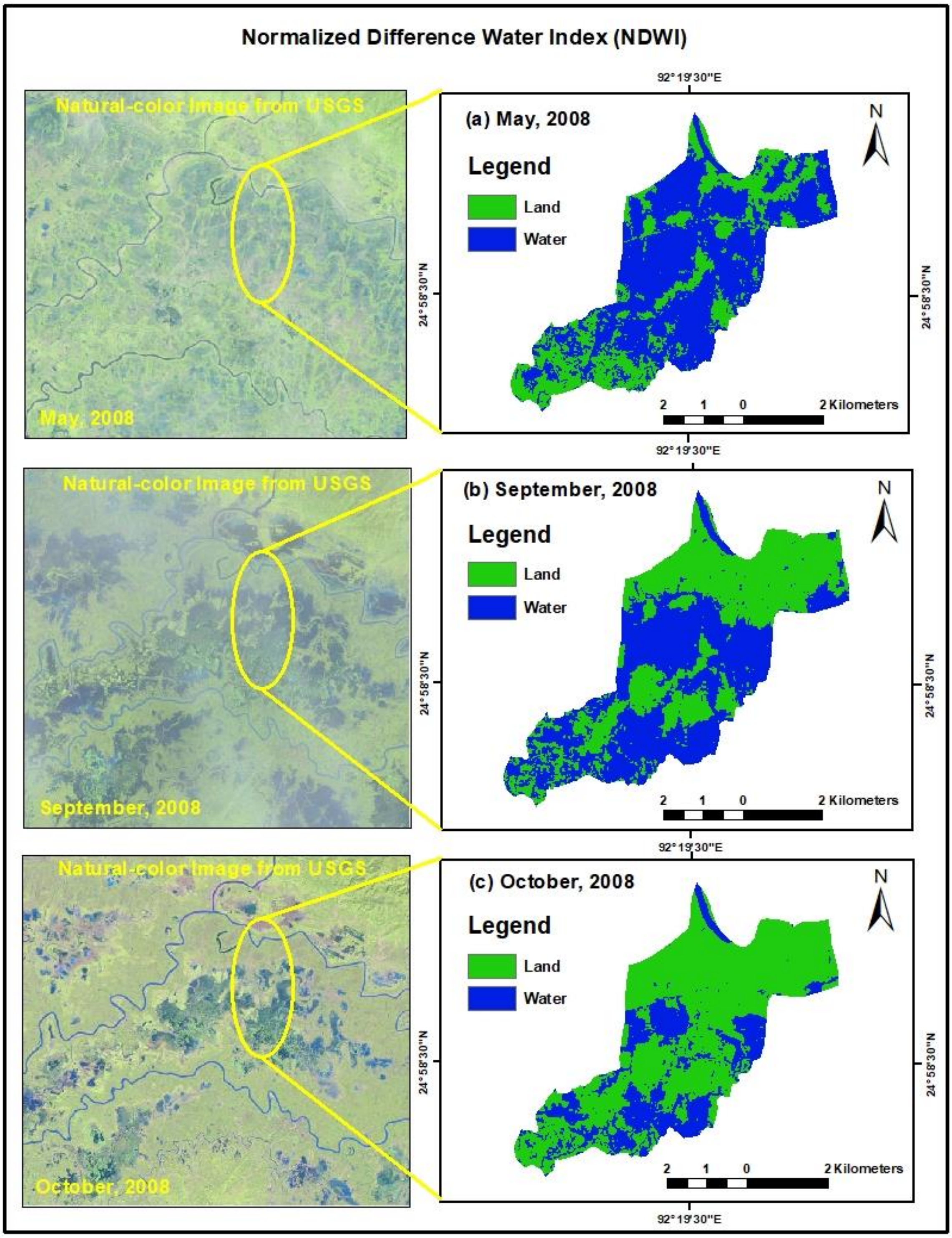

Figure 4.71: Water surface area detection map of Sonamoral Haor scheme for the year 2010 (a) April, (b) August and (c) October

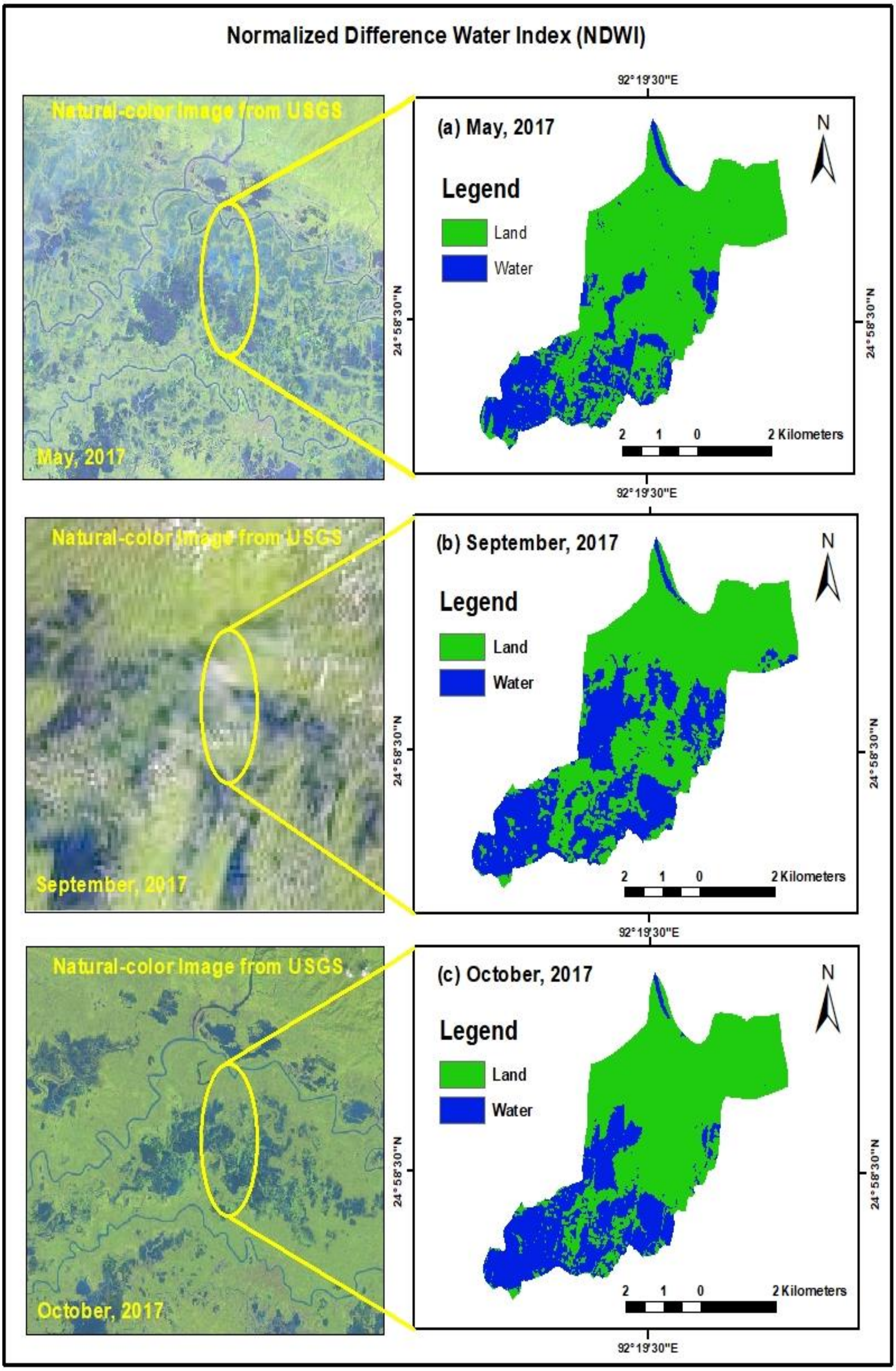

Figure 4.72: Water surface area detection map of Sonamoral Haor scheme for the year 2017 (a) May, (b) June and (c) October

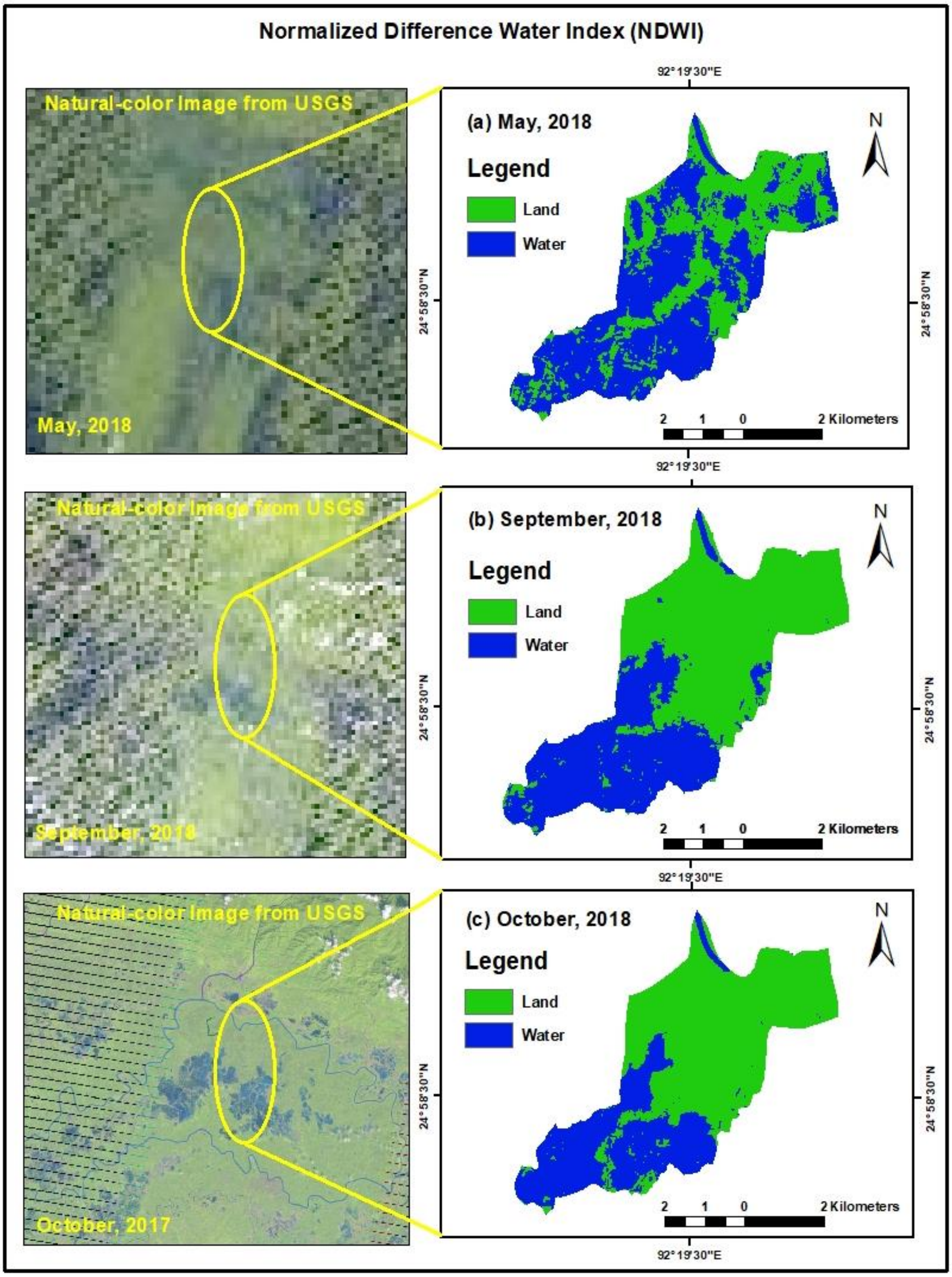

Figure 4.73: Water surface area detection map of Sonamoral Haor scheme for the year 2018 (a) May, (b) September and (c) October

This haor is very deeply to deeply flooded during the monsoon season. The early flooding of the haor is largely caused by the linked river systems and the external hoars that are residing outside the Sonamoral haor. HYV Boro remains more in the vulnerable condition against flash flood, as it is harvested one month later than the local variety. But the crops grown in these areas are frequently damaged by flash flood in the month of April and May. This is the major problem in the agricultural sector in the haor region as well in Sonamoral Haor scheme associated with the crop loss due to pre-monsoon flash flood. Besides that physical condition of the Daulatpur Regulator (2-vent), Jurdhar Regulator (3-vent), Doarar Regulator (2-vent) and Kukurmara Regulator (2-vent) is poor and non-functional which is another reason of early flash flood. Raise this section of the submersible embankment height up to 3 to 4 feet and firm protective work for breached locations in respective locations may more delay the entrance of flash floods into the Sonamoral Haor scheme.

From the Figure 4.71 to Figure 4.73, it has been observed that land area of Sonamoral Haor scheme from the year 2010 to 2018 has been inundated and maximum area went under water during the month of pre-monsoon and monsoon season accordingly.

For the year 2010, the water area was 15.2 km^2 in April, 29.4 km^2 in August and 32.3 km^2 in October. For the year 2017, the water area was 35.1 km^2 in May, 34.9 km^2 in June and 35.4 km^2 in October. For the year 2018, the water area was 11.3 km^2 in May and 34 km^2 in October and in September, the water cover area was 34.2 km^2 which is 3.03 times of water area in May and 3.01 times of water area in October. The ratio of land and water 2.3 is highest in post-scheme period in May, 2018. Results from the images of Landsat 5 and Landsat 8 from the year 2010 to 2018 has been presented in the Table 4.15.

Table 4.15: Sonamoral Haor scheme area derived from Landsat 5 and Landsat 8 images for the year 2010 to 2018

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land **:** Water
2010	April	15.2	39.0	23.7	61.0	1.6
	August	29.4	77.7	8.4	22.3	0.3
	October	32.3	85.4	5.5	14.6	0.2
2017	May	35.1	92.8	2.7	7.2	0.1
	June	34.9	92.3	2.9	7.7	0.1
	October	35.4	93.6	2.4	6.4	0.1
2018	May	11.3	29.9	26.5	70.1	2.3
	September	34.2	90.4	3.6	9.6	0.1
	October	34.0	90.0	3.8	10.0	0.1

Figure 4.74 shows that the water area for different year’s corresponding to the month. From the Figure 4.74, it has been observed that the flash flood occurred at the end of the April and in May for the year of 2008, 2017 and 2018. But the water area in pre-monsoon of 2010 and 2018 was less compared to 2017. The inundated area simultaneously change its pattern.

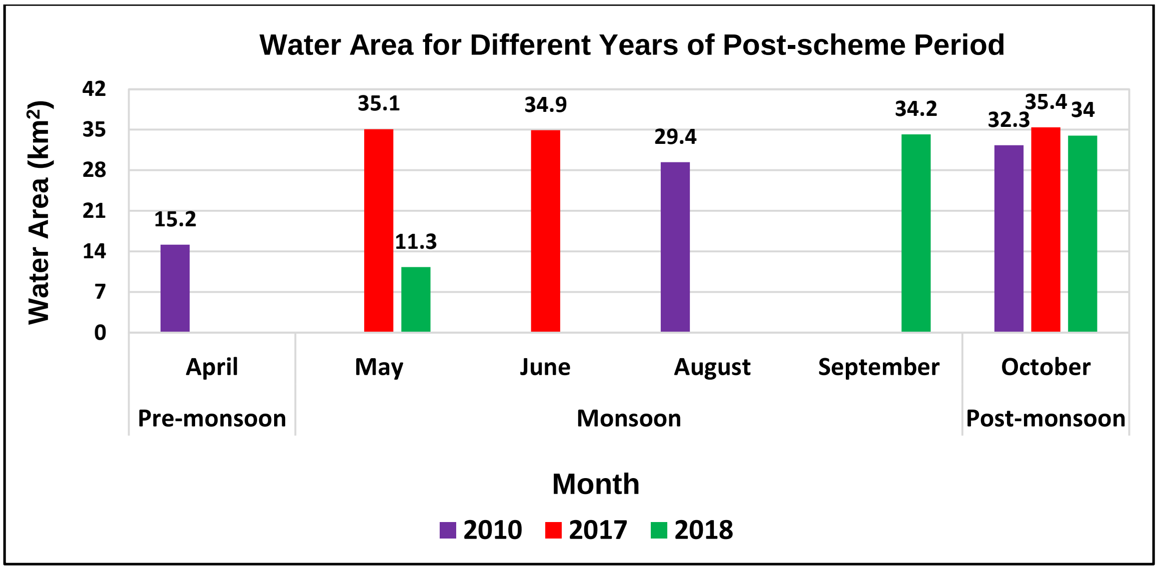

Figure 4.74: Water area for different years of post-scheme period of Sonamoral Haor scheme

4.4.2 Spatial Changes of Water Area

Normalized Difference Water Index (NDWI) has been calculated for detecting the water area change. Here in the following section, the scenario of water area change for Shafique Haor scheme and Sonamoral Haor scheme has been described. The pre-scheme scenario and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme has been described accordingly in the following section.

(a) Pre-scheme Scenario of Shafique Haor Scheme

Water cover maps for the Shafique Haor scheme has been developed by using the Normalized Difference Water Index (NDWI) values from the year 1990 to 1996. Figure 4.75 to Figure 4.77 shows spatial distribution of water areas for the Shafique Haor scheme during the pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Water area is shown in blue and land area is shown in green.

From Figure 4.75, it has been observed that land area of Shafique Haor scheme is small as maximum scheme area is inundated due to pre-monsoon flash flood. Pre-monsoon flash flood from the neighboring hilly region of India is a common phenomenon which damages the only possible Boro crop of the region. Most of the rivers in these area are originated from nearby area of India. These rivers are extremely flashy that is characterized by sudden and wide variation in flows as a result of excessive rainfall. The figure of pre-monsoon season has been presented on the following pages.

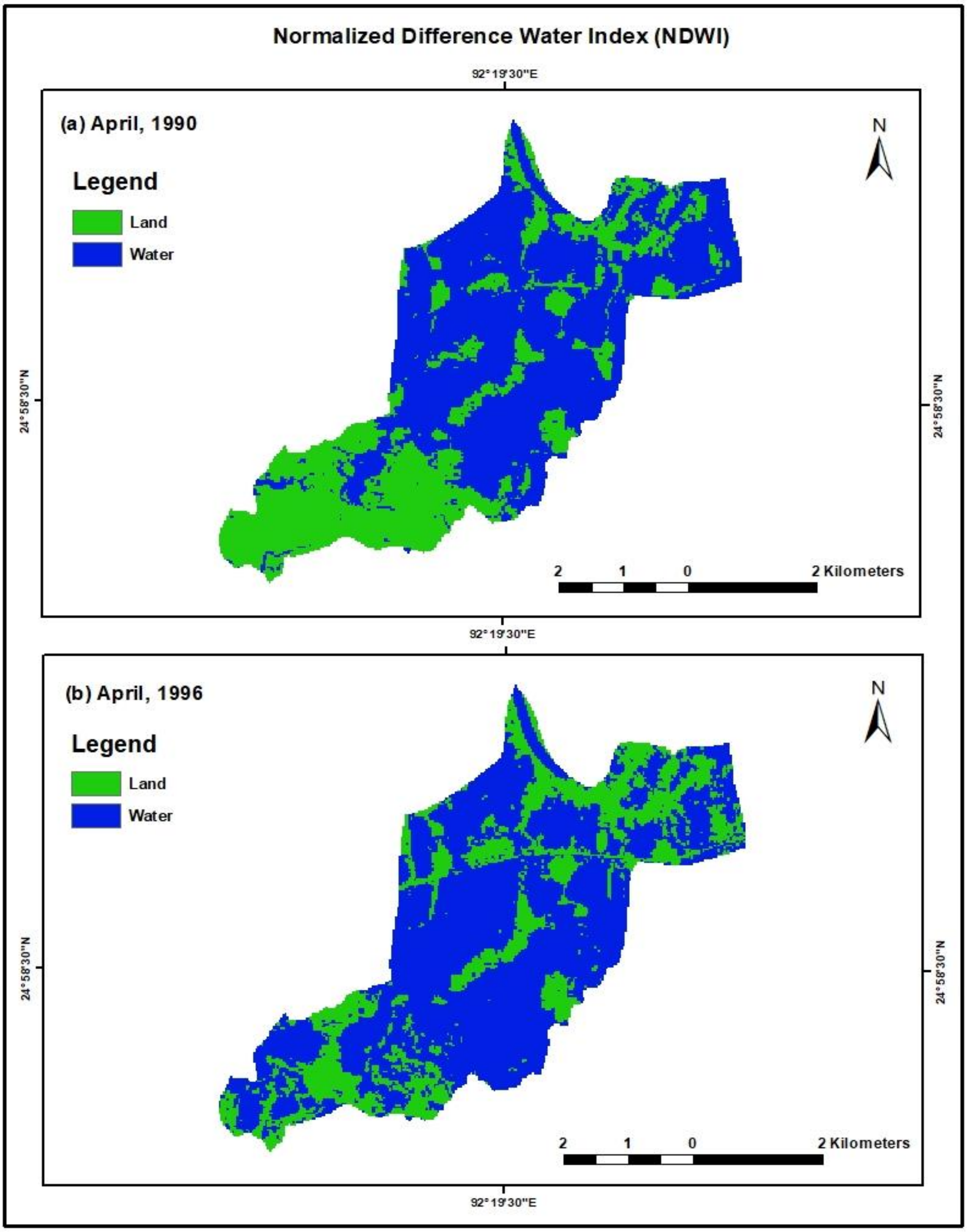

Figure 4.75: Spatial distribution of NDWI for the Shafique Haor scheme during pre-monsoon season from the year 1990 to 1996

From Figure 4.75, it has been observed that flash flood occurred in Shafique Haor scheme and the percentage of inundated area of Shafique Haor scheme was 63% in 1990 and 70% in 1996. According to spatial distribution of Normalized Difference Water Index (NDWI), Shafique Haor scheme during pre-monsoon season from the year 1990 to 1996 has been presented in the Table 4.16.

Table 4.16: Shafique Haor scheme area derived from Landsat 5 images from the year of 1990 to 1996 during pre-monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
1990	April	15.1	62.5	9.1	37.5	0.6
1996	April	16.8	69.8	7.3	30.2	0.4

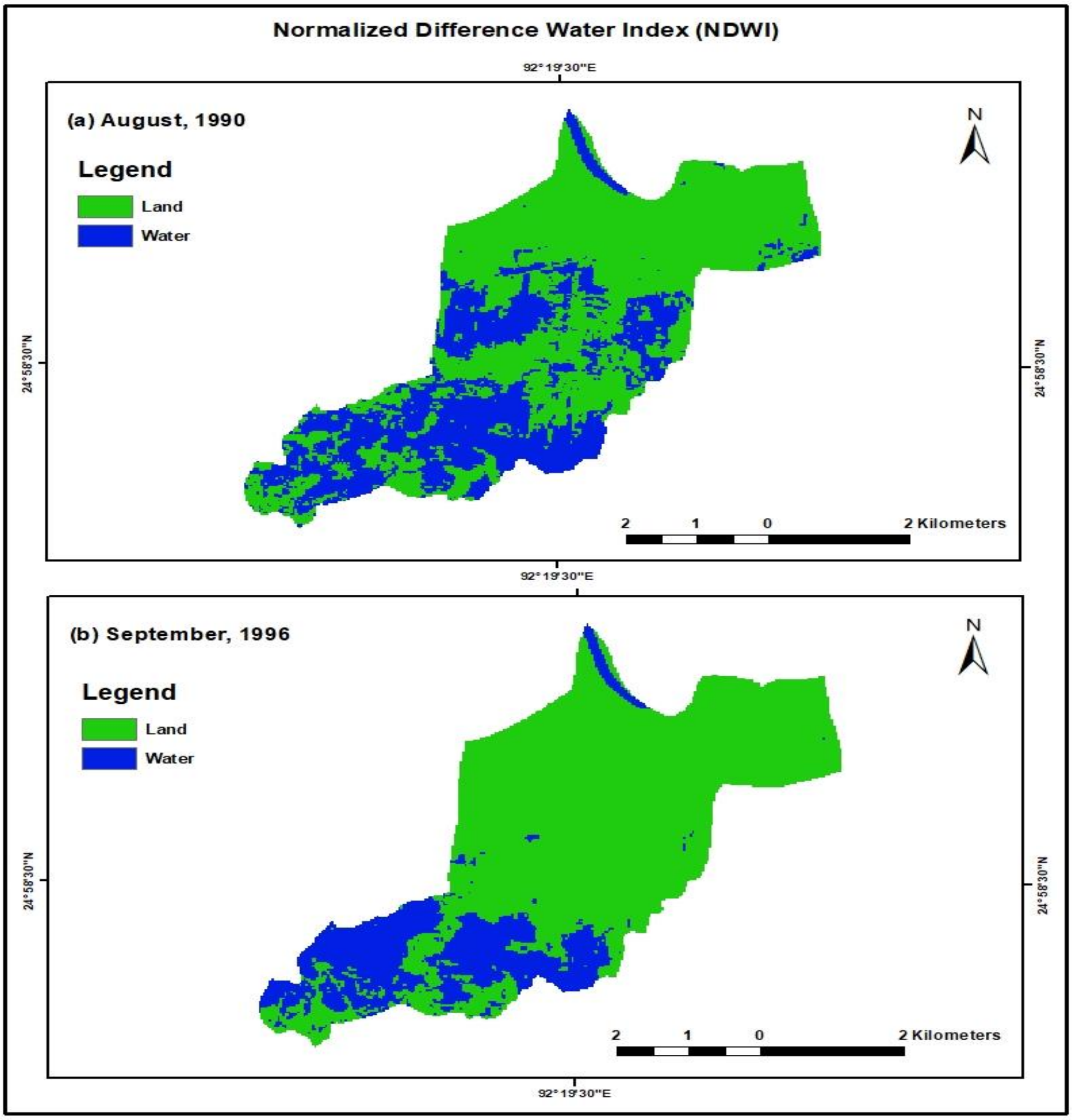

Figure 4.76: Spatial distribution of NDWI for the Shafique Haor scheme during monsoon season from the year 1990 to 1996

From Figure 4.76, it has been observed that the land was inundated periodically by pre-monsoon flash flood and monsoon flood. Inundated water area during August was 36% in 1990 which is 14.3% greater than September, 1996 (21.5%). The water areas varies in year to year. According to spatial distribution of NDWI, Shafique Haor scheme area during monsoon season from the year 1990 to 1996 has been presented in the Table 4.17.

Table 4.17: Shafique Haor scheme area derived from Landsat 5 images from the year of 1990 to 1996 during monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
1990	August	8.7	35.8	15.5	64.0	1.8
1996	September	5.2	21.5	18.9	78.5	3.6

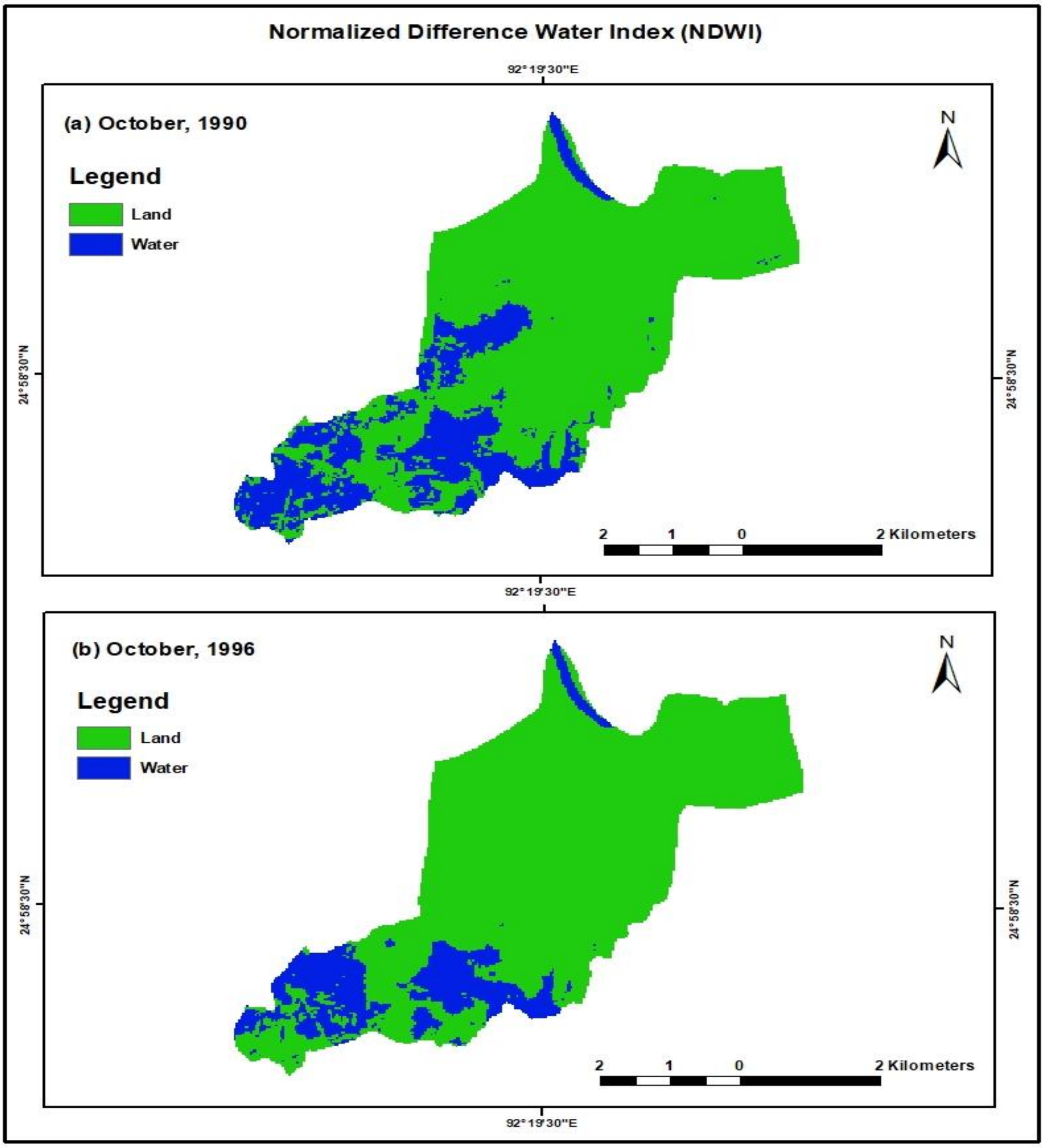

Figure 4.77: Spatial distribution of NDWI for the Shafique Haor scheme during post-monsoon season from the year 1990 to 1996

From Figure 4.77, it has been observed that the percentage of land area of Shafique Haor scheme was increased in post-monsoon season. According to spatial distribution of Normalized Difference Water Index (NDWI), Shafique Haor scheme during post-monsoon season from the year 1990 to 1996 has been presented in the Table 4.18.

Table 4.18: Shafique Haor scheme area derived from Landsat 5 images from the year of 1990 to 1996 during post-monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
1990	October	5.5	22.6	18.7	77.4	3.4
1996	October	3.5	14.6	20.6	85.4	5.8

(b) Post-scheme Scenario of Shafique Haor Scheme

Water cover maps for the Shafique Haor scheme has been developed by using the NDWI values from the year 2008 to 2018. Figure 4.78 to Figure 4.80 shows spatial distribution of water areas for the Shafique Haor scheme during the pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Water area is shown in blue and land area is shown in green.

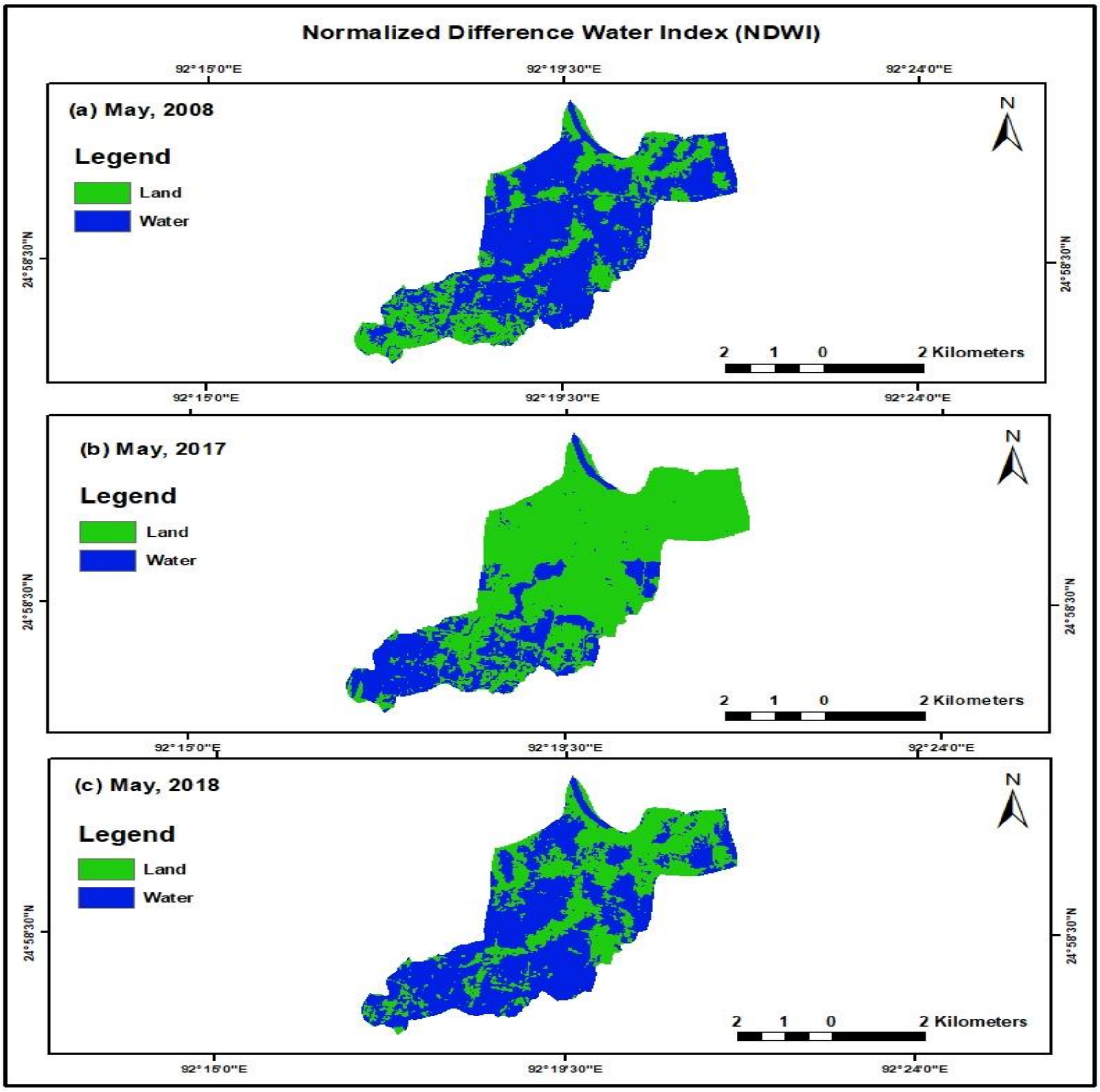

Figure 4.78: Spatial distribution of NDWI for the Shafique Haor scheme during pre-monsoon season from the year 2008 to 2018

From Figure 4.78, it has been observed that flash flood occurred in Shafique Haor scheme and the percentage of inundated area was 67% in 2008, 26% in 2017 and 30% in 2018 during pre-monsoon season. According to spatial distribution of Normalized Difference Water Index (NDWI), Shafique Haor scheme during pre-monsoon season from the year 2008 to 2018 has been presented in the Table 4.19.

Table 4.19: Shafique Haor scheme area derived from Landsat 5, Landsat 7 and Landsat 8 images for the year 2008 to 2018 during pre-monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2008	May	16.1	67	8.0	33.1	0.5
2017	May	6.2	26	17.9	74.2	2.9
2018	May	14.6	30	9.5	70.1	2.3

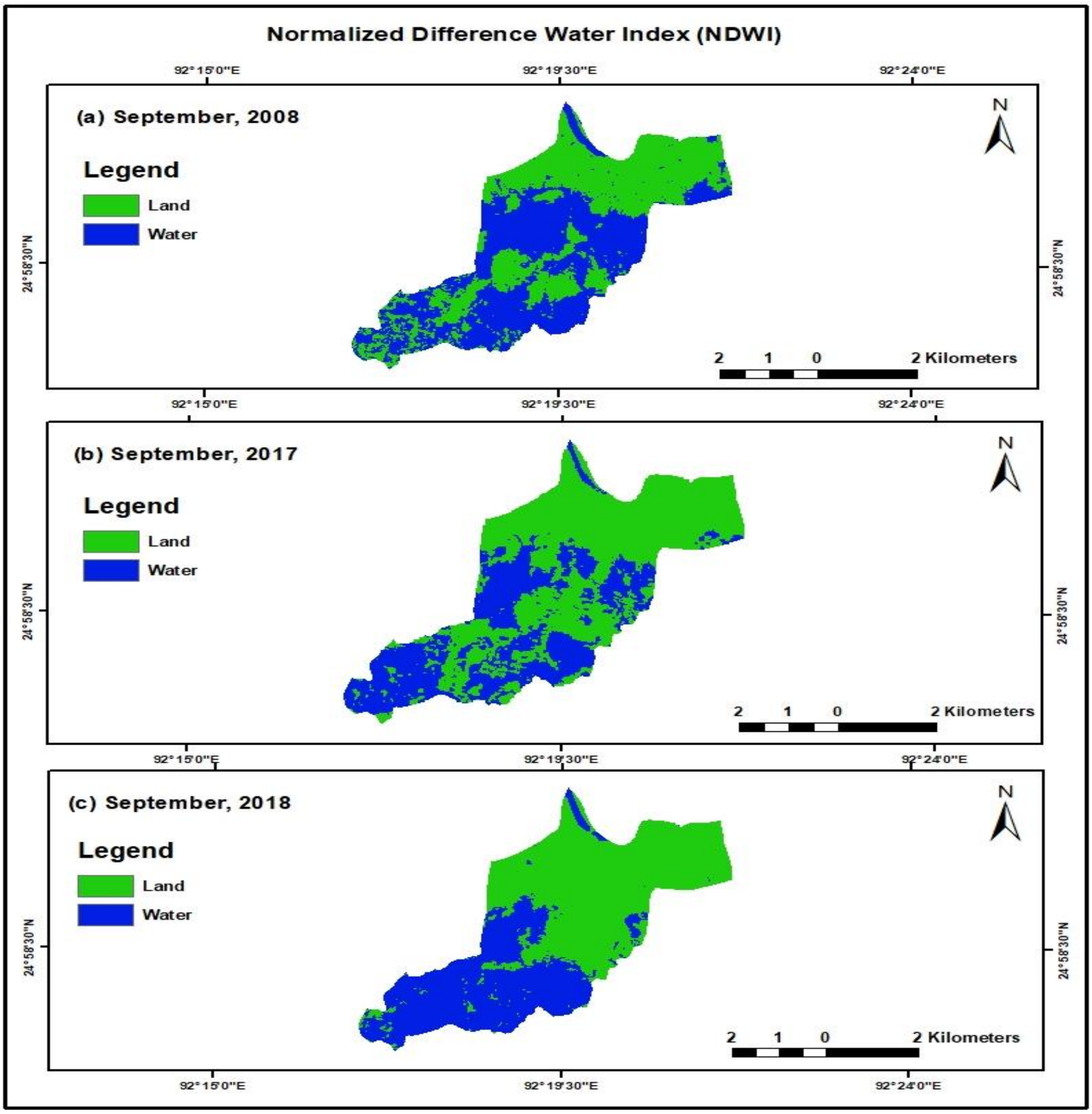

Figure 4.79: Spatial distribution of NDWI for the Shafique Haor scheme during monsoon season from the year 2008 to 2018

From Figure 4.79, it has been observed that the land was inundated periodically by pre-monsoon flash flood and monsoon flood. The inundated water area during monsoon season was 51% in 2008, 35.3% in 2017 and 41% in 2018. The water areas varies in year to year. According to spatial distribution of NDWI Shafique Haor scheme area during monsoon season from the year 2008 to 2018 has been presented in the Table 4.20.

Table 4.20: Shafique Haor scheme area derived from Landsat 5, Landsat 7 and Landsat 8 images for the year 2008 to 2018 during monsoon season.

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2008	September	12.2	51	11.9	49.3	1.0
2017	September	9.2	38.3	14.9	62	1.6
2018	September	9.9	41	14.2	59	1.4

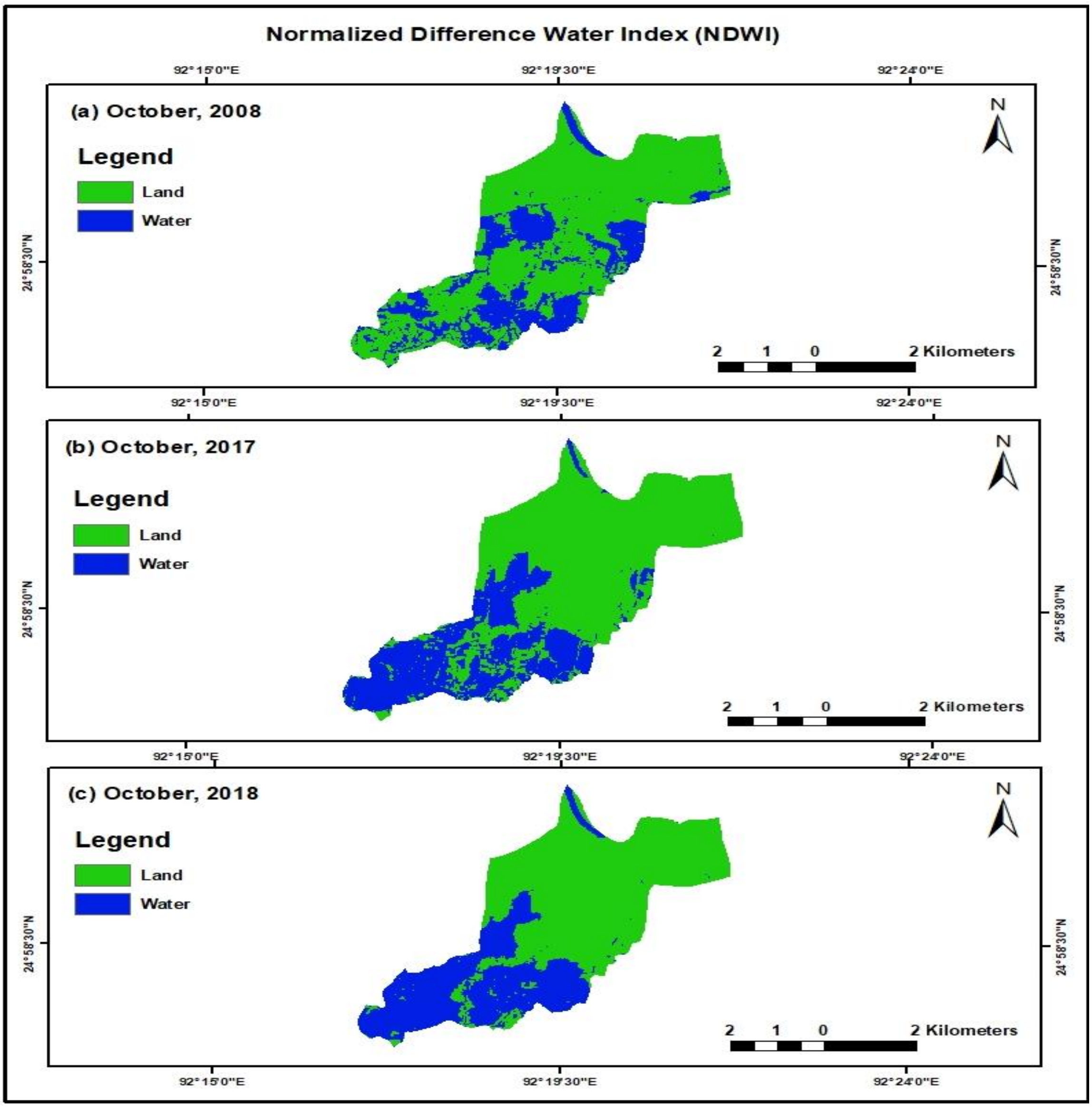

Figure 4.80: Spatial distribution of NDWI for the Shafique Haor scheme during post-monsoon season from the year 2008 to 2018

From Figure 4.80, it has been observed that the percentage of land area of Shafique Haor scheme was increased in post-monsoon season. According to spatial distribution of Normalized Difference Water Index (NDWI), Shafique Haor scheme during post-monsoon season from the year 2008 to 2018 has been presented in the Table 4.21.

Table 4.21: Shafique Haor scheme area derived from Landsat 5, Landsat 7 and Landsat 8 images for the year 2008 to 2018 during post-monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2008	October	6.7	27.6	17.5	72.4	2.6
2017	October	7.8	32.2	16.4	67.8	2.1
2018	October	8.4	34.9	15.7	65.1	1.9

(c) Pre-scheme Scenario of Sonamoral Haor Scheme

Over the past decade, various multi-resolution satellite images has been used to extract the water body information using the Normalized Difference Water Index (NDWI). Recording images, such as from satellite, sometimes does not reflect the distinguished characteristics of water with non-water features. The images and observations obtained from the satellite are subject to many issues especially the quality. The quality of observations from the satellite is associated with numerous problems including the instrument saturation, topographic shading, cloud shadows and instrument failure. Along with this, poor geolocation is also one of the main factors that lead to poor pixel quality of the observed data and images. Pixel saturation, band continuity, cloud shadow and terrain shadow are some quality indicators that helps to improve the quality of the image. There was no available Landsat image with high spatial resolution of pre-monsoon, monsoon and post-monsoon season for pre-scheme scenario. As a result, the analysis and water cover maps of spatial changes has not been developed for pre-scheme period of Sonamoral Haor scheme.

(d) Post-scheme Scenario of Sonamoral Haor Scheme

Water cover maps for the Sonamoral Haor scheme has been developed by using the Normalized Difference Water Index (NDWI) values from the year 2010 to 2018. Figure 4.81 to Figure 4.83 shows spatial distribution of water areas for the Sonamoral Haor scheme during the pre-monsoon season (April to May), monsoon season (June to September) and post-monsoon season (October to November). Water area is shown in blue and land area is shown in green.

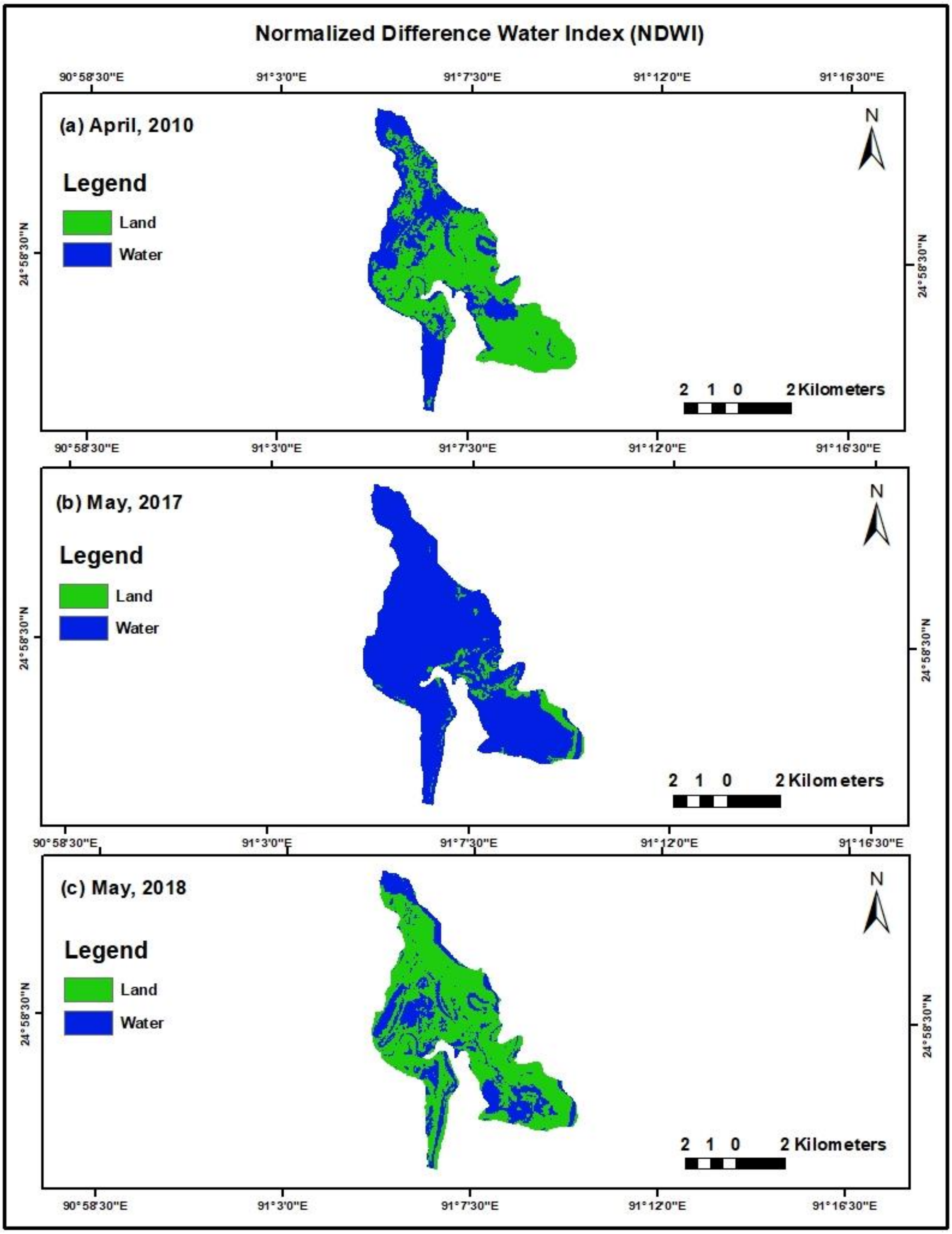

Figure 4.81: Spatial distribution of NDWI for the Sonamoral Haor scheme during pre-monsoon season from the year 2010 to 2018

From Figure 4.81, it has been observed that flash flood occurred in Sonamoral Haor scheme in 2017 and the percentage of inundated area was almost 93%. The percentage of inundated area was almost 39% in 2010 and 30% in 2018. According to spatial distribution of NDWI, Sonamoral Haor scheme during pre-monsoon season from the year 2010 to 2018 has been presented in the Table 4.22.

Table 4.22: Sonamoral Haor scheme area derived from Landsat 5 and Landsat 8 images for the year 2010 to 2018 during pre-monsoon season.

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2010	April	15.2	39.0	23.7	61.0	1.6
2017	May	35.1	92.8	2.7	7.2	0.1
2018	May	11.3	29.9	26.5	70.1	2.3

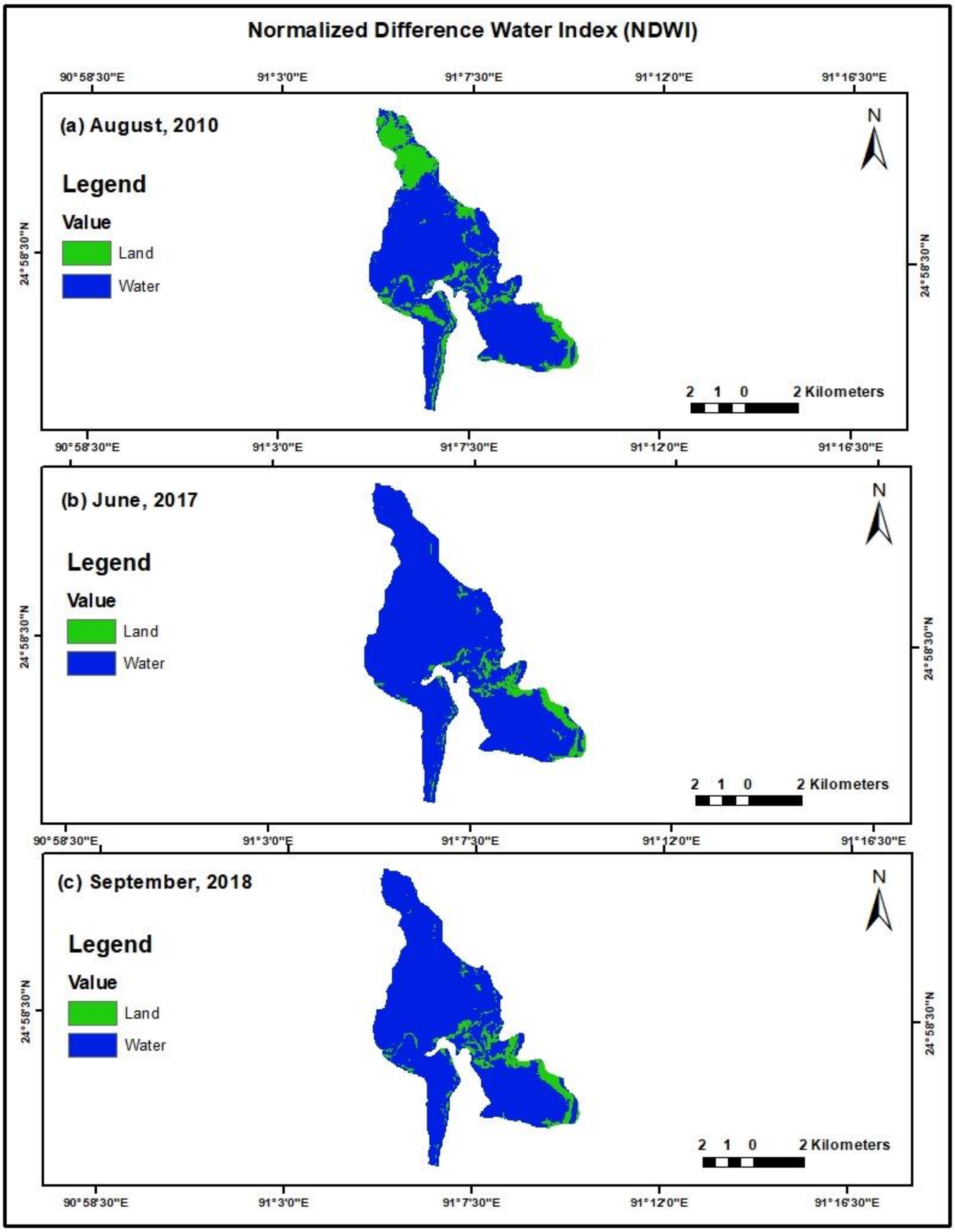

Figure 4.82: Spatial distribution of NDWI for the Sonamoral Haor scheme during monsoon season from the year 2010 to 2018

From Figure 4.82, it has been observed that the land was inundated periodically by pre-monsoon flash flood and monsoon flood. The inundated water area during monsoon season were 78% in 2010, 92.3% in 2017 and 90.4% in 2018. According to spatial distribution of NDWI Shafique Haor scheme area during monsoon season from the year 2010 to 2018 has been presented in the Table 4.23.

Table 4.23: Sonamoral Haor scheme area derived from Landsat 5 and Landsat 8 images for the year 2010 to 2018 during monsoon season

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2010	August	29.4	77.7	8.4	22.3	0.3
2017	June	34.9	92.3	2.9	7.7	0.1
2018	September	34.2	90.4	3.6	9.6	0.1

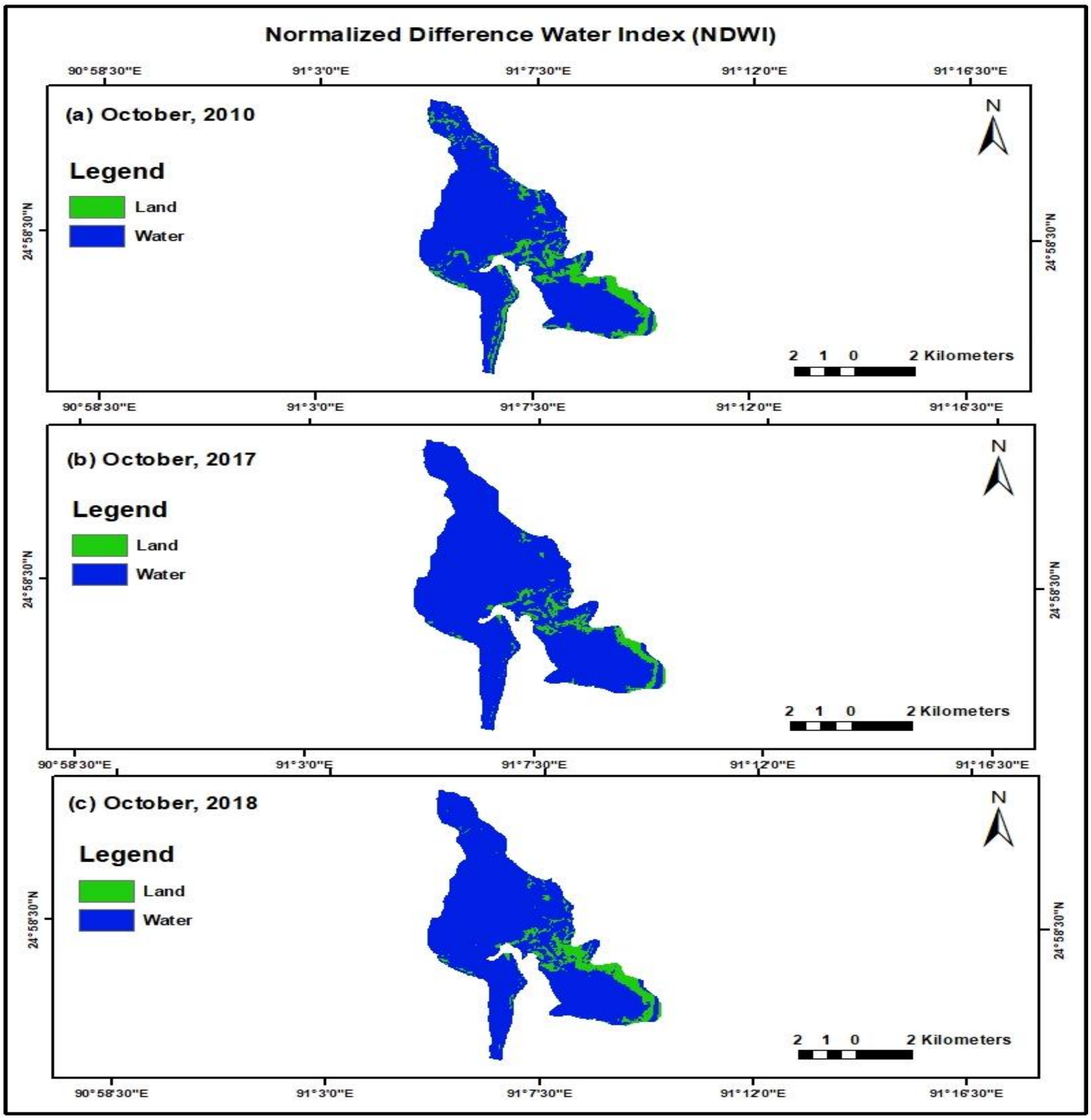

Figure 4.83: Spatial distribution of NDWI for the Sonamoral Haor scheme during post-monsoon season from the year 2010 to 2018

From Figure 4.83, it has been observed that the percentage of land area of Sonamoral Haor scheme was increased in post-monsoon season. According to spatial distribution of Normalized Difference Water Index (NDWI), Sonamoral Haor scheme during post-monsoon season from the year 2010 to 2018 has been presented in the Table 4.24.

Table 4.24: Sonamoral Haor scheme area derived from Landsat 5 and Landsat 8 images for the year 2010 to 2018 during post-monsoon season.

Year	Month	Area of water (km^2)	% of water area	Area of land (km^2)	% of land area	Land : Water
2010	October	32.3	85.4	5.5	14.6	0.2
2017	October	35.4	93.6	2.4	6.4	0.1
2018	October	34.0	90.0	3.8	10.0	0.1

4.4.3 Performance Assessment of Flood Management Infrastructure

There have major investment in infrastructure and embankments along the main rivers of Shafique Haor scheme and Sonamoral Haor scheme. From the analysis of Landsat image, it has been observed that interventions delayed the entrance of flood water by one to two weeks in both the schemes. The intended target of delayed onset of flood has been achieved in the Shafique Haor scheme and Sonamoral Haor scheme. However, flash flood sometimes enters early due to heavy rainfall in the upstream region due to delayed repairing of embankment, non-functional regulator, public cuts and lack of proper maintenance.

4.5 Agricultural Analysis

Boro rice is the main crop in haor areas. In most cases, pre-matured or matured Boro crops are damaged by early flash flood which generally happened due to pre-monsoon heavy rainfall in the haor areas. Cropping pattern, cropping intensity and crop production have been selected for assessing the change on agriculture resources due to structural interventions in Shafique Haor scheme and Sonamoral Haor scheme. The information of these indicators for agricultural analysis were collected from secondary sources.

4.5.1 Cropping Pattern

Haor is deeply flooded (5 to 7m) from May to October while winter is the single cropping season. The major crops are Boro rice, vegetables and some others. The pre-scheme scenario and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme has been described accordingly in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Pre-scheme Scenario:

About 90% of the total project area was under agricultural practices. Before the scheme interventions, the Net Cultivated Area (NCA) was 2,140 hectares where major crops of the scheme were T. Aman (Local and HYV), Boro (Local and HYV), B. Aman, and T. Aus in Shafique Haor scheme. The land type of this scheme area was medium highland (about 45%) followed by medium lowland and lowland as presented in Table 4.25. Farmers usually grew T Aman (Local and HYV) and B Aman crops in Rabi season. Only 10% of Net Cultivated Area (NCA) was covered by Boro (HYV).

Detailed cropping pattern by land type during pre-scheme period in Shafique Haor scheme is presented in Table 4.25.

Table 4.25: Cropping pattern in Safique Haor scheme during pre-scheme period

Land Type	Kharif-I (Mar-Jun)	Kharif-II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	% of the NCA
Medium highland (F_1)	Fallow	Fallow	T Aman (HYV)	214	10
	Fallow	Fallow	T Aman (Local)	642	30
	Fallow	T Aus	T Aman (HYV)	107	5
Medium lowland (F_2)	Fallow	B Aman	B Aman	321	15
	Boro (HYV)	Fallow	Fallow	214	10
	Fallow	Fallow	Fallow	107	5
Lowland (F_3)	Boro (Local)	Fallow	Fallow	428	20
	Fallow	Fallow	Fallow	107	5
			Total	2,140	100

Source: (CEGIS, 2006)

Post-scheme Scenario:

The scheme area became protected from early flash flood due to the interventions, which influence farmers to grow HYV Boro and Hybrid Boro instead of Local Boro. HYV Boro and Hybrid Boro produces higher yield than local varieties. Other crops of the scheme are T. Aman (Local and HYV), B. Aman, and T. Aus. The Net Cultivated Area (NCA) has been decreased to 1,990 hectares after interventions. Dominant cropping pattern of the project area is Fallow-Fallow-Boro (HYV) covering 65% of the Net Cultivated Area (NCA).

Detailed cropping pattern by land type during post-scheme in Shafique Haor scheme is presented in Table 4.26.

Table 4.26: Cropping pattern in Safique Haor scheme during post-scheme period

Land Type	Kharif-I (Mar-Jun)	Kharif-II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	% of the NCA
Medium highland (F1)	Fallow	T Aman (Local)	Boro (HYV)	220	11
	Fallow	T Aus	T Aman (Local)	110	6
	Fallow	Fallow	T Aman (HYV)	240	12
Medium lowland (F2)	Fallow	B Aman	B Aman	70	4
	Fallow	Fallow	Boro (HYV)	530	27
	Fallow	Fallow	Hybrid Boro	150	8
Lowland (F3)	Fallow	Fallow	Boro (HYV)	540	27
	Fallow	Fallow	Hybrid Boro	130	7
			Total	1,990	100

Source: (Upazila Office of DAE, 2019)

Impact Assessment on Cropping Pattern in Shafique Haor Scheme:

The Net Cultivated Area (NCA) has been decreased 7% (150 hectare) after the interventions of the scheme. Rice based cropping patterns continued, but the coverage of high yielding varieties in Rabi (Boro) seasons increased with corresponding reduction in the coverage of local varieties in all the three cropping seasons. Impact on cropping pattern in Shafique Haor scheme has been shown in Table 4.27 and Figure 4.84.

Table 4.27: Impact assessment on cropping pattern in Safique Haor scheme

	Pre-scheme period				Post-scheme period			
Land Type	Kharif I (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	Kharif I (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)
Medium highland (F_1)	Fallow	Fallow	T Aman (HYV)	214	Fallow	T Aman (Local)	Boro (HYV)	220
	Fallow	Fallow	T Aman (Local)	642	Fallow	T Aus	T Aman (Local)	110
	Fallow	T Aus	T Aman (HYV)	107	Fallow	Fallow	T Aman (HYV)	240
Medium lowland (F_2)	Fallow	B Aman	B Aman	321	Fallow	B Aman	B Aman	70
	Boro (HYV)	Fallow	Fallow	214	Fallow	Fallow	Boro (HYV)	530
	Fallow	Fallow	Fallow	107	Fallow	Fallow	Hybrid Boro	150
Lowland (F_3)	Boro (Local)	Fallow	Fallow	428	Fallow	Fallow	Boro (HYV)	540
	Fallow	Fallow	Fallow	107	Fallow	Fallow	Hybrid Boro	130
			Total	2,140			Total	1,990

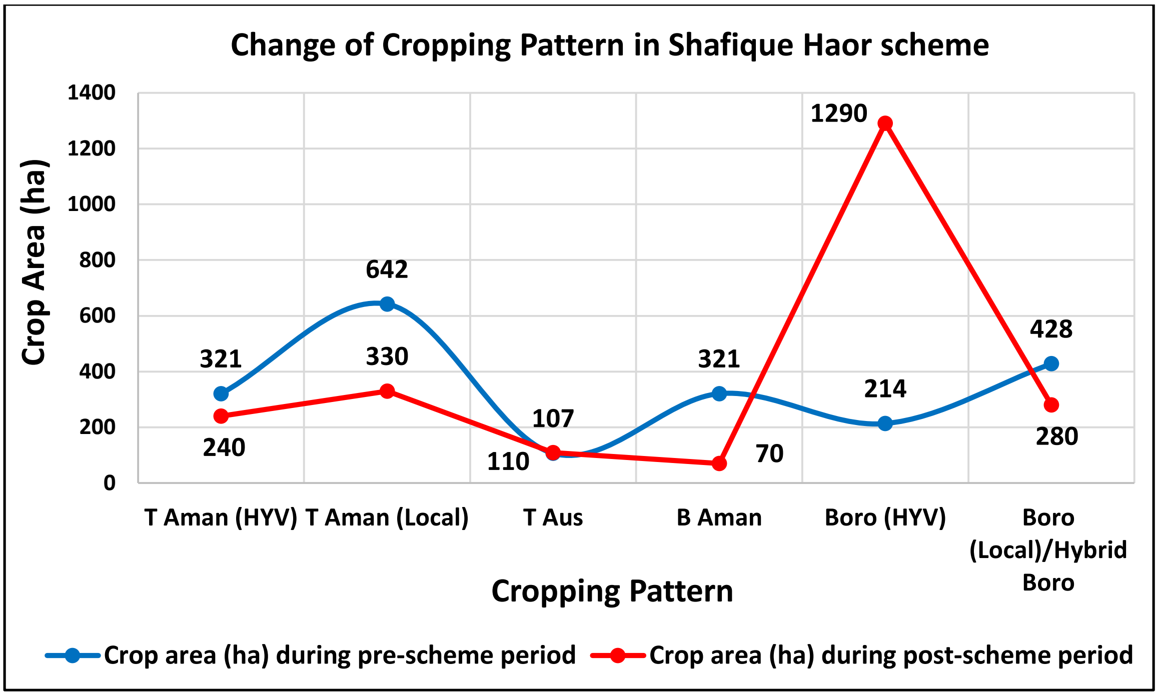

Figure 4.84: Change of crop area of cropping pattern in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Pre-scheme Scenario:

Before implementation of the scheme interventions, the Net Cropped Area (NCA) was 3,097 hectares, where dominant cropping pattern was Fallow - Follow - Boro (Local). The land type of this area was very low land (about 67% of NCA) followed by low land as presented in Table 4.28. Only 33% of Net Cultivated Area (NCA) was covered by Boro (HYV).

Detailed cropping pattern by land type during pre-scheme period in Sonamoral Haor scheme is presented in Table 4.28.

Table 4.28: Cropping pattern in Sonamoral Haor scheme during pre-scheme period

Land Type	Kharif I (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	% of the NCA
Lowland (F3)	Fallow	Fallow	Boro (HYV)	1,011	33
Very lowland (F4)	Fallow	Fallow	Boro(Local)	2,086	67
			Total	3,097	100

Source: (Arif, 2010)

Post-scheme Scenario:

Present cropping patterns continued to be rice-based, but with dominance of high yielding varieties with higher yield potential after implementation of the interventions in the scheme area. The Net Cultivable Area (NCA) has been increased to 3,160 hectares after interventions. Dominant cropping pattern of the scheme area is Fallow - Fallow - Boro (HYV). The farmer goes after HYV with the expectation of more food grains to contain his increasing number of family members. The land type of this area is very low land (about 60% of NCA) followed by low land as presented in Table 4.29. It may be mentioned that Department of Agricultural Extension (DAE) was introducing difference technologies through demonstration.

Detailed cropping pattern by land type during post-scheme in Sonamoral Haor scheme is presented in Table 4.29.

Table 4.29: Cropping pattern in Sonamoral Haor scheme during post-scheme period

Land Type	Kharif I (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	% of the NCA
Lowland (F3)	Fallow	Fallow	Boro (HYV)	1,264	40
Very lowland (F4)	Fallow	Fallow	Boro (Local)	1,896	60
			Total	3,160	100

Source: (Arif, 2010)

Impact Assessment on Cropping Pattern in Sonamoral Haor Scheme:

The Net Cultivated Area (NCA) has been increased 2% (63 hectares) after the interventions. Rice based cropping patterns continued, but the coverage of high yielding varieties in Rabi (Boro) seasons increased with corresponding reduction in the coverage of local varieties in all the three cropping seasons. The cultivated area of Local Boro has been gradually decreased and replaced by HYV Boro variety after completion of scheme due to its higher yield rate and ensured early flash flood protection by project interventions. Impact on cropping pattern in Sonamoral Haor scheme has been presented in Table 4.30 and Figure 4.85.

Table 4.30: Impact assessment on cropping pattern in Sonamoral Haor scheme

	Pre-scheme period				Post-scheme period			
Land Type	Kharif I (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)	KharifI (Mar-Jun)	Kharif II (Jul-Oct)	Rabi (Nov-Feb)	Total area (ha)
Lowland (F_3)	Fallow	Fallow	Boro (HYV)	1,011	Fallow	Fallow	Boro (HYV)	1,264
Very lowland (F_4)	Fallow	Fallow	Boro (Local)	2,086	Fallow	Fallow	Boro (Local)	1,896
			Total	3,097			Total	3,160

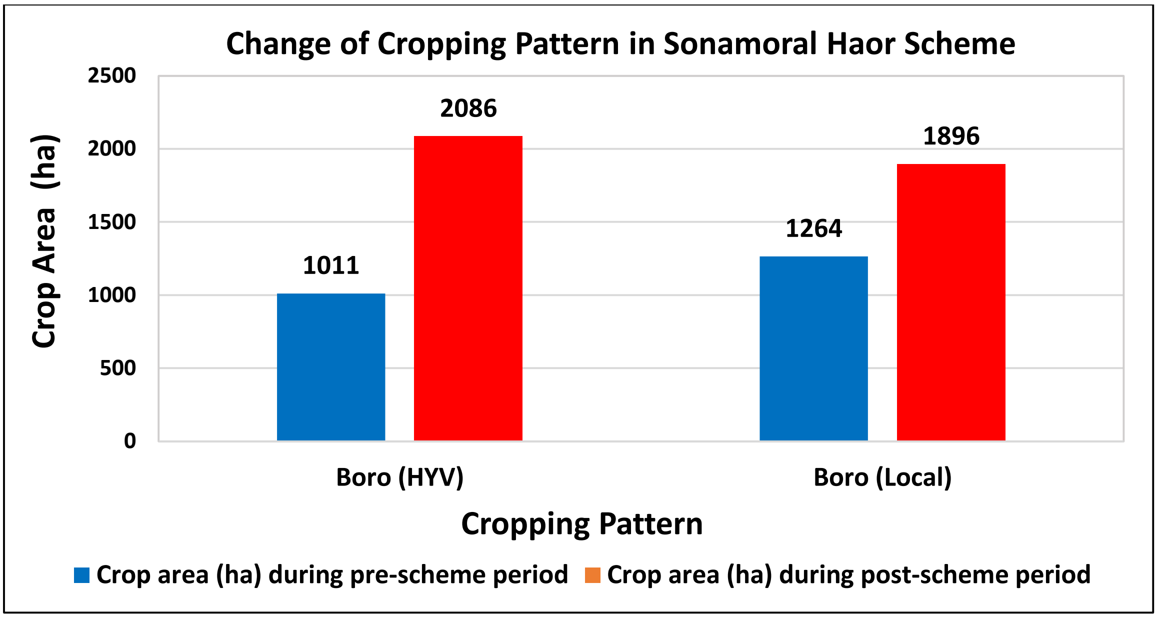

Figure 4.85: Change of crop area of cropping pattern in Sonamoral Haor scheme

4.5.2 Cropping Intensity

The pre-scheme scenario and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme has been described accordingly in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Pre-scheme Scenario:

Total cropped area, grown in three seasons, was 2,033 hectares. Single cropped area was 1,819 hectares and double cropped area was 214 hectares. The area was predominantly single cropped. The cropping intensity was about 95%. Details have been presented in Table 4.31.

Table 4.31: Cropping intensity in Shafique Haor scheme during pre-scheme period

Parameters	Area (ha)
Single cropped area	1,819
Double cropped area	214
Total Cropped Area	2,033
Cropping intensity	95%

Source: (CEGIS, 2006)

Post-scheme Scenario:

During the post-scheme period, total cropped area is 2,320 hectares. Single cropped area is 1,660 hectares and double cropped area is 600 hectares. The cropping intensity is 117%. Details have been presented in Table 4.32.

Table 4.32: Cropping intensity in Shafique Haor scheme during post-scheme period

Parameters	Area (ha)
Single cropped area	1,660
Double cropped area	600
Total Cropped Area	2,320
Cropping intensity	117%

Source: (Upazila Office of DAE, 2019)

Impact Assessment on Cropping Intensity in Shafique Haor Scheme:

Data presented in the Table 4.33 and Figure 4.86 show that crop diversity during post-scheme period increased, resulting in 22% increase in cropping intensity.

Table 4.33: Impact assessment on cropping intensity in Shafique Haor scheme

Parameters	Pre-scheme period	Post-scheme period
	Area (ha)	Area (ha)
Single cropped area	1,819	1,660
Double cropped area	214	600
Total Cropped Area	2,033	2,320
Cropping intensity	95%	117%

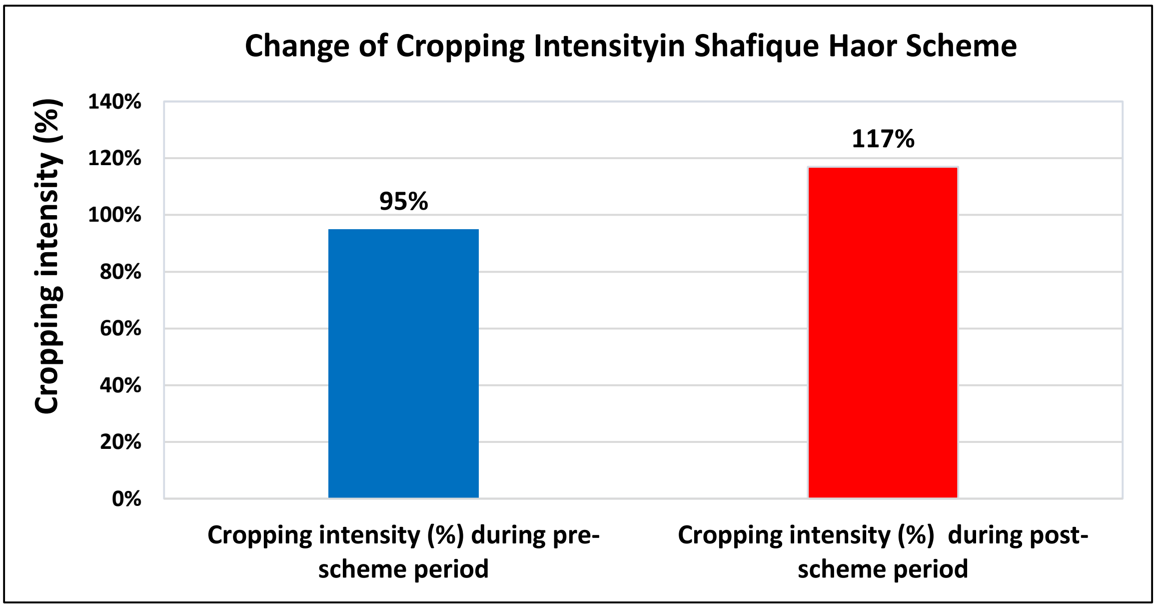

Figure 4.86: Change of cropping intensity in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Pre-scheme Scenario:

Total cropped area, grown in three seasons, was 3,097 hectares. Single cropped area was 3,097 hectares. The area was predominantly single cropped. The cropping intensity was about 100%. Details have been presented in Table 4.34.

Table 4.34: Cropping intensity in Sonamoral Haor scheme during pre-scheme period

Parameters	Area (ha)
Single cropped area	3,097
Total Cropped Area	3,097
Cropping intensity	100%

Source: (Arif, 2010)

Post-scheme Scenario:

During the post-scheme period, total cropped area is 3,160 hectares. Single cropped area is 3,160 hectares. The cropping intensity is 100%. Details are presented in Table 4.35.

Table 4.35: Cropping intensity in Sonamoral Haor scheme during post-scheme period

Parameters	Area (ha)
Single cropped area	3,160
Total Cropped Area	3,160
Cropping intensity	100%

Source: (Arif, 2010)

Impact Assessment on Cropping Intensity in Sonamoral Haor Scheme:

Data presented in the Table 4.36 and Figure 4.87 show that crop diversity is same for pre-scheme period and post-scheme period which is 100% cropping intensity.

Table 4.36: Impact assessment on cropping intensity in Sonamoral Haor scheme

Parameters	Pre-scheme period	Post-scheme period
	Area (ha)	Area (ha)
Single cropped area	3,097	3,160
Total Cropped Area	3,097	3,160
Cropping intensity	100%	100%

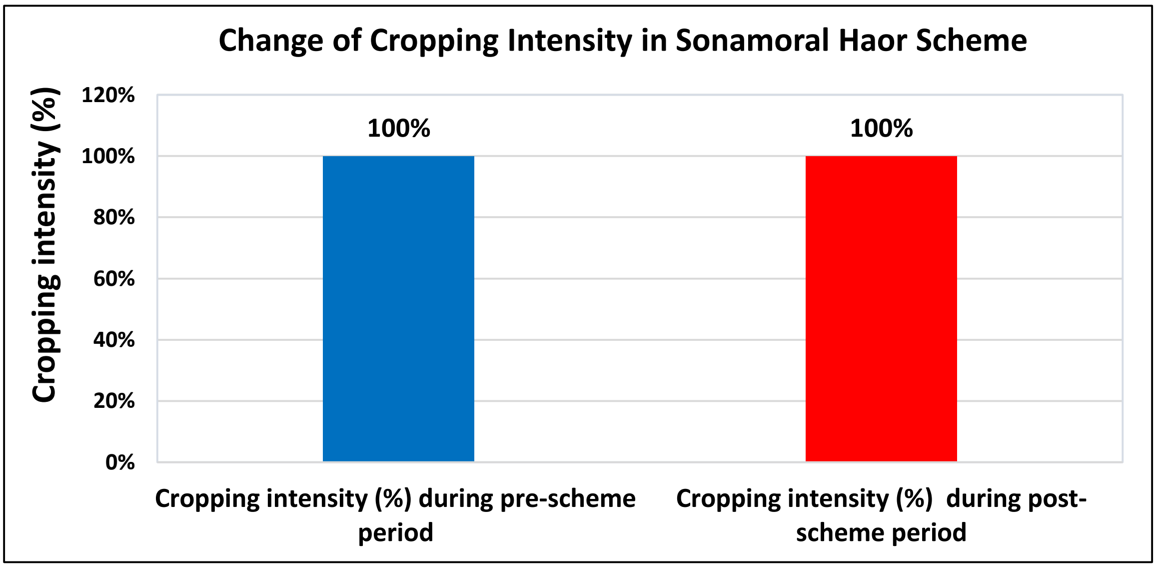

Figure 4.87: Change of cropping intensity in Sonamoral Haor scheme

4.5.3 Crop Production

Assessment of the impacts of existing flood management infrastructures analyzing pre-scheme scenario and post-scheme scenario of identified indicator i.e crop production. The pre-scheme scenario and post-scheme scenario of Shafique Haor scheme and Sonamoral Haor scheme has been described accordingly in the following section.

(a) Pre-scheme and Post-scheme Scenario of Shafique Haor Scheme

Pre-scheme Scenario:

The estimated total annual crop production of the scheme was about 5,282 tons after loss of 400 tons before any interventions. Flash flood was the main cause of crop damage in pre-project situation. Before harvesting of Boro crop, water entered into the haor area and damaged the crops. So, farmer of this area suffered due to the damaging of their crops in every year. Total crop damage in the project area was 400 tons annually. Detailed crop production and crop yield statistics before interventions in Shafique Haor scheme has been presented in Table 4.37.

Table 4.37: Annual crop production in Shafique Haor scheme during pre-project period

Name of crop	Crop Area (ha)	Damage free Area		Damage area		Total production (ton)	Production lost by flood (ton)
		Area (ha)	Yield rate (ton/ha)	Area (ha)	Yield rate (ton/ha)		
T Aman (HYV)	321	321	3.6	-	-	1,156	-
T Aman (Local)	642	642	2.1	-	-	1,348	-
T Aus	107	96	2.4	11	1.0	241	16
B Aman	321	241	2.1	80	1.0	586	88
Boro (HYV)	214	160	4.5	54	2.0	828	135
Boro (Local)	428	321	3.0	107	1.5	1,123	161
					Total	5,282	400

Source: (CEGIS, 2006)

Post-scheme Scenario:

After the implementation of the scheme, hydrological regime of the scheme area has been changed. Farmers started to cultivate Hybrid and HYV Boro crops mainly due to presence of submersible embankment and sluicegate, which protect their crops from early flash flood. Other crops of the scheme area T. Aman (Local and HYV), B. Aman, and T. Aus. Hence, total annual crop production is about 10,748 tons with loss of 292 tons after interventions. However, the crop damage has decreased after the interventions significantly. Detailed estimation of crop production and crop yield statistics after interventions in Shafique Haor scheme has been presented in Table 4.38.

Table 4.38: Annual crop production in Shafique Haor scheme during post-project period

Name of crop	Crop area (ha)	Damage free area		Damaged area		Total Production (ton)	Production lost by flood (ton)
		Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)		
T Aman (HYV)	240	240	5	-	-	1,200	-
T Aman (Local)	330	330	2.3	-	-	759	-
T Aus	110	100	1.8	10	1	190	8
B Aman	70	60	2	10	1	130	10
Boro (HYV)	1,290	1,170	5.8	120	4	7,266	216
Hybrid Boro	280	255	4.5	25	2.2	1,203	58
					Total	10,748	292

(Source: Upazila Office of DAE, 2019)

Impact Assessment on Crop Production in Shafique Haor Scheme:

Additional 103% (5,466 tons) rice has been produced in post-scheme situation. The rice production has been increased due to the protection of flash flood which encourages the farmers for practicing high yielding variety instead of local variety. Impact on crop production in Shafique Haor scheme has been presented in Table 4.39 and Figure 4.88.

Table 4.39: Impact assessment on crop production in Shafique Haor scheme

Pre-scheme period			Post -scheme period		
Name of crop	Crop Area (ha)	Total production (ton)	Crop name	Crop Area (ha)	Total production (ton)
T Aman (HYV)	321	1,156	T Aman (HYV)	240	1,200
T Aman (Local)	642	1,348	T Aman (Local)	330	759
T Aus	107	241	T Aus	110	190
B Aman	321	586	B Aman	70	130
Boro (HYV)	214	828	Boro (HYV)	1,290	7,266
Boro (Local)	428	1,123	Hybrid Boro	280	1,203
	Total	5,282		Total	10,748

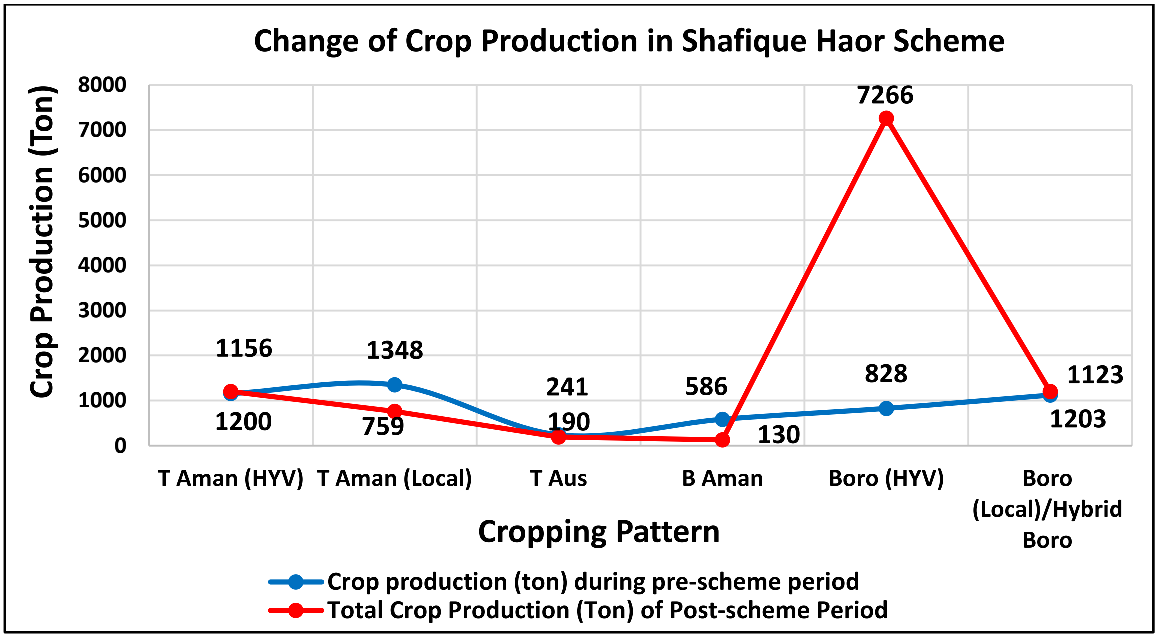

Figure 4.88: Change of crop production in Shafique Haor scheme

(b) Pre-scheme and Post-scheme Scenario of Sonamoral Haor Scheme

Pre-scheme Scenario:

The estimated total annual crop production of the scheme area was about 7,711 tons after loss of 874 tons before any interventions. Total crop damage in the project area was 874 tons annually. Detailed estimation of crop production and crop yield statistics before interventions in Sonamoral Haor scheme has been presented in Table 4.40.

Table 4.40: Annual crop production in Sonamoral Haor scheme during post-project period

Name of crop	Crop area (ha)	Damage free area		Damaged area		Total Production (ton)	Production lost by flood (ton)
		Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)		
Boro (HYV)	1,011	868	3.8	143	1.7	3,539	303
Boro (Local)	2,086	1,500	2.2737	586	1.3	4,172	571
					Total	7,711	874

Source: (Arif, 2010)

Post-scheme Scenario:

After the implementation of the scheme, hydrological regime of the project area has been changed. Farmers started to cultivate Boro crops due to presence of submersible embankment and sluicegate, which protect their crops from early flash flood. Hence, total annual crop production is about 9,038 tons with loss of 822 tons after interventions.

Detailed estimation of crop production and crop yield statistics after interventions in Sonamoral Haor scheme has been presented in Table 4.41.

Table 4.41: Annual crop production in Sonamoral Haor scheme during post-project period

Name of crop	Crop area (ha)	Damage free area		Damaged area		Total Production (ton)	Production lost by flood (ton)
		Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)		
Boro (HYV)	1,264	948	4.6	316	2.2	5,056	758
Boro (Local)	1,896	1,422	2.1333	474	2	3,982	63
					Total	9,038	822

Source: (Arif, 2010)

Impact Assessment on Crop Production in Sonamoral Haor:

Additional 17% (1,327 tons) rice has been produced in post scheme situation. The rice production has been increased due to the protection of flash flood which encourages the farmers for practicing high yielding variety instead of local variety. Detailed estimation of impact on crop production is presented in Table 4.42.

Table 4.42:Impact assessment on crop production in Sonamoral Haor scheme

Pre-scheme period			Post-scheme period		
Name of crop	Crop area (ha)	Total production (ton)	Name of crop	Crop area (ha)	Total production (ton)
Boro (HYV)	1,011	3,539	Boro (HYV)	1,264	5,056
Boro (Local)	2,086	4,172	Boro (Local)	1,896	3,982
	Total	7,711		Total	9,038

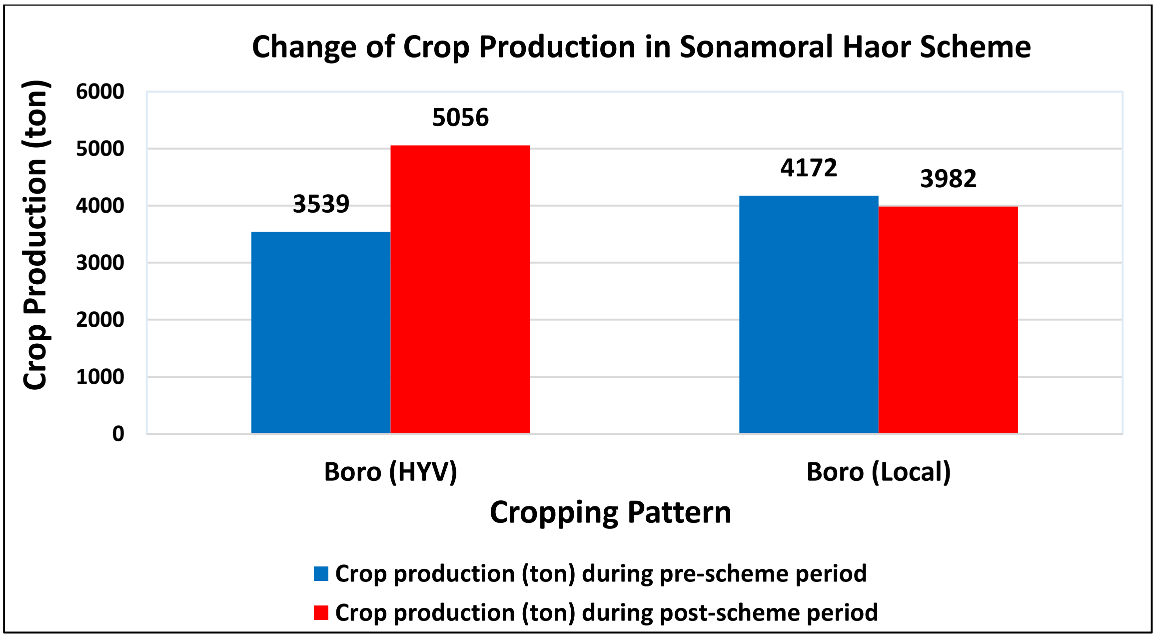

Figure 4.89: Change of crop production in Sonamoral Haor scheme

4.6 Impact Assessment

Main objective of each of the flood management schemes in haor area were to protect Boro crop from early flash floods. Different kind of water management structures i.e. submersible embankment, regulator, sluices, box culverts, fish pass, irrigation inlets and drainage outlets etc has been constructed under the schemes to facilitate crop production.

In this section, impact has been assessed and summarized on changes in flash flood frequency and Boro crop production of Shafique Haor scheme and Sonamoral Haor scheme. In this regard, information and secondary data has been collected for each of the identified indicators and baseline has been created for pre-scheme scenario and post-scheme scenario under each of the schemes. Later, impact has been assessed by subtracting or comparing pre-scheme scenario status from post-scheme scenario status. Utmost effort has been made to quantify impact of indicators, otherwise impact has been assessed qualitatively.

4.6.1 Shafique Haor Scheme

Impact assessment has been determined by comparing the pre-scheme scenario and post-scheme scenario of Shafique Haor scheme. Summary of the impacts of Shafique Haor scheme has been presented in the following sections.

Table 4.43: Summary impact matrix of flash flood frequency in Shafique Haor scheme

Indicators	Pre-scheme period	Post-scheme period	Impact
Annual rainfall	Average of annual rainfall was 4,082 mm.	Average of annual rainfall is 4,124 mm.	It has been increased by 1%.
Annual discharge	Average of annual discharge was 534 m^3/s.	Average of annual discharge is 556 m^3/s.	It has been increased by 4%.
Annual water level	Average of annual discharge was 8.24 m+PWD in the pre-scheme period.	Average of annual water level is 8.44 m+PWD.	It has been increased by 2%.
Entrance of flash flood	Before implementation of the scheme, the haor was inundated frequently during mid-March to early April.	Delayed the early entrance of flash floods by one or two weeks due to interventions.	Risk of earlier entrance of flood has been reduced.
Inundated area during different seasons	Pre-monsoon season: 63% ~ 70% Monsoon season: 22% ~ 36% Post-monsoon season: 23% ~15%	Pre-monsoon season: 26% ~ 67% Monsoon season: 38% ~ 51% Post-monsoon season: 28% ~ 35%	There is an enormous change in inundated area for different seasons

Table 4.44: Summary impact matrix of Boro crop production in Shafique Haor scheme

Indicators	Pre-scheme period	Post-scheme period	Impact
Net Cultivated Area (NCA)	2,140 hectares	1,990 hectares	The Net Cropped Area (NCA) has been decreased to 7% which is about 150 hectares after interventions.
Cropped area	2,033 hectares	2,320 hectares	Total cropped area has been increased by 14% which is about 287 hectares.
Cropping intensity	95 %	117 %	The maximum cultivated area is covered with single and some double cropped area. So, cropping intensity of this area has been increased by 22%.
Crop production	5,282 tons	10,748 tons	Additional 103% which is about 5,466 tons crops has been produced in post-scheme period. The rice production is increased due to the protection of flash flood which encourages the farmers for practicing high yielding variety instead of local variety.
Crop damage	400 tons	292 tons	Crop damage area has been decreased by 2% after interventions and the crop damage has decreased by 108 tons.

4.6.2 Sonamoral Haor Scheme

Summary of impacts of Sonamoral Haor scheme has been presented in the following Table 4.45 by comparing the pre-scheme and post-scheme scenario of Sonamoral Haor scheme.

Table 4.45: Summary impact matrix of flash flood frequency in Sonamoral Haor scheme

Indicators	Pre-scheme period	Post-scheme period	Impact
Annual rainfall	Average of annual rainfall was 3,981 mm.	Average of annual rainfall is 4,153mm.	It has been increased by 4%.
Annual discharge	No available data for pre-scheme period.	Average of annual discharge is 225 m^3/s.	Impact has not been determined due to the lack of data availability.
Annual water level	Average of annual discharge was 5.75 m+PWD.	Average of annual water level is 6.41 m+PWD.	It has been increased by 11%.
Entrance of flash flood	Before implementation of the scheme, the haor was inundated frequently during mid-March to early April.	After implementation of the interventions, entrance of flash floods got delayed by one or two weeks.	Interventions of the haor have reduced the risk of entrance of flood water and saved the crops from damage.
Inundated area during different seasons	Pre-monsoon season: 36% Monsoon season: 63% Post-monsoon season: 75 %	Pre-monsoon season: 30% ~ 93% Monsoon season: 78% ~ 92% Post-monsoon season: 85% ~ 94%	There is an enormous change in inundated area for different seasons

Table 4.46: Summary impact matrix of Boro crop production in Sonamoral Haor scheme

Indicators	Pre-scheme period	Post-scheme period	Impact
Net Cultivated Area (NCA)	3,097 hectares	3,160 hectares	The Net Cropped Area (NCA) has been increased to 2% which is about 63 hectares after interventions.
Cropped area	3,097 hectares	3,160 hectares	Total cropped area has been increased by 2% which is about 63 hectares.
Cropping intensity	100 %	100 %	The cultivated area is covered with single cropped area.
Crop production	7,711 tons	9,038 tons	Additional 17% which is about 1,327 tons crops has been produced in post-scheme period. The rice production is increased due to the protection of flash flood which encourages the farmers for practicing high yielding variety instead of local variety.
Crop damage	874 tons	822 tons	Crop damage area has been decreased by 6% after interventions and the crop damage has decreased by 52 tons.

4.7 Summary

The assessment of Shafique Haor scheme and Sonamoral Haor scheme has been analyzed for the pre-scheme period and post-scheme period. Hydrological analyses, image analyses, and agricultural analyses have been carried out in this study. Hydrological analyses include trend analysis, frequency analysis and Landsat satellite image analysis. It has been observed from trend and frequency analysis that the annual rainfall, annual discharge and annual water level are gradually increasing with the course of time. From the Normalized Difference Water Index (NDWI) maps, it has been also found that the entrance of flash flood has been delayed by 7-14 days. It helped the local farmer to harvest the Boro crop before flash flood. In case of agricultural analysis, additional 5,466 tons and 1,327 tons crops have been produced during post-scheme situation in Shafique Haor scheme and Sonamoral Haor scheme accordingly. There are some extend of crop damage area due to malfunctioning of the interventions and reduced water carrying as well as retention capacity of surrounding rivers, khals and beels. After conducting the assessment and comparison between pre-scheme and post-scheme scenario, it has been revealed that Shafique Haor scheme and Sonamoral Haor scheme compliance with the objective to protect Boro crop from early flash floods and to facilitate crop production.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. General

This chapter contains the overall conclusions of the study which has been derived from the various analyses. This study focuses on the effectiveness of the Shafique Haor scheme and Sonamoral Haor scheme by comparison of pre-scheme scenario and post-scheme scenario. Finally, a set of recommendations has been also included in this chapter.

5.2. Conclusions of the Study

The following conclusions has been drawn from the present study:

1. In case of trend analysis and frequency analysis, it has been observed that the rainfall, discharge and water level are gradually increasing with the course of time. For Shafique Haor scheme, the annual rainfall, annual discharge and annual water level have been increased by 1%, 4% and 2% accordingly. For Sonamoral Haor scheme, the annual rainfall and annual water level have been increased by 4% and 11% accordingly. Change of discharge has not been assessed in Sonamoral Haor scheme due to the lack of data availability during the pre-scheme period.

2. From the NDWI maps, it has been observed that there is an enormous change in inundated area for different years. In case of pre-scheme period in Shafique Haor scheme, the percent of inundated area varies from 63 % to 70%, 22% to 36% and 23% to 15 % during pre-monsoon, monsoon and post-monsoon season accordingly. Also for post-scheme period in Shafique Haor scheme, the percent of inundated area varies from 26 % to 67%, 38% to 51% and 28% to 35% during pre-monsoon, monsoon and post-monsoon season accordingly. In case of Sonamoral Haor scheme, it has been also found from pre-scheme period that the percent of inundated area is about 36 %, 63% and 75% during pre-monsoon, monsoon and post-monsoon season accordingly. Also for post-scheme period in Sonamoral Haor scheme, the percent of inundated area varies from 30 % to 93%, 78% to 92% and 85% to 94% during pre-monsoon, monsoon and post-monsoon season accordingly.

3. In case of agricultural analysis, additional 5,466 tons (103%) and 1,327 tons (17%) Boro crops have been produced in post-scheme situation in Shafique Haor scheme and Sonamoral Haor scheme accordingly.

4. After implementation of the schemes in haor area, crop damage area has been decreased by 108 tons (2%) in Shafique Haor scheme and 52 tons (6%) in Sonamoral Haor scheme. Even then there are some extend of crop damage area due to malfunctioning of the interventions and reduced water carrying as well as retention capacity of surrounding rivers, khals and beels.

5. After conducting the assessment and comparison between pre-scheme and post-scheme scenario, it has been observed that Shafique Haor scheme and Sonamoral Haor scheme compliance with the objective to protect Boro crop from early flash floods and to facilitate crop production.

5.3. Recommendations for Further Study

Shafique Haor and Sonamoral Haor is playing a vital role to keep the balance of the surrounding vast region. From the above study, some recommendations can be summarized for further study:

1. Trend analysis and frequency analysis is a widespread application to examine how the meteorological and hydrological variables change over the time period on mean and extreme state. In this regard, the rainfall, discharge and water level data should be collected regularly to predict the change accurately.

2. The detail analysis of satellite images can provide improved data for future mathematical modeling. For this purpose, high-resolution imagery as well as long-term time-series of satellite data are required for better understanding of the haor behavior.

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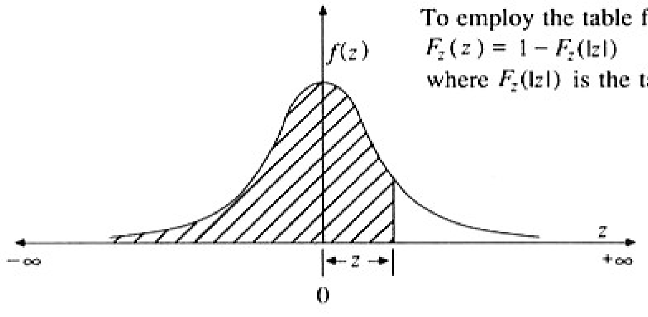
APPENDICES

Appendix-A: Cumulative Probability of the Standard Normal Distribution

Cumulative probability of the standard normal distribution

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Source: Grant, E. L., and R. S. Leavenworth, *Statistical Quality and Control*, Table A, p.643, McGraw-Hill, New York, 1972. Used with permission.



To employ the table for $z < 0$, use
$F_z(z) = 1 - F_z(|z|)$
where $F_z(|z|)$ is the tabulated value.

Appendix-B: Frequency Factors for Pearson Type III Distribution (Positive Skew)

K_T values for Pearson Type III distribution (positive skew)

Skew coefficient	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
C_s or C_w	0.50	0.20	0.10	0.04	0.02	0.01	0.005
3.0	−0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	−0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	−0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	−0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	−0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	−0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	−0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	−0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	−0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	−0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	−0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	−0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	−0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	−0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	−0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	−0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	−0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	−0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	−0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	−0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	−0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	−0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	−0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	−0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	−0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	−0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	−0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	−0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	−0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	−0.017	0.836	1.292	1.785	2.107	2.400	2.670
0.0	0	0.842	1.282	1.751	2.054	2.326	2.576

Appendix-C: Frequency Factors for Pearson Type III Distribution (Negative Skew)

K_T values for Pearson Type III distribution (negative skew)

Skew coefficient C_s or C_w	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
	0.50	0.20	0.10	0.04	0.02	0.01	0.005
−0.1	0.017	0.846	1.270	1.716	2.000	2.252	2.482
−0.2	0.033	0.850	1.258	1.680	1.945	2.178	2.388
−0.3	0.050	0.853	1.245	1.643	1.890	2.104	2.294
−0.4	0.066	0.855	1.231	1.606	1.834	2.029	2.201
−0.5	0.083	0.856	1.216	1.567	1.777	1.955	2.108
−0.6	0.099	0.857	1.200	1.528	1.720	1.880	2.016
−0.7	0.116	0.857	1.183	1.488	1.663	1.806	1.926
−0.8	0.132	0.856	1.166	1.448	1.606	1.733	1.837
−0.9	0.148	0.854	1.147	1.407	1.549	1.660	1.749
−1.0	0.164	0.852	1.128	1.366	1.492	1.588	1.664
−1.1	0.180	0.848	1.107	1.324	1.435	1.518	1.581
−1.2	0.195	0.844	1.086	1.282	1.379	1.449	1.501
−1.3	0.210	0.838	1.064	1.240	1.324	1.383	1.424
−1.4	0.225	0.832	1.041	1.198	1.270	1.318	1.351
−1.5	0.240	0.825	1.018	1.157	1.217	1.256	1.282
−1.6	0.254	0.817	0.994	1.116	1.166	1.197	1.216
−1.7	0.268	0.808	0.970	1.075	1.116	1.140	1.155
−1.8	0.282	0.799	0.945	1.035	1.069	1.087	1.097
−1.9	0.294	0.788	0.920	0.996	1.023	1.037	1.044
−2.0	0.307	0.777	0.895	0.959	0.980	0.990	0.995
−2.1	0.319	0.765	0.869	0.923	0.939	0.946	0.949
−2.2	0.330	0.752	0.844	0.888	0.900	0.905	0.907
−2.3	0.341	0.739	0.819	0.855	0.864	0.867	0.869
−2.4	0.351	0.725	0.795	0.823	0.830	0.832	0.833
−2.5	0.360	0.711	0.771	0.793	0.798	0.799	0.800
−2.6	0.368	0.696	0.747	0.764	0.768	0.769	0.769
−2.7	0.376	0.681	0.724	0.738	0.740	0.740	0.741
−2.8	0.384	0.666	0.702	0.712	0.714	0.714	0.714
−2.9	0.390	0.651	0.681	0.683	0.689	0.690	0.690
−3.0	0.396	0.636	0.666	0.666	0.666	0.667	0.667

Source: U. S. Water Resources Council (1981).

Appendix-D: Frequency Factors for Extreme Value I Distribution

Sample size (n)	Return Period 5	10	15	20	25	50	75	100	1000
15	0.967	1.703	2.117	2.410	2.632	3.321	3.721	4.005	6.265
20	0.919	1.625	2.023	2.302	2.517	3.179	3.563	3.836	6.006
25	0.888	1.575	1.963	2.235	2.444	3.088	3.463	3.729	5.842
30	0.866	1.541	1.922	2.188	2.393	3.026	3.393	3.653	5.727
35	0.851	1.516	1.891	2.152	2.354	2.979	3.341	3.598	
40	0.838	1.495	1.866	2.126	2.326	2.943	3.301	3.554	5.576
45	0.829	1.478	1.847	2.104	2.303	2.913	3.268	3.520	
50	0.820	1.466	1.831	2.086	2.283	2.889	3.241	3.491	5.478
55	0.813	1.455	1.818	2.071	2.267	2.869	3.219	3.467	
60	0.807	1.446	1.806	2.059	2.253	2.852	3.200	3.446	
65	0.801	1.437	1.796	2.048	2.241	2.837	3.183	3.429	
70	0.797	1.430	1.788	2.038	2.230	2.824	3.169	3.413	5.359
75	0.972	1.423	1.780	2.029	2.220	2.812	3.155	3.400	
80	0.788	1.417	1.773	2.020	2.212	2.802	3.145	3.387	
85	0.785	1.413	1.767	2.013	2.205	2.793	3.135	3.376	
90	0.782	1.409	1.762	2.007	2.198	2.785	3.125	3.367	
95	0.780	1.405	1.757	2.002	2.193	2.777	3.116	3.357	
100	0.779	1.401	1.752	1.998	2.187	2.770	3.109	3.349	5.261
α	0.719	1.305	1.635	1.866	2.044	2.592	2.911	3.137	4.936

Appendix-E: Landsat Satellite Specification

1. Landsat 2

Landsat 2 was launched onboard a Delta 2910 rocket from Vandenberg Air Force Base, California on January 22, 1975. Originally named ERTS-B (Earth Resource Technology Satellite B), the spacecraft was renamed Landsat 2 before launch. On February 25, 1982 after seven years of service, Landsat 2 was removed from operations due to yaw control problems; it was officially decommissioned on July 27, 1983.

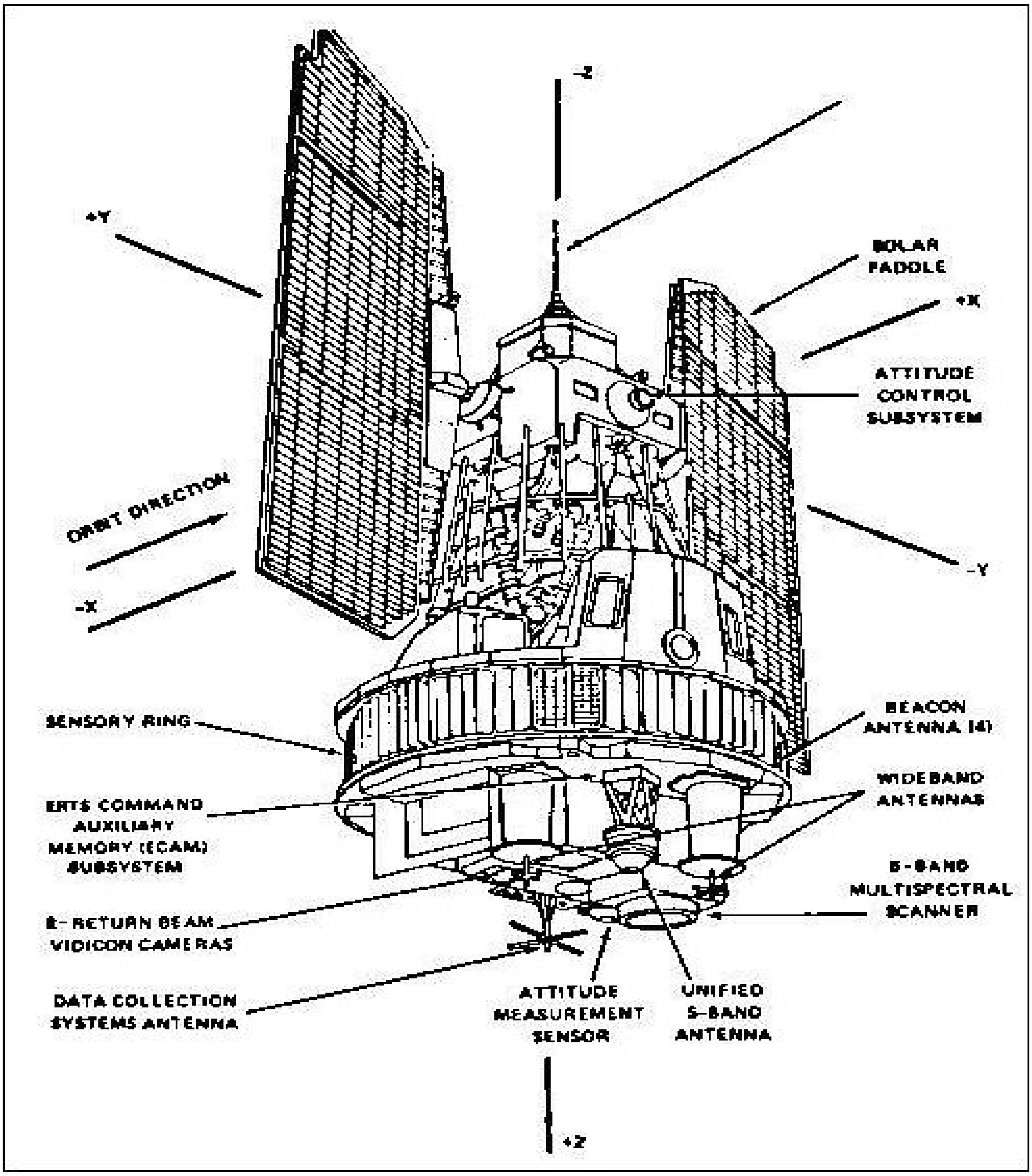


Figure E1: Alternate illustration of LS-1, LS-2, and LS-3 spacecraft (Source: https://earth.esa.int/web/eoportal/satellite-missions/l/landsat-1-3, 2019)

Landsat 2, like its predecessor Landsat 1, orbited the Earth in a sun-synchronous, near-polar orbit (99.2 degrees inclination) at a nominal altitude of 900 km (559 miles), circling the Earth every 103.34 minutes, completing 14 orbits per day. The satellite had a repeat cycle of 18 days and had an equatorial crossing time of 9:45 a.m. mean local time (+/- 15 minutes). Landsat 2 data were acquired on the Worldwide Reference System-1 (WRS-1) path/row system, with swath overlap (or side lap) varying from 14 percent at the Equator to a maximum of approximately 85 percent at 81 degrees north or south latitude. Data products created from over 240,000 Landsat 2 MSS scenes are available to download from EarthExplorer, GloVis, and the LandsatLook Viewer.

Landsat 2 Instruments:

Landsat 2 carried the same sensors as Landsat 1: the Return Beam Vidicon (RBV) and the Multispectral Scanner System (MSS).

Return Beam Vidicon (RBV):

The RBV sensor utilized vidicon tube instruments containing an electron gun that read images from a photoconductive faceplate similar to television cameras. The data stream received from the satellite was analog-to-digital preprocessed to correct for radiometric and geometric errors.

- 80 meter-ground resolution.
- Three cameras operating in the following spectral bands:
  - Band 1 Visible blue-green (475-575 nm).
  - Band 2 Visible orange-red (580-680 nm).
  - Band 3 Visible red to Near-Infrared (690-830 nm).
- Data recorded to 70 millimeter (mm) black and white film rolls.
- Data: 3.5 MHz FM video.

RBV data was rarely used and considered useful for engineering evaluation purposes rather than science analysis. Visit RBV Film Only for more information.

Multispectral Scanner (MSS):

The MSS sensors were line-scanning devices observing the Earth perpendicular to the orbital track. The cross-track scanning was accomplished by an oscillating mirror; six lines were scanned simultaneously in each of the four spectral bands for each mirror sweep. The forward motion of the satellite provided the along-track scan line progression.

- 80-meter ground resolution in four spectral bands:
    - Band 4 Visible green (0.5 to 0.6 µm).
    - Band 5 Visible red (0.6 to 0.7 µm).
    - Band 6 Near-Infrared (0.7 to 0.8 µm).
- Band 7 Near-Infrared (0.8 to 1.1 µm).
- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.
- Scene size: 170 km x 185 km (106 mi x 115 mi).

Landsat 2 Spacecraft Facts:

Landsats 1, 2, and 3 were modified Nimbus meteorological satellites.

- Weight: approximately 953 kg (2,100 lbs).
- Overall height: 3 m (10 ft).
- Diameter: 1.5 m (5 ft).
- Solar array paddles extend out to a total of 4 m (13 ft).
- 3-axis stabilized using 4 wheels to +/-0.7° attitude control.
- Twin solar array paddles (single-axis articulation).
- S-Band and Very High Frequency (VHF) communications.
- Hydrazine propulsion system with 3 thrusters.

2. Landsat 3

Landsat 3 (originally named Landsat C) was launched into space onboard a Delta 2910 rocket from Vandenberg Air Force Base, California on March 5, 1978. The objective of Landsat 3 was to extend the period of space-acquired Earth imagery, started by Landsat 1 and Landsat 2. The satellite was placed in standby mode on March 31, 1983 and decommissioned on September 7, 1983. Landsat 3, like Landsat 1 and Landsat 2, orbited the Earth in a sun-synchronous, near-polar orbit (99.2 degrees inclination) at a nominal altitude of 917 km (570 miles), circling the Earth every 103.34 minutes, completing 14 orbits per day. The satellite had a repeat cycle of 18 days and had an equatorial crossing time of 9:30 a.m. mean local time (+/- 15 minutes).

Data products created from over 140,000 Landsat 3 MSS scenes are available to download from EarthExplorer, GloVis, and the LandsatLook Viewer.

Landsat 3 Instruments:

Landsat 3 carried the modified versions of the sensors placed on Landsat 1 and Landsat 2: the Return Beam Vidicon (RBV) and the Multispectral Scanner System (MSS).

Return Beam Vidicon (RBV):

The RBV sensor utilized vidicon tube instruments containing an electron gun that read images from a photoconductive faceplate similar to television cameras. The data stream received from the satellite was analog-to-digital preprocessed to correct for radiometric and geometric errors. The RBV system was redesigned for Landsat 3 to use two cameras, mounted side-by-side, with panchromatic spectral response and higher spatial resolution than on Landsat 1 and Landsat 2, to complement the multispectral coverage provided by the MSS. Each of the cameras produced a swath of about 90 km (for a total swath of 180 km).

- 40-meter-ground resolution.
- Two cameras operating in one broad spectral band (green to near-infrared; 0.505–0.750 µm).
- Data recorded to 70 millimeter (mm) black and white film rolls.
- Data: 3.5 MHz FM video.

Multispectral Scanner (MSS):

The MSS sensor was a line-scanning device observing the Earth perpendicular to the orbital track. The cross-track scanning was accomplished by an oscillating mirror; six lines were scanned simultaneously in each of the four spectral bands for each mirror sweep. The forward motion of the satellite provided the along-track scan line progression. The MSS sensor on Landsat 3 originally had five spectral bands, but one failed shortly after launch.

- 80-meter ground resolution in four spectral bands:
  - Band 4 Visible green (0.5 to 0.6 µm).
  - Band 5 Visible red (0.6 to 0.7 µm).
  - Band 6 Near-Infrared (0.7 to 0.8 µm).
  - Band 7 Near-Infrared (0.8 to 1.1 µm).

- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.
- Scene size: 170 km x 185 km (106 mi x 115 mi).

Landsat 3 Spacecraft Facts:

- Manufactured by General Electric (GE) Astros pace.
- Weight: approximately 953 kg (2,100 lbs).
- Overall height: 3 m (10 ft) and diameter: 1.5 m (5 ft).
- Solar array paddles extend out to a total of 4 m (13 ft).
- 3-axis stabilized using 4 wheels to +/-0.7° attitude control.
- Twin solar array paddles (single-axis articulation).
- S-Band and Very High Frequency (VHF) communications.
- Hydrazine propulsion system with 3 thrusters.

3. Landsat 5

Landsat 5 was launched from Vandenberg Air Force Base in California on March 1, 1984, and like Landsat 4, carried the Multispectral Scanner (MSS) and the Thematic Mapper (TM) instruments. Landsat 5 delivered Earth imaging data nearly 29 years - and set a Guinness World Record for 'Longest Operating Earth Observation Satellite', before being decommissioned on June 5, 2013.

The Landsat 5 satellite orbited the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km (438 mi), inclined at 98.2 degrees, and circled the Earth every 99 minutes. The satellite had a 16-day repeat cycle with an equatorial crossing time: 9:45 a.m. +/- 15 minutes. Landsat 5 data were acquired on the Worldwide Reference System-2 (WRS-2) path/row system, with swath overlap (or side lap) varying from 7 percent at the Equator to a maximum of approximately 85 percent at extreme latitudes. Landsat 5 long outlived its original three-year design life. Developed by NASA and launched in 1984, Landsat 5 has orbited the planet over 150,000 times while transmitting over 2.5 million images of land surface conditions around the world. Data products created from over 600,000 Landsat 5 Multispectral Scanner (MSS) and more than 2.7 million Landsat 5 Thematic Mapper (TM) scenes are available to download from EarthExplorer, GloVis, and the LandsatLook Viewer.

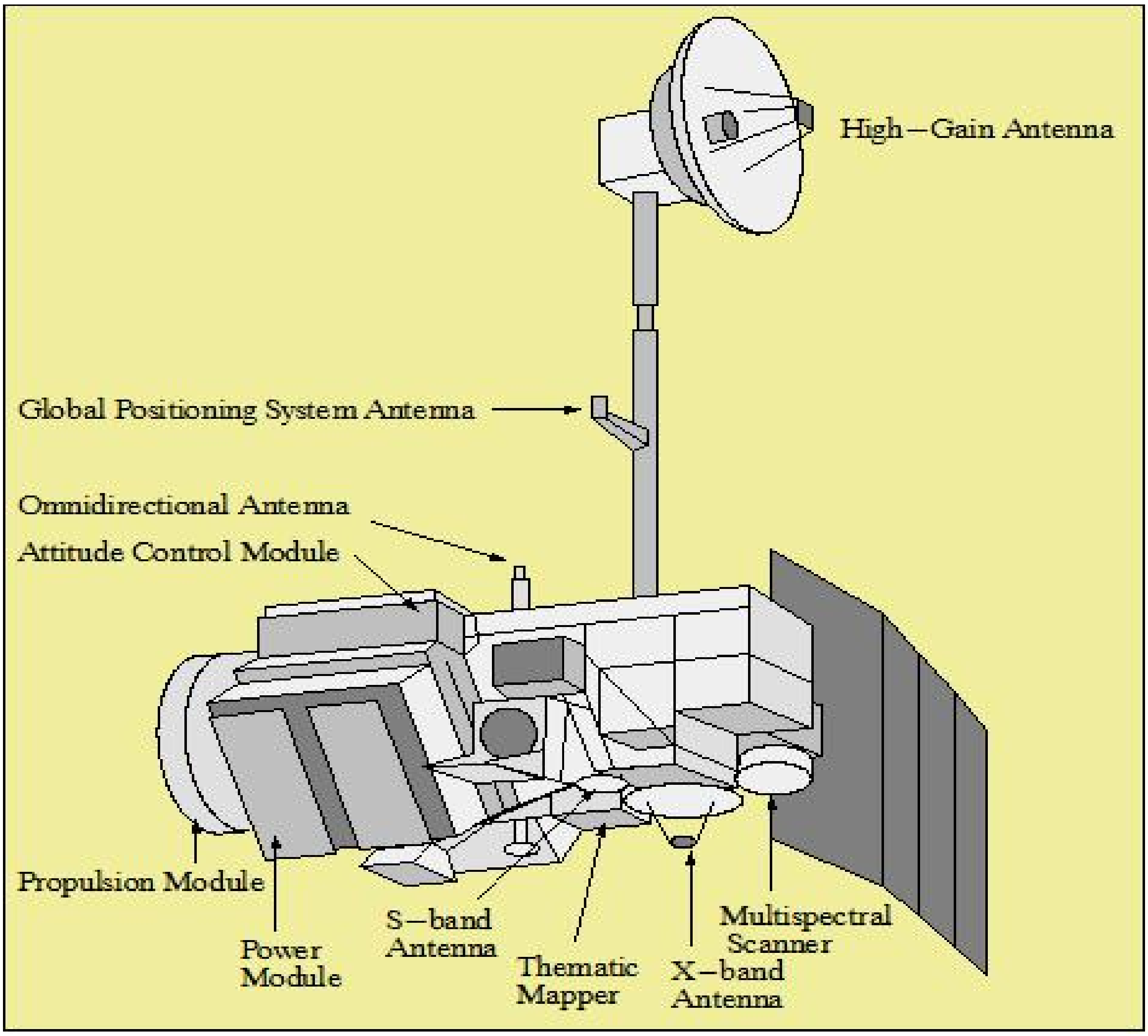


Figure E2: Rendering of the Landsat 4 and Landsat 5 satellites (Source: https://directory.eoportal.org, 2019)

Landsat 5 Spacecraft Facts:

- 3-axis stabilized, zero momentum with control of 0.01 degrees using reaction wheels.
- Aluminum with graphite struts.
- Hydrazine propulsion system.
- Single solar array with 1-axis articulation.
- Three Nickel Cadmium (NiCd) batteries provide 100 Ampere-Hour (AHr) total.
- Retractable boom (4 m long) with 2 powered joints supports the articulated High Gain Antenna, which downlinks data via Tracking and Data Relay Satellite System (TDRSS).
- Communications system uses S, X, L, and Ku Bands.
- Weight: approximately 4,800 lbs (2,200 kg).

Landsat 5 Instruments:

Landsat 5 carried the Multispectral Scanner (MSS) and the new Thematic Mapper (TM) sensors. MSS data acquisitions over the United States ceased in 1992 and global acquisitions ended in 1999. After the TM sensor failed in November 2011, the MSS instrument was brought back online. From June 2012 until January 2013, over 15,000 MSS scenes were collected.

Multispectral Scanner (MSS):

- Four spectral bands (identical to Landsat 1 and 2):
    - Band 4 Visible green (0.5 to 0.6 µm).
    - Band 5 Visible red (0.6 to 0.7 µm).
    - Band 6 Near-Infrared (0.7 to 0.8 µm).
    - Band 7 Near-Infrared (0.8 to 1.1 µm).
- Six detectors for each spectral band provided six scan lines on each active scan.
- Ground Sampling Interval (pixel size): 57 x 79 m.

Thematic Mapper (TM):

- Added the mid-range infrared to the data.
- Seven spectral bands, including a thermal band:
    - Band 1 Visible (0.45 - 0.52 µm) 30 m.
    - Band 2 Visible (0.52 - 0.60 µm) 30 m.
    - Band 3 Visible (0.63 - 0.69 µm) 30 m.
    - Band 4 Near-Infrared (0.76 - 0.90 µm) 30 m.
    - Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
    - Band 6 Thermal (10.40 - 12.50 µm) 120 m.
    - Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m.
- Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal.

4. Landsat 7

Landsat 7 was launched from Vandenberg Air Force Base in California on April 15, 1999 on a Delta II rocket. The satellite carries the Enhanced Thematic Mapper (ETM+) sensor. Since June 2003, the sensor has acquired and delivered data with data gaps caused by the Scan Line Corrector (SLC) failure. In late 2020, the Landsat 9 satellite will replace the

Landsat 7 in orbit. The Landsat 7 satellite orbits the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km (438 mi), inclined at 98.2 degrees, and circles the Earth every 99 minutes. The satellite has a 16-day repeat cycle with an equatorial crossing time: 10:00 a.m. +/- 15 minutes. Landsat 7 data are acquired on the Worldwide Reference System-2 (WRS-2) path/row system, with swath overlap (or side lap) varying from 7 percent at the Equator to a maximum of approximately 85 percent at extreme latitudes.

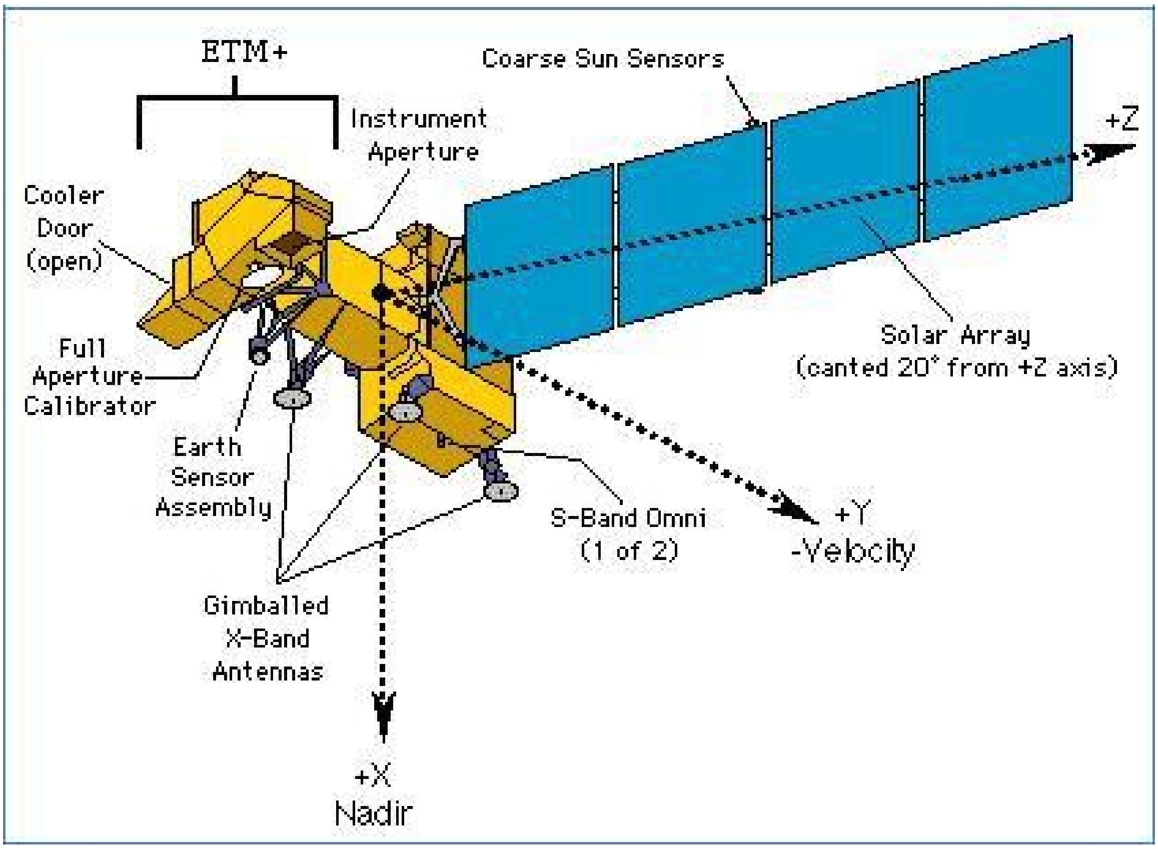


Figure E3: Illustration of Landsat-7 Spacecraft (Source: http://science.nasa.gov/missions/landsat-7/, 2019)

Data products created from over 2.5 million Landsat 7 Enhanced Thematic Mapper Plus (ETM+) scenes are available to download from EarthExplorer, GloVis, and the LandsatLook Viewer.

Landsat 7 Spacecraft Facts:

- Power provided by a single Sun-tracking solar array and two 50 Ampere-Hour (AHr), Nickel Cadmium (NiCd) batteries.
- Attitude control provided through four reaction wheels (pitch, yaw, roll, and skew); three 2-channel gyros with celestial drift updating; a static Earth sensor; a 1750 processor; and torque rods and magnetometers for momentum uploading.

- Orbit control and backup momentum unloading provided through a blow-down monopropellant hydrazine system with a single tank containing 270 pounds of hydrazine, associated plumbing, and twelve 1-pound-thrust jets.
- Weight: approx. 4,800 lbs (2,200 kg).
- Length: 4.3 m (14 ft).
- Diameter: 2.8 m (9 ft).
- Direct Downlink with Solid State Recorders (SSR).
- Data rate: 150 Mbps.

Landsat 7 Instrument:

Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+) sensor, an improved version of the Thematic Mapper instruments that were onboard Landsat 4 and Landsat 5. Landsat 7 products are delivered as 8-bit images with 256 grey levels. Descriptions of Landsat 7 band designations and comparisons of all Landsat sensors are available.

Enhanced Thematic Mapper Plus (ETM+):

- Eight spectral bands, including a pan and thermal band:
    - Band 1 Visible (0.45 - 0.52 µm) 30 m.
    - Band 2 Visible (0.52 - 0.60 µm) 30 m.
    - Band 3 Visible (0.63 - 0.69 µm) 30 m.
    - Band 4 Near-Infrared (0.77 - 0.90 µm) 30 m.
    - Band 5 Near-Infrared (1.55 - 1.75 µm) 30 m.
    - Band 6 Thermal (10.40 - 12.50 µm) 60 m Low Gain / High Gain.
    - Band 7 Mid-Infrared (2.08 - 2.35 µm) 30 m.
    - Band 8 Panchromatic (PAN) (0.52 - 0.90 µm) 15 m.
- Ground Sampling Interval (pixel size): 30 m reflective, 60 m thermal.
- Added the Band 6 Low and High gain 60 m thermal bands.
- On-board calibration was added to Landsat 7: a Full Aperture Solar Calibrator (FASC) and a Partial Aperture Solar Calibrator (PASC), in addition to the 2 calibration lamps.

Scan Line Corrector Failure:

On May 31, 2003 the Scan Line Corrector (SLC) in the ETM+ instrument failed. The SLC consists of a pair of small mirrors that rotate about an axis in tandem with the motion of the main ETM+ scan mirror. The purpose of the SLC is to compensate for the forward motion (along-track) of the spacecraft so that the resulting scans are aligned parallel to each other. Without the effects of the SLC, the instrument images the Earth in a "zig-zag" fashion, resulting in some areas that are imaged twice and others that are not imaged at all. The net effect is that approximately 22% of the data in a Landsat 7 scene is missing when acquired without a functional SLC.

Following the SLC failure, an Anomaly Response Team (ART) was assembled, consisting of representatives from the USGS, NASA, and Hughes Santa Barbara Remote Sensing (the manufacturer of the ETM+ instrument). The team assembled a list of possible failure scenarios, most of which pointed at a mechanical problem with the SLC itself. Since there is no backup SLC, a mechanical failure would indicate that the problem was permanent. However, the team was unable to rule out the possibility of an electrical failure, though such a possibility was deemed remote. Nevertheless, on September 3, 2003, USGS director Charles G. Groat authorized the Landsat project to reconfigure the ETM+ instrument and various other subsystems on board Landsat 7 to use the spacecraft's redundant ("Side-B") electrical harness.

With this authorization, the USGS flight operations team at the NASA Goddard Space Flight Center uploaded a series of commands to the spacecraft, instructing it to operate using the redundant electrical harness. This operation was successful, and on September 5, 2003, the ETM+ instrument was turned on and acquired data that was sent to the Landsat ground system at EROS outside Sioux Falls, South Dakota. It was immediately apparent that the migration to the Side-B electrical harness had not fixed the problem with the SLC. Following this, the instrument was reconfigured again to use its primary electrical harness. The subsequent conclusion of the ART was that the SLC problem was mechanical and permanent in nature.

Landsat 7 continues to acquire data in this mode. Data products are available with the missing data optionally filled in using other Landsat 7 data selected by the user. In 2013, Landsat 7 was joined by Landsat 8.

5. Landsat 8

Landsat 8 (first known as the Landsat Data Continuity Mission) was launch on February 11, 2013 from Vandenberg Air Force Base, California on an Atlas-V rocket.

The Landsat 8 satellite orbits the Earth in a sun-synchronous, near-polar orbit, at an altitude of 705 km (438 mi), inclined at 98.2 degrees, and circles the Earth every 99 minutes. The satellite has a 16-day repeat cycle with an equatorial crossing time: 10:00 a.m. +/- 15 minutes. Landsat 8 data are acquired on the Worldwide Reference System-2 (WRS-2) path/row system, with swath overlap (or side lap) varying from 7 percent at the Equator to a maximum of approximately 85 percent at extreme latitudes. The scene size is 170 km x 185 km (106 mi x 115 mi).

Data products created from over 1.3 million. Landsat 8 OLI/TIRS scenes are available to download from EarthExplorer, GloVis, and the LandsatLook Viewer.

Figure E4: Illustration of the Landsat 8 Satellite (Source: https://www.usgs.gov/media/images/landsat-8-illustration-above-earth, 2019)

Landsat 8 Instruments:

Operational Land Imager (OLI) - Built by Ball Aerospace & Technologies Corporation.

- Nine spectral bands, including a pan band:
    - Band 1 Visible (0.43 - 0.45 µm) 30 m.
    - Band 2 Visible (0.450 - 0.51 µm) 30 m.
    - Band 3 Visible (0.53 - 0.59 µm) 30 m.
    - Band 4 Red (0.64 - 0.67 µm) 30 m.

- Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m.
- Band 6 SWIR 1(1.57 - 1.65 µm) 30 m.
- Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m.
- Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m.
- Band 9 Cirrus (1.36 - 1.38 µm) 30 m.

OLI captures data with improved radiometric precision over a 12-bit dynamic range, which improves overall signal to noise ratio. This translates into 4096 potential grey levels, compared with only 256 grey levels in Landsat 1-7 8-bit instruments. Improved signal to noise performance enables improved characterization of land cover state and condition.

The 12-bit data are scaled to 16-bit integers and delivered in the Level-1 data products. Products are scaled to 55,000 grey levels, and can be rescaled to the Top of Atmosphere (TOA) reflectance and/or radiance using radiometric rescaling coefficients provided in the product metadata file (MTL file).

Thermal Infrared Sensor (TIRS) - Built by NASA Goddard Space Flight Center.

- Two spectral bands:
    - Band 10 TIRS 1 (10.6 - 11.19 µm) 100 m.
    - Band 11 TIRS 2 (11.5 - 12.51 µm) 100 m.

Landsat 8 Spacecraft Facts:

- Built by Orbital Science Corporation.
- 3.14 terabit solid-state data recorder.
- Power provided by a single 9 x 0.4 meter solar array and one 125 Ampere-Hour (AHr), Nickel-Hydrogen (NiH2) battery.
- Weight: 2,071 kg (4,566 lbs) fully loaded with fuel (without instruments).
- Length: 3 m (9.8 ft).
- Diameter: 2.4 m (7.9 ft).
- Direct Downlink with Solid State Recorders (SSR).
- Data rate: 384 Mbps on X-band frequency; 260.92 Mbps on S-band frequency.

Landsat 8 Pre-WRS-2 Data Products:

Nearly 10,000 scenes were acquired by the Operational Land Imager (OLI) and/or Thermal Infrared Sensor (TIRS) sensors after launch (February 11, 2013) through April 10, 2013, when the satellite achieved operational orbit (WRS-2). The earliest images are TIRS data only. These data are also visible and can be downloaded from EarthExplorer or GloVis.

While these data meet the quality standards and have the same geometric precision as data acquired on and after April 11, 2013, the geographic extents of each scene may differ. Most data will be processed to the highest level possible, however there may be some differences in the spatial resolution of the early TIRS images due to telescope temperature changes, but they should be within +/- 1 percent.