Assessment of the Impact of Overflows from Special Sewage Diversion Structures on the Water Quality of Hatirjheel

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The thesis titled **"Assessment of the Impact of Overflows from Special Sewage Diversion Structures on the Water Quality of Hatirjheel"** submitted by Md. Atauzzaman, Roll No. 0412042101 F, Session- April, 2012 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Civil Engineering (Environmental) on 14 November, 2015.

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

Md. Atauzzaman

DEDICATION

Dedicated to my parents

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LIST OF ABBREVIATIONS

BGMEA	Bangladesh Garment Manufacturers and Exporters Association
BMD	Bangladesh Meteorological Department
BOD	Biochemical Oxygen Demand
BRTC	Bureau of Research, Testing and Consultation
BUET	Bangladesh University of Engineering and Technology
BWDB	Bangladesh Water Development Board
COD	Chemical Oxygen Demand
DAP	Detail Area Plan
DCC	Dhaka City Corporation
DIT	Dhaka Improvement Trust
DMDP	Dhaka Metropolitan Development Plan
DNCC	Dhaka North City Corporation
DO	Dissolved Oxygen
DSCC	Dhaka South City Corporation
DTW	Deep Tubewell
DWASA	Dhaka Water Supply and Sewerage Authority
ECR	Environment Conservation Rules
GIS	Geographic Information System
GPS	Global Positioning System
JICA	Japan International Cooperation Agency
MLD	Million Liters per Day
NGO	Non Government Organization
PPM	Parts per Million
PWD	Public Works Datum
RAJUK	Rajdhani Unnayan Kartripakkha
SSDS	Special Sewage Diversion Structure
SWTP	Saidabad Water Treatment Plant
TAN	Total Ammonia Nitrogen
TDS	Total Dissolved Solid
TS	Total Solid
TSS	Total Suspended Solid
UIA	Un-ionized Ammonia
USEPA	United States Environmental Protection Agency
WTC	World Trade Centre

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ABSTRACT

Hatirjheel, which is now the largest surface water body within Dhaka, serves very important hydrologic functions of draining and detaining storm water from a large area of Dhaka city. As a part of a restoration project, eleven especially designed sewage diversion structures (SSDSs) have been constructed at eleven major storm sewer outfall locations around Hatirjheel. The SSDSs are connected to a peripheral "diversion sewer" network. Although designed to carry storm water, the storm sewers discharging into Hatirjheel carry both storm water and domestic sewage. During the dry season, the entire flow (consisting of sewage) carried through the storm sewers up to Hatirjheel is diverted downstream along the peripheral "diversion sewers". The SSDSs are designed to allow overflow of storm water into Hatirjheel during wet season. However, since the storm sewers carry both storm water and sewage, the overflows discharging into Hatirjheel during wet season cause deterioration of water quality of Hatirjheel. In this study, assessment of the capacity of the main diversion sewers to accommodate future flows has been made; and water quality of Hatirjheel has been assessed through a year-long water quality monitoring.

The combined total catchment area of all 11 SSDSs of Hatirjheel is about 23.73 km^2. The SSDS-1 and SSDS-10 have the highest catchment areas; 6.1 km^2 and 4.87 km^2, respectively. It has been found that the main diversion sewer system running along the periphery of Hatirjheel might not be able to accommodate the increased sewage flow in the near future (beyond 2015). The water quality of Hatirjheel is poor throughout the year, but is especially poor during the wet season when rainwater-sewage mixture overflows into Hatirjheel through the SSDSs. Water quality of Hatirjheel is particularly poor in near the SSDSs through which rainwater-sewage overflows during the wet season (SSDSs-1, 2, 7, 9). For example, during the wet season of 2014 (June to October 2014), the highest BOD_5 and COD values recorded for water samples collected in front of SSDS-1 were 90 mg/l and 175 mg/l, respectively. Total ammonia nitrogen (TAN) (and free ammonia) concentration in Hatirjheel water increased during the wet season due to entry of rainfall-sewage mixture; ammonia concentration continued to increase after the end of wet season (up to January 2015), most likely due to release of ammonia into water column from the decomposition of organic matter present in overflow water. Ammonia concentration in Hatirjheel water exceeds the USEPA standards for natural water by a huge margin. Ammonia concentration in Hatirjheel water is so high that fish species are unlikely to survive in this environment. The BOD_5 and Ammonia concentration of Hatirjheel water is much higher than the corresponding Bangladesh standards, and Hatirjheel water appears to be unsuitable for any purpose including fisheries, recreational and irrigation. Nitrate concentration in Hatirjheel water increased at the end of wet season, possibly due to oxidation of ammonia to nitrate; subsequent reduction in nitrate concentration is possibly due to incorporation into algal mass. Sulfate and phosphate concentrations in Hatirjheel water are relatively high throughout Hatirjheel throughout the year. Sulfide concentration was relatively higher but reduced significantly during the dry season.

Due to increase in wastewater/sewage flow, the overflow of sewage-storm water mixture into Hatirjheel during the wet season will continue to increase in the future; in fact, in the future, overflow of sewage from SSDSs could take place even during the dry period. This is likely to cause significant pollution of Hatirjheel throughout the year. In order to improve water quality of Hatirjheel, the domestic sewer connections to the storm sewer system must be disconnected gradually by DWASA. In this regard, catchment of SSDS-1 should be given priority. If domestic sewer connections to storm sewer could be disconnected within this catchment, then pollution load discharging into Hatirjheel (through SSDS-1) would be reduced significantly and water quality of Hatirjheel is expected to improve considerably. Efforts should be made to assess possible diversion of sewage flows from certain sections of the Hatirjheel catchment in order to avoid overloading of the main diversion sewer system of Hatirjheel.

Chapter One
Introduction

1.1 Background

Hatirjheel serves very important hydrologic functions of draining and detaining storm water from a large area (~30 km^2) of Dhaka (BRTC 2005). The low-lying areas of Hatirjheel used to receive storm water discharges through storm sewer outfalls. However, due to illegal connections, the storm sewers also carry domestic/industrial sewage (BRTC 2006). As a result, Hatirjheel was turned into a virtual wasteland and contributed to deterioration of water quality in the Begunbari Khal-Balu-Shitalakhya River system (Alam et al., 2012). As a part of a major restoration project, special sewage diversion structures (SSDSs) have been constructed at 11 outfall locations surrounding Hatirjheel. The SSDSs are now diverting the entire dry season flow consisting of domestic/industrial sewage through large diameter "main diversion sewers" laid along the periphery of Hatirjheel. During wet season, a part of the combined flow of storm water and sewage overflows into Hatirjheel through SSDSs, causing pollution of the water body. It was expected that gradual separation of domestic/ industrial connections to storm sewers would improve the situation. However, there is no sign of this taking place; on the contrary, with increase in population, the pollution load is increasing, intensifying the pollution of Hatirjheel.

The SSDSs and the main diversion sewers of Hatirjheel were designed based on surveys carried out in 2007. Water quality modeling suggested reasonable water quality of Hatirjheel, except for a brief period at the beginning of each wet season (Samad, 2009). However, continuously increasing population density and expansion of storm sewer network are putting extra pressure (both hydraulic and waste-load) on Hatirjheel water management system. Water quality of Hatirjheel deteriorated significantly during wet seasons of 2012 through 2015 due to huge overflows of mixed rainwater-sewage; there was significant spatial variation in water quality (as was evident from visual observation), depending on locations of SSDSs; water quality at locations close to SSDS-1 and SSDS-2 was particularly poor during wet seasons. It is important to assess whether the SSDS and the main diversion sewer system of Hatirjheel would be able to handle the hydraulic load and extent of water quality deterioration of Hatirjheel for present and future years, especially if no corrective measures are adopted.

1.2 Objectives

The specific objectives of the study were:

1. Estimation of storm water flows through the SSDSs considering catchment areas under each SSDS, and analysis of storm sewer network of DWASA.
2. Estimation of present and future (up to 2025) wastewater flows through storm sewers discharging into Hatirjheel SSDSs, and overflow of rainwater-sewage into Hatirjheel.
3. Assessment of the capacity of the SSDSs and the associated sewer systems to accommodate present and future storm water and sewage flows.
4. Monitoring of water quality of Hatirjheel at specific locations in order to assess spatial and temporal variation of water quality of Hatirjheel.

1.3 Outline of Methodology

Storm water flows through 11 SSDSs have been estimated by identifying catchments under each SSDS and analyzing storm sewer network maps of DWASA. The storm sewer network maps, collected from DWASA, have been superimposed on GIS-based map of Dhaka city. A rainfall scenario with a 5 year return period has been used for estimation of storm water discharges through different SSDSs.

Sewage flows through storm sewer network have been estimated by analyzing locations of deep tubewells and population distribution within Hatirjheel catchment. Discussions with DWASA officials have been held to estimate wastewater flow rates and to understand the status of domestic sewage connection to storm sewer network. Estimates of future (up to 2025) sewage flows have been made based on population projections. Assessment of capacity of SSDSs in accommodating present/future flows have been made based on design configurations and conditions (e.g., reduced capacity due to accumulation of sludge in sewers) of sewers.

In order to assess spatial and temporal variation of water quality, water samples have been collected from selected locations throughout Hatirjheel, considering locations of SSDSs, connections with adjoining lakes (Banani and Gulshan lakes) and physical configuration of Hatirjheel. Water quality monitoring has been carried out over a period of 12 months (June 2014 to May 2015), roughly at the frequency of one sampling per month. The water/ wastewater samples have been tested (following standard methods) for a range of parameters including pH, Conductivity, Turbidity, Color, NO_3^-, NO_2^-, NH_3, PO_4^{3-}, SO_4^{3-}, S^{2-}, Cl^{2-}, COD, BOD_5, TS, TDS and TSS.

1.4 Organization of the Report

This thesis comprises of five chapters. The contents of each chapter are summarized below:

Chapter One: This introductory chapter describes the background and objectives of the present study. It also presents a brief overview of the methodology followed in this study.

Chapter Two: This chapter presents literature review covering background information on the Hatirjheel area and its environmental significance. It describes the drainage system (storm drainage, flood protection etc.) of Dhaka city. It also briefly describes the detention and drainage functions of Hatirjheel. Some information about water quality management of lakes and rivers has also been given in this chapter.

Chapter Three: This chapter describes in detail the methodology followed in this study, including details of water sample collection and testing from Hatirjheel. It also describes the methodology followed for estimation of present and future sewage and storm water flows for areas within Hatirjheel catchment.

Chapter Four: This chapter presents the results obtained from this study. It provides detail analysis of wastewater and storm water flows through Hatirjheel system, and the ability of Hatirjheel sewer system to carry these flows. It also presents the water quality characteristics of Hatirjheel based on a year-long monitoring program.

Chapter Five: This final chapter summarizes the major conclusions from the present study. It also presents some recommendations for future study.

Chapter Two
Literature Review

2.1 General

The city of Dhaka was established by the Mogul Emperor Jahangir in 1608 on the bank of the Buriganga River. By the virtue of being located by a river, the city has been subjected to periodic flooding since its early days. Attempts were therefore made early to protect the city from floods. The Buckland Flood Protection Embankment was the first such attempt. Since then, however, the inundation pattern of the city has undergone many changes as the city continued to grow and new flood control structures were put in place. In 1988, when the worst ever flood in living memory hit the largely unprotected city, almost all of the eastern part and about 70% of the western part of the capital went under water (Khan, 2006). In 1998, the city was hit by the severest flood in history. This time, the city protection embankment and floodwall protected most of the western part of the city. Even then, during peak flooding, about 23% of the western part went under water. Another major problem the city is facing is water logging in the streets due to heavy rainfall. Ponds/ basins within city areas for detention of storm water during rainy season (when water level of the peripheral rivers remain high) could significantly reduce water logging and prolonged flooding.

A preliminary study was carried out (BRTC, 2005) during 2004-05 by BUET in 2005 to assess the development potentials of the Hatirjheel area, given the existing critical drainage conditions of the area. The study revealed that the lowlands behind the Sonargaon Hotel and Hatirjheel perform the very important functions of detention and conveyance of accumulated storm runoff generated from the adjoining catchments area of over 30 sq. km. While it was recommended that the low-lying floodplain areas of Hatirjheel must be preserved for the retention of storm runoff from a large catchments area, the study also recognized, from traffic points of view, that there exist a missing link between the Tongi Diversion Road and the Pragati Swarani. Based on the recommendations of this and other studies, the government came up with proposals for the development of Hatirjheel lowlands and constructions of at-grade roadway and walkway along the periphery of the Hatirjheel in 2007. The project had three major objectives:

1. Restoration and conservation of environment in and around the project area,
2. Preserving the low-lying floodplain areas of Hatirjheel and the lowlands behind Sonargaon Hotel for the retention of storm runoff from a large catchment area, and
3. Alleviating local traffic congestions through constructions of peripheral road and walkways.

Hatirjheel and the lowlands behind the Sonargaon Hotel used to receive storm runoff, domestic wastewater (sewage) and industrial wastewater through a number of major outlets. During the dry period of the year, the storm sewers discharging into the lowland of the project area primarily carried domestic sewage, which came into these sewers through illegal domestic connections. The lowlands of the project area thus received a huge quantity of liquid wastewater, which eventually drained through the Begunbari khal-Norai khal-Balu River system into the Shitalakhya River. Thus, besides polluting the Hatirjheel lowlands, the wastewater carried through the Norai khal-Balu River also caused significant pollution of the Shitalakhya River. This was a major threat to the water quality at the Saidabad Water Treatment Plant (SWTP), which draws raw water from the Shitalakhya River.

As part of the integrated development of Hatirjheel area, special sewage diversion structures (SSDSs) have been constructed at 11 outfall locations surrounding Hatirjheel. The SSDSs are now diverting the entire dry season flow consisting of domestic/industrial sewage through large diameter "main diversion sewers" laid along the periphery of Hatirjheel. During wet season, a part of the combined flow of storm water and sewage overflows into Hatirjheel through SSDSs, causing pollution of the water body. It was expected that gradual separation of domestic/industrial connections to storm sewers would improve the situation. However, there is no sign of this taking place; on the contrary, with increase in population, the pollution load is increasing, intensifying the pollution of Hatirjheel.

This Chapter presents an overview of the drainage system of Dhaka city. It also presents a detail assessment of the functions of Hatirjheel in detention and drainage of storm water. This Chapter then presents an assessment of water quality of Hatirjheel based on available data and information. It also identifies the important parameters for characterization of water quality of a water body, and discusses the significant of these important water quality parameters.

2.2 Drainage System of Dhaka City

Dhaka is located in the central region of the flat deltaic alluvial plain of the three large rivers: the Ganges, the Brahmaputra and the Meghna. The city is surrounded by the distributaries of these major rivers. The greater Dhaka city having an area of approximately 275 km^2 (JICA, 1991) is surrounded by the Tongi canal in the north, the Buriganga River in the south, the Balu River in the east and the Turag River in the west. Water levels in these rivers are lowest in January-February and the highest in August-September. Based on flood control infrastructures, greater Dhaka is divided in two parts, Dhaka West and Dhaka East where the lowlands are within the floodplain of the Balu River (Khan, 2006). These parts are divided by Mymensingh road, Pragati Swarani, DIT road and Biswa road that were raised after devastating flood of 1988 to perform as road-cum-embankment. Areas covered by Dhaka West and Dhaka East are156 km^2 and 119 km^2 respectively. Most built-up areas in greater Dhaka are at elevations between 6.5 and 8.5 m PWD (Public Works Datum, a

National datum) covering at 75 km^2 (JICA, 1987) whereas 70% area lies about 0.5 and 5 m PWD. The built-up areas included planned and unplanned residential areas and large commercial complexes, while approximately 30% of the urban population lives in slums situated mostly in the low-lying areas.

Dhaka has a tropical monsoon climate with four climatological seasons: pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and dry season (December to February). The monsoon is the rainy season with heavy rainfall. Annual average rainfall in Dhaka is approximately 2000mm. Maximum daily rainfall during this period is about 200 mm (Hossain et al., 2004). The pick monthly rainfall occurs before surrounding rivers attain the highest stage. The mean monthly temperature varies between 20°C and 30°C, while the mean monthly evaporation varies between about 80 mm in November and about 130 mm in August (JICA, 1991). Runoff from urban areas as a result of rainfall is generally higher than those from rural areas due to many impervious surfaces viz., roofs of houses, paved roads, parking lots, etc. in the urban areas.

2.2.1 Storm Water Drainage System

The natural drainage system in Greater Dhaka is composed of several lakes and lowlands, and about 40 khals, that drain storm-water from 80% of the city area to the surrounding rivers, comprising three major khal systems: (1) Degun-Ibrahimpur-Kallyanpur khal system which drains to Turag River; (2) Dhanmondi-Paribag-Gulshan-Banani-Mahakhali-Hatirjheel khal system which drains to Balu River; (3) Segubagicha-Gerani-Dholai khal system which drains to Balu and Buriganga Rivers. There are several lakes and lowlands that provide detention storage for internal storm-water in Dhaka West. Table 2.1 shows storage related parameters of major lakes and detention areas. Hatirjheel, a part of the Dhanmondi-Gulshan-Begunbari khal system that drains about one-third of Dhaka West through the Rampura regulator, is a major detention area in Dhaka West and provides both storage and conveyance to the storm-water flow. The catchment area of the khals in the Dhaka West varies from 6 to 40 sq. km.

Table 2.1: Storage related parameters of major depression storages in Dhaka West

Name	Length (m)	Average depth (m)	Area (km^2)	Volume (m^3)
Dhanmondi lake	2400	2.5	0.176	440,000
Ramna lake	400	4.5	0.020	90,000
Crescent lake	650	2.5	0.016	40,000
Gulshan lake	3800	2.5	0.480	1,200,000
Hatirjheel	3000	2.0	1.078	2,160,000

Source: Khan, 2006

The natural drainage system receives storm-water from a drainage network covering about 140 km^2 and managed by DWASA. The storm sewer system of this network includes 225 km of underground pipes and 8 km of box culvert. The sewer system of DWASA was originally designed as two separate systems: one for sanitary sewage and the other for storm sewage. Present storm water drainage network under DWASA covers an area of approximately 140 sq. km. (DWASA). Important components of the drainage network are briefly summarized below.

- 22 open canals having width of 10 to 30 m and total length of approximately 65 km.
- 185 km of underground pipes having diameter ranging from 450 to 3000 mm.
- 6.5 km of box culvert of sizes from 2.5 m x 3.4 m to 6 m x 4.1 m.
- 3 permanent pump stations in Dhaka West at Goran-Chatbari (capacity of 22 cumec, cubic meter per second), Kallyanpur and Dholaikhal, having combined pumping capacity of 54 cumec compared to an estimated peak storm runoff of 140 cumec. 2 storm water pumping stations of capacity of 9.6 and 10 cumec at Narinda and Kallyanpur, respectively. In recent years, Dhaka City Corporation (DCC) has constructed another storm water pumping station, having capacity of 22 cumec, at the outfall of Dholaikhal into Buriganga River. DWASA has taken over the operation and maintenance of the pumping station.
- Moreover, DCCs (DNCC and DSCC) have constructed and maintain at least 130 km small diameter underground drains and approximately 1200 km surface drains, which carry storm water to the main sewer lines. Rajdhani Unnayan Kartripakkha (RAJUK) also constructs road side drainage lines during construction of new roads.

The flood mitigation and storm water drainage plan in the Master Plan for greater Dhaka Protection Project (JICA, 1991) was prepared following several previous studies. A subsequent feasibility study (JICA, 1992) has been also conducted. This plan includes several structural measures by dividing Greater Dhaka in 3 drainage compartments: DA, DB and DC, and a number of sub-compartments. These compartments are rearranged drainage zones of previous study done by JICA (1987). The flood mitigation plan was laid out mainly for Dhaka east, which includes an eastern embankment along the Balu River and 3 cross-embankments.

The storm water drainage plan demarcates pumping and gravity drainage areas. In addition to the 3 pump stations installed in Dhaka west, 4 pump stations with about 180 cumec of total pumping capacity was required in Dhaka East. The pumps were expected to operate from June to October, when the regulator and sluice gates would be closed because of relatively high external (river) water level. However, since this plan has been implemented only in Dhaka west, drainage zones F, G and C, which were planned to pump water through Dhaka East, remain as gravity drainage areas. The design rainfall in the hydraulic design criteria is 245 mm, which is 2-day cumulative rainfall having 5-year return period. The 2-day draining period by the pumps has been selected based on technical and economical justifications. A runoff ratio 0.8 was used for estimating the specific capacity of pumps and specific storage volume of retarding ponds, which were selected to be 1.14 cu. m/sec and 0.12×10^6 cu. m per sq. km of catchment area, respectively. However, Chowdhury (2001) found much lower runoff in the range 0.4-0.7 based on measured data in different catchments of Dhaka city.

2.2.2 Flooding and Drainage Conditions

Severe floods in the Greater Dhaka City are mainly caused by spill from surrounding rivers namely Turag River, Balu River and Buriganga River. These rivers are connected to the major rivers of the country and receive water discharges from the Brahmaputra-Jamuna River. Turag and Buriganga Rivers are distributaries of the old Brahmaputra River and Balu River is the tributary of the Lakhya River, while Tongi khal connects the Turag River with the Balu River. Flooding in the Dhaka city usually occurs during July to September when the surrounding rivers cannot accommodate the water flow within the main courses. The water levels in the surrounding rivers are affected by backwater from Dhaleswari, Shitalakhya and Meghna Rivers. The Balu, Turag and Buriganga Rivers are under influence of the tides in the Lower Meghna and the recession of flood is delayed if peak flood occurs during spring tides.

In recent years, Bangladesh experienced major floods in 1988, 1998 and 2004. After the 1998 flood, priority measures were undertaken to protect Dhaka West from river floods, which were partially completed before the 1998 flood. Although Dhaka West was empoldered after 1998, drainage improvement actions became necessary because of the ensuing internal storm water flooding occurrences. In 1998, Dhaka West was flooded mostly because of floodwater intrusion through incomplete parts of the protection work and failure of control structures (Chowdhury et al., 1998). Additionally, storm water flooding occurred in some areas after the regulator and sluice gates were closed. There is a special embankment at the Hazrat Shahjalal International Airport of 10.53 km length. Another rail/road cum embankment is proposed for the eastern part of the city that will run along the Balu River for a length of 29 km. The flood control and drainage works have brought major changes in the flood regime in Dhaka West (JICA, 1990). Important components of protection measure in Dhaka are as follows:

- Approximately 30 km of earthen embankment along Tongikhal, Turag River and Buriganga River.
- Approximately 37 km of raised road and flood wall.
- A total of 11 regulators at the outfall of khals to the surrounding rivers along the embankment.
- One regulator and 12 sluice gates on the khals at the crossing with Biswa road, DIT road, Pragati Swarani, Mymensingh road and Railway line at Uttar khan.

- One pump station at the outfall of Kallyanpur khal to the Turag River and another one at the outfall of Dholai khal to the Buriganga River. These pump stations are for draining rainwater from some parts of the Dhaka West.

Dhaka was moderately affected by storm water flooding in July 2004. After the July flood, a second spell of storm water flooding, caused high-intensity rainfall, affected Dhaka West in mid-September of 2004. This extreme event was the result of a low pressure formed in the Bay of Bengal (Khan, 2006) that later transformed into a land depression while moving inland. The recorded highest daily rainfall of 341 mm compared to a mean monthly rainfall of 264 mm in September and a 5-day cumulative rainfall of 600 mm occurred during this period. Both the 1-day and 7-day cumulative rainfall during this event had return periods of about 100 years. Although the stages in the rivers around Dhaka were low at this time, the drainage system of Dhaka partly collapsed due to excessive amount of runoff and faulty operation of drainage system.

To alleviate the drainage problems, a storm water drainage improvement plan was undertaken by DWASA (JICA, 1991). As part of the plan, many sections of the natural khals have been replaced by concrete box culverts, which have been converted to box shape concrete drain, are Dhanmondi khal, Paribag khal, Begunbari khal, Mohakhali khal, Segubagicha khal, Dholai khal, etc. These khals do not exist anymore. Beside those, along with the rapid urbanization in the city in past years, many khals and lakes have been encroached. A number of khals have already disappeared. A study by JICA (1987) observed that many portions of the major drainage khals were subject to encroachment due to earth filling, deposit of city garbage and construction of buildings and roads. Again due to mismanagement of collection and disposal of solid waste in Dhaka, substantial portion of waste finds its way into the storm drainage system. Sediment samples collected from storm sewers show presence of polythene bags, plastic, cloths, rubber, metal strips, glass, paper, leaves, bones, etc. in addition to soil (Khan and Chowdhury, 1998). Moreover, unplanned and uncontrolled expansion of urban area has stretched rapidly towards the low-lying areas adjacent to the flood protection embankments. These are deeply flooded floodplain areas close to the river. Land development through land filling process in low-lying areas is causing drastic reduction of water storage areas. As a result, water logging has become a common phenomenon during monsoon along with flood. The city is experiencing severe problem of rainfall flooding in the last few years. This internal rainfall flood situation worsens when runoff generated from high intensity rainfall combines with high water level in the surrounding rivers. Moderate rainfall causes serious problems for some areas of the city, namely Malibag, Mauchak, Shantinagar, Rajarbagh, Fakirapul, Purana Paltan, Green Road, etc. Drainage congestion results in local floods with ankle to knee-deep water on the streets. This water logging problem is creating environmental and health hazards in the city.

2.2.3 Situation in Dhaka West

Storm water drainage in Dhaka West is accomplished by a combination of pump and gravity drainage. At present, there are five pump stations in the city, to pump out logged water in case of any emergency situation. The stations are at Kamalapur, Rampura, Dholai khal, Kallyanpur and Goran Chand Bari. The permanent pump stations at Dholai khal, Kallyanpur and Goran-Chatbari are located in drainage zones B, H and J plus K, respectively. Although gravity drainage of relatively high lands in zone I is satisfactory, temporary pumps had to be installed to pump out storm water from zones A, C and F plus G. Table 2.2 shows zone-wise storm runoff generated from design and 2-day peak rainfall events for a runoff ratio of 0.8, and available pumping capacity in 2004.

Table 2.2: Gravity and pump drainage in Dhaka West in 2004

Drainage Zone	Area (km^2)	Generated storm runoff (cumec)			Pumping capacity (cumec)	Remarks
		Design	July	Sep		
A	7.25	8.2	2.5	16.7	5.2	Temporary pumps, 7 locations
B	7.24	8.2	2.4	16.7	22.0	Through Dholai khal
C	10.92	12.4	3.7	25.1	3.1	Temporary pumps through Janapath
F	13.70	15.5	4.6	31.5	9.1	Temporary pumps through Rampura
G	17.64	20.0	6.0	40.6		
H	17.60	20.0	5.9	40.6	10.0	Through Kallyanpur
I	31.42	35.6	10.6	72.3	0.0	Gravity drainage
J	7.69	8.7	2.6	17.7	22.0	Through Goran-Chatbari
K	25.85	29.3	8.7	59.5		

Source: Khan, 2006

During July and September flooding, the highest 2-day rainfall amounts were already filled up from antecedent rainfall during the peak events. Approximately 0.25 cumec of domestic waste water might have been added to the calculated runoff. Temporary 5 cusec pumps, running at about 60% efficiency, were generally unable to drain runoff generated by the design rainfall or an average rainfall as in July 2004 from the gravity drainage zones A, C, F and G. Fig. 2.1 shows (Khan, 2008) a comparison of the water levels inside and outside the regulator at Rampura when temporary pumps were in operation.

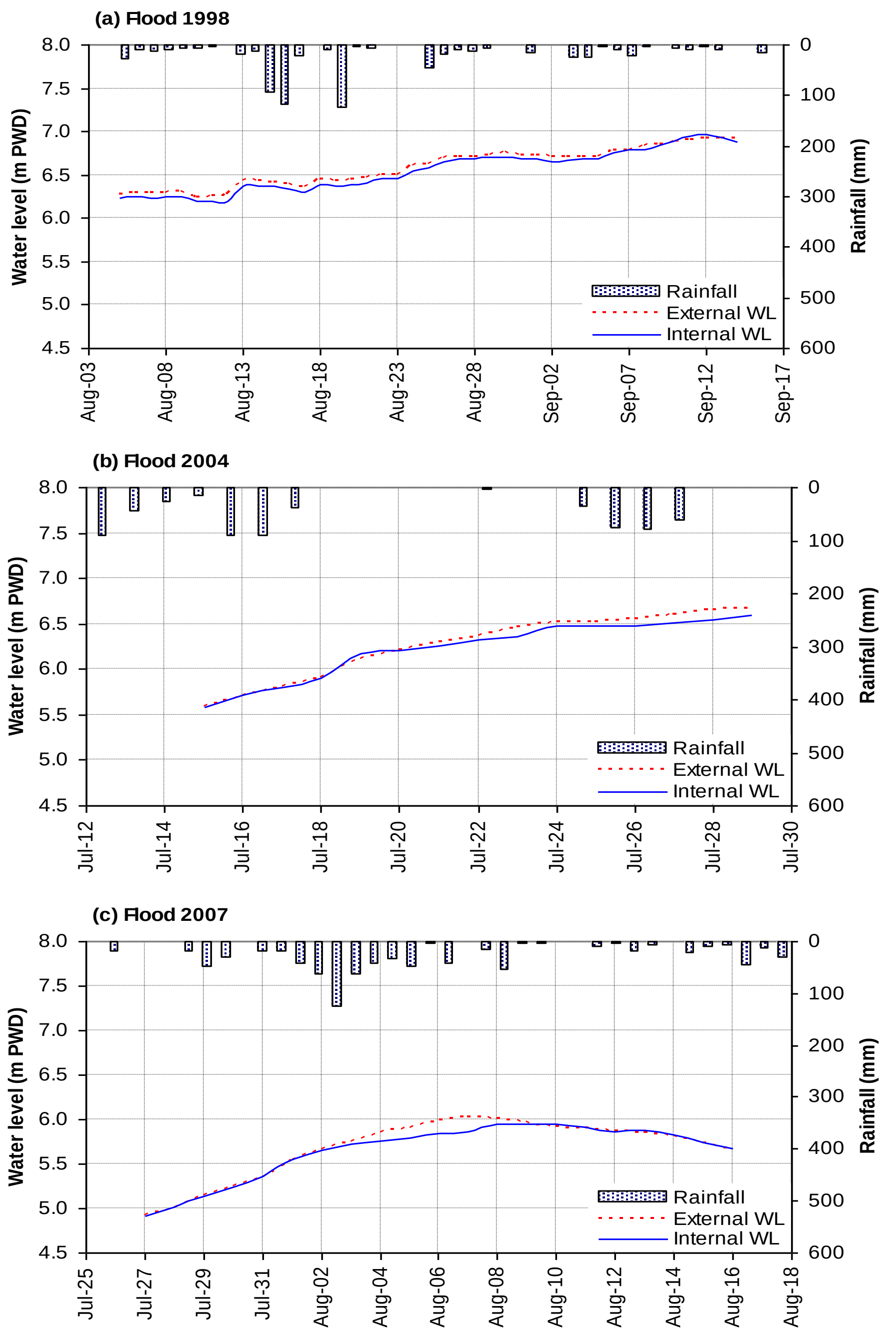

Fig. 2.1: Observed water level at Rampura during major floods (Khan, 2008)

Inability of the temporary pumps to drain out the storm runoff accumulated inside the regulator resulted in overflowing of the Hatirjheel detention area. Permanent pump stations, on the other hand, were adequate to drain the runoff generated in July. Runoff generated in September exceeded these design or average conditions. Operation of the permanent pump stations at Kallyanpur and Dholai khal was disrupted by malfunction and power outage. Although most of the catchments of Kallyanpur pump were flood-free in July 2004 (Khan, 2006), drainage routes to the retarding pond were obstructed because of inadequate storm water passage through the newly constructed cross-roads, encroachment of drainage canals and unplanned development activities, which caused local flooding.

The present retarding pond area of the Kallyanpur pump station is less than the design requirement. The retarding pond area of the Goran-Chatbari pump station has decreased due to land-filling activities along the perimeter (Khan, 2006). However, the service area of this pump is not yet fully developed, which allows additional detention storage in the low-lying areas. Large scale encroachment and unauthorized development activities have also taken place in the Hatirjheel detention area in zone F. Several structures have been constructed by extending the residential area into Gulshan Lake in zone G, significantly reducing the runoff detention capacity of the lake. Conveyance capacity of the storm sewer system in most drainage zones is inadequate because of accumulation of solids in the sewers. A significant portion of these solids includes construction debris and solid wastes generated in the catchment areas or dumped through open manholes (Khan and Chowdhury, 1998). The quality of storm-water is generally objectionable due to discharge of domestic sewage into storm sewers.

In many areas, the water quality is further degraded because of sanitary sewer breakdown and overflow, and subsequent mixing of sanitary sewage with storm sewage. Drainage of zones F and G through the Hatirjheel at Rampura and zone C through the Segunbagicha khal at Janapath may be improved by installing pump stations with required retarding pond capacities as intermediate measures until the road-cum-embankment, called 'Eastern bypass', is constructed along the Balu River. However, the decision to install pump stations warrants detailed analysis of possible consequences. According to the design criteria set forth by the master plan, 16 cumec pumping capacity and 1.64×10^6 m^3 retarding pond volume is required for zone F alone, assuming Gulshan Lake has sufficient detention storage for zone G. The present volume of Hatirjheel, only possible retarding pond site, may not be able to meet the requirement. However, the development of Hatirjheel has been under construction. Similarly, approximately 13 cumec pumping capacity and 1.31×10^6 m^3 retarding pond volume will be required for zone C (Khan, 2006). There is no existing site for a retarding pond in this zone. Installation of pump stations at these two sites may cause flooding in the downstream reaches if the conveyance capacity of the canals is not adequate for the pumped out water.

2.3 Hatirjheel and its Environmental Importance

Considering the drainage problem and water logging in Dhaka city, even after light rain, requirement of some retarding basin was felt necessary. As part of city development Hatirjheel has been chosen to develop as a retarding pond where rain water will be kept for a certain time in the event of rainfall and the lake will also be used for some recreation.

2.3.1 Areas Surrounding Hatirjheel

As noted earlier, a comprehensive baseline survey has been carried out for the entire project area including the low-lying areas adjacent to the Sonargaon Hotel and the

Hatirjheel. The baseline survey report provides a detailed description of the existing conditions of natural as well as socio-economic environment in and around the project area. Relevant information on geology, topography, climatic condition, and storm water drainage and water quality have been gathered and presented in this report.

The low-lying area adjacent to Sonargaon Hotel is located in an area that is rapidly developing into a major business district of the capital city Dhaka. Four major roads of the city encircle the area, located in the heart of the Dhaka City. The area, measuring about 13.84 acres, is bounded by Panthapath to the north, Kazi Nazrul Islam Avenue to the west, Tongi diversion road to the east and commercial and residential settlements and Eskaton road to the south. The boundary is shown in Fig. 2.2. Bangladesh Garment Manufacturers and Exporters Association (BGMEA) are constructing its headquarters on a piece of land adjacent to the eastern boundary of the project. Adjacent to the BGMEA headquarters, there was a plot earmarked for the World Trade Centre (WTC). A number of car workshops and some other small shops are located to the north of the site along the Panthapath road. Makeshift residential houses, mostly illegal, are occupying a large part of the southern boundary of the project area. Part of the low-lying land is used for small-scale agricultural activities during the dry season.

Fig. 2.2: Hatirjheel project area (Google Earth)

2.3.2 Drainage Functions of the Project Area

As shown in Fig. 2.2, a drainage channel flows, more or less straight, through the center of the Hatirjheel lowlands. This channel carries the combined storm water and wastewater flow that is discharged into the low-lying area. The low-lying area behind the Sonargaon Hotel receives storm runoff and wastewater flows from three major sources: one box culvert coming from the west along the Panthapath, a brick sewer (formerly Paribagh khal) comes from the south-west, and a major storm sewer coming from the Kawranbazar area. During the dry period of the year, these storm sewers primarily carry domestic wastewater, which is carried downstream along the drainage channel that runs through the project area. The quality of this dry-season wastewater (which is primarily sewage) is extremely poor. During the rainy season, storm water flows through the sewers increases significantly and the entire low-lying area behind Sonargaon becomes submerged with drainage water. This area, along with the low-lying areas of Hatirjheel, serves the very important purpose of retaining drainage water during the rainy season, especially when the Rampura regulator is kept closed for two to three months (to prevent intrusion of river water into the City).

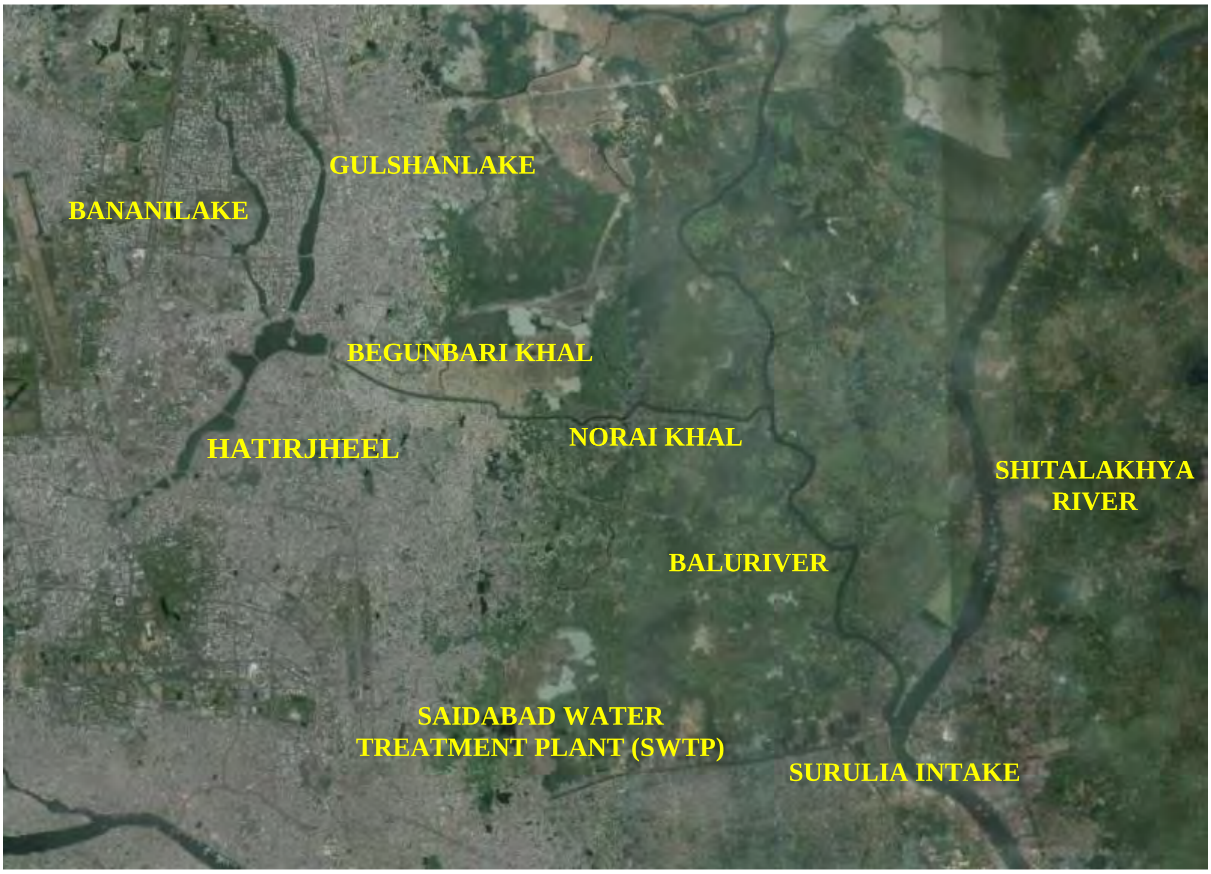

Fig. 2.3: Hatirjheel drainage function (Google Earth)

Storm runoff accumulated in the low-lying areas behind Sonargaon is gradually drained to the Balu River through the Hatirjheel area (see Fig. 2.3). Extensive land filling activities were been observed in the lowlands between Tongi diversion road and the rail line near the

Sonargaon Hotel; fortunately this area, re-excavated as a part of Hatirjheel project, is now a part of Hatirjheel. Land filling activities were also been observed in some parts of Hatirjheel. Fortunately, as a part of Hatirjheel project, most of these illegal filling activities could be stopped, and the filled areas were brought back under Hatirjheel.

2.3.3 Detention and Drainage Functions of Hatirjheel

The Hatirjheel system provides detention storage and drainage passage to about 31.3 km^2 area of western Dhaka city, of which 13.7 km^2 are in drainage zone F and 17.6 km^2 are in zone G (see Fig. 2.4). Storm runoff from zone F (Fig. 2.5) is drained to the lowlands behind the Sonargaon Hotel and Hatirjheel by local khals, underground sewers and box culverts. Important commercial, residential and industrial areas are located in the Shahbag, Paribagh, Elephant road, Mirpur road, Panthapath, Green road, Farmgate, Kawranbazar, Maghbazar, Malibagh and Tejgaon areas in zone F. Gulshan and Banani lakes are in zone G. Hatirjheel and Gulshan-Banani lakes meet approximately 1 km upstream of the Rampura bridge. The combined storm runoff from F and G ones is drained through the Rampura regulator just downstream of the Rampura Bridge.

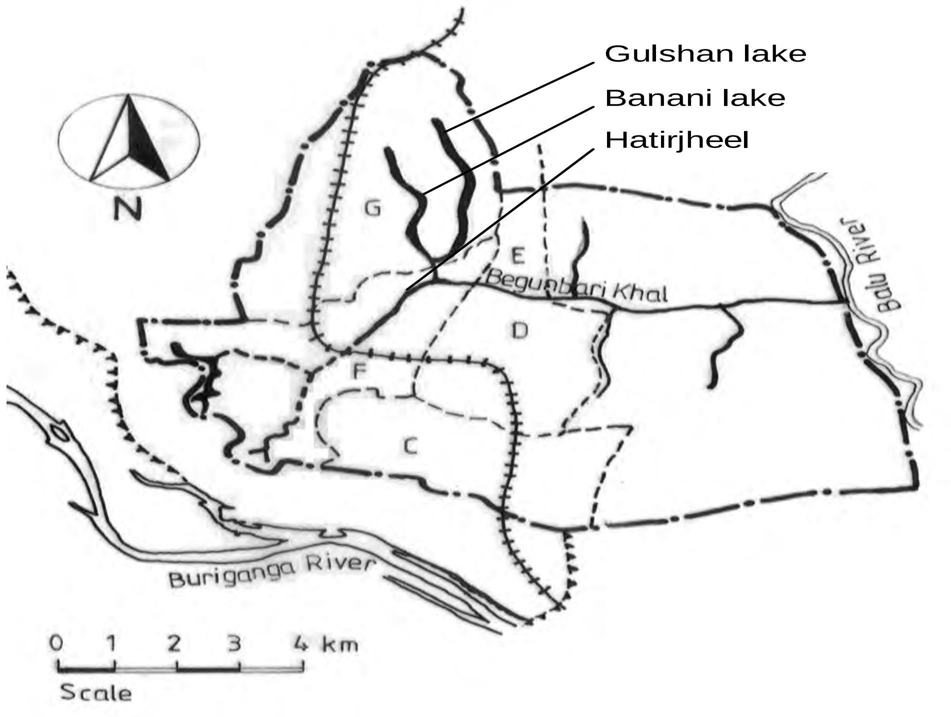

Fig. 2.4: Drainage zones related to the Hatirjheel system

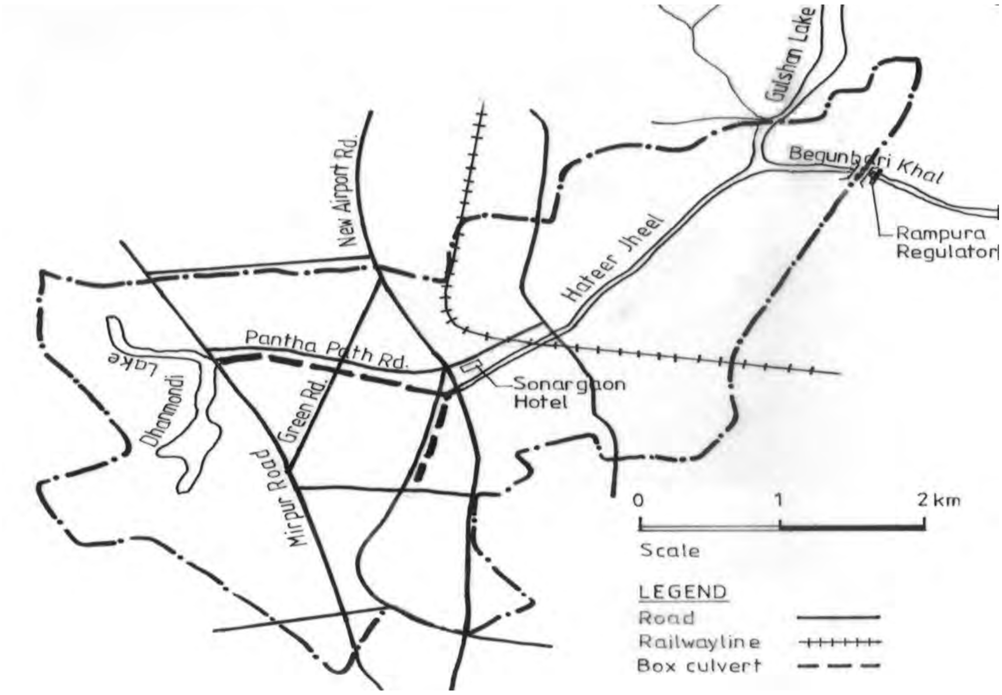

Fig. 2.5: Drainage zone F

Hatirjheel and the lowlands adjacent to the Sonargaon Hotel perform important storm water detention and gravity drainage functions for drainage zones F and G in Dhaka city. Storm runoff from these drainage zones is temporarily stored in the detention area and subsequently drained to the Balu River through the Begunbari khal. When the water level in the Balu River is relatively high, the regulator gates at Rampura are closed to protect the internal areas from river flooding. During this period internally-accumulated storm water is detained in Hatirjheel. The natural gravity drainage and detention capacity of Hatirjheel has been already reduced due to reduction in size of the detention area. Further reduction in the size of Hatirjheel will pose a serious threat of storm water flooding in the western part of the city.

As discussed earlier, as a part of Hatirjheel restoration project, "main diversion sewers" have been constructed along the periphery of Hatirjheel, which are carrying the entire dry weather flow (diverted at the SSDSs). During wet season, a part of the combined flow is diverted to the main diversion sewer, while the remaining part is discharged into Hatirjheel through the overflow structure of the SSDSs. The main diversion sewers of Hatirjheel, which were designed to carry the entire dry weather flow that comes through the storm sewer network, have been designed based on estimated sewage flow rates estimated in 2007. However, in the absence of expansion of domestic sewer network in Dhaka city and increasing population in the city, more and more domestic sewage are being diverted into the storm sewer network. It is therefore important to assess whether and for how long the drainage system of Hatirjheel (consisting of main diversion sewer and the SSDSs) would be able to accommodate the dry weather.

2.3.4 Water Quality of Hatirjheel

As noted earlier, the storm sewers discharging into the low-lying areas behind Sonargaon Hotel carry domestic sewage during the dry season, and mixture of storm water and sewage during the wet season. In June 2004, drainage water samples were collected from three different locations- from behind Sonargaon Hotel, from Hatirjheel area near Tongi diversion road, and from drainage canal east of Rampura regulator. Drainage water collected from the low-lying area behind Sonargaon Hotel was of very poor quality with very high BOD_5 and solids content, and its characteristics are similar to that of domestic sewage. The quality of drainage water improved to some extent as one moves downstream to Tongi diversion road and then to the Rampura bridge. However, characteristics of drainage water even at these sites are far worse than that could be expected for storm runoff.

In 2008 (i.e., before the construction of the SSDSs and main diversion sewers), a detail wastewater survey was carried out through collected and analysis of samples from all major storm sewer outfalls discharging into Hatirjheel during both dry (January-March) and wet season (July-August 2008) (Samad, 2009). Tables 2.3(a) and 2.3(b) show the characteristics of dry weather flow discharging into Hatirjheel during January-March 2008. Table 2.4(a) and 2.4(b) show characteristics of wastewater of selected outfalls during the wet season (July-August 2008). It should be noted that the characteristics of mixed wastewater coming through the storm sewers during wet season vary significantly depending on the quantity of precipitation. The characteristics of mixed wastewater reported in Table 2.4 therefore represent condition of a particular time only.

Table 2.3(a): Characteristics of dry weather flow (January-March 2008) discharging into Hatirjheel (Samad, 2009)

Sampling Location (nearest SSDS)	Parameters										
	pH	EC (μS/cm)	TDS (mg/l)	TDS/EC	TSS (mg/l)	PO_4 (mg/l)	NO_3 (mg/l)	NH_3 (mg/l)	NO_2 (mg/l)	Cl^- (mg/l)	SO_4 (mg/l)
SSDS-1	7.11	--	490	--	570	10.22	0.3	25.98	0.0036	40	40.0
SSDS-2	7.05	--	430	--	668	9.52	0.4	21.53	0.0041	35	40.8
SSDS-7	8.94	--	731	--	1038	3.23	0.2	31.73	0.0064	54	38.6
SSDS-4	7.01	--	471	--	704	9.68	0.3	22.58	0.0033	45	48.0
SSDS-10	7.01	943	494	0.52	725	10.04	0.3	41.88	0.0301	95	30.9
SSDS-6	7.04	950	466	0.49	520	8.75	0.3	38.18	0.0169	85	9.4
SSDS-11	7.05	975	489	0.50	553	9.91	0.3	38.43	0.0198	95	17.5

Table 2.3(b): Characteristics of dry weather flow (January-March 2008) discharging into Hatirjheel (Samad, 2009)

Sampling Location (nearest SSDS)	Parameter							
	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	COD/ BOD	Pb (ppm)	Hg (ppb)	Cr (ppm)	Cd (ppm)
SSDS-1	0.11	80	302	3.78	0.02	-	0.008	0.001
SSDS-2	0.1	190	343	1.81	0.028	-	0.009	0.001
SSDS-7	0.09	210	315	1.50	0.034	1.31	0.01	0.001
SSDS-4	0.1	240	622	2.59	0.033	-	0.009	0.002
SSDS-10	0.15	68	555	8.16	0.33	11.67	0.038	0.002
SSDS-6	0.13	84	256	3.05	0.031	-	0.009	0.001
SSDS-11	0.15	80	257	3.21	0.118	-	0.008	0.001

The dry weather flows discharged though the major outfalls in 2008 were found to contain high concentrations of BOD, COD, ammonia, phosphate and very low DO. The characteristics of the dry weather flow have been found to be comparable to those of medium and high strength domestic sewage. The high COD to BOD ratios (up to 8.16) of wastewater at some of the outfalls are indicative of the presence of non-biodegradable industrial effluent. The characteristics of wastewater improved to some extent during the wet season, due to dilution with rainwater.

Table 2.4(a): Characteristics of wet season flow discharging into Hatirjheel during wet season (July-August 2008) (Samad, 2009)

Sampling Location (nearest SSDS)	Parameters										
	pH	EC (µS/cm)	TDS (mg/l)	TDS/EC	TSS (mg/l)	PO_4 (mg/l)	NO_3 (mg/l)	NH_3 (mg/l)	NO_2 (mg/l)	Cl^- (mg/l)	SO_4 (mg/l)
SSDS-1	7.01	710	386	0.54	735	6.792	0.5	26.78	0.0225	9	29.6
SSDS-2	6.98	740	389	0.53	703	7.332	0.4	25.65	0.0086	8.5	23.4
SSDS-10	7.05	695	254	0.37	293	3.648	0.3	12.03	0.0032	6.5	7.4
SSDS-6	7.01	686	338	0.49	638	6.268	0.2	17.68	0.0015	8.5	18.1
SSDS-11	7.01	633	332	0.52	589	6.152	0.1	18.73	0.0032	8.5	9.4

Table 2.4(b): Characteristics of wet season flow discharging into Hatirjheel during wet season (July-August 2008) (Samad, 2009)

Sampling Location (nearest SSDS)	Parameters			
	DO (mg/l)	BOD_5 (mg/l)	COD (mg/l)	COD/BOD
SSDS-1	0.68	188	275	1.46
SSDS-2	0.71	250	346	1.38
SSDS-10	1.78	42	76	1.81
SSDS-6	0.78	63	83	1.32
SSDS-11	0.75	56	81	1.45

2.4 Significance of Water Quality Parameters

Hatirjheel is now the largest water body within Dhaka. Hatirjheel has been developed not only as a water detention area, but also as a major recreational area, where thousands of people gather almost on a daily basis to enjoy the open environment and water body. As discussed earlier, water quality of Hatirjheel remains poor, particularly during the wet season, when combined storm water and sewage are discharged into Hatirjheel through the SSDSs. The water quality appears to improve marginally during the dry season. The poor water quality of Hatirjheel is often apparent from the blackish and greenish color and offensive smell as some locations, particularly during the wet season. Despite being the largest water body within Dhaka, there does not appear to be any significant fish species within Hatirjheel. Therefore, it is important to systematically assess the water quality of Hatirjheel, including its spatial and temporal variation. A detail characterization is a pre-requisite for development of remedial measures of Hatirjheel. This section identifies some of the important parameters for characterization of water quality of a water body and their environmental significance.

pH

The balance of positive hydrogen ions (H^+) and negative hydroxide ions (OH^-) in water determines how acidic or basic the water is. The pH scale ranges from 0 (high concentration of positive hydrogen ions, strongly acidic) to 14 (high concentration of negative hydroxide ions, strongly basic). In pure water, the concentration of positive hydrogen ions is in equilibrium with the concentration of negative hydroxide ions, and the pH measures exactly 7.In a lake or pond, the water's pH is affected by its age and the chemicals discharged by communities and industries. Most lakes are basic (alkaline) when they are first formed and become more acidic with time due to the build-up of organic materials. As organic substances decay, carbon dioxide (CO_2) forms and combines with water to produce a weak acid, called "carbonic" acid - the same stuff that's in carbonated soft drinks. Large amounts of carbonic acid lower water's pH. Most fish can tolerate pH values of about 5.0 to 9.0, but serious anglers look for waters between pH 6.5 and 8.2.

When acid waters (waters with low pH values) come into contact with certain chemicals and metals, they often make them more toxic than normal. As an example, fish that usually withstand pH values as low as 4.8 will die at pH 5.5 if the water contains 0.9 mg/L of iron. Mix an acid water environment with small amounts of aluminum, lead or mercury, and you have a similar problem - one far exceeding the usual dangers of these substances.

Ammonia

Ammonia can enter the aquatic environment via direct means such as municipal effluent discharges and the excretion of nitrogenous wastes from animals, and indirect means such as nitrogen fixation, air deposition, and runoff from agricultural lands. Ammonia accumulates easily in aquatic systems because it is a natural byproduct of fish metabolism.

Besides, if the fish are overfed, uneaten food sinks to the bottom, decays and releases ammonia, increasing the load on the nitrifying bacteria in the pond and filter. Too many fish in the pond or system can mean that the wastes produced exceed the capacity of the nitrifying bacteria.

In water, ammonia occurs in two forms, which together are called total ammonia nitrogen, or TAN. Chemically, these two forms are represented as NH_4^+ and NH_3. NH_4^+ is called ionized ammonia, and NH_3 is called un-ionized ammonia (UIA).Tests for ammonia usually measure total ammonia (NH_3 plus NH_4^+). The toxicity to ammonia is primarily attributable to the un-ionized form (NH_3). In general, more NH_3 and greater toxicity exists at higher pH. The relative concentration of each can be known if pH and temperature of the water is known (see Fig. 2.6).

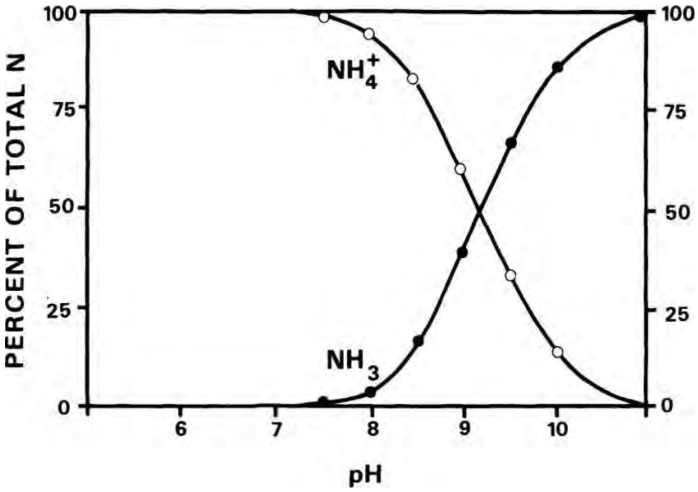

Fig. 2.6: Relative proportions of ammonia and ammonium as function of pH

Of all the water quality parameters that affect fish, ammonia is the most important after oxygen, especially in intensive systems. Unlike other forms of nitrogen, ammonia causes direct toxic effects on aquatic life. Ammonia causes stress and damages gills and other tissues, even in small amounts. Fish exposed to low levels of ammonia over time are more susceptible to bacterial infections, have poor growth, and will not tolerate routine handling as well as they otherwise would. Ammonia is a killer when present in higher concentrations, and many unexplained production losses have likely been caused by ammonia.

Ammonia accumulates easily in aquatic systems because it is a natural byproduct of fish metabolism. All animals excrete some waste in the process of metabolizing food into the energy, nutrients, and proteins they use for survival and growth. In fish, the principal metabolic waste product is ammonia. When ammonia is present in water at high enough levels, it is difficult for aquatic organisms to sufficiently excrete the toxicant, leading to toxic buildup in internal tissues and blood, and potentially death.

The main local problem of ammonia released into air is the unpleasant odor, which is detectable even at low concentrations. At particularly high concentrations it can also harm vegetation. If a large release of ammonia occurs the vapor will likely burn the leaves of nearby downwind vegetation. Ammonia contributes to eutrophication, a result of nutrient pollution (from deposition or run-off) into natural waters. It promotes excessive plant growth and decay, and is likely to cause severe reductions in water quality. In aquatic environments, enhanced growth of choking aquatic vegetation or algal blooms disrupt normal functioning of the ecosystem, causing problems such as a lack of oxygen in the water, needed for fish and other aquatic life to survive. The water then becomes cloudy, colored a shade of green, yellow, brown, or red.

Anytime the UIA is higher than 0.05 mg/L, the fish are being damaged. As the concentration rises above 0.05 mg/L, it causes more and more damage. When levels reach 0.2 mg/L, sensitive fish like trout and salmon begin to die. At 2.0 mg/L, the fish will die. But this danger for fish depends on the water's temperature and pH, along with the dissolved oxygen and carbon dioxide levels. There is no standard of ammonia for natural water body in Bangladesh. There is however an effluent discharge standard of 50 mg/l (as N) for ammonia.

USEPA recommends an acute criterion magnitude of 17 mg Total Ammonia Nitrogen (TAN) per liter at pH 7 and 20°C for a one-hour average duration, not to be exceeded more than once every three years on average (Table 2.5). USEPA recommends a chronic criterion magnitude of 1.9 mg TAN/L at pH 7 and 20°C for a 30-day average duration, not to be exceeded more than once every three years on average. In addition, the highest four-day average within a 30-day period should not exceed 2.5 times the chronic criterion magnitude (e.g. 1.9 mg TAN/L x 2.5 = 4.8 mg TAN/L at pH 7 and 20°C) more than once in three years on average.

Table 2.5: Comparison of past and current USEPA- recommended aquatic life water quality criteria magnitudes for ammonia. Criteria magnitudes are expressed as total ammonia nitrogen (mg TAN/L) at pH 7 and 20°C.

Criterial Duration	1999 Criteria	2009 Draft Updated Criteria	2013 Final Updated Criteria
Acute (1-hour average)	24	19	17
Chronic (30-day rolling average)	4.5*	0.91*	1.9*
* Not to exceed 2.5 times the criterion continuous concentration as a 4-day average within a 30-day period.			
Criteria frequency: Not to be exceeded more than once in three years on average.			

Nitrite and Nitrate

Nitrite and Nitrate are forms of the element Nitrogen, which makes up about 80 percent of the air we breathe. As an essential component of life, nitrogen is recycled continually by plants and animals, and is found in the cells of all living things. Organic nitrogen (nitrogen combined with carbon) is found in proteins and other compounds. Inorganic nitrogen may exist in the free state as a gas, as ammonia (when combined with hydrogen), or as nitrite or nitrate (when combined with oxygen). Nitrites and nitrates are produced naturally as part of the nitrogen cycle, when a bacteria 'production line' breaks down toxic ammonia wastes first into nitrite, and then into nitrate.

Nitrites are relatively short-lived because they're quickly converted to nitrates by bacteria. Nitrites produce a serious illness (brown blood disease) in fish, even though they don't exist for very long in the environment. Nitrites also react directly with hemoglobin in human blood to produce methemoglobin, which destroys the ability of blood cells to transport oxygen. This condition is especially serious in babies under three months of age as it causes a condition known as methemoglobinemia or "blue baby" disease. Water with nitrite levels exceeding 1.0 mg/L should not be given to babies. Nitrite concentrations in drinking water seldom exceed 0.1 mg/L.

Nitrate is a major ingredient of farm fertilizer and is necessary for crop production. When it rains, varying nitrate amounts wash from farmland into nearby waterways. Nitrates also get into waterways from lawn fertilizer run-off, leaking septic tanks and cesspools, manure from farm livestock, animal wastes (including fish and birds), and discharges from car exhausts.

Phosphate

The element phosphorus is necessary for plant and animal growth. Nearly all fertilizers contain phosphates (chemical compounds containing the element, phosphorous). When it rains, varying amounts of phosphates wash from farm soils into nearby waterways. Phosphates stimulate the growth of plankton and water plants that provide food for fish. This may increase the fish population and improve the waterway's quality of life. If too much phosphate is present, algae and water weeds grow wildly, choke the waterway, and use up large amounts of oxygen. Many fish and aquatic organisms may die.

Phosphates come from fertilizers, pesticides, industry and cleaning compounds. Natural sources include phosphate-containing rocks and solid or liquid wastes. Phosphates enter waterways from human and animal wastes (the human body releases about a pound of phosphorus per year), phosphate-rich rocks, wastes from laundries, cleaning and industrial processes, and farm fertilizers. Phosphates also are used widely in power plant boilers to prevent corrosion and the formation of scale.

Alkalinity

Alkalinity is not a pollutant. It is a total measure of the substances in water that have "acid-neutralizing" ability. Alkalinity is important for fish and aquatic life because it protects or buffers against pH changes (keeps the pH fairly constant) and makes water less vulnerable to acid rain. The main sources of natural alkalinity are rocks, which contain carbonate, bicarbonate, and hydroxide compounds. Borates, silicates, and phosphates may also contribute to alkalinity. Limestone is rich in carbonates, so waters flowing through limestone regions generally high alkalinity - hence its good buffering capacity. Conversely, granite does not have minerals that contribute to alkalinity. Therefore, areas rich in granite have low alkalinity and poor buffering capacity.

Carbon Dioxide

Carbon dioxide is an odorless, colorless gas produced during the respiration cycle of animals, plants and bacteria. All animals and many bacteria use oxygen and release carbon dioxide. Green plants, in turn, absorb the carbon dioxide and, by the process of photosynthesis, produce oxygen and carbon-rich foods. The general formulas for plant photosynthesis and respiration are summarized below.

Photosynthesis (in the presence of light and chlorophyll):

Carbon dioxide	+	Water	→	Oxygen	+	Carbon-rich foods
CO_2		H_2O		O_2		$C_6H_{12}O_6$

Respiration:

Carbon-rich foods	+	Oxygen	→	Carbon Dioxide	+	Water
$C_6H_{12}O_6$		O_2		CO_2		H_2O

Green plants carry on photosynthesis only in the presence of light. At night, they respire and burn the food they made during the day. Consequently, more oxygen is used and more carbon dioxide enters waterways at night than during the daytime. When carbon dioxide levels are high and oxygen levels are low, fish have trouble respiring (taking up oxygen), and their problems become worse as water temperatures rise.

It’s lucky for fish that "free" carbon dioxide (by "free" we mean it is not combined with anything) levels rarely exceed 20 mg/L (milligrams per liter), because most fish are able to tolerate this carbon dioxide level without bad effects. When several days of heavy cloud cover occur, plants’ ability to photosynthesize is reduced. When that happens in a pond containing lots of plant life, fish can be hurt in two ways: by low dissolved oxygen and by high carbon dioxide levels.

Carbon dioxide quickly combines in water to form carbonic acid, a weak acid. The presence of carbonic acid in waterways may be good or bad depending on the water’s pH and alkalinity. If the water is alkaline (high pH), the carbonic acid will act to neutralize it. But if the water is already quite acid (low pH), the carbonic acid will only make things worse by making it even more acid.

DO

Dissolved oxygen (DO) is oxygen that is dissolved in water. Oxygen enters water as a result of two processes:

1. Diffusion- diffusion of oxygen into water is accelerated when the water turbulence is increased (moving through rapids and waterfalls) and when there is a strong wind blowing. Additionally, oxygen will diffuse into cold water at a higher rate than it will into warm water.
2. Photosynthesis- during daylight hours, aquatic plants use the sun's energy to create energy they can use for growth. A by-product of this process is oxygen which is released into surrounding water.

Photosynthesis (in the presence of light and chlorophyll):

Carbon dioxide	+	Water	→	Oxygen	+	Carbon-rich foods
CO_2		H_2O		O_2		$C_6H_{12}O_6$

Fish and aquatic animals cannot split oxygen from water (H_2O) or other oxygen-containing compounds. Only green plants and some bacteria can do that through photosynthesis and similar processes. Virtually all the oxygen we breathe is manufactured by green plants. A total of three-fourths of the earth's oxygen supply is produced by phytoplankton in the oceans. If water is too warm, there may not be enough oxygen in it. When there are too many bacteria or aquatic animal in the area, they may overpopulate, using DO in great amounts.

Oxygen levels also can be reduced through over fertilization of water plants by run-off from farm fields containing phosphates and nitrates (the ingredients in fertilizers). Under these conditions, the numbers and size of water plants increase a great deal. Then, if the weather becomes cloudy for several days, respiring plants will use much of the available DO. When these plants die, they become food for bacteria, which in turn multiply and use large amounts of oxygen.

How much DO an aquatic organism needs depends upon its species, its physical state, water temperature, pollutants present, and more. Consequently, it's impossible to accurately predict minimum DO levels for specific fish and aquatic animals. For example, at 5^oC (41^oF), trout use about 50-60 milligrams (mg) of oxygen per hour; at 25^oC (77^oF), they may need five or six times that amount. Fish are cold-blooded animals, so they use more oxygen at higher temperatures when their metabolic rate increases. Numerous scientific studies suggest that 4-5 parts per million (ppm) of DO is the minimum amount that will support a large, diverse fish population. The DO level in good fishing waters generally averages about 9.0 parts per million (ppm). When DO levels drop below about 3.0 parts per million, even the rough fish die. The table in this section shows some representative comparisons.

BOD_5 and COD

The decomposition of organic matter whether from natural or anthropogenic sources puts a demand on the dissolved oxygen concentrations in water bodies. Measures of this demand include biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). Chemical and biochemical oxygen demand (COD and BOD) are measures of the amount of oxygen consumed when a substance degrades.

The amount of oxygen required by microorganisms to oxidize organic wastes aerobically is called the biochemical oxygen demand (BOD). The oxygen demand parameter for biodegradable materials in a study area is BOD, 5-day, 20 degrees, which is the amount of dissolved oxygen required by aerobic microorganism to decompose the organic matter in 1 liter of water over 5 days at 20 degrees Celsius. This measurement has been found to be approximately two-thirds of the total oxygen required to decompose all organic matter in the sample. BOD may have various units, but most often, it is expressed in milligrams of oxygen required per liter of wastewater (mg/l). BOD is the laboratory measurement of the amount of oxygen consumed by microorganisms in the biological processes that break down organic matter in water. The greater the BOD, the greater is the degree of pollution. Materials such as food waste and dead plant or animal tissue use up dissolved oxygen in the water when they are degraded through chemical or biological processes. BOD levels are indicative of the effect of the waste on fish or other aquatic life, which require oxygen to live.

Chemical Oxygen Demand (COD) is the laboratory measurement of the amount of oxygen required to oxidize all compounds, both organic and inorganic, in water due to the addition of wastes. A major objective of conventional wastewater treatment is to reduce the chemical and biochemical oxygen demand.

Temperature

Fish and most aquatic organisms are cold-blooded. Consequently, their metabolism increases as the water warms and decreases as it cools. Each species of aquatic organism has its own optimum (best) water temperature. If the water temperature shifts too far from the optimum, the organism suffers. Cold-blooded animals can’t survive temperatures below 0^oC (32^oF), and only rough fish like carp can tolerate temperatures much warmer than about 36^oC (97^oF).

Fish can regulate their environment somewhat by swimming into water where temperatures are close to their requirements. Fish usually are attracted to warm water during the fall, winter and spring and to cool water in the summer. Fish can sense very slight temperature differences. When temperatures exceed what they prefer by 1-3 ^{o}C, they move elsewhere!

Fish migration often is linked to water temperature. In early spring, rising water temperatures may cue fish to migrate to a new location or to begin their spawning runs. The autumn drop in temperature spurs baby marine fish and shrimp to move from their nursery grounds in the estuaries out into the ocean, or into rivers, as the case may be. As you can see, all sorts of physiological changes take place in aquatic organisms when water temperatures change.

Turbidity

Turbidity may be defined as "the optical property of a water sample that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample." In simple terms, turbidity answers the question, "How cloudy is the water?"

Light's ability to pass through water depends on how much suspended material is present. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibers, sawdust, wood ashes, chemicals and coal dust. Any substance that makes water cloudy will cause turbidity. The most frequent causes of turbidity in lakes and rivers are plankton and soil erosion from logging, mining, and dredging operations.

Color

It may be true that a bit of color in water may not make it harmful to drink but it certainly makes it unappealing to drink. So, color in water does matter when it comes to drinking it, as well as in water for other home uses, industrial uses, and in some aquatic environments.

Color in water can be imparted in two ways: dissolved and suspended components. Most of the color in water comes from suspended material. Algae and suspended sediment particles are very common particulate matter that causes natural waters to become colored. Even though the muddy water below would not be appealing to swim in, in a way that water has less color than the water containing dissolved tannins. That is because suspended matter can be filtered out of even very dirty-looking water. If the water is put into a glass and left to settle for a number of days, most of the material will settle to the bottom (this method is used in sewage-treatment facilities) and the water will become clearer and have less color. So, if an industry wanted needed some color-free water for an industrial process, they would probably rather start with the sediment-laden water, rather than the tannin colored water. Suspended material in water bodies may be a result of natural causes and/or human activity. Transparent water with a low accumulation of dissolved materials appears blue. Dissolved organic matter, such as humus, peat or decaying plant matter, can produce a yellow or brown color. Some algae or dinoflagellates produce reddish or deep yellow waters. Water rich in phytoplankton and other algae usually appears green. Soil runoff produces a variety of yellow, red, brown and gray colors.

Highly colored water has significant effects on aquatic plants and algal growth. Light is very critical for the growth of aquatic plants and colored water can limit the penetration of light. Thus a highly colored body of water could not sustain aquatic life which could lead to the long term impairment of the ecosystem. Very high algal growth that stays suspended in a water body can almost totally block light penetration as well as use up the dissolved oxygen in the water body, causing a eutrophic condition that can drastically reduce all life in the water body. At home, colored water may stain textile and fixtures and can cause permanent damage, as the picture of the sink above shows.

Chapter Three
Methodology

3.1 General

Hatirjheel serves very important hydrologic function of draining and detaining storm water from a large area of Dhaka city. Hatirjheel extends from the eastern side of Tongi-diversion road up to Rampura Bridge on Pragati Swarani. Hatirjheel receives a huge amount of discharge through 11 major storm sewer outfalls, connected to Special Sewage Diversion Structures (SSDSs) on the periphery of Hatirjheel. The SSDSs have been constructed at all major storm sewer outfalls discharging into Hatirjheel. During dry season, only domestic and industrial wastewater flows through the storm sewers, and these flows are diverted to the main diversion sewers of Hatirjheel at the SSDSs. In dry season the overflow gate of each SSDS is closed/ raised. So, wastewater cannot flow into Hatirjheel. The SSDSs divert the entire dry weather flow to main diversion sewers laid along the periphery of Hatirjheel. At present, the main diversion sewers carry the wastewater downstream and discharge the wastewater just upstream of the Rampura bridge; from here the wastewater flows either by gravity (during dry season) or pumped (during wet season, at the "interim pumping station constructed upstream of Rampura bridge) into Begunbari khal. Thus, the untreated wastewater flows into Balu River via Begunbari khal-Norai khal. The wastewater is eventually discharged into Shitalakhya River. During monsoon, both storm water and wastewater flows through the storm sewer network and reach the SSDSs. A portion of the combined flow (mixture of storm water and wastewater) is diverted toward the main diversion sewer, while the rest (i.e., the portion in excess of the capacity of the main diversion sewers) is discharged into Hatirjheel through the overflow structures of the SSDSs. This discharge comprising of storm water and wastewater (sewage) significantly deteriorates the water quality of Hatirjheel during the wet season.

This chapter presents a description of the Hatirjheel drainage system, comprising of the SSDSs and the main diversion sewers; a proper understanding of which is essential for assessment of water quality of Hatirjheel. This chapter presents detailed methodology for estimation of the catchment area of Hatirjheel and catchment area under each SSDS. It then presents the methodology followed for estimation of storm water flows into Hatirjheel. It presents the methods used for estimation and prediction (for up to the year 2025) of wastewater (sewage) flows through the storm sewers under Hatirjheel catchment. This chapter also presents the methodology for the year-long water sampling campaign from Hatirjheel, and analysis of these water samples at the Environmental Engineering Laboratory.

3.2 Drainage System of Hatirjheel

Hatirjheel drainage system consists of Special Sewage Diversion Structures (SSDSs) and the peripheral main diversion sewers. There are 11 SSDSs around Hatirjheel; six SSDSs (SSDS-1 to SSDS-6) are located along the southern periphery of Hatirjheel, while five SSDSs (SSDS-7 to SSDS-11) are located along the northern periphery of Hatirjheel. Among these 11 SSDSs, 9 SSDSs (except SSDS-6 and SSDS-11) are major contributors of flows (in the form of overflows) to Hatirjheel. Overflows from SSDS-6 and SSDS-11 directly flow into Begunbari khal just upstream of Rampura Bridge. Banani and Gulshan Lakes are also connected to Hatirjheel, and contribute significantly to the inflow into Hatirjheel. Significant water enters into Hatirjheel through Gulshan Lake and Banani Lake carrying storm water and wastewater from Gulshan-1, Baridhara and Banani areas. Fig. 3.1 shows the locations of 11 SSDSs along the periphery of Hatirjheel. The SSDSs are described below:

1. The SSDS-1, behind the Sonargaon Hotel, is the largest one in terms of flow. It receives storm water and wastewater coming from Panthapath area (through Panthapath box culvert) in the west and Kawranbazar from the east. It also receives storm water/ wastewater coming from the eastern part of Dhanmondi Lake and Kalabagan area.
2. The SSDS-2 is located immediately to the east of Tongi diversion road on the southern periphery of Hatirjheel. It receives storm water and wastewater mainly from a portion of Ramna, Baily road and Eskaton area.
3. The SSDS-3 is located at Madhubagh, Wireless Road, Nayatola (at Gudaraghat). The Tejgaon Sewage Lifting Station of DWASA is located just on the other side of Hatirjheel at this location. It receives storm water and wastewater from a portion of areas under Ramna Thana.
4. The SSDS-4 is located north of Mohanagar Housing Area. It is located on the southern periphery of Hatirjheel close to the Bridge-1 (over Hatirjheel) that connects Tejgaon and Gulshan to Mohanagar Housing Area. It receives storm water and wastewater mainly from Mohanagar Housing Area.
5. The SSDS-5 located along the southern periphery of Hatirjheel receives storm sewer and wastewater that comes from Ulon area.
6. The SSDS-6 receives storm water and wastewater from Mouchak-Rampura area. It is located immediately to the west of the Pragati Swarani (close to Rampura Bridge). The northern portion of the surrounding Rampura DIT Road areas also contributes to it. The sewage flows from Mouchak, outer circular road also go to SSDS-6 through storm sewer network. The overflow from SSDS-6 does not discharge within Hatirjheel, rather it is discharged into Begunbari khal just upstream of Rampura Bridge.
7. The SSDS-7 is located immediately to the east of Tongi Diversion Road on the northern side of Hatirjheel. It receives storm water and wastewater (including industrial discharge) from a part of Tejgaon industrial area.

8. The SSDS-8 receives storm water and wastewater (including industrial wastewater) from a part of Tejgaon area. SSDS-8 is located along the northern periphery of Hatirjheel just to the east of Bridge-2 that connects Tejgaon to Gudaraghat at Madhubagh.
9. The SSDS-9 receives storm water and wastewater (including industrial wastewater) from a part of Tejgaon area.
10. The SSDS-10 has been built at the outfall location of Mohakhali box culvert. The box culvert (5.5 m × 3.8 m box culvert) carries storm water and wastewater from Nakhalpara and Niketon areas. The overflow from SSDS-10 combines with the flow of Banani Lake before discharging into Hatirjheel.
11. The SSDS-11 receives storm sewer and wastewater flows from the Badda area. The overflow from SSDS-11 does not discharge within Hatirjheel, rather it is discharged into Begunbari khal just upstream of Rampura Bridge.

Fig. 3.1: Locations of 11 SSDSs along the periphery of Hatirjheel (Google Earth)

3.3 Estimation of Storm Water Flow

Storm water flows reaching the 11 SSDSs through existing storm sewer network have been estimated by identifying catchments under each SSDS and analyzing storm sewer network map of DWASA. The storm sewer network maps, collected from DWASA, have been superimposed on GIS-based map of Dhaka city. A GIS based map has been prepared for catchment contributing to each SSDS.A rainfall scenario with a 5 year return period has been used for estimation of storm water discharges reaching different SSDSs. Thus, the main activities carried out for estimation of storm water reaching the SSDSs of Hatirjheel included: (a) Analysis of storm sewer network of DWASA; (b) Preparation of catchment map of Hatirjheel using GIS; and (c) Using a rainfall scenario with a 5 year return period for estimation of runoff.

3.3.1 Identification of Catchment Areas of SSDSs

Dhaka city sewer map and drainage map have been analyzed to identify the direction of flow of storm water in different areas adjacent to Hatirjheel. The major khals and drainage zone of Dhaka have been identified from JICA report. The drainage system is managed by DWASA. The sewer system of DWASA was originally designed as two separate systems. But according to DWASA during monsoon all the sewer networks act as combined sewer system.

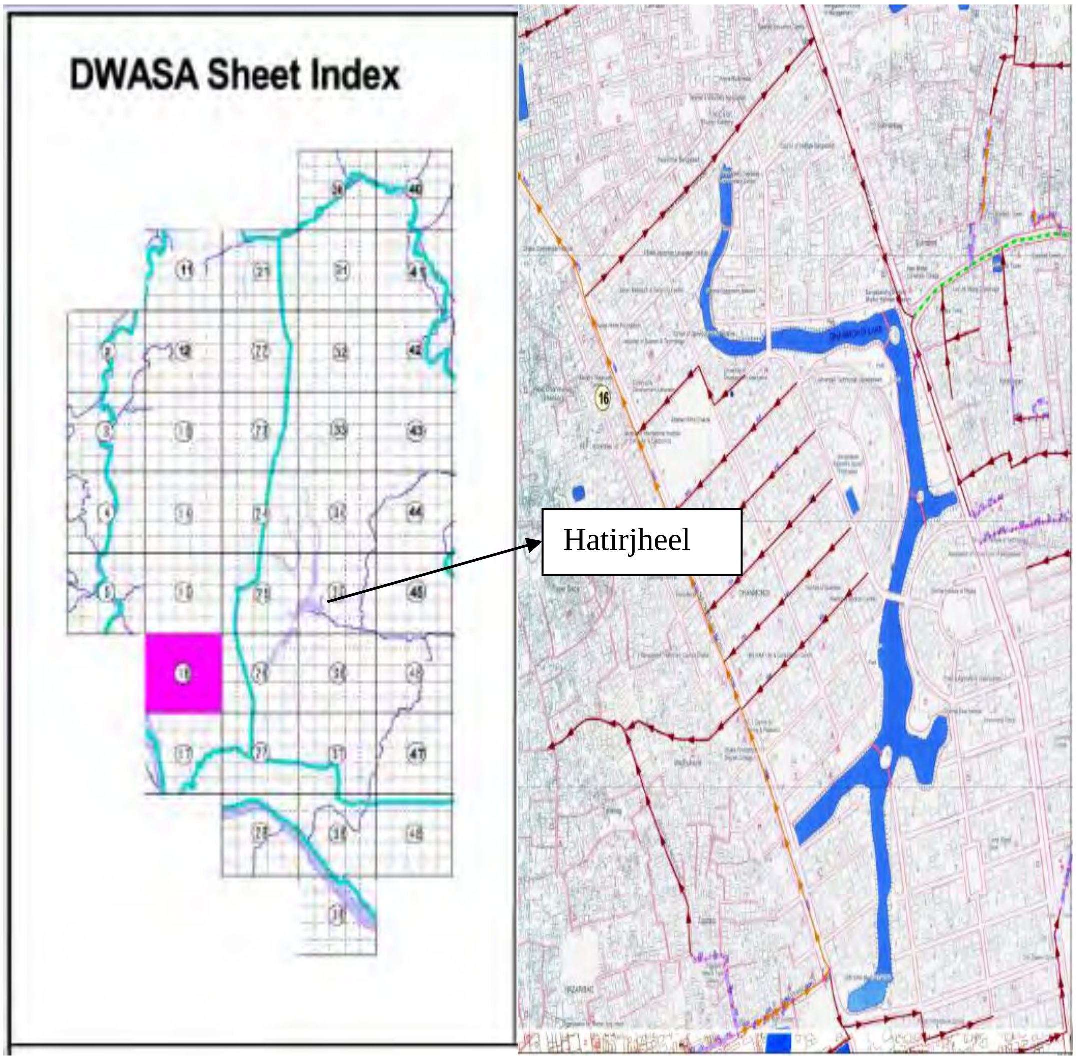

Fig. 3.2: Drainage network system by DWASA

A GIS based map of drainage network system of the areas surrounding Hatirjheel has been analyzed. The direction of flow of storm water of different areas surrounding Hatirjheel has been identified from the drainage map and by discussion with DWASA. The catchment areas that contribute to different SSDSs have also been identified.

Storm water from the eastern part of Dhanmondi Lake, Kalabagan, Panthapath, Kathalbagan, Nilkhet, Bangla Motor, Kawranbazar, Tejturipara, Shangshad Bhaban, Katabon, Farm Gate, Raja Bazar, Manipuri Para areas discharges into Hatirjheel through SSDS-1. New Eskaton, Baily Road and a part of Maghbazar and Siddheswari contribute to the catchment of SSDS-2. The catchment of SSDS-3 includes Nayatola and Madhubagh areas. Storm water from Mohanagar housing area falls into Hatirjheel through SSDS-4.Storm water from a part of Ulon area flows through SSDS-5, the rest part flows through SSDS-6. Storm water from Mouchak area flows through SSDS-6. Tejgaon industrial area contributes to the catchment of SSDS-7, SSDS-8 and SSDS-9. The catchment of SSDS-10 is huge. It includes Nakhalpara, Niketon and a part of Mohakhali DOHS area. Gulshan Lake and Banani Lake also discharge into Hatirjheel from the surrounding areas of Gulshan and Banani. Storm water from south Badda area up to Pragati Swarani is discharged into SSDS-11. Catchment areas of all 11 SSDSs have been identified from the GIS based Drainage map of Dhaka city.

3.3.2 Preparation of Catchment Map of Hatirjheel using GIS

After identification of the catchment areas of different SSDSs contributing to Hatirjheel, a GIS-based map was prepared for the catchment areas. The process followed was as follows: (a) The map of Hatirjheel was superimposed on a GIS-based map of Dhaka city and the location of 11 SSDSs were identified on the map; (b) the catchment area contributing to each SSDS was marked (which was done through discussion with DWASA and analysis of the present condition of the existing sewer network of Dhaka city); and (c) the catchment area of each SSDS was calculated from the GIS-based map.

A detail area plan (DAP) report on Dhaka city was prepared by RAJUK in 2007. In this report, Dhaka city has been divided into a number of groups to study the land use pattern and other details extensively. The Thana boundary, sewer line, structures, roads, water body and other details are included in the report, and GIS map has been published by RAJUK in detail area plan (DAP) report. The catchment areas of Hatirjheel lie in Group-C and Location-10. A map of Hatirjheel (drawn in AutoCAD software) was collected from BUET. The Hatirjheel map was superimposed on the GIS map of Dhaka city prepared by RAJUK. The latitude and longitude of 11 SSDSs were recorded using a hand-held GPS. These locations were marked in the prepared GIS map to identify the locations of the 11 SSDSs. Then this GIS map (prepared by RAJUK and modified by including the map of Hatirjheel and 11 SSDSs) was used to analyze the catchment area of Hatirjheel.

3.3.3 Estimation of Storm Water Flows Reaching the SSDSs

The storm water flows reaching the different SSDSs were estimated for a rainfall scenario with a 5 year return period. For each SSDS, the storm water flows were estimated according to the following equation:

$$Q = CIA \qquad (3.1)$$

Where,

Q = Storm flow discharge (m^3/s)

C = Run-off coefficient

I = Intensity of rainfall with a 5 year return period (m/s)

A = Catchment area (m^2)

For each SSDS, the catchment area (A) was taken from the prepared GIS-based map. The co-efficient of runoff was assumed to be 0.8 for all catchment areas (Ahmed and Rahman, 2000). While it is recognized that runoff coefficient would vary depending on the land use pattern and would change with changes in land use (Afrin, 2015), for gross estimation of runoff in an urban setting, a fixed runoff coefficient appears to be reasonable. It was also assumed that the existing storm sewer network surrounding Hatirjheel are able to carry these flows up to Hatirjheel. This assumption may not be accurate for the catchment of some SSDSs; water logging is observed in many areas surrounding Hatirjheel during heavy rainfall, indicating inadequate capacity of the storm sewer network in draining storm water. However, assessment of capacity of storm sewer network was beyond the scope of the present study.

3.4 Estimation and Prediction of Wastewater Flow

Two approaches have been used to estimate the wastewater (sewage) flow in the catchment areas of Hatirjheel. The first approach is based on population estimation under each catchment, and then calculating generation of wastewater based on a per capita water use. The other approach involved locating DWASA deep tubewells (DTWs) in the catchment areas of Hatirjheel, followed by estimation of wastewater generation based on the quantity of water supply from these DTWs. The wastewater flows obtained from these two approaches were compared with dry weather flows measured in the catchment of Hatirjheel in 2007 (BRTC-BUET, 2007). Prediction of wastewater flow for future years was done assuming the increase in wastewater flow is proportional to population growth.

3.4.1 Approach-1: Through Population Estimation under each Catchment

The GIS based catchment map of Hatirjheel was superimposed on Dhaka city map with Thana boundary. The area of different Thanas in the catchment of each SSDS was estimated with GIS software. The population in the different Thana was obtained from the population census of Dhaka City 2011. Thus, the total population contributing to wastewater generation in the catchment of Hatirjheel was calculated. Per capita water use was assumed to be 120 lpcd, after discussion with DWASA. Multiplying the population with per capita water used yielded an estimate of daily wastewater flow. However, this value was found to be much lower than the measured values of wastewater flows carried out in 2007. This is probably due to use of water for purposes other than domestic use, which was not considered in this estimation.

3.4.2 Approach-2: Through Estimating DWASA Water Supply

Table 3.1 shows number of tubewells in different DWASA zones. The GIS shape file containing Dhaka city deep tubewell locations was superimposed on the catchment map of Hatirjheel. Fig. 3.3 shows location of deep tubewells (DTWs) in the catchment of different SSDSs of Hatirjheel. The number of deep tubewells in the catchment of different SSDSs was then estimated. The average water production per deep tubewell was considered to be 3.02 MLD (Source: Final report of Preparation of Detailed Area Plan (DAP) for DMDP Area: Group-C, RAJUK).

Thus, the total water production of all deep tubewells present in the catchment of each SSDS of Hatirjheel was obtained. It was assumed that 90 percent of this water turns into wastewater. The wastewater flow rate estimated by this method was found to be close to the measured wastewater flows in 2007. These estimations were then used for prediction of future wastewater flows (for the years 2015, 2021 and 2025), based on population growth rate (population census of Dhaka city 2011).

Table 3.1: Thana wise location of deep tubewells in Dhaka city

Sl. No.	Location of pump house (Thana)	WASA Zone	No. of Deep Tubewells (zone wise)	No. of Deep Tubewells (in operation)
1	Demra; Shyampur; Sutrapur; Sobujbag	1	77	52
2	Hazaribag; Lalbag; Kotowali	2	41	33
3	Dhanmondi; Motijheel; Mohammadpur	3	70	68
4	Mirpur; Kafrul; Pallobi	4	95	76
5	Badda; Gulshan; Tejgaon	5	87	35
6	Khilgaon; Motijheel; Ramna	6	77	61
	Total		447	325

Source: DWASA, 2007

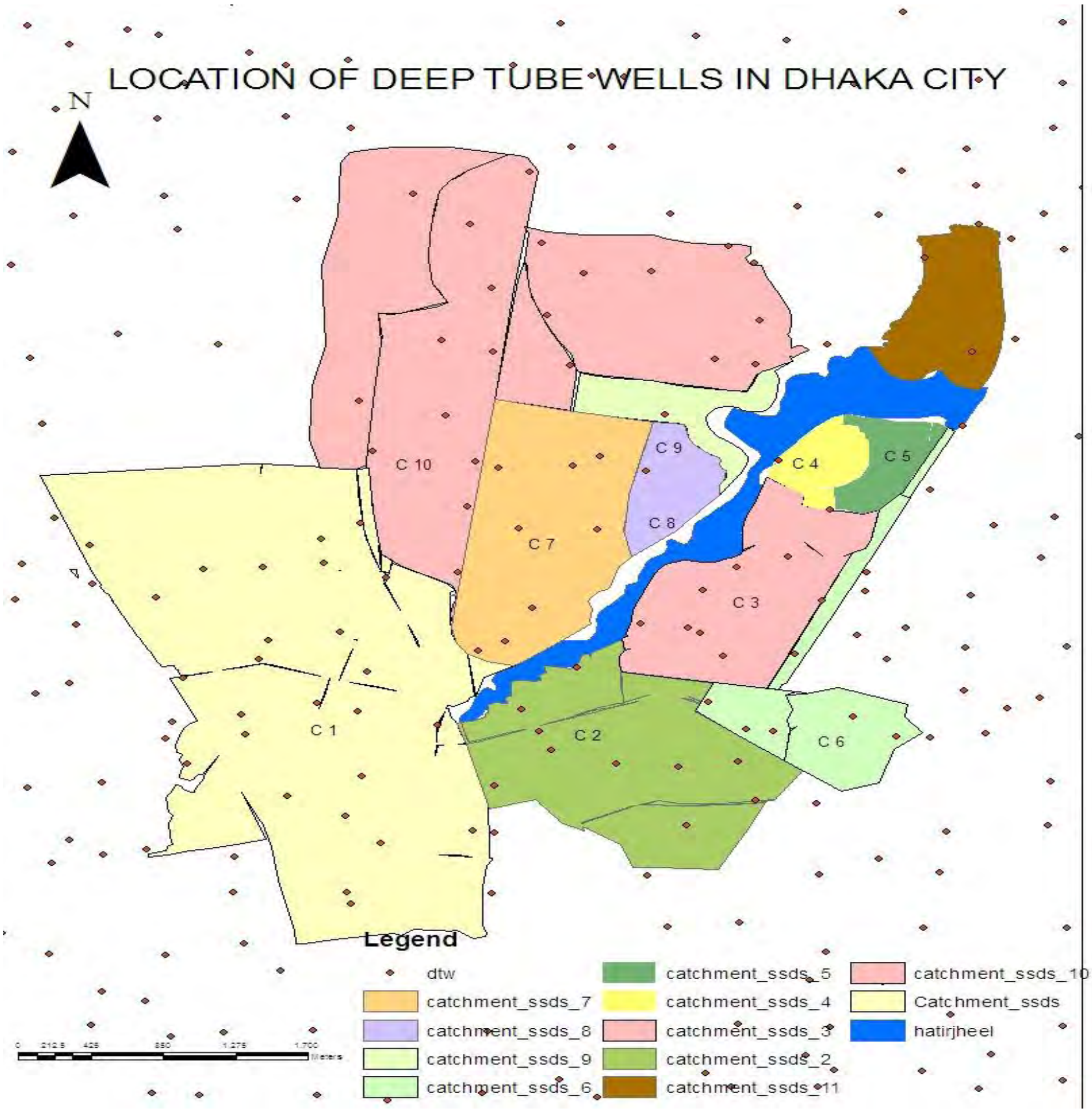

Fig. 3.3: Location of deep tubewells in the catchment of different SSDSs of Hatirjheel

3.5 Monitoring of Water Quality of Hatirjheel

3.5.1 Collection of Water Sample

In order to assess spatial and temporal variation of water quality, water samples were collected from selected locations of Hatirjheel, and analyzed for important water quality parameters. Water samples were collected from the locations of 9 SSDSs within the Hatirjheel (i.e., all SSDSs except SSDS-6 and SSDS-11). In addition, water sample were also collected from Gulshan and Banani Lakes, just upstream of their confluence with Hatirjheel. It should be noted that water samples could not be collected from the middle of Hatirjheel because there was no water vessel (boat) to get into the middle of Hatirjheel. Table 3.2 shows the details of the sampling locations. Water samples were collected from Hatirjheel during the period June 2014 to May 2015, roughly at the frequency of one sample per month; a total of 10 samplings were carried out during this period. Table 3.3 shows the sampling dates.

Table 3.2: Locations of water sample collection points at Hatirjheel

Sample Collection Point	Coordinates		Description
	Latitude	Longitude	
SSDS-1	$23^0$44’55’’	$90^0$23’41’’	At about 300 feet downstream of the discharge point of SSDS-1
SSDS-2	$23^0$45’10’’	$90^0$24’07’’	At the location where overflow from SSDS is discharged
SSDS-3	$23^0$45’39’’	$90^0$24’36’’	At the location where overflow from SSDS is discharged
SSDS-4	$23^0$45’59’’	$90^0$24’47’’	At the location where overflow from SSDS is discharged
SSDS-5	$23^0$46’07’’	$90^0$25’04’’	At the location where overflow from SSDS is discharged
SSDS-7	$23^0$45’21’’	$90^0$24’09’’	At the location where overflow from SSDS is discharged
SSDS-8	$23^0$45’43’’	$90^0$24’31’’	At the location where overflow from SSDS is discharged
SSDS-9	$23^0$46’03’’	$90^0$24’34’’	At the location where overflow from SSDS is discharged
SSDS-10	$23^0$46’19’’	$90^0$24’53’’	Downstream of the bridge on the Tejgaon-Gulshan Link Road
Banani Lake	$23^0$46’28’’	$90^0$24’51’’	Downstream of the bridge on the Niketon-Gulshan Link Road
Gushan Lake	$23^0$46’25’’	$90^0$25’07’’	At about 300 feet upstream of the bridge at the confluence of Gulshan Lake and Hatirjheel

Table 3.3: Sampling schedule for characterization of Hatirjheel water

Sampling Cycle	Date of Sample Collection	Season
1	29 June 2014	Rainy/monsoon
2	09 August 2014	Rainy/monsoon
3	07 September 2014	Rainy/monsoon
4	18 October 2014	Onset of dry season
5	06 December 2014	Dry/winter
6	17 January 2015	Dry/winter
7	28 February 2015	Dry/winter
8	28 March 2015	Dry
9	25 April 2015	Summer
10	30 May 2015	Summer

During each sampling campaign, samples were collected in the morning (between 8:30 a.m. to 1:00 p.m.). From each sampling point, two liters of samples were collected in pre-washed plastic bottles with polypropylene caps; the bottles were also rinsed with Hatirjheel water at the sampling location three times before collecting water samples from that particular point. The samples were kept in ice boxes and were transported to the environmental engineering laboratory of BUET within a couple of house of sample collection. Fig. 3.4 shows the collection of water sample from selected location of Hatirjheel.

Fig. 3.4: Collection of Water Sample from selected location of Hatirjheel

3.5.2 Analysis of Water Sample

The water samples collected from Hatirjheel were tested (following standard methods) for a range of parameters including pH, Conductivity, Turbidity, Color, NO_3^-, NO_2^-, NH_3, PO_4^{3-}, SO_4^{3-}, S^{2-}, Cl^-, COD, BOD_5, TS, TDS and TSS. In the laboratory, pH was measured by a pH meter (Geotech) attached with a pH electrode (WTW, Sen Tix 41), Conductivity was measured by a Conductivity meter (Hach), and Turbidity by a Turbidimeter (Hach, 2100P). Ammonia, Nitrate, Nitrite, Phosphate, Sulfate, and Sulfide concentrations were measured with a Spectrophotometer (HACH, DR4000U). Ammonia was measured by the Nessler method, Nitrate by the Cadmium Reduction Method, Nitrite by the Diazotization method, and Phosphate by the Molybdenum Blue method. Other parameters (e.g. TDS, TSS) were measured following Standard Methods.

Chapter Four
Results and Discussions

4.1 Introduction

The low lying areas of Hatirjheel serve very important hydrologic function of draining and detaining storm water from a large area of Dhaka city. As a part of Hatirjheel restoration project, eleven Special Sewage Diversion Structures (SSDSs) have been constructed at all major outfalls discharging into Hatirjheel. During dry season, the SSDSs divert the entire dry weather flow to the “main diversion sewers” that run along the periphery of Hatirjheel. The main diversion sewers were designed considering the measured dry weather flow (i.e., sewage) at the outfall locations in 2007. It was expected that gradual separation of domestic connections to storm sewers would improve the situation. However, there is no sign of this taking place; on the contrary, with increase in population, the dry weather flow is increasing. The present study has made an assessment of the capacity of the main diversion sewers to carry dry weather flow (i.e., sewage) in the future, if corrective measures (i.e., separation of domestic connection to storm sewers) are adopted. This study has also carried out a detailed assessment of the water quality of Hatirjheel based on a year-long monitoring of water quality. This Chapter presents the results of these assessments.

4.2 Estimation of Capacity of Main Diversion Sewers of Hatirjheel

4.2.1 Catchment Areas of SSDSs

Based on analysis of the Dhaka city GIS based map of DWASA sewer network, a GIS based map of the catchment of 11 SSDSs of Hatirjheel has been prepared. The catchment map was prepared by discussion with DWASA. As noted earlier, the storm sewer network of Dhaka acts as combined sewer as both storm water and wastewater/sewage flow through this network. Catchment areas for different SSDSs have been marked on the map according to the distribution of sewer network around the SSDS. Fig. 4.1 shows the catchment areas of different SSDSs. Table 4.1 shows that the total catchment of Hatirjheel is about 23.73 km^2, SSDS-1 and SSDS-10 account for large catchment areas.

Storm water from Kawranbazar, Shangshad road, eastern part of Dhanmondi Lake, Panthapath, and Nilkhet Road flows to Hatirjheel through SSDS-1. SSDS-1 has the largest catchment area, estimated at 6.1 km^2. SSDS-10, with an estimated catchment area of 4.87 km^2, carries storm water from Mohakhali, Niketon, and Nakhalpara areas. Storm water flows from Gulshan and Banani enter into Hatirjheel directly though Gulshan and Banani Lake. The catchment area of Gulshan Lake and Banani Lake is 5.23 km^2.

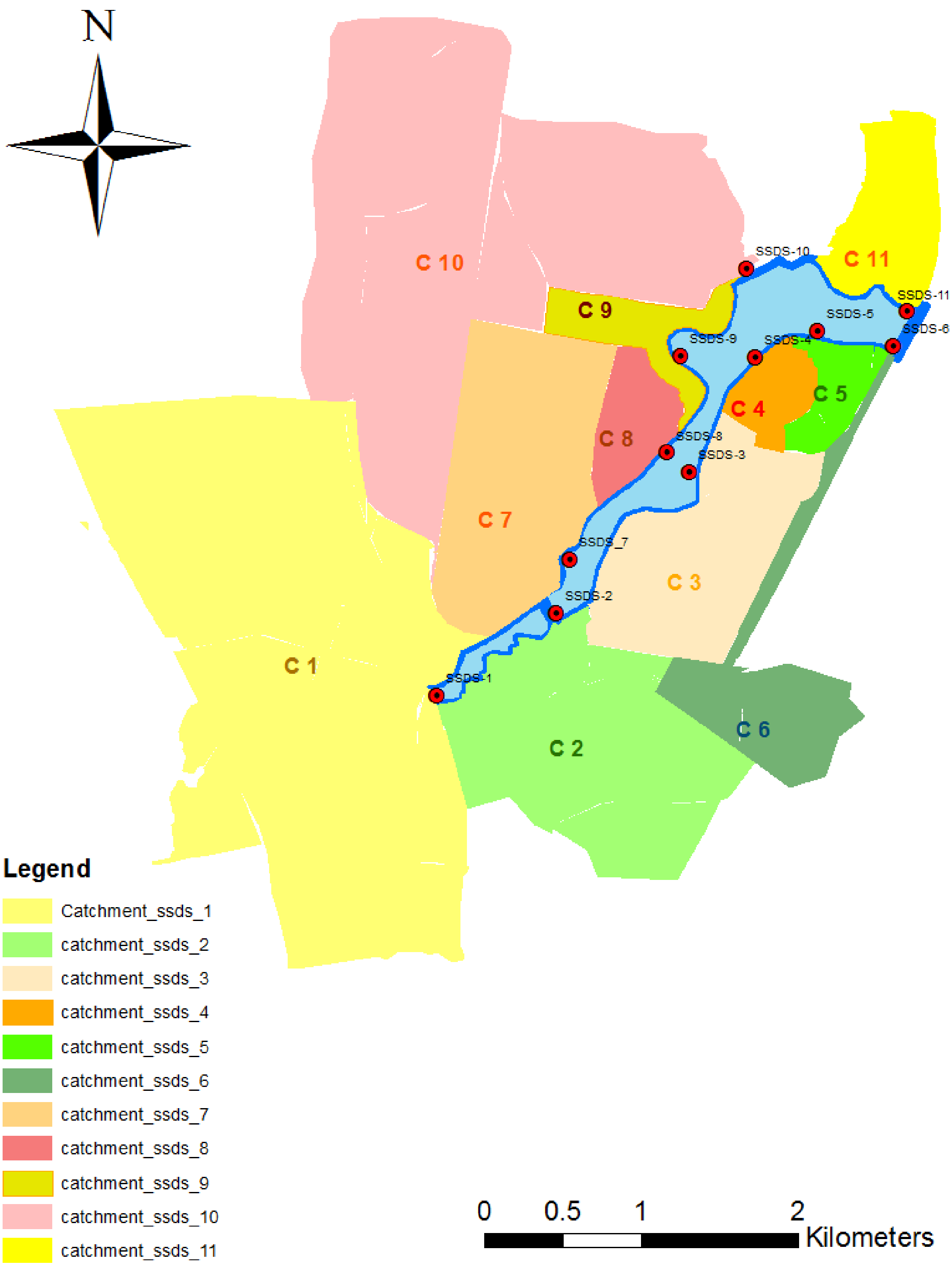

Fig. 4.1: Catchment areas of different SSDSs of Hatirjheel

Table 4.1: Catchment areas of different SSDSs of Hatirjheel

SSDS	Catchment areas of SSDS (km^2)
SSDS-1	6.10
SSDS-2	1.90
SSDS-3	1.30
SSDS-4	0.20
SSDS-5	0.30
SSDS-6	0.79
SSDS-7	1.60
SSDS-8	0.40
SSDS-9	0.40
SSDS-10	4.87
Gulshan and Banani Lake	5.23
SSDS-11	0.64
Total catchment area	**23.73**

4.2.2 Estimation of Sewage Flow and Capacity of Main Diversion Sewer

Two approaches have been used to estimate the sewage flow generated within the catchment of different SSDSs of Hatirjheel. The first approach involved estimation of population (in 2007) under each catchment (from census data) and then estimation of sewage generation assuming a generation rate of 120 lpcd. The other approach involved locating DWASA deep tubewells (DTWs) in the catchment areas of different SSDSs of Hatirjheel (for the year 2007) and estimating sewage generation in each catchment area from water production (at the DTWs) data. The estimated sewage flows obtained by these two approaches were compared with the dry weather flow measured at selected outfalls of Hatirjheel in 2007. The estimates made from population data were much lower compared to the measured values (in 2007). On the other hand, sewage flows estimated from water production data (at DWASA DTWs in 2007) matched the measured flows better (except for SSDS-10), and hence were used for prediction of sewage flow for future years. It was assumed that the entire sewage generated is carried through the storm sewer, and the increase in wastewater flow is proportional to population growth.

Table 4.2 shows the estimated sewage flows that could potentially reach different SSDSs of Hatirjheel through storm sewer network. Table 4.2 shows that estimated sewage flows at SSDS-7 (12 cfs) and SSDS-10 (42 cfs) in 2007 are much higher compared to the measured values in 2007 (2 cfs and 22 cfs respectively). This probably indicates that not all domestic sewage generated within the catchment of these SSDSs flows through the storm sewer network.

As explained earlier, the domestic sewage generated within the catchment areas of Hatirjheel are mostly carried through the storm sewer network up to the SSDSs. During dry season, this entire flow is diverted toward the “main diversion sewer” at the SSDSs, which carries it downstream (currently toward Begunbari khal). As part of this study, efforts were made to assess whether the main diversion sewers of Hatirjheel would be able to accommodate the increased sewage flows (due to increase in population) in the future. For this purpose, the capacity of different sections of the main diversion sewer system of Hatirjheel was estimated and compared with the estimated sewage flows that could potentially flow through these sections of the main diversion sewer system (see Table 4.2). Considering accumulation of sludge within sewers, the capacity of main diversion sewers were assumed to be equivalent to 70% of the full flow capacity. Table 4.3 shows capacity of different sections of the main diversion sewers of Hatirjheel.

Table 4.2: Estimated sewage flows that could potentially reach different SSDSs through storm sewer network

SSDS	Estimated wastewater flow (cfs)				
	2007 (base year)[1]	2011	2015	2021	2025
SSDS-1	61 (68)	66	93.5	124	153
SSDS-2	12 (10)	13	18	24	30
SSDS-3	8	8	12	16	19
SSDS-4	1	1.2	1.5	2	3
SSDS-5	1	1.2	1.5	2	3
SSDS-6	9 (11)	10	13	18	22
SSDS-7	12 (2)	12	17	22	27
SSDS-8	1	1	2	2.5	3
SSDS-9	1	1	2	2.5	3
SSDS-10	42 (22)	45	64	84	104
SSDS-11	5 (4)	5	7	11	14

[1]Number within brackets indicate measured flows in 2007

Table 4.3: Capacity of different sections of the main diversion sewer system of Hatirjheel

Main Diversion Sewer Section	Description of Main Diversion Sewer System	Capacity of Sewer System (cfs)
SSDS-1 to SSDS-6	Twin 1830 mm sewer	115
SSDS-7 to SSDS-8	Single 1200 mm sewer	18.7
SSDS-8 to SSDS-10	Single 1524 mm sewer	35.3
SSDS-10 to SSDS-11	Twin 1830 mm sewer	115

Fig. 4.2(a) through 4.2(c) show estimated sewage (wastewater) flows at different sections of the main diversion sewer along with capacity of the sewer sections for the years 2015, 2020 and 2025. It shows that in 2015 certain sections of the main diversion sewers of Hatirjheel (from SSDS-3 to SSDS-6) may not be able to accommodate the dry weather flow (i.e., sewage), if the entire sewage generated within the catchment of Hatirjheel reach the SSDSs of Hatirjheel through the strom sewer network. In 2015, the section of main diversion sewer from SSDS-3 to SSDS-6 along the southern periphery of Hatirjheel will become overloaded. In 2021 and beyond, the main diversion sewer along the entire southern periphery of

Hatirjheel (i.e. from SSDS-1 to SSDS-6) will become overloaded. Along the northern periphery, the section from SSDS-7 to SSDS-8 will become overloaded in 2021; and by 2025 the section from SSDS-10 to SSDS-11 will also become overloaded, if entire sewage flows are carried through the storm sewer network. Thus, if the main diversion sewers are unable to carry the increased sewage flows, then the excess sewage (beyond the capacity of the main diversion sewers) would overflow into Hatirjheel, and pollute Hatirjheel even during the dry season. Therefore, this issue should be addressed with utmost importance.

4.2.3 Estimation of Storm Flow and their Overflow into Hatirjheel

The storm water flows that reach different SSDSs of Hatirjheel during wet season have been estimated considring the catchment areas contributing to each SSDS and a rainfall scenario with a 5 year return period. Currently, the main diversion sewer system of Hatirjheel carries entire sewage flows (i.e., dry weather flow from about November to April) that reach different SSDSs of Hatirjheel through storm sewer network. However, during rainy season, when both storm/rain water and sewage flows start to reach the SSDSs (from around May until October) through the storm sewer network, the capacity of the main diversion sewers are exceeded, and the excess flows discharge into Hatirjheel. The overflow of rainwater-sewage mixture from the SSDSs (into Hatirjheel) has been estimated by subtracting a flow "equivalent to the effective capacity of the sewer associated with the SSDS" (see Table 4.3) from the combined (rainwater-sewage) flow reaching the SSDS. Due to large catchment areas, SSDS-1 and SSDS-10 receive large wastewater as well as strom water flows. The overflow from these two SSDSs have therefore been estimated for future years. Fig. 4.3 shows estimated overflows into Hatirjheel from SSDS-1 and SSDS-10 for the year 2025. Fig. 4.3 shows that even in the dry season of 2025 there will be some overflows (of sewage) into Hatirjheel for these two SSDSs. As discussed in Section 4.2.2, this is because of the fact that in 2025 the estiamted sewage flows to be generated within the catchment of these SSDSs would exceed the capacity of the main diversion sewers associated with these SSDSs. Thus, possible discharge of raw/undiluted sewage into Hatirjheel in the dry season (in addtion to the overflows during the wet season) could severely pollute Hatirjheel in the future.

Fig. 4.2(a): Estimated sewage (wastewater) flow requirements at different sections of the main diversion sewer of Hatirjheel along with capacity of the main diversion sewer for the year 2015

Fig. 4.2(b): Estimated sewage (wastewater) flow requirements at different sections of the main diversion sewer of Hatirjheel along with capacity of the main diversion sewer for the year 2021

Fig. 4.2(c): Estimated sewage (wastewater) flow requirements at different sections of the main diversion sewer of Hatirjheel along with capacity of the main diversion sewer for the year 2025

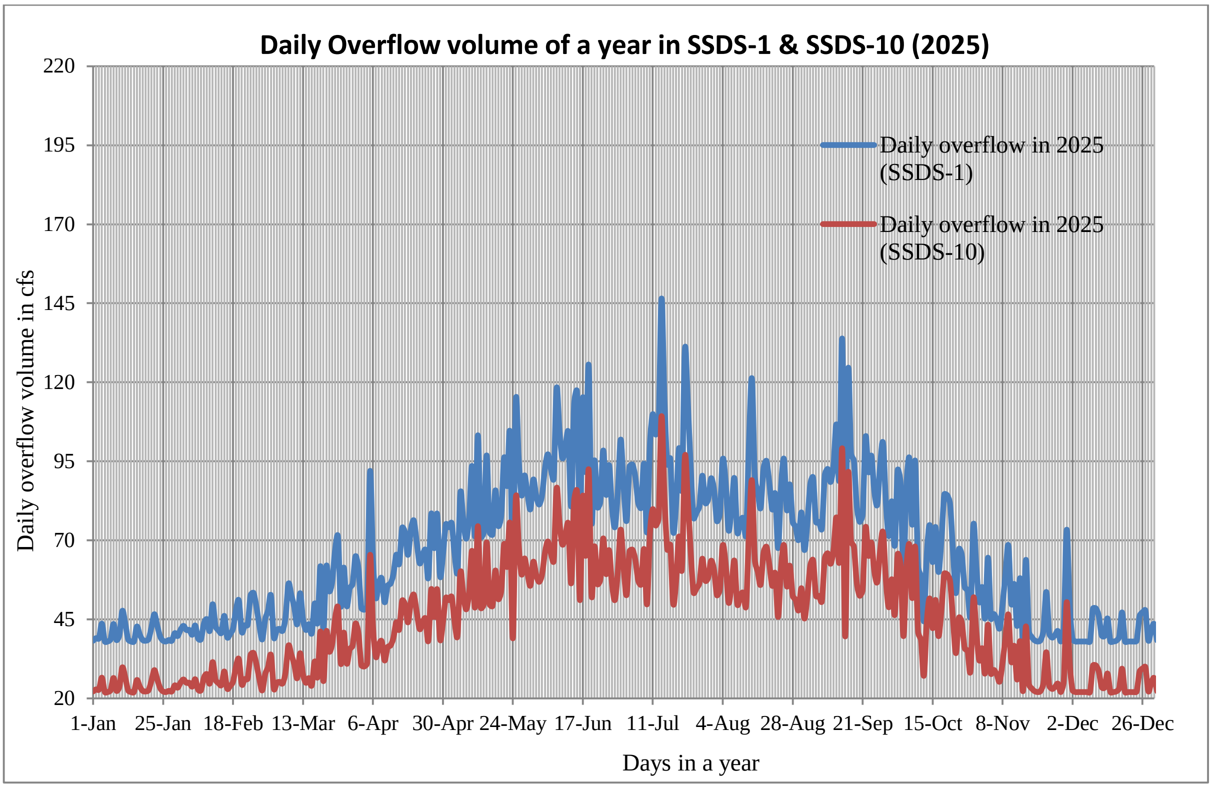

Fig. 4.3: Estimated overflows into Hatirjheel from SSDS-1 and SSDS-10 in the year 2025

4.3 Water Quality of Hatirjheel

In order to assess water quality of Hatirjheel, water quality monitoring was carried out during June 2014 to May 2015. Water samples were collected from the front of nine SSDSs (except SSDS-6 and SSDS-11) of Hatirjheel, Banani Lake and Gulshan Lake; Water samples were collected from Hatirjheel during the period June 2014 to May 2015, roughly at the frequency of one sample per month; a total of 10 samplings were carried out during this period. This section presents an assessment of water quality of Hatirjheel based on year-long monitoring. Appendix A presents the characteristics of all water samples collected from Hatirjheel.

4.3.1 General Assessment of Water Quality

In this study, the water quality sampling was carried out during June 2014 to May 2015. During June to October 2014 rainfall occurred, which resulted in overflow of rainwater-sewage mixture through a number of SSDSs of Hatirjheel. This caused significant deterioration of the water quality of Hatirjheel. During November 2014 to March 2015 there was no rainfall and therefore no overflow took place through the SSDSs. During this period, the water quality of Hatirjheel improved (due to “self-cleansing” processes occurring within Hatirjheel), as there was no inflow of pollutants into it. But with the commencement of wet season (i.e., in April 2015) there was rainfall and therefore overflow took place through a number of SSDSs of Hatirjheel and water quality began to deteriorate.

The water quality of Hatirjheel is characterized by high concentrations of organics (BOD_5 and COD), nutrients (ammonia, phosphate, sulfate, sulfide), and dissolved solids. Some significant spatial variation is also observed in the water quality. A careful analysis also revealed that the water quality of Hatirjheel (in front of SSDSs) is very closely related to the overflow from the respective SSDSs. During the last wet season (from June to October 2014), overflow of rainwater-sewage mixture occurred regularly (during and after rainfall events) at SSDS-1 and SSDS-2; the highest overflow occurred through SSDS-1. Some overflow also took place through SSDS-7 in the event of heavy rainfall; and on a few occasions overflow of rainwater-sewage also occurred at SSDS-9 during very heavy downpour. No overflow of rainfall-sewage mixture took place at SSDS-3, 4, 5, 8 and 10. As explained earlier, overflow of rainwater-sewage mixture from SSDSs cause pollution of Hatirjheel water. Thus, water quality of Hatirjheel is expected to be particularly poor in front of those SSDSs through which significant overflow (of rainwater-sewage) takes place during the wet season. In fact, this has been confirmed through the water quality tests carried out in this study.

The water quality of Hatirjheel has been found to be the worst in front of SSDS-1 and SSDS-2, through which overflow of rainwater-sewage mixture occurred throughout the wet season of 2014 (during and after rainfall). At these two locations (i.e., front of SSDS-1 and SSDS-2) water quality is characterized by high concentrations of COD (average 155 and 112 mg/l, respectively), BOD_5 (average 58 and 37 mg/l, respectively), TDS (average 347 and 308 mg/l, respectively), Total Ammonia Nitrogen (TAN) (average 20 and 13 mg/l, respectively), and sulfide (64 and 33 µg/l, respectively). Presence of high concentration of sulfide at these locations indicate anaerobic environment. Water quality of Hatirjheel in front of SSDS-7 and SSDS-9 has also been found to be poor, with average COD of 95 and 96 mg/l, respectively; average BOD_5 18 and 20 mg/l, respectively; and average TAN 13 and 10 mg/l, respectively. Water quality of Hatirjheel in front of other 5 SSDSs, although not good, show relatively less level of pollution (see Appendix A). Very high COD to BOD_5 ratio (1.94-4.20, 1.71-4.61, 3.88-12.38, 3.00-7.08, 2.94-9.00, 3.10-10.09, 3.16-11.20, 3.00-11.18, 2.85-8.80 in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10, respectively) and relatively high concentration of sulfate found at all sampling locations possibly indicate presence of wastewater of industrial origin in the overflows from SSDSs. The significant temporal variation of water quality at the sampling locations also appears to be related to the overflow from SSDSs, which in turn was related to the rainfall event.

Table 4.4 shows the Bangladesh standards (according to Environment Conservation Rules 1997) for inland surface water for different purposes. Comparison of Table 4.4 and data presented in Appendix A shows that the BOD_5 and Ammonia concentration of Hatirjheel water is much higher than the corresponding standards; and unsuitable for any purpose including fisheries, recreational and irrigation.

Table 4.4: Bangladesh standard for inland surface water for different purposes

Sl. No.	Best Practice Based Classification	Parameter			
		pH	BOD (mg/l)	DO (mg/l)	Total Coliform (#/100 ml)
a	Source of drinking water for supply only after disinfection	6.5-8.5	≤ 2	≥ 6	≤ 50
b	Water usable for recreational activity	6.5-8.5	≤ 3	≥ 5	≤ 200
c	Source of drinking water for supply after conventional treatment	6.5-8.5	≤ 6	≥ 6	≤ 5000
d	Water usable by fisheries	6.5-8.5	≤ 6	≥ 5	--
e	Water usable for by various process and cooling industries	6.5-8.5	≤ 10	≥ 5	≤ 5000
f	Water usable for irrigation	6.5-8.5	≤ 10	≥ 5	≤ 1000

Notes:
(1) In water used for pisciculture, maximum limit of presence of ammonia as nitrogen is 1.2 mg/l
(2) Electrical conductivity for irrigation water 2250 μS/cm (at a temperature at 25 °C); Sodium less than 26%; Boron less than 0.2%

4.3.2 Organic Pollution

The variation of BOD_5 and COD with time in front of SSDS-1 is shown in Fig. 4.4. It shows that BOD_5 or COD in front of SSDS-1 is high from June to October 2014 (i.e., BOD_5 maximum 90 mg/l and COD 175 mg/l), i.e., during the rainy season when rainwater-sewage mixture overflows into Hatirjheel through SSDS-1. From November to March-April (i.e., during dry season when there is no overflow through SSDS-1), water quality improves to some extent; during this period, minimum BOD_5 of 18 mg/l and minimum COD of 30 mg/l were recorded in front of SSDS-1. With commencement of rainfall in April-May, water quality in front of SSDS-1 began to deteriorate once again.

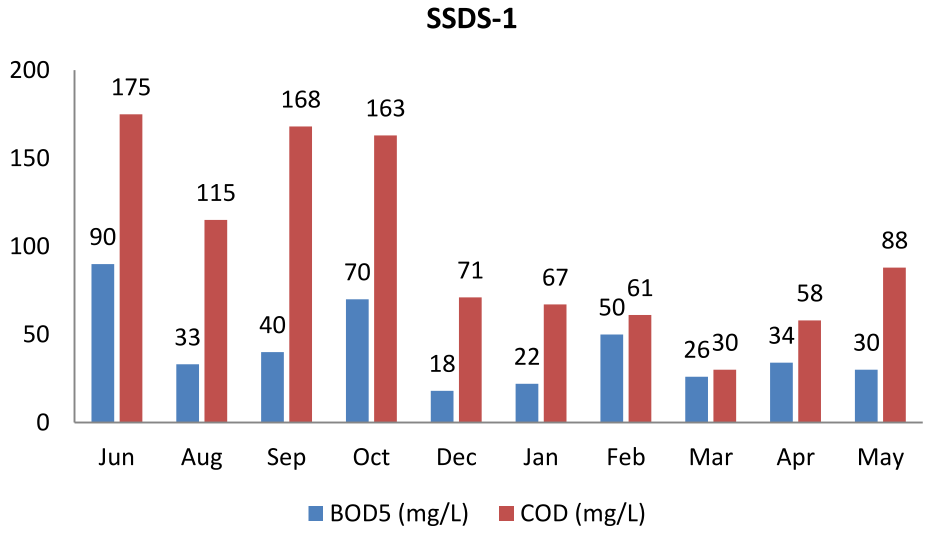

Fig. 4.4: Variation of $BOD_5$and COD (mg/l) with time in front of SSDS-1

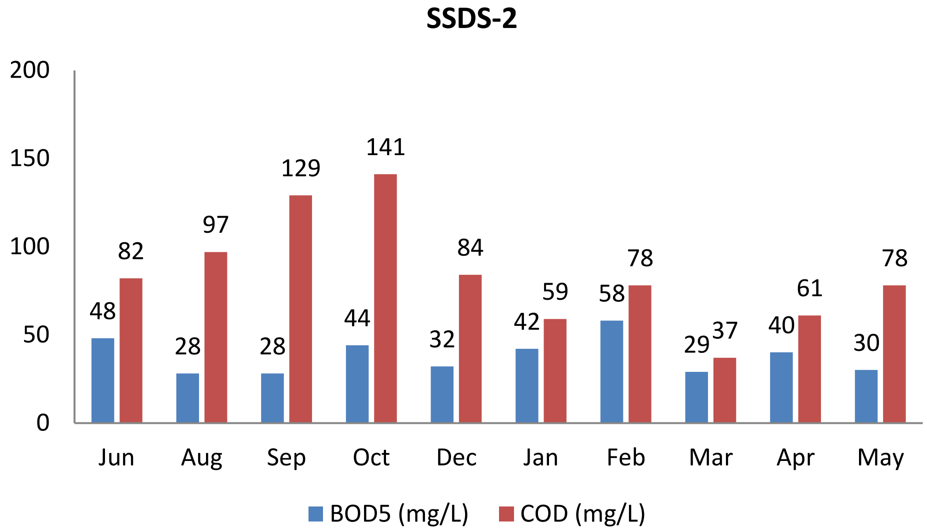

Fig. 4.5: Variation of BOD_5 and COD (mg/l) with time in front of SSDS-2

Fig. 4.5 shows variation of BOD_5 and COD in front of SSDS-2, through which significant overflows of rainwater-sewage mixture takes place during the wet season. It shows a similar trend in water quality, with poor quality during the wet season (June to October), and some improvement during the dry season (when there is no overflow). In fact, water quality of Hatirjheel in front of SSDS-1, 2, 7 and 9 (SSDSs through which overflows took place) has been found to improve during November 2014 to March 2015, with average COD of 57, 65, 68 and 79 mg/l, respectively; and average BOD_5 (29, 40, 39 and 40 mg/l, respectively). Very high COD to BOD_5 ratio found at all sampling locations (1.94-4.20, 1.71-4.61, 3.88-12.38, 3.00-7.08, 2.94-9.00, 3.10-10.09, 3.16-11.20, 3.00-11.18, 2.85-8.80 in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10, respectively) possibly indicate presence of wastewater of industrial origin in the overflows from SSDSs.

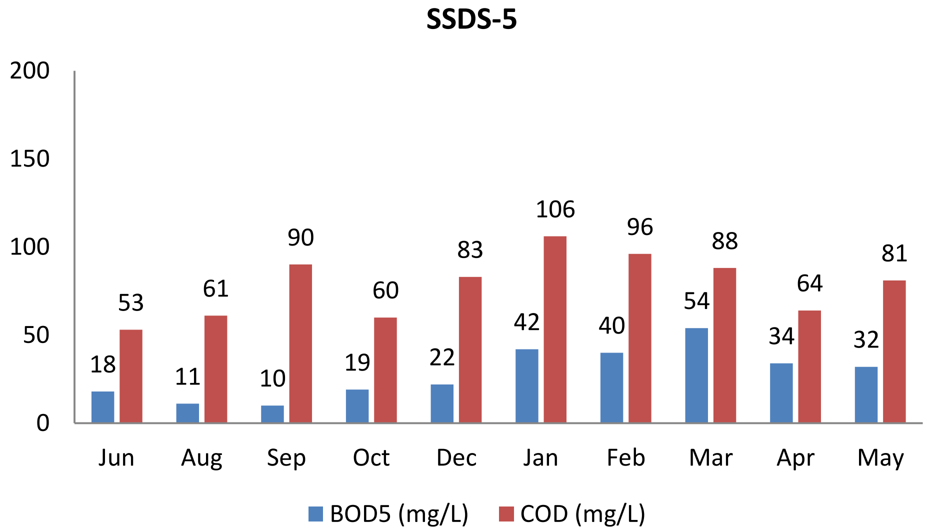

Fig. 4.6: Variation of BOD_5 and COD (mg/l) with time in front of SSDS-5

Fig. 4.6 shows variation of BOD_5 and COD in front of SSDS-5; no overflow of rainwater-sewage was allowed through this SSDS. Fig. 4.6 and water quality data presented in Appendix A show that although no overflows were allowed through SSDSs-3, 4, 5, 8 and 10, water quality in front of these SSDSs were also poor (with BOD_5 and COD as high as 18, 21, 19, 26, 28 mg/l, respectively and 99, 92, 90, 112, 111 mg/l, respectively during the wet season). This possibly indicates that the water of Hatirjheel is relatively well-mixed.

Fig. 4.7(a) and Fig. 4.7(b) shows that the variation of BOD_5 and COD in front of all SSDSs for September 2014 (wet season) and April 2015 (dry season). Fig. 4.7(a), Fig. 4.7(b) and data presented in Appendix A clearly show that water quality of Hatirjheel is poor throughout the year, and not suitable for any productive use such as recreation, fisheries or irrigation according to Bangladesh standards (see Table 4.4).

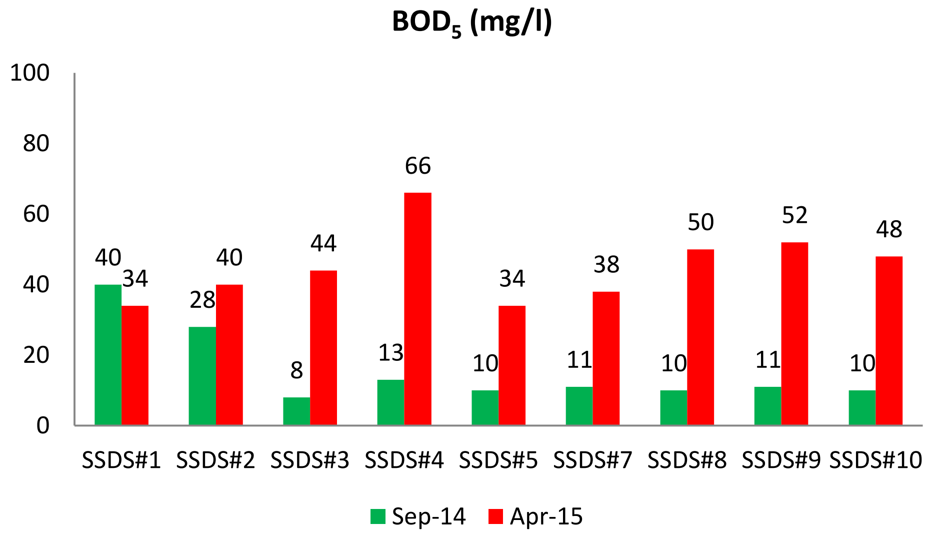

Fig. 4.7(a): Variation of BOD_5 (mg/l) in front of SSDSs for September 2014 and April 2015

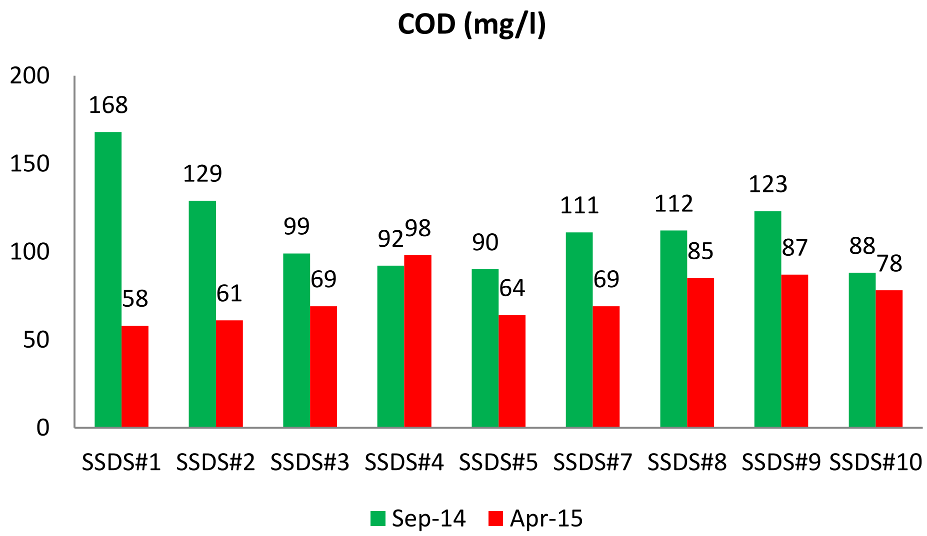

Fig. 4.7(b): Variation of COD (mg/l) in front of SSDSs for September 2014 and April 2015

4.3.3 Ammonia and Other Nutrients

4.3.3.1 Ammonia

Fig. 4.8(a) and Fig 4.8(b) show variations of total ammonia nitrogen (TAN) and free ammonia (NH_3-N) in front of SSDS-1. Fig. 4.8(a) shows that total ammonia nitrogen (TAN) concentration increases from August 2014 to January 2015, and then begin to decrease; Fig. 4.8(b) shows a similar trend for NH_3-N. Thus, unlike BOD_5 and COD, ammonia concentration continues to increase even after the end of rainy season (up to January). This is most likely due to release of ammonia into water column from the decomposition of organic matter present in overflow water from SSDS.

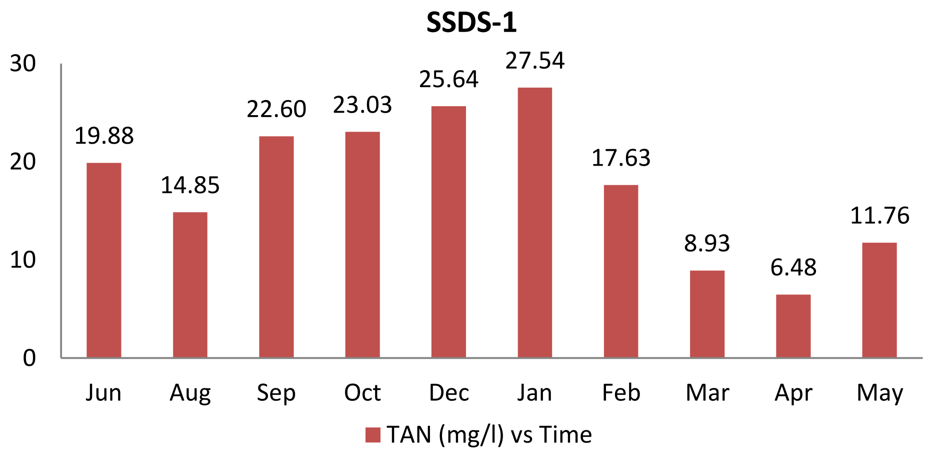

Fig. 4.8(a): Variation of total ammonia nitrogen (mg/l) with time in front of SSDS-1

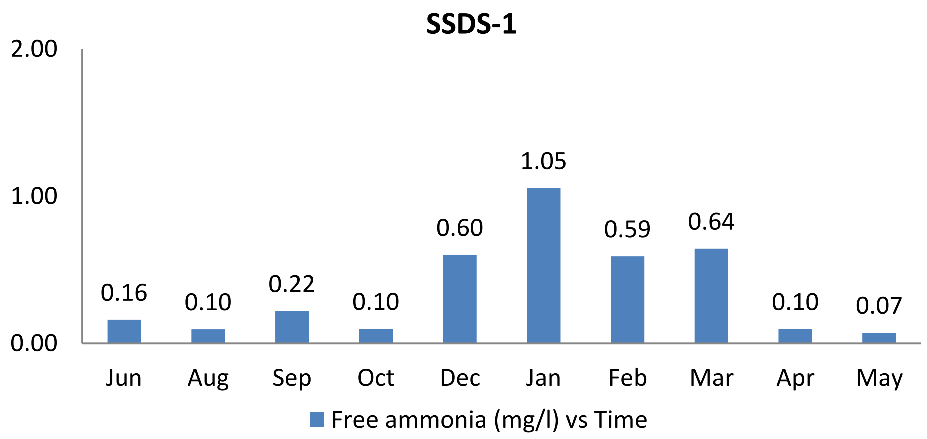

Fig. 4.8(b): Variation of free ammonia (NH_3-N) (mg/l) with time in front of SSDS-1

As discussed earlier, ammonia is the most important parameter for fish species. Anytime free ammonia (NH_3) is higher than 0.05 mg/l, the fish are being damaged; at higher, it causes more and more damage. When levels reach 0.2 mg/l, sensitive fish like trout and salmon begin to die. At 2.0 mg/l, the fish will die. During the entire sampling period in this study (i.e., June 2014 to May 2015), the free ammonia (NH_3) concentration throughout Hatirjheel was higher than 0.05 mg/l; NH_3 concentration in front of SSDS-2 in December 2015 was the highest at 2.5 mg/l. Thus, it can be concluded that ammonia concentration in Hatirjheel is so high that fish species are unlikely to survive in this environment. Fig. 4.9 shows free ammonia (NH_3) concentration at all sampling locations in September 2014 and April 2015.

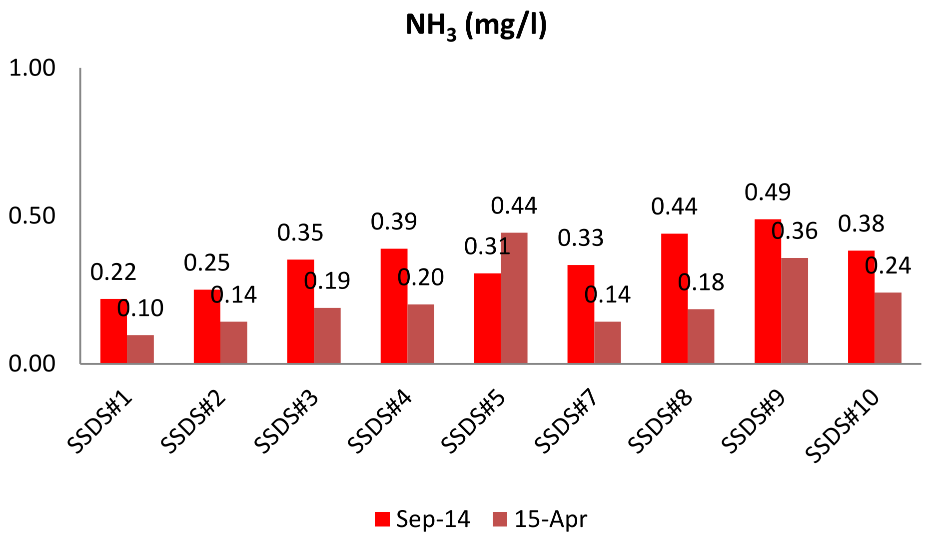

Fig. 4.9: NH_3 concentration at all sampling locations in September 2014 and April 2015

Fig. 4.10 shows total ammonia nitrogen (TAN) concentration in front of SSDS-2 during the sampling period, and Fig. 4.11 shows TAN concentration at all sampling locations in September 2014 and April 2015. Appendix A shows detail data for all sampling locations.

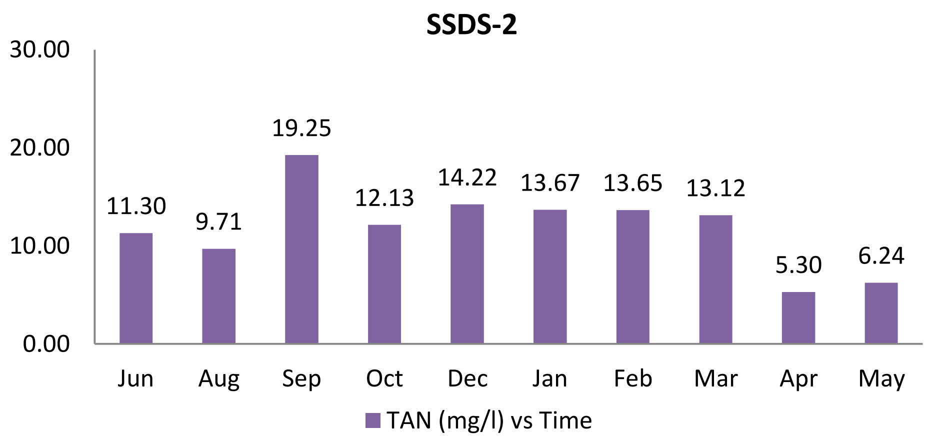

Fig. 4.10: Variation of total ammonia nitrogen (mg/l) with time in front of SSDS-2

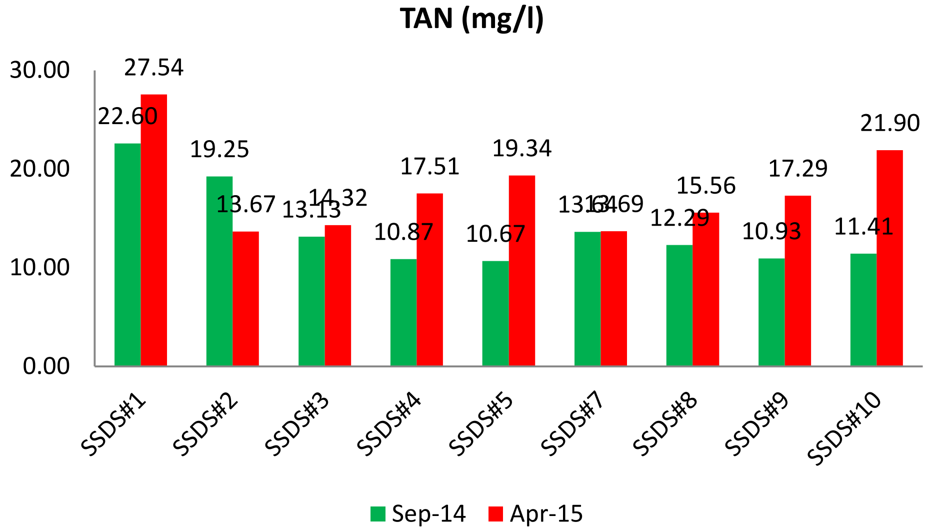

Fig. 4.11: TAN concentration at all sampling locations in September 2014 and April 2015

As explained in Chapter 2 (see Table 2.5), USEPA recommends an acute criterion magnitude of 17 mg Total Ammonia Nitrogen (TAN) per liter at pH 7 and 20°C for a one-hour average duration, not to be exceeded more than once every three years on average. USEPA recommends a chronic criterion magnitude of 1.9 mg TAN/L at pH 7 and 20°C for a 30-day average duration, not to be exceeded more than once every three years on average. In addition, the highest four-day average within a 30-day period should not exceed 2.5 times the chronic criterion magnitude (e.g. 1.9 mg TAN/L x 2.5 = 4.8 mg TAN/L at pH 7 and 20°C) more than once in three years on average. Thus, it is clear that the water of Hatirjheel exceed the USEPA criteria by a huge margin. The concentration of TAN (total ammonia nitrogen) throughout Hatirjheel is much higher than the USEPA chronic ammonia criteria throughout the year. This indicates that the water of Hatirjheel is completely unsuitable for survival of fish species. It is therefore not surprising that no fish species could be identified anywhere within Hatirjheel.

4.3.3.2 Nitrate and Nitrite

The variations of nitrate with time in front of SSDS-1 and SSDS-5 are shown in Fig. 4.12. The concentration of nitrate in front of both SSDSs (i.e., SSDS-1 and 5) increased from December 2014 to April 2015 (from about 0.5 mg/l in December 2014 to maximum 5.0 and 4.9 mg/l respectively in April 2015). Thus, nitrate concentration does not increase during the overflow of rainwater-sewage mixture into Hatirjheel, but begin to increase later on. In fact, this trend is expected. The rainwater-sewage mixture which overflows into Hatirjheel brings in significant organic matter and ammonia, but not much nitrate. With passage of time the organic matter undergoes decomposition and increases ammonia concentration further. Subsequently, part of this ammonia is oxidized into nitrate, and nitrate concentration begins to increase (starting in February according to Fig. 4.12). Finally, nitrate (as well as ammonia) concentration is reduced, possibly as a result of incorporation into algal mass which eventually overflows out of Hatirjheel into Begunbari khal through the overflow structure at the eastern end of Hatirjheel near Rampura.

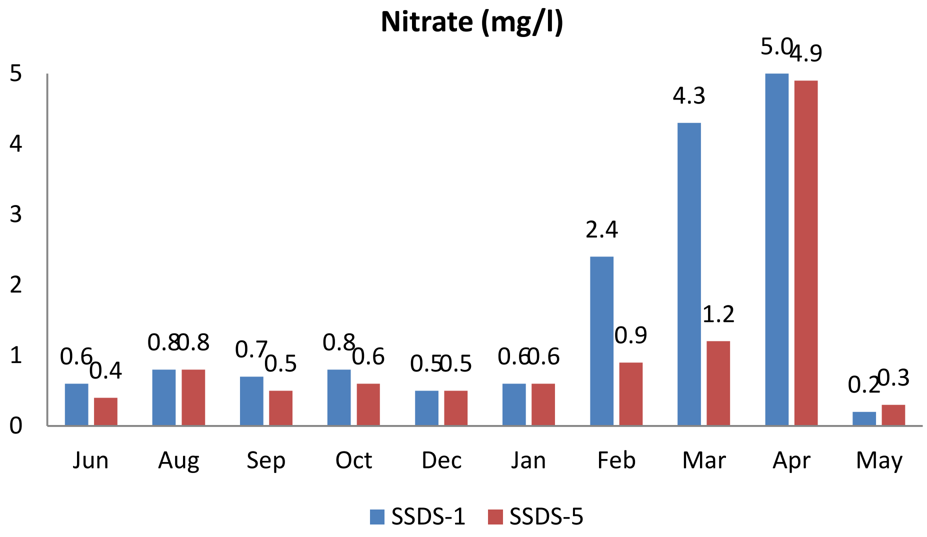

Fig. 4.12: Variation of nitrate (mg/l) with time in front of SSDS-1 and SSDS-5

4.3.3.3 Sulfate and Sulfide

Sulfate concentration in Hatirjheel water is found to be relatively high throughout Hatirjheel throughout the year (see data in Appendix A). During the wet season (i.e., from June to October 2014), average sulfate concentrations in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10 were 26, 21, 28, 30, 28, 27, 29, 29 and 25 mg/l, respectively. The sulfate concentration decreases slightly during the dry season. Fig. 4.13 shows variation of sulfate concentration in front of SSDS-1 during the sampling period.

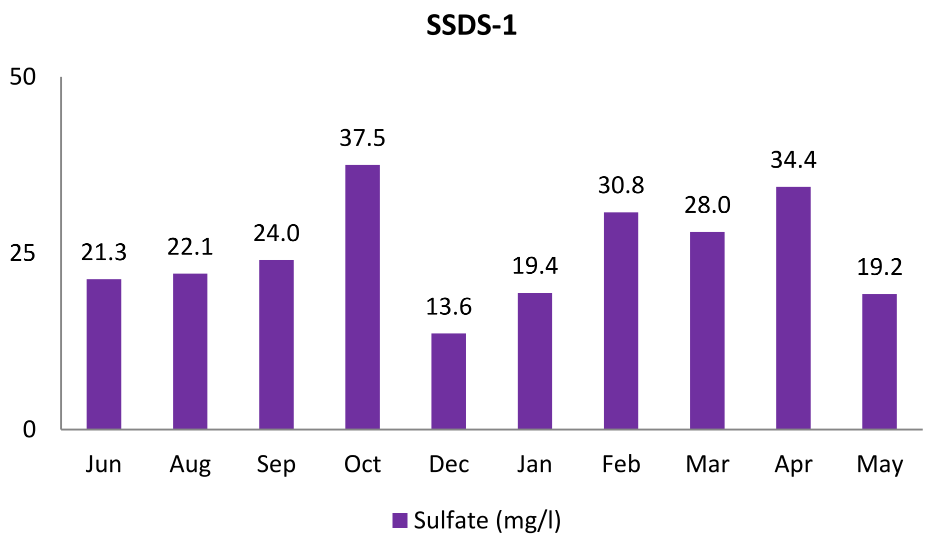

Fig. 4.13: Variation of sulfate (mg/l) concentration in front of SSDS-1

Unlike sulfate, sulfide appears to have a seasonal variation, with higher concentration during the wet season and lower concentration during the dry season. During the wet season (i.e., from June to October 2014), average sulfide concentrations in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10 were 64, 33, 27, 20, 23, 29, 24, 23 and 25 µg/l, respectively. Sulfide concentration reduced significantly during the dry season. Fig. 4.14 shows variation of sulfide concentration in front of SSDS-1. These data suggest that sulfide enters into Hatirjheel with overflows of rainwater-sewage mixture during the wet season.

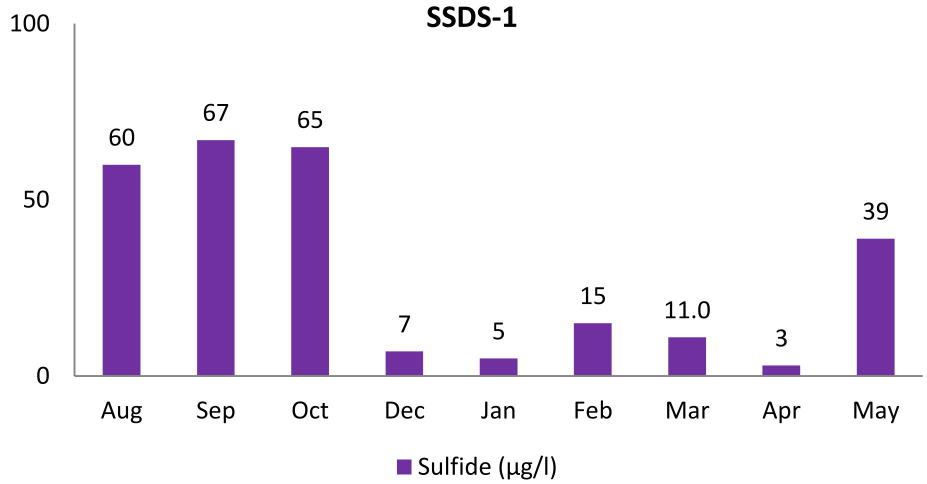

Fig. 4.14: Variation of sulfide (µg/l) concentration in front of SSDS-1

4.3.3.4 Phosphate

The variation of phosphate with time in front of SSDS-1 and SSDS-5 are shown in Fig. 4.15. The concentration of phosphate in front of SSDS-1 through which overflows took place during wet season was found relatively more (maximum of 9.29 mg/l in January 2015) than SSDS-5 through which no overflow took place (maximum of 6.06 mg/l in January 2015).

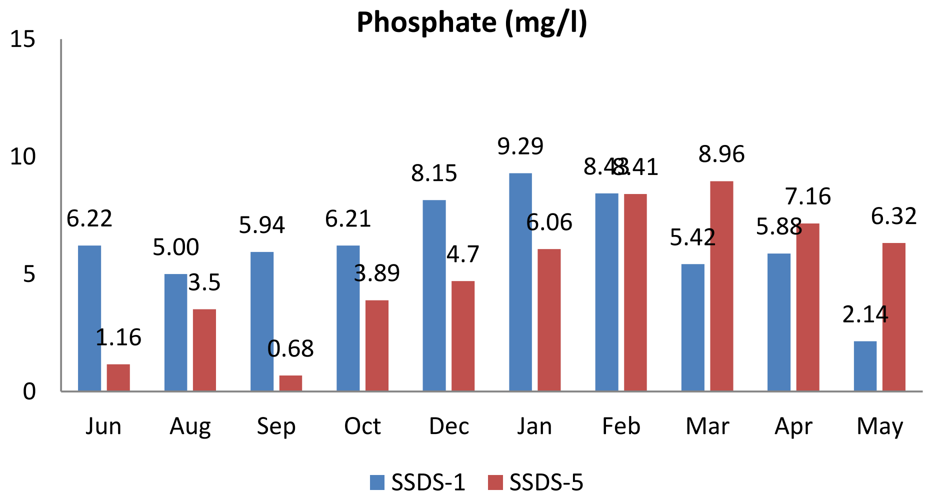

Fig. 4.15: Variation of phospate (mg/l) with time in front of SSDS-1 and SSDS-5

Relatively high concentration of phosphate has been found throughout Hatirjheel. During the wet season (i.e., from June to October 2014), average phosphate concentration in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10 were 6, 4, 3, 3, 2, 3, 3, 3 and 3 mg/l, respectively. Phosphate concentration appears to increase after the end of wet season. Domestic sewage contains significant amount of phosphate; so phosphate appears to enter into Hatirjheel with overflows of rainfall-sewage mixture. However, the increase of phosphate concentration at the end of wet season possibly indicates release of phosphate from decomposition process (e.g., algae). Fig. 4.16 shows variation of phosphate concentrations in front of SSDSs in September 2014 and April 2015.

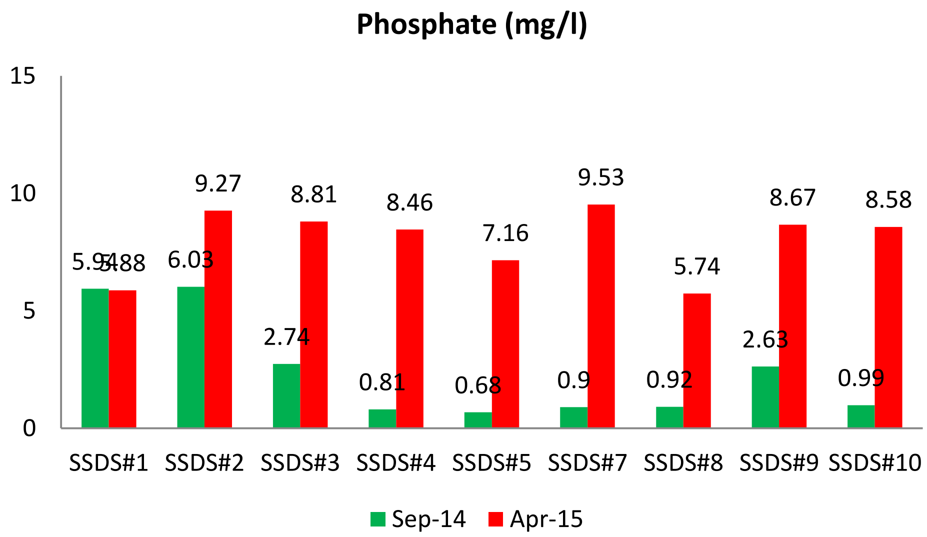

Fig. 4.16: Variation of phosphate (mg/l) concentrations in front of SSDSs in September 2014 and April 2015

4.3.4 Solids

4.3.4.1 Conductivity and TDS

During the wet season (i.e., from June to October 2014), the average Conductivity in front of SSDS-1, 2, 3, 4, 5, 7, 8, 9 and 10 were 671, 587, 567, 553, 529, 589, 571, 543 and 537 µS/cm, respectively and average TDS were 347, 308, 298, 278, 287, 300, 295, 284 and 272 mg/l, respectively. Maximum Conductivity of 738 µS/cm was recorded in September 2014 in front of SSDS-1 and maximum TDS of 388 mg/l was recorded in September 2014 in front of SSDS-1. At the end of dry season, Conductivity and TDS continued to increase at some of the sampling locations, possibly due to release of dissolved decomposition products. Fig. 4.17 shows variation of Conductivity (µS/cm) and TDS (mg/l) with time in front of SSDS-1.

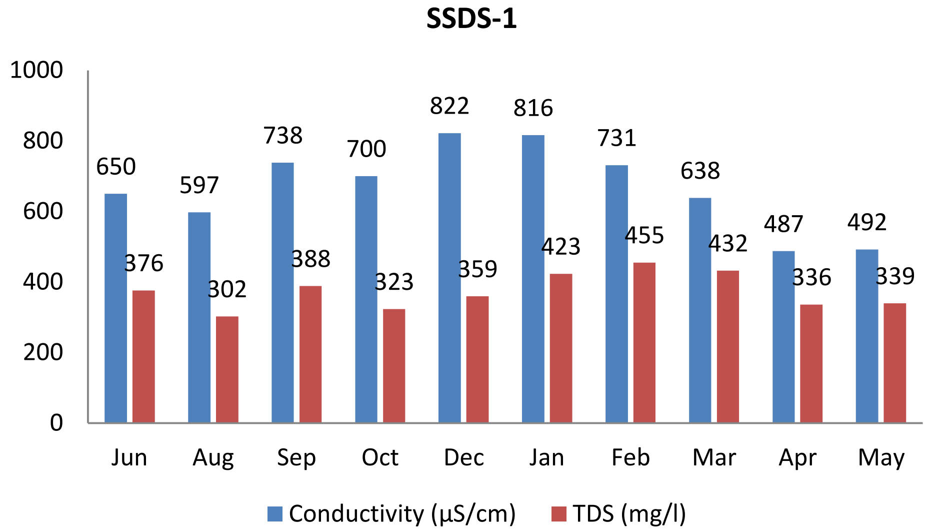

Fig. 4.17: Variation of Conductivity (µS/cm) and TDS (mg/l) with time in front of SSDS-1

4.3.4.2 Turbidity and TSS

During the wet season (i.e., from June to October 2014), the average Turbidity in front of SSDS-1, 2, 7, 8, 9 and 10 were 60, 70, 71, 51, 54 and 60 NTU, respectively; and average TSS in front of SSDS-7, 8, 9 and 10 were 34, 47, 42, and 47 mg/l, respectively. Maximum Turbidity of 107 NTU was recorded in October 2014 in front of SSDS-2 and maximum TSS of 110 mg/l was recorded in August 2014 in front of SSDS-10. High turbidity and TSS values were recorded at the sampling locations even during the dry season when there was no overflow of rainfall-sewage mixture into Hatirjheel. Fig. 4.18 shows variation of turbidity (NTU) and TSS (mg/l) with time in front of SSDS-1.

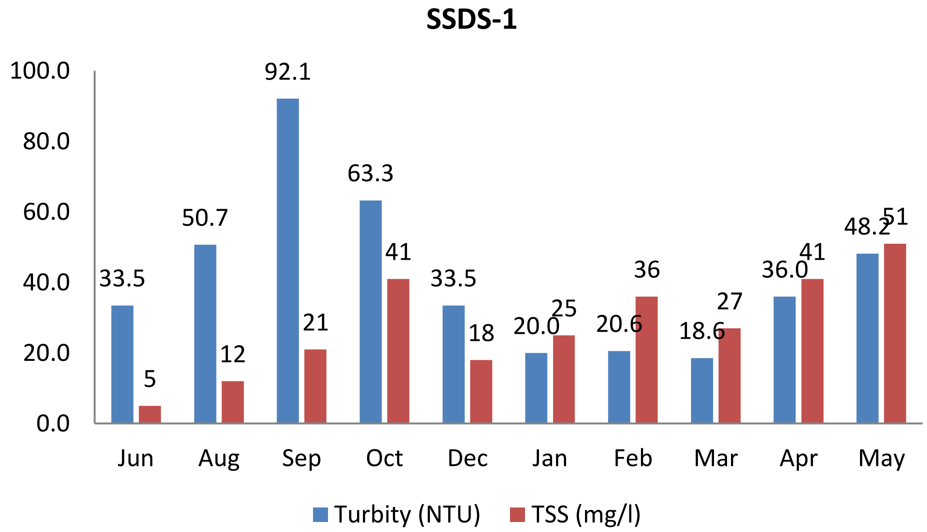

Fig. 4.18: Variation of Turbidity (NTU) and TSS (mg/l) with time in front of SSDS-1

4.3.5 Color

Relatively high level of Color was detected throughout Hatirjheel during the entire sampling period. During wet season, color of water in front of SSDS-1 and SSDS-2 were black; this was due to overflow of dark colored rainfall-sewage mixture through these two SSDSs. Fig. 4.19 shows variation of color with time in front of SSDS-1 during the sampling period.

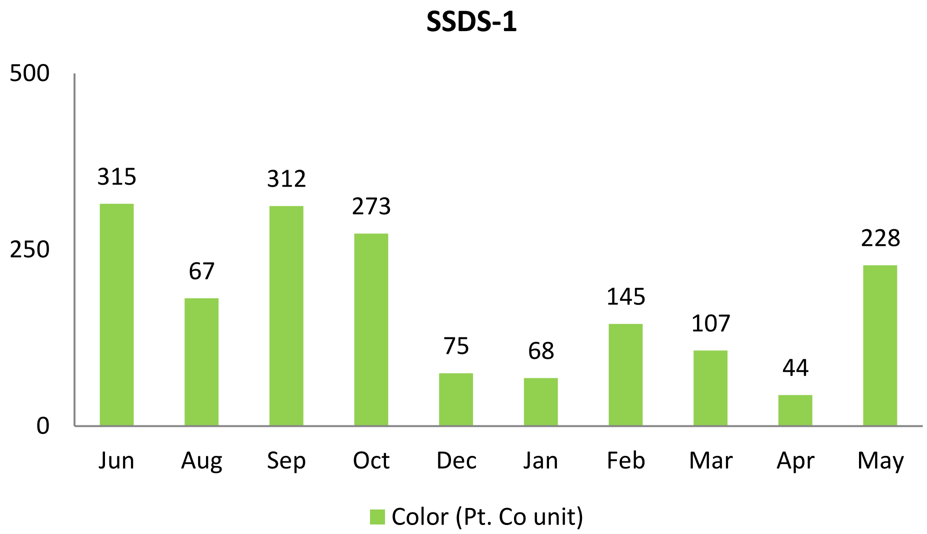

Fig. 4.19: Variation of Color (Pt. Co unit) with time in front of SSDS-1

The color of water in front of other SSDSs was mostly green due to high algal bloom. The high level of color recorded throughout Hatirjheel during the dry season (when there was no overflow) was due to algal bloom. In fact, the green color of water was clearly visible with naked eye. Fig. 4.20 shows variation of color (Pt. Co unit) in front of all SSDSs in September 2014 and April 2015.

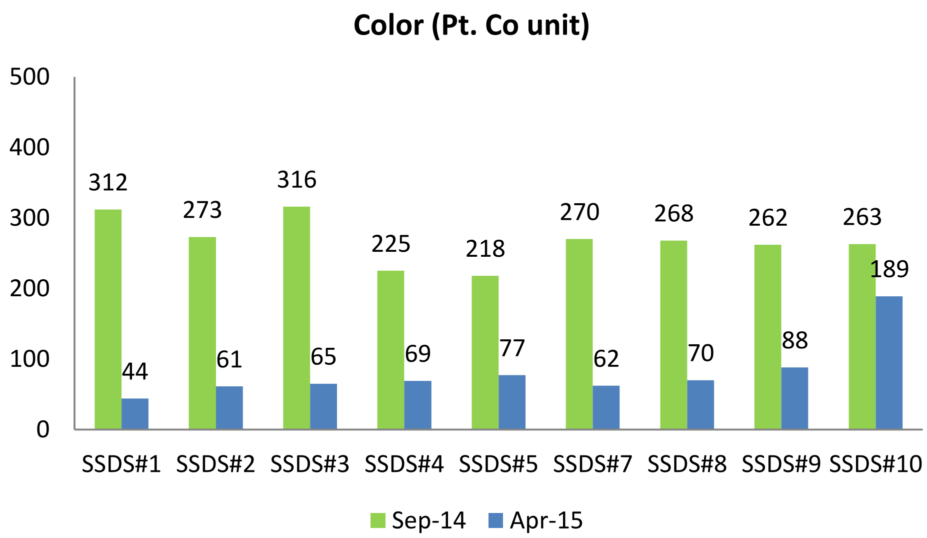

Fig. 4.20: Variation of color (Pt. Co unit) in front of all SSDSs in September 2014 and April 2015

4.3.6 pH

The pH of water samples collected from different SSDSs during the sampling period varied from 6.93 to 8.63. In all cases, the water samples were slightly alkaline. The maximum pH of 8.63 was recorded in SSDS-2 in December 2014. The minimum pH of 6.93 was recorded for SSDS-1 in October 2014. Table 4.5 shows variation of pH at different SSDSs during the sampling period. The higher pH values (exceeding 8) could be due to formation of algae, which is often accompanied by a rise in pH.

Table 4.5: Variation of pH at the sampling locations during the sampling period

SSDS	Variation of pH during sampling period
SSDS-1	6.93-8.19
SSDS-2	7.42-8.63
SSDS-3	7.50-8.54
SSDS-4	7.66-8.40
SSDS-5	7.59-8.61
SSDS-7	7.39-8.50
SSDS-8	7.49-8.45
SSDS-9	7.44-8.62
SSDS-10	7.34-8.52

Chapter Five

Conclusions and Recommendations

5.1 Introduction

Hatirjheel serves very important hydrologic functions of draining and detaining storm water from a large area (~30 km^2) of Dhaka. As a part of a major restoration project, special sewage diversion structures (SSDSs) have been constructed at 11 outfall locations surrounding Hatirjheel. The SSDSs are now diverting the entire dry season flow consisting of domestic/industrial sewage through large diameter "main diversion sewers" laid along the periphery of Hatirjheel. During wet season, a part of the combined flow of storm water and sewage overflows into Hatirjheel through SSDSs, causing pollution of the water body. It was expected that gradual separation of domestic/industrial connections to storm sewers would improve the situation. However, there is no sign of this taking place; on the contrary, with increase in population, the pollution load is increasing, intensifying the pollution of Hatirjheel. It is important to assess whether the SSDS and the main diversion sewer system of Hatirjheel would be able to handle the hydraulic load and extent of water quality deterioration of Hatirjheel for present and future years. This study presents an assessment of the capacity of the main diversion sewers of Hatirjheel to accommodate future flow. It also presents a detail assessment of the water quality of Hatirjheel based on a year-long water quality monitoring. This Chapter presents the major conclusions drawn from the study. It also presents recommendations for future study and action.

5.2 Conclusions

Major conclusions that are obtained from this study are as follows:

1. The combined total catchment area of all 11 SSDSs of Hatirjheel is about 23.73 km^2. The SSDS-1 and SSDS-10 have the highest catchment areas; 6.1 km^2 and 4.87 km^2, respectively. A map has been prepared showing catchments of individual SSDSs.
2. The main diversion sewer system running along the periphery of Hatirjheel may not be able to accommodate the increased sewage flow in the near future.
3. The water quality of Hatirjheel is poor throughout the year, but is especially poor during the wet season when rainwater-sewage mixture overflows into Hatirjheel through the SSDSs.
4. Water quality of Hatirjheel is particularly poor in near the SSDSs through which rainwater-sewage overflows during the wet season (SSDSs-1, 2, 7, 9). For example, during the wet season of 2014 (June to October 2014), the highest BOD_5 and COD values recorded for water samples collected in front of SSDS-1 were 90 mg/l and 175 mg/l, respectively.

5. Total ammonia nitrogen (TAN) (and free ammonia) concentration in Hatirjheel water increased during the wet season due to entry of rainfall-sewage mixture; ammonia concentration continued to increase after the end of wet season (up to January 2015), most likely due to release of ammonia into water column from the decomposition of organic matter present in overflow water.
6. Ammonia concentration in Hatirjheel water exceeds the USEPA standards for natural water by a huge margin. Ammonia concentration in Hatirjheel water is so high that fish species are unlikely to survive in this environment.
7. The BOD_5 and Ammonia concentration of Hatirjheel water is much higher than the corresponding Bangladesh standards, and Hatirjheel water appears to be unsuitable for any purpose including fisheries, recreational and irrigation.
8. Nitrate concentration in Hatirjheel water increased at the end of wet season, possibly due to oxidation of ammonia to nitrate; subsequent reduction in nitrate concentration is possibly due to incorporation into algal mass.
9. Sulfate and phosphate concentrations in Hatirjheel water were relatively high throughout Hatirjheel throughout the year. Sulfide concentration was relatively higher but reduced significantly during the dry season.
10. Due to increase in wastewater/sewage flow, the overflow of sewage-storm water mixture into Hatirjheel during the wet season will continue to increase in the future; in fact, in the future, overflow of sewage from SSDSs could take place even during the dry period. This is likely to cause significant pollution of Hatirjheel throughout the year.
11. In order to improve water quality of Hatirjheel, the domestic sewer connections to the storm sewer system must be disconnected gradually. In this regard, catchment of SSDS-1 should be given priority. If domestic sewer connections to storm sewer could be disconnected within this catchment, then pollution load discharging into Hatirjheel (though SSDS-1) would be reduced significantly and water quality of Hatirjheel is expected to improve considerably.

5.2 Recommendations

Major recommendations are as follows:

1. Study should be carried out to assess the potential of diverting sewage flows now entering Hatirjheel sewer system to other areas.
2. In this study the estimated values of dry weather flow have been used to check capacity of the SSDSs to accommodate the sewage flow. Actual measurement of the dry weather flow is necessary for more reliable assessment.
3. A model should be developed based on water quality parameters measured in this study to predict the water quality of Hatirjheel in rainy season and for the improvement of water quality of Hatirjheel.

4. In this study only water samples were collected from selected locations of Hatirjheel (i.e., in front of SSDS or bank of the Hatirjheel) and analyzed for important water quality parameters.
5. Water samples may be collected from the middle of Hatirjheel and analyzed for all water quality parameters to predict the water quality of Hatirjheel in rainy season and for the improvement of water quality of Hatirjheel.

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Appendix A

Appendix A(1): Characteristics of Hatirjheel water close to SSDS-1

Parameters	**Unit**	**Concentration**									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	7.21	7.11	7.29	6.93	7.68	7.90	7.84	8.19	7.48	7.09
Conductivity	µS/cm	650	597	738	700	822	816	731	638	487	492
Turbidity	NTU	33.5	50.7	92.1	63.3	33.5	20.0	20.6	18.6	36	48.2
Color	PtCo	315	181	312	273	75	68	145	107	44	228
NO_3^-	mg/l	0.6	0.8	0.7	0.8	0.5	0.6	2.4	4.3	5.0	0.2
NO_2^-	mg/l	0.0080	0.0111	0.0159	0.0172	0.0500	0.0610	0.3780	1.4660	1.1011	0.0213
TAN	mg/l	19.88	14.85	22.6	23.03	25.64	27.54	17.63	8.93	6.48	11.76
NH_3	mg/l	0.16	0.10	0.22	0.10	0.60	1.05	0.59	0.64	0.10	0.07
PO_4^{3-}	mg/l	6.22	5.00	5.94	6.21	8.15	9.29	8.43	5.42	5.88	2.14
SO_4^{2-}	mg/l	21.3	22.1	24.0	37.5	13.6	19.4	30.8	28.0	34.4	19.2
S^{2-}	µg/l	-	60	67	65	7	5	15	11	3	39
Cl^-	mg/l	-	54	66	57	70	73	68	68	52	54
COD	mg/l	175	115	168	163	71	67	61	30	58	88
BOD_5	mg/l	90	33	40	70	18	22	50	26	34	30
TS	mg/l	381	314	409	364	377	448	591	459	377	390
TDS	mg/l	376	302	388	323	359	423	455	432	336	339
TSS	mg/l	5	12	21	41	18	25	186	27	41	51

Appendix A(2): Characteristics of Hatirjheel water close to SSDS-2

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	7.69	7.68	7.42	7.99	8.63	7.76	7.97	7.97	7.74	7.65
Conductivity	µS/cm	558	520	700	569	595	582	637	654	552	482
Turbidity	NTU	50.7	64.8	56.7	107	35.7	17.1	35.9	29.0	60	56.1
Color	PtCo	142	142	273	91	98	129	127	102	61	86
NO_3^-	mg/l	0.5	0.5	0.6	0.6	0.5	0.5	1.3	1.6	5.3	0.2
NO_2^-	mg/l	0.0060	0.0098	0.0125	0.0131	0.1388	0.1456	0.0420	0.0586	0.1794	0.0466
TAN	mg/l	11.30	9.71	19.25	12.13	14.22	13.67	13.65	13.12	5.30	6.24
NH_3	mg/l	0.27	0.23	0.25	0.57	2.50	0.38	0.61	0.59	0.14	0.14
PO_4^{3-}	mg/l	5.58	0.19	6.03	3.72	5.05	7.56	7.27	9.15	9.27	6.02
SO_4^{2-}	mg/l	24.9	9.9	18.7	28.4	16.8	15.4	16.5	19.8	22.6	23.9
S^{2-}	µg/l	-	26	58	16	13	17	16	12	5	11
Cl^-	mg/l	-	46	64	49	52	54	60	62	56	53
COD	mg/l	82	97	129	141	84	59	78	37	61	78
BOD_5	mg/l	48	28	28	44	32	42	58	29	40	30
TS	mg/l	344	308	369	310	337	342	381	460	425	397
TDS	mg/l	310	290	348	282	310	313	336	413	370	335
TSS	mg/l	34	18	21	28	27	29	45	47	55	62

Appendix A(3): Characteristics of Hatirjheel water close to SSDS-3

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	8.29	7.92	7.74	7.50	8.32	7.97	8.15	8.54	7.75	7.79
Conductivity	µS/cm	522	532	612	603	621	591	640	634	569	494
Turbidity	NTU	26.8	48.0	40.2	34	23.7	28.2	27.8	89.6	57	50.4
Color	PtCo	84	67	316	100	154	181	122	104	65	82
NO_3^-	mg/l	0.4	0.5	0.4	0.5	0.6	0.6	1.3	1.4	4.8	0.4
NO_2^-	mg/l	0.0080	0.0093	0.0168	0.0168	0.2295	0.1988	0.2865	0.3592	0.5498	0.1082
TAN	mg/l	8.10	8.84	13.13	17.39	16.96	14.32	15.15	12.57	6.89	6.34
NH_3	mg/l	0.72	0.35	0.35	0.27	1.61	0.64	1.00	1.86	0.19	0.19
PO_4^{3-}	mg/l	1.68	1.58	2.74	4.35	5.22	7.65	7.47	7.96	8.81	6.94
SO_4^{2-}	mg/l	30.0	20.7	29.0	32.6	18.1	10.1	14.5	18.6	23.9	23.5
S^{2-}	µg/l	-	14	53	13	19	17	15	11	6	10
Cl^-	mg/l	-	46	56	50	50	52	60	64	56	53
COD	mg/l	70	77	99	62	69	85	91	80	69	76
BOD_5	mg/l	18	14	8	16	24	60	46	58	44	22
TS	mg/l	329	300	348	290	332	359	404	480	444	389
TDS	mg/l	315	284	313	278	308	340	377	412	386	340
TSS	mg/l	14	16	35	12	24	19	27	68	58	49

Appendix A(4): Characteristics of Hatirjheel water close to SSDS-4

Parameters	Unit	Concentration									
		29/06/14	09/08/14	07/09/14	18/10/14	06/12/14	17/01/15	28/02/15	28/03/15	25/04/15	30/05/15
pH	-	-	8.20	7.87	7.71	8.14	7.86	8.15	8.40	7.66	7.81
Conductivity	µS/cm	-	507	581	570	631	625	649	645	589	501
Turbidity	NTU	-	61.9	40.0	39	21.7	23.8	30.1	80.9	66	58.2
Color	PtCo	-	61	225	107	172	179	128	112	69	102
NO_3^-	mg/l	-	0.7	0.4	0.5	0.6	0.5	1.5	1.5	4.6	0.3
NO_2^-	mg/l	-	0.1218	0.0086	0.0111	0.0955	0.0215	0.3870	0.3332	0.5398	0.1037
NH_3	mg/l	-	0.69	0.39	0.40	1.10	0.61	0.99	1.47	0.20	0.24
TAN	mg/l	-	9.39	10.87	15.78	17.07	17.51	14.93	13.19	8.98	7.78
PO_4^{3-}	mg/l	-	2.80	0.81	4.38	6.02	6.65	6.85	8.21	8.46	7.56
SO_4^{2-}	mg/l	-	20.6	32.8	36.5	17.3	17.7	18.6	19.2	27.1	21.3
S^{2-}	µg/l	-	9	36	15	20	18	14	12	6	11
Cl^-	mg/l	-	43	50	43	49	48	62	61	54	50
COD	mg/l	-	83	92	63	70	82	98	41	98	73
BOD_5	mg/l	-	20	13	21	18	42	50	36	66	26
TS	mg/l	-	298	333	275	338	375	388	478	491	413
TDS	mg/l	-	288	308	239	324	358	371	409	419	366
TSS	mg/l	-	10	25	36	14	17	17	69	72	47

Appendix A(5): Characteristics of Hatirjheel water close to SSDS-5

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	7.94	8.00	7.77	7.65	8.16	7.89	8.13	8.61	7.92	7.59
Conductivity	µS/cm	506	513	558	539	629	634	663	640	520	512
Turbidity	NTU	30.7	48.5	48.5	34	21.1	40.0	34.5	99.2	60	51.4
Color	PtCo	84	67	218	120	203	219	164	101	77	119
NO_3^-	mg/l	0.4	0.8	0.5	0.6	0.5	0.6	0.9	1.2	4.9	0.3
NO_2^-	mg/l	0.0090	0.0115	0.0099	0.0129	0.0267	0.0281	0.1585	0.1818	0.7930	0.0385
TAN	mg/l	10.15	9.26	10.67	14.66	17.26	19.34	17.44	13.43	11.07	10.98
NH_3	mg/l	0.42	0.44	0.31	0.32	1.17	0.72	1.10	2.28	0.44	0.21
PO_4^{3-}	mg/l	1.16	3.50	0.68	3.89	4.70	6.06	8.41	8.96	7.16	6.32
SO_4^{2-}	mg/l	28.8	21.0	27.1	33.6	16.2	17.0	29.4	18.7	26.5	18.3
S^{2-}	µg/l	-	13	38	19	22	19	18	10	8	13
Cl^-	mg/l	-	43	46	42	48	60	58	65	46	48
COD	mg/l	53	61	90	60	83	106	96	88	64	81
BOD_5	mg/l	18	11	10	19	22	42	40	54	34	32
TS	mg/l	299	300	360	276	346	393	419	486	415	412
TDS	mg/l	279	292	314	264	338	365	391	409	351	359
TSS	mg/l	20	8	46	12	8	28	28	77	64	53

Appendix A(6): Characteristics of Hatirjheel water close to SSDS-7

Parameters	Unit	Concentration									
		29/06/14	09/08/14	07/09/14	18/10/14	06/12/14	17/01/15	28/02/15	28/03/15	25/04/15	30/05/15
pH	-	-	7.92	7.70	7.39	8.50	7.83	7.84	8.24	7.70	7.44
Conductivity	µS/cm	-	530	635	602	600	578	649	656	575	503
Turbidity	NTU	-	109.0	52.6	51	25.3	16.2	25.1	36.4	69	56.2
Color	PtCo	-	110	270	89	105	158	131	95	62	90
NO_3^-	mg/l	-	0.5	0.5	0.5	0.4	0.5	1.5	1.6	5.1	0.3
NO_2^-	mg/l	-	0.0152	0.0119	0.0138	0.0566	0.0229	0.4355	0.0866	0.5348	0.0763
TAN	mg/l	-	9.66	13.64	14.86	14.68	13.69	15.35	12.60	5.82	6.45
NH_3	mg/l	-	0.39	0.33	0.18	2.01	0.45	0.51	1.01	0.14	0.09
PO_4^{3-}	mg/l	-	0.29	0.90	6.35	7.25	7.41	8.36	7.88	9.53	6.31
SO_4^{2-}	mg/l	-	24.1	26.6	29.9	21.4	17.1	17.6	18.8	25.9	21.5
S^{2-}	µg/l	-	22	49	16	14	15	17	10	5	9
Cl^-	mg/l	-	47	58	51	51	54	62	61	59	52
COD	mg/l	-	108	111	65	75	64	94	38	69	78
BOD_5	mg/l	-	23	11	21	22	54	44	34	38	24
TS	mg/l	-	365	346	289	329	366	382	429	474	439
TDS	mg/l	-	309	333	257	313	319	331	399	392	368
TSS	mg/l	-	56	13	32	16	47	51	30	82	71

Appendix A(7): Characteristics of Hatirjheel water close to SSDS-8

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	-	8.45	7.87	7.54	8.19	7.76	7.95	8.39	7.70	7.49
Conductivity	µS/cm	-	515	605	594	624	598	653	648	586	511
Turbidity	NTU	-	76.1	45.7	32	19.6	17.1	26.8	69.1	79	47.3
Color	PtCo	-	67	268	96	162	158	133	103	70	98
NO_3^-	mg/l	-	0.6	0.6	0.7	0.5	0.5	1.2	1.4	5.2	0.3
NO_2^-	mg/l	-	0.0609	0.0157	0.0169	0.0550	0.0219	0.2635	0.3142	0.8675	0.0694
TAN	mg/l	-	8.03	12.29	14.67	15.89	15.56	15.99	13.12	7.52	7.60
NH_3	mg/l	-	0.99	0.44	0.25	1.14	0.44	0.68	1.44	0.18	0.12
PO_4^{3-}	mg/l	-	1.83	0.92	4.75	4.59	8.45	7.22	8.52	5.74	6.73
SO_4^{2-}	mg/l	-	22.8	30.0	33.2	12.8	16.7	19.7	17.8	19.4	20.5
S^{2-}	µg/l	-	12	46	14	19	16	22	11	7	11
Cl^-	mg/l	-	47	55	50	50	53	58	62	56	52
COD	mg/l	-	88	112	60	69	65	76	62	85	82
BOD_5	mg/l	-	20	10	19	26	56	38	37	50	40
TS	mg/l	-	388	344	296	324	353	365	467	477	410
TDS	mg/l	-	289	334	263	313	331	329	405	388	374
TSS	mg/l	-	49	10	33	11	22	36	62	89	36

Appendix A(8): Characteristics of Hatirjheel water close to SSDS-9

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	8.62	8.21	7.97	7.44	8.30	7.75	7.82	8.33	7.82	7.64
Conductivity	µS/cm	499	507	586	580	627	619	678	657	593	513
Turbidity	NTU	47.6	87.5	44.0	37	22.5	24.1	28.6	63.3	91	60.1
Color	PtCo	80	66	262	102	164	199	132	110	88	102
NO_3^-	mg/l	0.8	1.3	0.5	0.5	0.5	0.6	1.3	1.5	4.5	0.2
NO_2^-	mg/l	0.1340	0.3087	0.0096	0.0108	0.0247	0.0201	0.2185	0.3772	0.3726	0.0712
TAN	mg/l	8.05	7.98	10.93	14.78	17.14	17.29	17.12	13.65	11.17	8.78
NH_3	mg/l	1.39	0.60	0.49	0.20	1.56	0.47	0.55	1.32	0.36	0.19
PO_4^{3-}	mg/l	2.87	0.40	2.63	5.48	6.47	7.21	7.77	8.97	8.67	7.54
SO_4^{2-}	mg/l	25.4	20.3	31.9	38.1	17.6	15.0	18.3	19.0	21.8	16.2
S^{2-}	µg/l	-	13	43	14	18	20	16	12	10	11
Cl^-	mg/l	-	44	52	46	49	52	59	62	58	48
COD	mg/l	105	98	123	57	90	79	88	59	87	79
BOD_5	mg/l	35	18	11	16	32	48	42	36	52	38
TS	mg/l	335	356	333	280	353	377	389	475	533	446
TDS	mg/l	283	287	319	248	332	351	345	406	427	364
TSS	mg/l	52	69	14	32	21	26	44	69	106	82

Appendix A(9): Characteristics of Hatirjheel water close to SSDS-10

Parameters	Unit	Concentration									
		29/06/14	**09/08/14**	**07/09/14**	**18/10/14**	**06/12/14**	**17/01/15**	**28/02/15**	**28/03/15**	**25/04/15**	**30/05/15**
pH	-	-	8.02	7.84	7.34	7.92	7.51	7.73	8.52	7.37	7.50
Conductivity	µS/cm	-	504	535	572	655	680	705	651	666	524
Turbidity	NTU	-	97.8	35.6	45	24.2	77.4	41.4	126.0	71	70.8
Color	PtCo	-	82	263	155	239	392	169	116	189	153
NO_3^-	mg/l	-	1.1	0.7	0.6	0.6	0.7	1.0	1.5	1.7	0.4
NO_2^-	mg/l	-	0.2495	0.0098	0.0123	0.0414	0.0262	0.4370	0.3582	0.1740	0.0320
TAN	mg/l	-	9.55	11.41	16.25	18.01	21.90	18.42	12.45	20.73	12.36
NH_3	mg/l	-	0.48	0.38	0.18	0.72	0.35	0.48	1.77	0.24	0.19
PO_4^{3-}	mg/l	-	2.47	0.99	5.68	9.87	6.53	7.50	9.27	8.58	5.93
SO_4^{2-}	mg/l	-	21.1	25.5	29.6	20.1	20.5	23.8	19.5	20.7	14.1
S^{2-}	µg/l	-	11	44	19	28	30	22	14	29	16
Cl^-	mg/l	-	41	44	43	52	59	65	62	58	48
COD	mg/l	-	111	88	77	79	130	96	88	78	126
BOD_5	mg/l	-	28	10	27	22	55	50	60	48	40
TS	mg/l	-	383	301	273	379	438	465	555	540	454
TDS	mg/l	-	273	281	263	354	408	432	453	452	375
TSS	mg/l	-	110	20	10	25	30	33	102	88	79

Appendix A(10): Characteristics of Banani Lake water

Parameters	Unit	Concentration									
		29/06/14	09/08/14	07/09/14	18/10/14	06/12/14	17/01/15	28/02/15	28/03/15	25/04/15	30/05/15
pH	-	-	-	-	7.36	7.49	7.45	7.09	7.54	7.41	7.21
Conductivity	µS/cm	-	-	-	577	789	711	830	802	705	559
Turbidity	NTU	-	-	-	37	55.0	95.0	68.0	51.0	82	48.1
Color	PtCo	-	-	-	172	412	275	388	202	281	197
NO_3^-	mg/l	-	-	-	0.5	0.5	0.6	0.5	1.1	1.2	0.6
NO_2^-	mg/l	-	-	-	0.0112	0.0436	0.0186	0.0580	0.0510	0.0083	0.0841
TAN	mg/l	-	-	-	17.15	28.20	23.13	27.45	23.47	23.53	15.81
NH_3	mg/l	-	-	-	0.19	0.43	0.32	0.17	0.40	0.30	0.13
PO_4^{3-}	mg/l	-	-	-	5.82	4.62	7.10	6.74	8.30	12.22	6.34
SO_4^{2-}	mg/l	-	-	-	21.7	17.3	17.6	19.9	26.4	21.3	10.5
S^{2-}	µg/l	-	-	-	24	46	22	21	29	34	25
Cl^-	mg/l	-	-	-	40	60	62	47	72	63	49
COD	mg/l	-	-	-	98	103	172	122	61	156	97
BOD_5	mg/l	-	-	-	26	35	78	84	34	64	50
TS	mg/l	-	-	-	290	405	465	501	521	538	426
TDS	mg/l	-	-	-	273	391	410	422	476	462	389
TSS	mg/l	-	-	-	17	14	55	79	45	76	37

Appendix A(11): Characteristics of Gulshan Lake water

Parameters	Unit	Concentration									
		29/06/14	09/08/14	07/09/14	18/10/14	06/12/14	17/01/15	28/02/15	28/03/15	25/04/15	30/05/15
pH	-	-	-	-	7.52	7.86	7.77	7.69	7.42	7.56	7.39
Conductivity	µS/cm	-	-	-	459	558	560	609	611	576	513
Turbidity	NTU	-	-	-	23	22.1	39.1	20.7	32.7	68	41.1
Color	PtCo	-	-	-	115	252	282	177	188	142	158
NO_3^-	mg/l	-	-	-	0.6	0.4	0.5	0.4	1.0	1.5	0.4
NO_2^-	mg/l	-	-	-	0.0153	0.0452	0.0199	0.0335	0.2918	0.3798	0.0290
TAN	mg/l	-	-	-	22.90	16.19	16.74	17.42	15.25	21.51	12.23
NH_3	mg/l	-	-	-	0.37	0.57	0.48	0.42	0.20	0.38	0.15
PO_4^{3-}	mg/l	-	-	-	3.29	3.83	10.08	6.66	9.61	10.19	9.39
SO_4^{2-}	mg/l	-	-	-	19.3	6.9	12.5	10.3	16.5	13.7	11.6
S^{2-}	µg/l	-	-	-	18	32	31	29	23	15	20
Cl^-	mg/l	-	-	-	31	38	45	75	50	45	43
COD	mg/l	-	-	-	32	79	108	88	31	73	81
BOD_5	mg/l	-	-	-	11	22	32	38	26	32	20
TS	mg/l	-	-	-	229	303	376	412	424	463	404
TDS	mg/l	-	-	-	218	297	326	368	386	395	361
TSS	mg/l	-	-	-	11	6	50	44	38	68	43