APPLICATION OF CONSTRUCTED FLOATING WETLAND (CFW) IN TREATING URBAN WASTE WATER: A CASE STUDY ON HATIRJHEEL LAKE

S M ANWAR HOSSAIN

A THESIS SUBMITTED FOR THE DEGREE OF

Master of Science in Civil Engineering

DEPARTMENT OF CIVIL ENGINEERING

MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY

2020

DECLARATION

I hereby declare that this thesis is my original work and it has been written by me in its entirety. I have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

Name: S M Anwar Hossain

20 November 2020

CERTIFICATE OF APPROVAL

The thesis titled "APPLICATION OF CONSTRUCTED FLOATING WETLAND (CFW) FOR TREATING URBAN WASTE WATER: A CASE STUDY ON HATIRJHEEL LAKE" submitted by S M Anwar Hossain, Roll No: 1014110003 is accepted as satisfactory in partial fulfillment for the degree of MSc in Civil Engineering.

BOARD OF EXAMINERS

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Professor
Department of Civil Engineering
Military Institute of Science and Technology (MIST)

Chairman
(Supervisor)

2. ....
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Head
Department of Civil Engineering
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Professor
Department of Civil Engineering
Bangladesh University of Engineering and Technology (BUET)

Member
(External)

ACKNOWLEDGEMENT

At the very outset, I express my deepest gratitude and sincere appreciation to the Almighty Allah for helping me to overcome all the obstacles and difficulties that I faced during the whole research work and for bringing this thesis into its completion.

I would first like to thank my thesis supervisor Prof Dr. Md. Tauhid Ur Rahman of the Civil Engineering Department, Military Institute of Science and Technology (MIST), for his constant guidance, valuable suggestions and advice during the entire duration of this research work.

My special thanks to the Hatirjheel Project Authority specially the Project Director Major General Sayeed Masud (Retd) and the Project Officers Major Shakil, Major Sadeque, Maj Faruk, Major Ashique and other support staffs for their relentless support behind this noble endeavour.

I am thankful to Engineer Tariquzzaman for his continuous support in setting up the experiment, guiding and monitoring the progress.

I would also like to thank the lab technician Mr Abul Kalam Azad of the Dept. of Civil Engineering, (MIST) for his significant support in doing the experiments.

Finally, I must express my very profound gratitude to my parents and to my family for providing me with untiring support and continuous encouragement throughout my years of study and through the process of research and writing this thesis. This accomplishment would not have been possible without them.

Dhaka — Thankfully

November 2020 — S M Anwar Hossain

DEDICATED TO ALL THE ENVIRONMENTALISTS

ABSTRACT

Integrated Development of Hatirjheel Area Including Begunbari Khal project was undertaken with a view to connect the eastern and western part of Dhaka City. During wet season number of storm sewers are carrying domestic sewage and industrial wastewater into the lake. Although the implementation of the project has brought about a significant change in the overall environment of Dhaka City, but the water quality of the lake and sludge deposition specially behind Hotel Sonargaon still remains as a serious concern.

Constructed Floating Wetland (FCW), a low-cost green treatment technology is a viable option to enhance the pollutant removal abilities of various water bodies. The system purifies water through the microorganism living in the plant roots of CFW. Bacteria colony grows up within nodule or root which helps to reduce the water pollution.

A primary research on removal ability of CFW for Hatirjheel Lake water was done with the two-fold objectives: (1) To evaluate the removal of pollutants including nutrients from the polluted surface water of Hatirjheel Lake through the application of CFW system and (2) To investigate the influence of seasonal variation on the removal process of pollutants. To conduct the research total eight plastic water containers of dimension 6'x3'x4' were used for the experimental set up behind Hotel Sonargaon. Two locally available plants like *Cana Indica* (Kolabati) and *Phragmites Australis* (Nol Ghas) were used and one-month time was given for plants to grow. Afterwards matching with the inlet and outlet flow pattern of Hatirjheel Lake, experimental containers were fed with 200 liters of daily dosing. Then water samples were taken from the container once in a week and were sent to MIST Lab for getting results on several water quality parameters like BOD_5, COD, DO, Nitrate, Ammonium, Orthophosphate, Colour, TDS and TSS. A total of eleven-week (20 October to 21 January 2018) data were collected during dry season and six-week (14 August to 20 September 2018) data during wet season. A blank/reference sample was taken to compare the water quality variation with time. The performance of the plants was evaluated in terms of removing nutrients, contaminants and heavy metals from the lake water. The removal ability during dry season was found much better than wet season. Removal capability of the system were found quite high for some parameters like (COD 82%, Color 83%, TSS 85%, Orthophosphate 78%, Ammonium 80% and BOD_5 55%) and moderate performance for other parameters like TDS 50%, Nitrate 62%, DO 32%. The experiment showed great potentials in terms of removing heavy metals like As, Cd, Cr, and Pb. As a whole the system was found to be effective as an environment friendly and low-cost technology for enhancing the water quality of Hatirjheel Lake and this approach can be applied in other lakes and waterbodies in Dhaka City.

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LIST OF ABBREVIATIONS

DWASA: Dhaka Water Supply and Sewerage Authority

BUET: Bangladesh University of Engineering and Technology

ECB : Engineer Construction Battalion

RAJUK: Rajdhani Unnayan Kartripakkha

BTV: Bangladesh Television

LGED: Local Government Engineering Department

USEPA: United States Environment Protection Authority

COD: Chemical Oxygen Demand

BOD_5: Biological Oxygen Demand

BRTC: Bangladesh Road Transport Corporation

DMA: Dhaka Metropolitan Area

SDS: Storm Diversion System

SSDS: Special Sewerage Diversion Structure

CFW: Constructed Floating Wetlands

TSS: Total Suspended Solids

JICA: Japan International Cooperation Agency

BGMEA: Bangladesh Garments Manufacturer and Exporters Association

O&M: Operation and Maintenance

DO: Dissolved Oxygen

ASTM: American Society for Testing and Materials

TDS: Total Dissolved Solids

ECB: Engineer Construction Battalion

TP: Total Phosphorus

CHAPTER 01 : INTRODUCTION

CHAPTER 01

INTRODUCTION

1.1 Background of the Study

Dhaka, with an estimated population of over 16 million, is the largest city in Bangladesh and the 8th largest city in the world. Rapid population growth together with unplanned urban development and industrial activities within the city has put tremendous pressure on its environment. Dhaka is surrounded by five rivers Buriganga, Turag, Sitalakhya, Balu, and Tongi khal. Besides these a large number of khals (canals) and lakes crisscrossing the city, which were hydraulically connected to the surrounding rivers. The khals and lakes within the city serve the very important hydraulic function of retaining and draining storm water during the rainy season. However, due to encroachment and filling up by vested quarters, many of the khals have completely disappeared, while others are under severe threat. This practice has given rise to significant water logging and drainage congestion within the city. More importantly poor storm water and wastewater management has severely polluted the water bodies both within and surrounding the city. Sewerage system covers only a small part (less than 20%) of Dhaka city, and there is only one municipal sewage treatment plant for the entire city. With increase in population density, the onsite sanitation system (primarily septic tank system, which relies on infiltration capacity of soil) also does not perform well, especially during the wet season. As a result, over the years, direct disposal of domestic (as well as non-residential) wastewater into storm water drainage network and open khals/canals/drains has become a common practice. Thus, the storm sewers and drains carry domestic/ non-residential sewage throughout the year, and mixture of sewage and storm water during the rainy season. The storm sewer networks in Dhaka are designed to discharge into khals and lakes within the city, from where the storm water drains into the surrounding rivers either by gravity (on the eastern side of the city) or by pumping (western side of the city). As a result, the khals and lakes within the city and the rivers surrounding it are continuously being polluted by sewage [1]. Hatirjheel Lake one of the main retention basins for Dhaka City is not different from them.

Hatirjheel is one of the major lakes in Dhaka city and approximately one third of the rainwater of Dhaka flows through this lake. Unlike the stagnant lakes of the metropolis, it was designed to channel out the rainwater of the capital. However, human waste and industrial waste are running into the water body through a total number of ten drains. The wastes from the nearby areas of Hatirjheel are severely polluting the water shrouding the leisure spots with malodor. Dhaka WASA which is responsible for human waste management, was supposed to build sewerage lines for the lake adjacent areas. As long as the wastes are being dumped into the lake, the environment would not be visitor-friendly, said BUET teacher Prof Mujibur Rahman. Currently a sewerage line is being constructed behind Hotel Pan Pacific Sonargaon-one of the points among the ten. However, there was no initiative for nine other points- Moghbazar-Tongi diversion road, Rampura, Badda, Tejgaon, Modhubagh, Begunbari, Niketon and two spots of Mohakhali. Wastes along with rainwater are being channeled into Hatirjheel through these points [2].

Figure 1.1: Untreated Discharge Being Released in Hatirjheel Lake

(Source- Photo Taken at Hatirjheel Lake)

1.2 Rationale of the Study

Building the entire Hatirjheel required 19.71 billion (19,710 million) taka and an area of 302 acres. From this, 10.48 billion (10,480 million) taka was spent in acquiring the site itself and 46% of the area belongs to RAJUK, which includes an area of 81 acres for a "court of walks", 141 acres for public lands and 1 acre for BTV. The construction began on December 2008, which took a further half year of time for expanding it. The total money in creating the project included the money of RAJUK (1,113.7 billion taka), LGED (2,760 million) and WASA (866.95 million). It has an area of 311.79 acres while some 8.80-kilometer service road and some 8.80-kilometer expressway have been constructed under the project. The entire area of Hatirjheel is designed with about four main and four minor bridges (viaducts), several overpasses (flyovers), footbridges (over bridges), 8.80 kilometers of footpaths, 9.80 kilometers walkway, one children park, and 13 viewing decks and there are sitting arrangements for pedestrians by the riverside. A lake flows through the heart of the project with a 16 km road surrounding it. During the dry season, the Hatirjheel lake can hold approximately 3.06 billion liters of water, and during the rainy season about 4.81 billion liters of water, making it the largest water body inside the capital of Bangladesh [3].

But due to odorous lake water, it is losing its charm day by day. Now a days, recreational facilities are decreasing in Dhaka city. Hatirjheel being one of the most attractive places in Dhaka city draws thousands of visitors daily who come to observe its natural beauty. This lake is also planned for the reservoir and drainage of rainwater. But due to pollution, the planning failed and every year thousand tons of sludge are accumulated in the bed of Hatirjheel Lake. Although the implementation of the project has brought about a significant change in the overall environment of Dhaka City, but the water quality of the lake and sludge deposition especially behind Hotel Sonargaon still remains as a serious concern to the project implementation authority.

1.3 Problem Statement

The low-lying areas behind Sonargaon Hotel and those of Hatirjheel Lake, starting from the eastern side of the Tongi-Diversion Road and end to the Rampura Bridge. It is playing a very important role for draining and detaining storm water and sewage water (due to overflow of drainage and uncontrolled flow) from an area about 30 km^2 of Dhaka City, especially when the Rampura regulator is kept closed for two to three months during the rainy season to prevent intrusion of river water back into the city [3]. Several major storm sewers discharge into the Hatirjheel lowland. During dry season, these storm sewers carry domestic sewage and industrial wastewater. During wet season, the storm sewers carry mixture of storm water and wastewater. A detailed survey has identified a total of 9 major outfalls discharging domestic and industrial wastewater into the Hatirjheel Lake [4]. These drains and sewers carry storm water during the rainy season. Results of analysis of wastewater samples discharging into Hatirjheel Lake show that, as expected, their composition is like domestic sewage. The very high COD values of wastewater samples from several outfalls, along with low BOD_5/COD ratio, are indicative of inputs from industrial sources. Thus, the wastewater discharging into Hatirjheel Lake is polluting the natures severely. Implementation of the Integrated Hatirjheel Lake including Begunbari Khal project has brought about a significant change in the overall environment including traffic system management of Dhaka City [5]. But the water quality of the lake remains to be a serious concern.

Figure 1.2: Wastewater Entering Hatirjheel Lake (Sonargaon Point)

(Source-Photo Taken at Sonargaon Point)

The scenic beauty of Hatirjheel lake is losing the charm as solid waste and smelly garbage are floating in the Lake. Since the opening in 2013, Hatirjheel Lake is drawing a large number of visitors and became one of the most popular recreational spots for the city dwellers, especially during the weekend and festivals. But polluted water in Hatirjheel Lake is spreading bad smell, polluting the air and causing inconvenience for the visitors. Communities and pedestrians visiting Hatirjheel Lake and the residents living around the project area are deeply frustrated as the water of Hatirjheel Lake is constantly spreading stench. Visitors and pedestrians have to put handkerchiefs and need to wear pollution masks on their nose to get rid of the smell. Hatirjheel Lake is being polluted as household waste and other garbage from different areas have mixed with the lake water through the drains. Besides, solid wastes enter the Hatirjheel Lake with rainwater through the drains [6].

Though Bangladesh Government has taken many initiatives till now, but the problem of water quality is not improving. Every year Hatirjheel project authority spent a huge amount of money to remove the sludge from lakebed. To ameliorate the prevailing situation some nature based sustainable solution for Hatirjheel Lake water is very much needed and Constructed Floating Wetland (CFW) can be a viable nature-based solution for this purpose. At the same time, it will help the integrated development of Hatirjheel Lake and clean the polluted water [7].

1.4 Objectives of the Study

The objectives of the study are two-folds:

a. To evaluate the removal of pollutants including nutrients from the polluted surface water of Hatirjheel Lake through the application of CFW system.

b. To investigate the influence of seasonal variation on the removal process of pollutants.

1.5 Thesis Structure

The structure of the project report is briefly described below:

Chapter 1: Background, objectives and importance of study.

Chapter 2: Literature review on relevant studies.

Chapter 3: Methodology including study area and methodological approach.

Chapter 4: Experimental Results.

Chapter 5: Discussions.

Chapter 6: Conclusion and Recommendations.

CHAPTER 02: LITERATURE REVIEW

CHAPTER : 02

LITERATURE REVIEW

2.1 Introduction

There are many studies conducted on drainage capacity, flow, velocity detention capacity etc. of Hatirjheel Lake. Most of the studies are based on the basic parameter of Hatirjheel Lake and future forecast of flow and related parameters. Among them, Bureau of Research, Testing and Consultation (BRTC) of BUET conducted a preliminary study from 2004-2005 to assess the development potential of Hatirjheel Lake. That project was funded by RAJUK. The study shows the existing drainage condition of Hatirjheel Lake and its critical condition. This study highlighted the importance of Hatirjheel Lake as detention and conveyance of accumulated storm runoff generated from the surrounding catchment area which is more than 30 sq. km. It also recommended that low laying area behind Sonargaon to Rampura Bridge must be preserved as detention pond of storm water of surrounding area and municipal wastewater drainage should be separated. To address the local traffic demand, the study also recommended that at-grade road-cum-embarkment could also be constructed through land acquisition and keeping the required width for drainage channel and storm runoff retention area undisturbed. Based on the recommendations of the earlier 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. Based on this, an integrated project to develop the Hatirjheel area including the Begun Bari khal started in year 2007. Land acquisition and illegal establishment removal took another two years and finally in year 2009 the physical work of the project started. The main objectives of that project were:

(i) Suggest development of Hatirjheel as rainwater retention lake to prevent flood, flush flood of Dhaka providing proper development plan, drainage plan as other essential planning of Hatirjheel Begunbari khal.

(ii) Planning and designing of sewer line and evacuate the illegal structure, stopping the illegal connection etc.

(iii) Planning integrated development of this area with preserving lake and constructing roads for traffic congestion at the same time.

2.2 Drainage System of Dhaka

Dhaka is highly prone to water-related hazards such as urban and river flooding, owing to its location, topography, climate, and proximity to rivers. It experiences major floods regularly, as in

1954, 1955, 1962, 1966, 1974, 1987, 1988, 1998, 2004, and 2009. Situated in the lower reaches of the Ganga delta, the Dhaka Metropolitan Area (DMA) is surrounded by rivers and tributaries: the Buriganga to the south, Turag to the west, Tongi Khal to the north, and the Balu - Shitalakhya to the east. The city is low lying, with an elevation that varies from 0.8 to 14 meters above mean sea level and is drained by numerous natural waterways and canals [8].

Dhaka is also among the most climate-vulnerable megacities in the world. Climate variability and change are expected to intensify the city's exposure to environmental risk and heighten the extent and duration of urban flooding and inundation. With rapid and unplanned urbanization, the vulnerability of the city, and particularly of its poorest residents is likely to increase unless measures to ensure resilience are put in place. During the 1998 floods, most of eastern Dhaka and some parts of western Dhaka were inundated for almost 65 days. The impact of flooding is widespread: it compromises the sewerage system, degrades drinking water, disrupts traffic, and increases the incidence of water-borne diseases. While city-level cost estimates of the damage from extreme floods are scarce, one study estimates the damage from the 1998 floods at approximately $171 million. At present, Dhaka is at a crossroads of development. The main planning agency, Rajdhani Unnayan Kartripakkha (Capital Development Authority, RAJUK) is drafting a Structure Plan (2016–35) for the next 20 years. The design and implementation of this plan will shape infrastructure development and the pattern of urbanization in the city for decades to come. The emerging plans and their implementation will also affect management of the city's water and ecological resources, influx of rural migrants into the city, supply of jobs and affordable housing, and adaptation to climate risks[8].

2.3 Contribution of Hatirjheel Lake in Water Drainage

Dhaka city is bounded by three rivers, the Buriganga in the South-West, the Turag River in the West and the North and the Balu River in the East. During rainy season the periphery of the city is inundated by backwater flow from these surrounding rivers and the storm water causes drainage congestion in the center of the city. In addition to surrounded rivers, the city has a number of medium and small khals. Begunbari Khal (also known as Rampura Khal or Banasree Khal) is one of the major drainages khals amongst these that carries storm runoff to the Balu River from catchments in eastern and central Dhaka. Three tributary khals, Shutibhola and Gojaria khals from the north and Nasirabad - Nandipara khal from the south, discharge runoff into this khal. Hatirjheel, which is now the largest surface water body within Dhaka, also plays an important role in the inflow of Begunbari Khal. It serves very important hydrologic functions of draining and detaining storm water from a large area of Dhaka city. Although designed to carry storm water, the storm sewers discharging into

Hatirjheel carry both storm water and dry weather flow. Hence, Hatirjheel -Begunbari Khal system is the largest and most important drainage system of Dhaka city. Precipitation intensity and pattern are expected to be altered under a climate change regime [9]. An increase of 4.26% was observed in the percent difference between the total annual precipitation (average of 34 meteorological station-data) of the past 20 years (1953-1972) and the recent 20 years on record (1985-2004) which represents that the annual rainfall follows an increasing trend[10]. The IPCC[11] Special Report on the Regional Impacts of Climate Change indicates that there would be drastic changes in the rainfall patterns in the warmer climate and Bangladesh may experience 5-6% increase of rainfall by 2030, which may create frequent massive and prolonged floods. Moreover, it is found that 34% area of 13 natural canals has been filled up by developers, private individuals and others. Between 1989 and 2007, area of wetland was reduced from 22.15% to 12.17% in the west Dhaka [12]. Thus, the wetlands are decreasing and on the contrary population is expanding at a rate of almost 0.8 million per year, which makes the drainage system of Dhaka City vulnerable [9].

Hatirjheel - Begunbari Lake is a large water reservoir situated at the heart of Dhaka city stretching from Panthapath to Rampura serves very important hydrological functions such as draining, detaining of storm water from a large area. These functions are particularly critical during monsoon. During dry season, storm water and illegally discharged wastewater drain through the storm diversion system (SDS) located along the bank line of the lake. The maximum storage capacity of the reservoir is estimated as 1.7 million m^3 for storm event of 1-5 hour. However, the physical capacity of the reservoir is 37.1 million m^3 indicating that the reservoir has the vast capacity to accommodate more storm runoff from adjoining areas [13]. Considering physical characteristics, topography, catchment area and the routes of existing drainage channels, the entire Dhaka city has been divided into three drainage divisions. This study includes parts of drainage divisions 1 and 3 as this study aims at assessing the capacity of Hatirjheel-Begunbari Khal drainage system and its catchments cover zones of the central Dhaka and eastern Dhaka. Begunbari Khal carries storm runoff to the Balu River from Hatirjheel and eastern side of Progati Sarani. Three tributary Khals, Shutibhola and Gojaria Khals from the north and Nasirabad-Nandipara Khal from the south, discharge runoff into this Khal. Moreover, storm water and sewage water from main diversion sewer lines of Hatirjheel are also discharged into this khal. Storm water from the eastern part of Dhanmondi Lake, Kalabagan, Panthopath, Kathalbagan, Nilkhet, Bangla Motor, Kawran Bazar, Tejturipara, Shangshad Bhaban, Katabon, Farm Gate, Raja Bazar, Manipuri Para areas discharge into Hatirjheel through SSDS-1. New Eskaton, Baily Road and apart of Moghbazar 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 Progati Sarani is discharged into SSDS-11 [14].

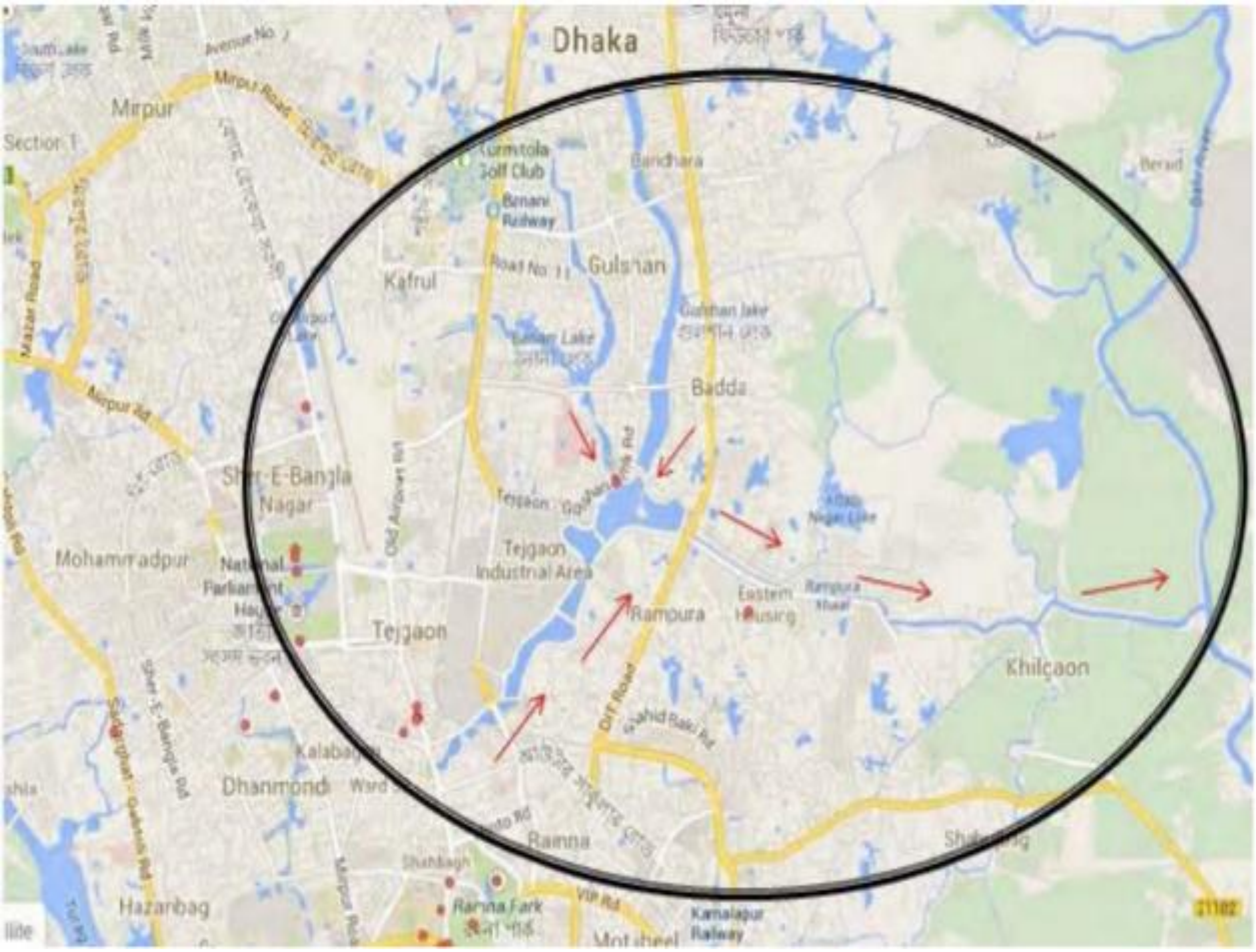


Figure 2.1: Hatirjheel Begunbari Khal Drainage System

As in the eastern catchment of Begunbari Khal (i.e. eastern side of Progoti Sarani), water flow is mainly governed by topography, so the use of DEM to delineate the watershed in the eastern part is logical. But in the western catchment of Begunbari storm water flow is not predominantly governed by topography due to previously established storm sewer network. Storm water are compelled to pass through the roadside storm sewer network. So, in case watershed boundary of western side, both the existing storm sewer network and topography were considered. Firstly, the DEM was clipped along the boundary of Dhaka city. After that the existing storm sewer network of Dhaka City was digitized along with their flow direction to develop a shape file representing the storm drain network of the area based on Drainage System map of Dhaka City. Then this storm sewer network and the stream network were overlaid upon the DEM.

Catchment area, catchment basin, drainage area or drainage basin is the area of land bounded by watersheds draining into a river, basin, or reservoir. Thus, the entire geographical area drained by a watercourse and its tributaries or an area characterized by all runoff being conveyed to the same outlet is called catchment area. In this study several small catchments were found as a result of catchment delineation. These s mall catchments were then grouped into seven major catchments for the convenient of further analysis. Area of each catchment were then determined with help of GIS. The table shows that Hatirjheel and Nasirabad-Nandipara consist of larger catchments (19 km² and 22 km² respectively) compared to others. The relative proportion of each catchment is shown in Figure. From the figure the total catchment of Nasirabad-Nandipara, Gozaria and Sutivolakhals are fund to be 59% depicting that Begunbari khal has a large catchment in eastern side in addition to western side [15].

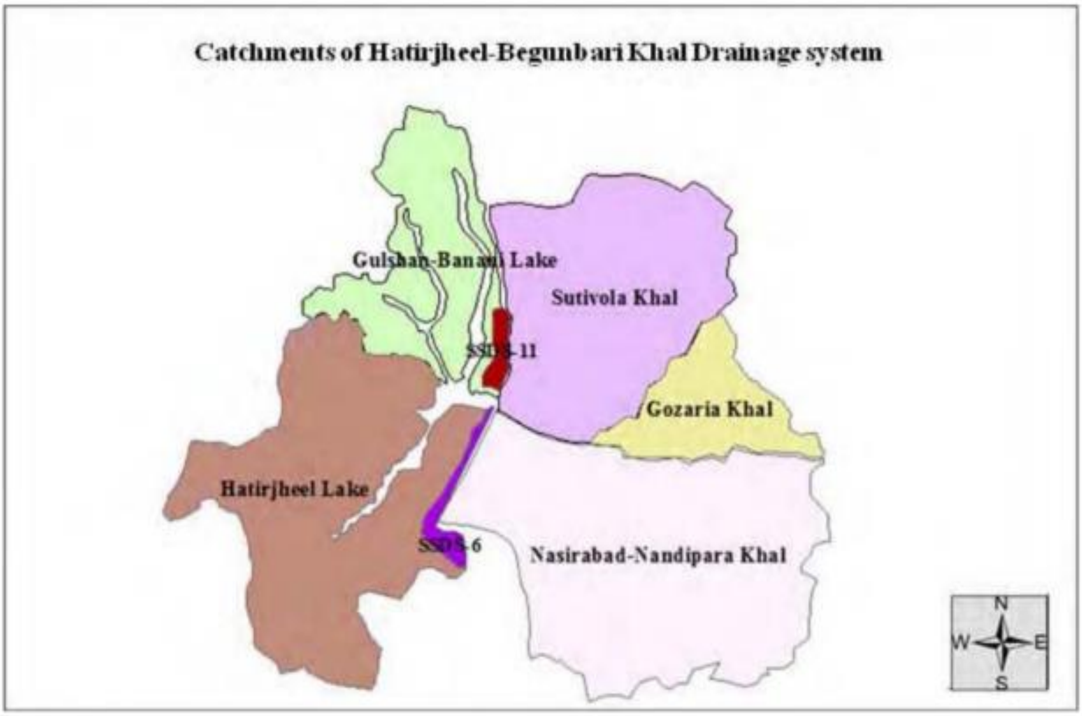


Figure 2.2: Catchment Area of Hatirjheel Lake [9]

Table 2.1: Area of seven major catchments in Dhaka

Catchment	Area (km^2)
Hatirjheel Lake	19.00
Gulshan-Banani Lake	8.27
Sutivola Khal	14.76
Gozaria Khal	4.87
Nasirabad-Nandipara Khal	22.00
Catchment of SSDS 6	0.65
Catchment of SSDS 11	0.44
Total Area	**70.00**

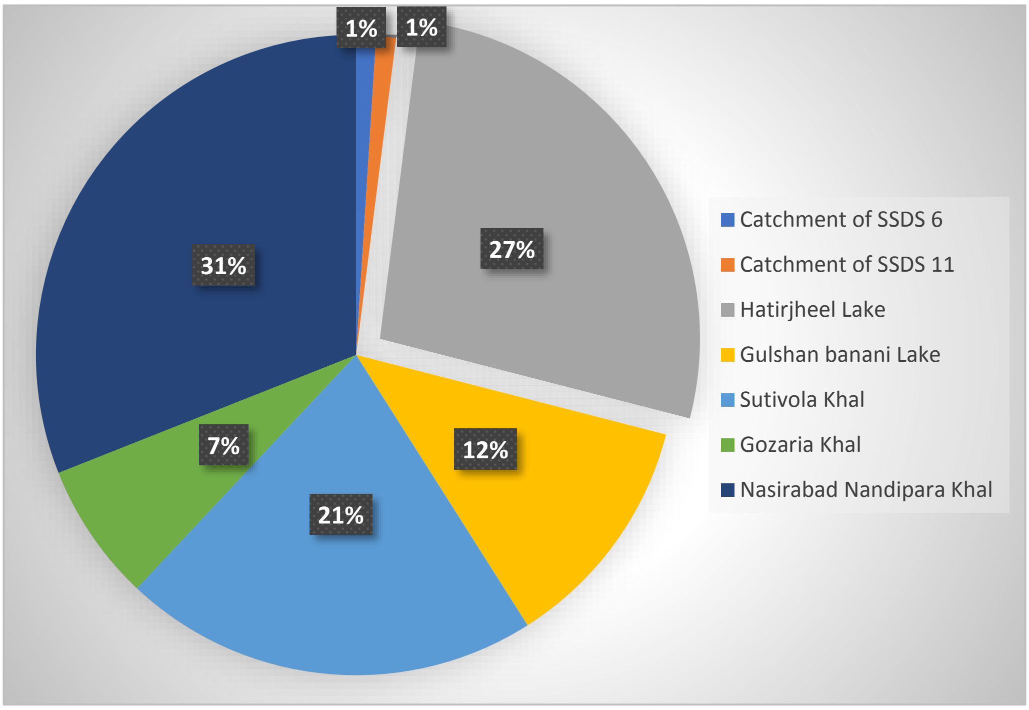


Figure 2.3: Relative Proportion of Major Catchments [9]

2.4 Pollution Status of Hatirjheel Lake

The colossal Hatirjheel-Begunbari Lake is now drifting across gray greenery and contaminated water with massive architecture clothed in dazzling lights. The express road, modern bridge, walkways are overflowing with crowds and wastes of all kinds. A sea of vehicles is gridlocked at the entrance to express roads, along the lake, stretching as far as one's eyes can see and the air is thick with the suffocating odor seeping from the water. Before the renovation project Hatirjheel could have been well described as the dumping zone of Dhaka, a ditch carrying household and industrial waste. Unfortunately, ten months after the inauguration of the new and improved beautiful lake, it is facing its old troubles. The area with its wide-open spaces is gradually losing charm and beauty due to noxious smells of the contaminated lake that is constantly burdened with garbage. The pollution of the lake is intensifying with each day. The Bangladesh University of Engineering and Technology (BUET) experts believe that without a proper waste water treatment plant, which they forgot to put in during the construction, there is no way out from the stagnant contaminated water. However, the responsible authority- Rajdhani Unnayan Kartripakkha (RAJUK) and Dhaka Water Supply and Sewerage Authority (DWASA) claim that they decided to allow the wastes into the lake only during the rainy season. But they also admit their decision will not help the present situation. The civil engineering department head of BUET, Professor Mujibur Rahman explains that the project has installed a screen at the entrance of the sewerage line to stop solid wastes from entering the lake. But in the rainy season the screen was blocked by huge solid wastes, so water flowed back and caused water blockage in Dhanmondi, Kalabagan and Panthapath areas, "DWASA removed the fixed screen as an instant solution to deal with the water stagnation and it made the condition worst. They supposed to separate the sewerage and storm water drainage system to keep your urban landscape and rainwater retention area neat and clean." The problem surfaced a few months after the inauguration, when the stench emanating from the contaminated water filled the lake and its adjacent areas. Experts believe that the absence of proper monitoring, a wastewater treatment plant and the illegal dumping of industrial waste and the connecting of the sewerage line with the rainwater collection channels has turned the situation from bad to worse. Even the Special Sewerage Diversion Structure (SSDS), which is designed especially for Hatirjheel, that reroutes the storm water and sewerage line, has proved inefficient to deal with the solid wastes. Following the SSDS only rainwater was supposed to enter the lake through different box culvert. The plan aimed at retaining the rainwater, but with the absurd connection, along with rainwater, solid wastes are now also entering the lake.

Figure 2.4: Polluted Water of Hatirjheel Lake [16]

2.5 Water Quality and Water Treatment Plan of Hatirjheel Lake

The Hatirjheel lake and Gulshan Banani lake within the project area receives discharge from both domestic and industrial sources. Polluted water flows to Rampura Khal from Gulshan Lake through Hatirjheel. This is one of the reasons of pollution of lake water. The rainwater was supposed to enter the lake through the Panthapath box culvert to hold the rainwater. But at present, solid waste also enters the lake. Screens were set up to stop solid waste from entering the lake, but piles of huge solid waste caused stagnation in the Dhanmondi, Kalabagan and Panthapath areas. Through physical, chemical and bacteriological analysis of water sample it has been observed turbidity, Total Suspended Solids, Ammonia, COD, BOD_5 etc. are way above the standard values. The test results are shown in table below :

Table 2.2: Average Values of lake water quality parameter within study area [3]

Water quality parameter	Concentration present
pH	7.1
Turbidity	74 NTU
Total Dissolved Solid (TDS)	288 mg/L
Total Suspended Solid (TSS)	60 mg/L
Phosphate	3.4 mg/L

Water quality parameter	Concentration present
Ammonia (NH_3)	12.5 mg/L
Nitrate (NO_3)	0.33 mg/L
Dissolved Oxygen (DO)	5.3 mg/L
Chemical Oxygen Demand (COD)	184 mg/l
Biochemical Oxygen Demand (BOD_5)	50 mg/L
Arsenic (As)	<.001 mg/L

2.6 Introducing Constructed Floating Wetlands

Constructed Floating Wetlands (CFW) are natural purification system where different types of natural treatment process works together to treat, polish and help natural water system to regain his own capacity of wastewater treatment. The system required significantly less amount for treating water comparing to chemical process. Constructed wetlands system is very much efficient to treat municipal wastewater, industrial wastewater, chemical waste, and metals. The main drawbacks of this system are it requires large area and has sometime slow treatment process with influence of climate. But for Hatirjheel Lake, it has enough free lake space to support the area. An efficient and proper design can solve the effect of climate problem. The major reasons to use CWs are as follows:

a. CFWs are very much cost effective compared to chemical process.
b. Treatment efficiency is very good.
c. Zero adverse effect on lake water, human, animals and environment.
d. Zero energy consumption.
e. Effective way to use natural system.
f. Helps polluted lake to regain its own pollution removal capacity.
g. Protect biodiversity of lake.
h. Green technology.
j. Required one-time investment and sustain long time.
k. Easy to operate.
l. Low cost treatment system.
m. No adverse health and safety impact on implementing and maintenance staffs.
n. Aesthetically Beautiful.

2.7 Different Types of Constructed Wetlands

The basic types of constructed wetlands are: surface flow and subsurface flow systems. In between these two, Surface flow system works almost like a natural wetland with flow of wastewater over saturated soil substrates (Usually < 60 cm deep). On the other hand, subsurface flow system water flows either horizontally or vertically through the media (plant growth supporter) and there it comes in contact with the microorganisms which lives on the surface of the plant roots and substrate allow the removal of pollutant from bulk liquid [17].

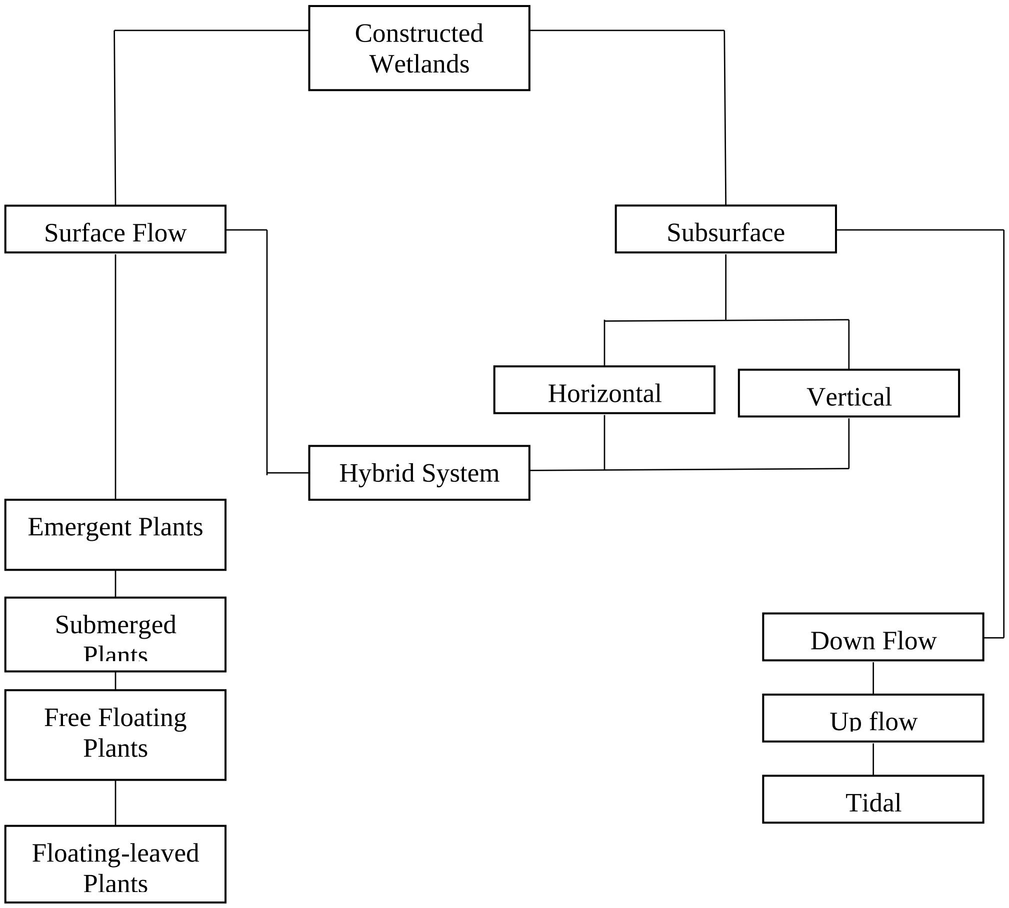


Figure 2.5 : Classification of CFWs [18]

Subsurface flow constructed wetlands are again classified into two groups: vertical flow system and horizontal flow system and these both are quite effective than surface systems because of efficiently removing mass pollutants per m^2 of system surface area [19]. Surface flow constructed wetlands are representation of natural wetlands and these require more land than subsurface flow systems for the equivalent amount of pollution reduction. However, Surface flow constructed wetlands are easier and cheaper for designing and building. Surface flow wetlands provides better aesthetic value and availability of more wildlife habitat. Unfortunately, these wetlands pose greater risk of exposure to pathogenic organisms and other harmful contaminants.

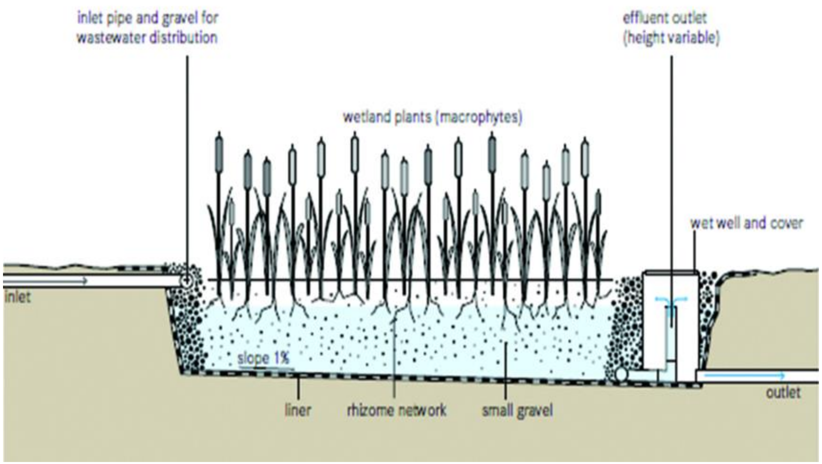


Figure 2.6 : Horizontal subsurface flow constructed wetland [20]

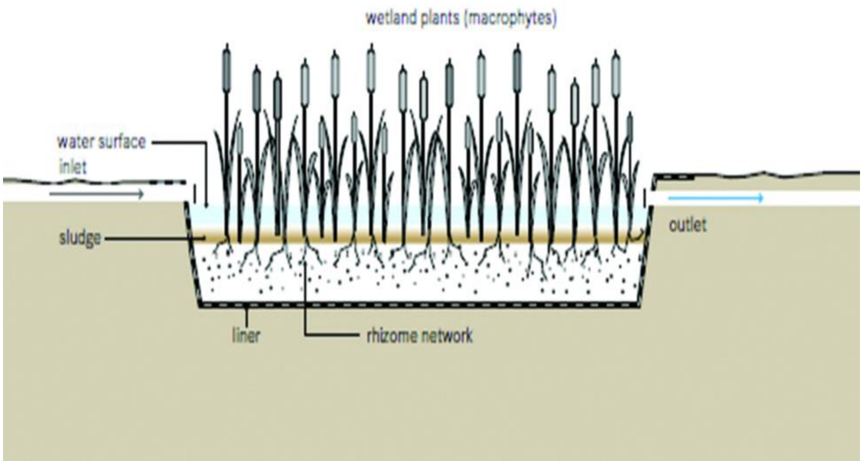


Figure 2.7 : Free water surface flow constructed wetland [20]

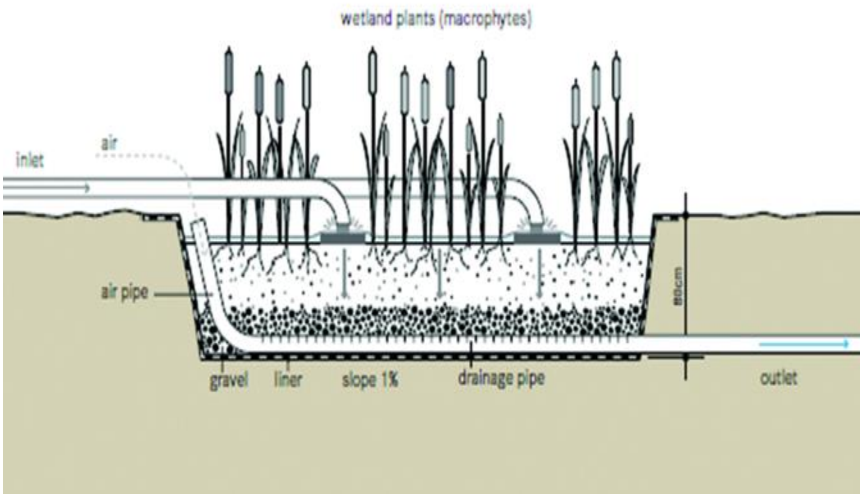


Figure 2.8 : Vertical flow wetland [20]

Generally, for any lake water treatment two different types of constructed wetlands are proposed and used, they are:

a. Constructed horizontal wetlands
b. Constructed floating wetlands

Constructed horizontal wetlands are constructed in bank of the lake. Generally full lake bank is covered with vegetation and sometimes water is allowed to flow free areas surroundings the vegetation as surface flow and sometimes rainwater is passed as subsurface flow below the ground but mostly surface flow is practiced.

Constructed floating wetlands are planted floating bed on lake water which treat lake water in natural way. The floating mat provide buoyancy force to float plants and plants root zone bacteria biologically degrade the nutrients and upgrade the water quality. With this plant has significant contribution to uptake heavy metal oil, grease and other pollutant. The root zone also removes the suspended and dissolve solids.

2.8 Treatment by CFW

Constructed Floating Wetlands (CFWs) consists of a buoyant structure planted with macrophytes (Fig. 2.5). The root of the plant grows directly into the water column and the roots along with root hairs provide a large surface area for the growth of biofilm [21]. CFWs are designed to represent the pollutant removal processes of natural floating marshes and islands [22]. CFWs provide a passive, low-maintenance and operationally simple water-treatment solution that enhances habitat, recreational and aesthetic values within the urban landscape [23]. Their buoyancy also allows them to adjust to large water-level changes associated with extreme-rainfall events that can be problematic for other BMPs. CFW plants acquire nutrients for growth directly from the water column [24]. Growth of the plants can be limited due to change in nutrient concentrations as per storm runoff [25]. By allocating more resources to below-ground tissue, CFW can increase their root length and produce thinner roots to increase the area from which to scavenge nutrients [26]. Total nutrient uptake by the CFW plant biomass represents the amount of nutrient removed from the water body [27]. Because of changing nutrient availability in the water column below the CFW, plant nutrient uptake may also change temporally, which largely depends on nutrient laden stormwater runoff. The total amount of nutrients removed from water by the plants, and the distribution of nutrients in different plant components, can be quantified and this can assist in optimizing shoot-harvesting strategies to eradicate nutrients permanently from the CFW water body [28].

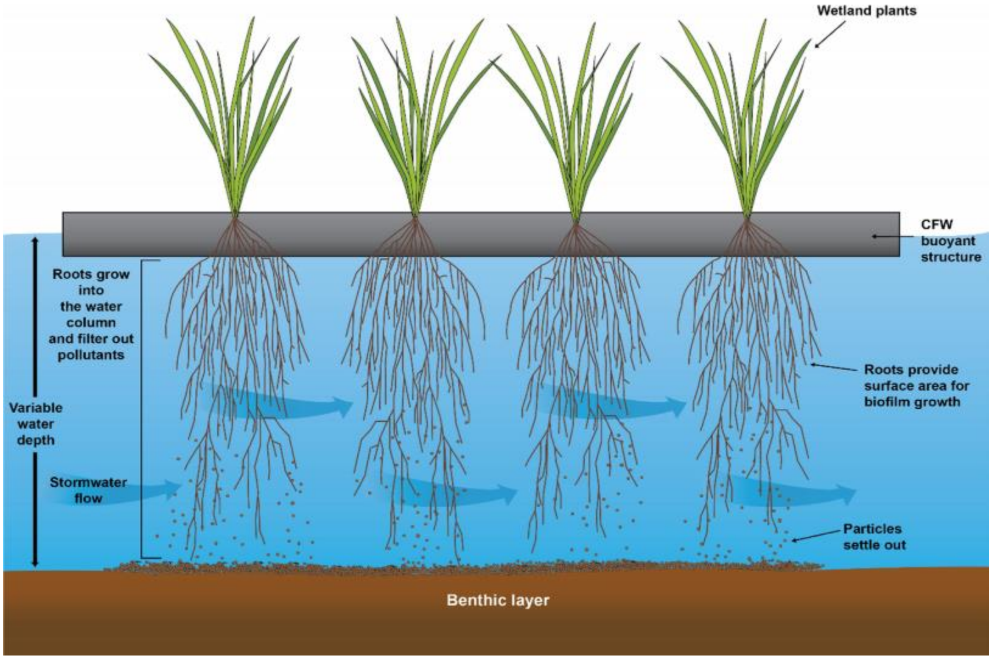


Figure 2.9: Schematic of a constructed floating wetland consisting of a buoyant structure planted with wetland plants whose roots filter pollutants and provide a surface for biofilm growth [18]

2.9 Important Functions of Floating Wetlands

2.9.1 Management of Stormwater

For maintaining better water quality, floating treatment wetlands method or system are quite unique and provides an innovative new solution to the existing water related problems. It can reduce nutrient problems related to phosphorus and nitrogen along with Total Suspended Solids (TSS) and metals. Severity of water quality related problems like algal issues can also be reduced using this technique.

2.9.2 Visual Augmentation

Floating wetlands not only provide a visually good-looking view to the pond or water body but also helps greatly to maintain the ecological balance of the surrounding ecosystem of the water body.

2.9.3 Management of Nutrients

Nutrient loading problem is a very crucial and significant issue which is experienced almost by all sorts of aquatic systems. Excess amount of nutrient not only causes virtual problems but also real ones as well. Which includes: odors, fish death, algal blooms and so on. Floating treatment wetlands in this sector can play a vital role which is proven and a natural approach for managing nutrient problems in the aquatic environments. Majority of the conventional problems associated with nutrient overloading can easily be tackled or halted floating treatment wetlands.

2.9.4 Creation of Habitat

As floating treatment wetlands are visually attractive and so despite of location, the system or arrangement will easily attract the wildlife. This technique of treatment is also unparalleled in case of creating fish habitat virtually in any aquatic environment and will attract both small and large fishes. This system is very much productive in terms of creating excellent fish community along with better surrounding ecosystem.

2.10 Available Plants in Bangladesh

Different types of plants are available in Bangladesh to use in constructed wetlands. A list of most commonly available plants in Bangladesh are provided below:

2.10.1 Canna Indica (Kolabati)

Canna Indica is a perennial growing to between 0.5 m and 2.5 m, depending on the variety. It is hardy to zone 10 and is frost tender [29]. The flowers are hermaphrodite. Canna Indicasps. Can be used for the treatment of industrial waste waters through constructed wetlands. It is effective for the removal of high organic load, color and chlorinated organic compounds from paper mill wastewater.

Figure 2.10 : Cana Indica

(Source: Photo taken by author on 17 September 2018)

2.10.2 Phragmites Australis (Nol Ghas)

Phragmites, the common reed, is a large perennial grass found in wetlands throughout temperate and tropical regions of the world. Phragmites Australis is sometimes regarded as the sole species of the genus Phragmites, though some botanists divide Phragmites Australis into three or four species. Phragmites Australis, common reed, commonly forms extensive stands (known as reed beds, which may be as much as 1 sq km (0.39 sq mi) or more in extent. Where conditions are suitable it can spread at 5 metres (16 ft) or more per year by horizontal runners, which put down roots at regular intervals. It can grow in damp ground, in standing water up to 1 metre (3 ft 3 in) or so deep, or even as a floating mat. The erect stems grow to 2–6 metres (6 ft 7 inch–19 ft 8 inch) tall, with the tallest plants growing in areas with hot summers and fertile growing conditions [30].

Figure 2.11 : Phragmites Australis

(Source: Photo taken by author on 8 July 2017)

2.10.3 Glyceria Maxima

Glyceria Maxima (Hartm.) Holmb. (syn. G. aquatica (L.) Wahlenb.G. spectabilisMert. & W.D.J. Koch; Molinia maxima Hartm.; Poaaquatica L.), commonly known as Great Manna Grass, Reed Manna grass, and Reed Sweet grass, is a species of rhizomatous perennial grasses in the manna grass genus native to Europe and Western Siberia and growing in wet areas such as riverbanks and ponds. It is highly competitive and invasive and is often considered to be a noxious weed outside its native range [31].

Figure 2.12 : Glyceria Maxima

(Source: photo taken by author on 7 July 2017)

2.10.4 Thalia Multiflora

Figure 2.13 : Thalia Multiflora

(Source: photo taken by author on 10 July 2017)

Figure 2.14 : Thalia Dealbata

(Source: photo taken by author on 7 July 2017)

2.10.5 Panicum Hemitomon

Panicum Hematoma is a species of grass known by the common name maiden cane. It is native to North America, where it occurs along the southeastern coastline from New Jersey to Texas [32]. It is also present in South America. This species is a common grass in coastal wetlands. It is only found in freshwater, not sea water or brackish water. It can be found in many types of freshwater wetlands as well as in ditches and disturbed or cultivated areas [33]. It is less sensitive to grazing than many associated species, but growth is reduced by competition from neighboring plants.

Figure 2.15 : Panicum Hemitomon

(Source: photo taken by author on 7 July 2017)

2.10.6 Pycreus Nitidus

A robust perennial plant with culms to 60 cm high, in or near permanent water in wetland area of Bangladesh. This plant is also found in low lands near pond area of Bangladesh also.

Figure 2.16 : Pycreus Nitidus

(Source: photo taken by author on 10 July 2017)

2.10.7 Chinese Arrow-head

Sagittaria Trifolia: the name of "Chinese Arrow-head" comes from the arrow-shaped leaves. Chinese Arrow-head grows in muddy shore with shallow water and can be as tall as half meter. This species is both cold-resistant and heat-resistant. The root tuber of Chinese Arrow-head, which grows just below the surface of the mud, is edible with starchy texture. It is particularly popular during Chinese New Year [34].

Figure 2.17: Chinese Arrow-head

(Source: Photo taken by author on 10 July 2017)

2.10.8 Chaba Lily

It is also known as the rocky shoal's Spider Lily, the Cahaba Lily is classified as Hymenocalliscoronaria. A perennial flowering plant, it can also be found in the states of South Carolina as well as Georgia. You can recognize it by its height of about 3 feet and also its production of white, big flowers that begin to bloom from the start of May to the end of June. Its fragrant flowers only bloom for a day, and it may normally be found in shallower areas of water in direct sunlight.

Figure 2.18 : Chaba Lily

(Source: Photo taken by author on 10 July 2017)

2.10.9 Water Fern

Water Fern is an aquatic or semi-aquatic herb. It can be found in ponds, paddy fields and other marshy areas. Water Fern is one of the few fern species that survive in marshes and wetland. Its leaves and stems can be used medicinally. Unfortunately, its population size and distribution areas have been decreasing in recent years. Thus, now this vulnerable fern is under state protection (category II) in China [35].

Figure 2.19 : Water Fern

(Source: Photo taken by author on 10 July 2017)

2.10.10 Hymenocallis Caribaea

Hymenocallis Caribaea is variegate commonly known as the Variegated Spider lily has attractive upright off-white striped foliage when not in bloom, but really comes alive when it blooms showy white flowers which resemble a mix of a bog lily and a daffodil. The Variegated Spider Lily has a clumping style growth habit reaching 1-2' tall and is hardy in zones 7-11 depending on winter protection [36]. The Variegated Spider Lily is a stylish plant perfect for brightening up dark corners of your pond or water garden. The beautiful variegation reinforces visually the long, strap-like leaves to enhance your pond design with a graphic vertical element. The deeply grooved leaves that grow up to 18" in length work together with the green and white variegated coloration to break up predictable planting schemes to truly showcase your pond or water garden [36].

Figure 2.20 : Variegate/Spider Lily

(Source: Photo taken by author on 7 July 2017)

Bangladesh are given bellow. Other than that, different types of plants are available (especially different types of lily) in wetlands area of Bangladesh. To understand their potentiality of treatment water details study required as like Canan Indical and Phragmites Australis.

CHAPTER 03: METHODOLOGY INCLUDING STUDY AREA AND METHODOLOGICAL APPROACH

CHAPTER : 03

METHODOLOGY INCLUDING STUDY AREA AND METHODOLOGICAL APPROACH

3.1 Study Area Profile

3.1.1 Introduction

Hatirjheel Lake is the essential for Dhaka's drainage, storm water retention, water-based transport and many other activities. The water was planned to provide various benefits, such as obtaining drinking water, industrial use and have usage in many other ways including transport. But the water is becoming polluted due to sewage, domestic and industrial wastewater. In addition, the condition of the water is so bad that even the exceptional improving tendency of the water quality of lakes is not visible due to the increase in pollutant load in these water resources because of the increase in industrialization and population. The climatic changes also play a harmful role in decaying the quality of water. The increasing pollution in water is adversely affecting the aquatic life. However, the maintenance of a healthy aquatic ecosystem is dependent on the physic-chemical properties of water and the biological diversity. Other than the industrial waste, solid waste is being deposited by the visitors each day.

Different study had been conducted to determine different water quality parameters, water flow and pollution of Hatirjheel Lake. The study being conducted is based on the cost-effective and eco-friendly methods for the treatment of contaminated lake water rather than the chemical treatments. It's being observed that the use of the chemical treatments can have adverse effect on the aquatic life as well as the human beings which consume the water after being treated. Chlorination is one of the water purification method. Though the method is useful in killing the bacteria present in the water, but excess chlorine in water is harmful as it amalgamates with organic material in the water to form substances such as tri halomethanes, which may cause health problems related to liver, kidney, or central nervous system, and the possibility of cancer also increases with the consumption of such water.

3.2 Study Area Data

Water quality of Hatirjheel Lake is the rising concern of people of Dhaka City and related authority now. Because Hatirjheel is one of the most important recreational places at the heart of capital of Bangladesh. There are so many researches on water quality and related parameter has already done and many initiatives are taken to solve this problem but in vain. There is a set of secondary data available for existing water quality, water volume, flow of water, sources of wastewater etc. Most of the baseline data are collected from primary sources by direct measurement, key informant interview, planning and design review and cross matched with secondary sources data. Information which are found from reliable sources and hard to collect from primary sources or financially not viable or not weightage value is less are taken from secondary sources.

3.2.1 Catchment Area and Pollution Sources

Hatirjheel and the Begunbari Khal drain storm water from approximately one-third area of Dhaka City. Hatirjheel Lake is the largest storm water retention basin in the city which is hydraulically linked with the Gulshan and Banani lakes. Banani Lake is linked with Hatirjheel Lake through a canal which also receives storm water from the Mohakhali box culvert. The outfall of this combined system covering the DWASA Drainage Zones F and G is located at Rampura where a regulator was constructed after the flood in 1988. The current practice of DWASA for storm water management in Zones F and G is to allow storm water detention in Hatirjheel Lake and gravity drainage through Rampura until the external river water level rises above +5.0 m PWD. The regulator gates are kept closed during the period the external water level is above +5.0 m PWD, and approximately 50 five-cusec temporary pumps are used to drain out runoff generated by internal rainfall [37].

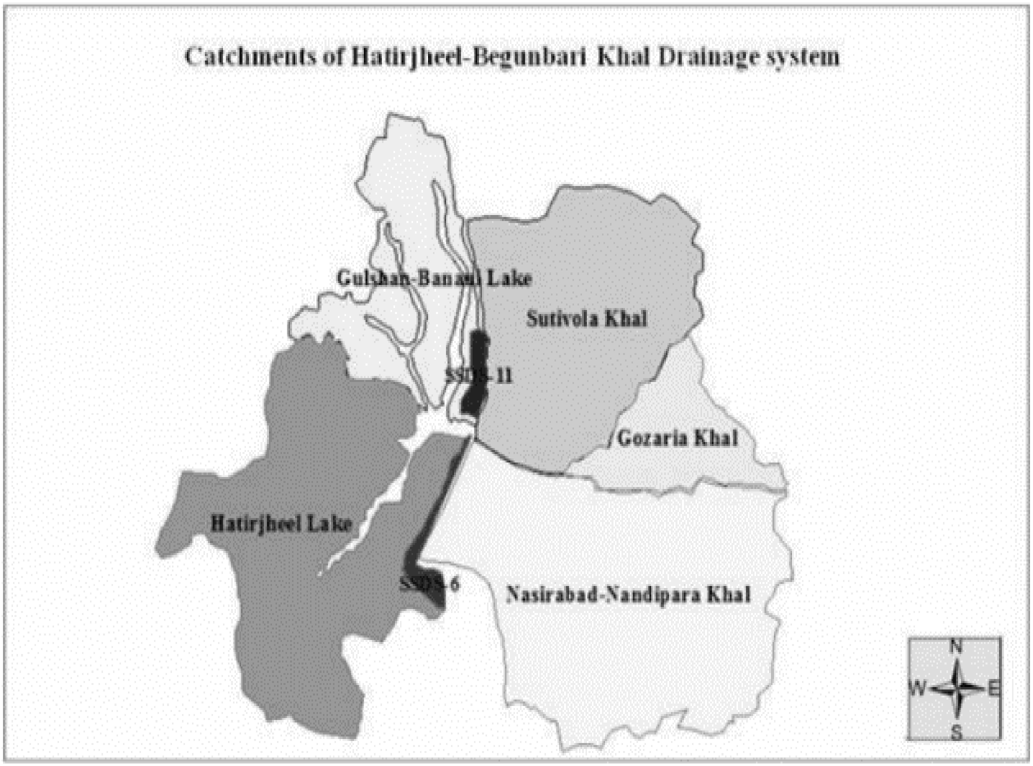


Figure 3.1: Catchment of Hatirjheel Lake [9]

The Hatirjheel combined system receives storm water from DWASA Drainage Zones F and G in western Dhaka city. Zones F and G are further divided into 8 and 4 sub catchments, respectively. The area of the Drainage Zones F and G combined is 27.468 km^2 [37]. Another study says that the catchment area is about 19 Km^2 [9].

3.2.2 Water Volume and Flow Characteristics

Most built up areas around the combined Hatirjheel Lake system are above +6.0 m PWD elevation . The minimum level of water is about +2.5 m PWD and maximum water level is maintained +5.5 m PWD. The total detention volumes at +5.5 m PWD and +2.5 m PWD levels is approx. 5.74 million m^3 and 3.07 million m^3 respectively [37].

Total length of Hatirjheel Lake from Sonargaon crossing to Rampura Bridge is about 4 km. Width of this lake varies in a great scale depending on its sharp bends of bank lines. Highest width of lake is found near Concord Police Plaza is about 470 meter and lowest width of 80 meter is at Panthapath near BGMEA Building. Average depth of this lake varies from 5-6 meter at different parts of the lake. Storm water is the main source recharging here and there are ten inlets in different locations on lake bank line to enter the water. During monsoon, the water level rises 1-1.5 meter because of extra rainfall. Generally, water flows from south to north here, the water is forced to flow in the direction of Rampura pump stations by following the natural gradient [38]. A long profile of Hatirjheel Lake from Sonargaon crossing to Rampura Bridge is shown in figure 3.2. Some cross-sections at different points of the Lake are also shown below in figure 3.3.

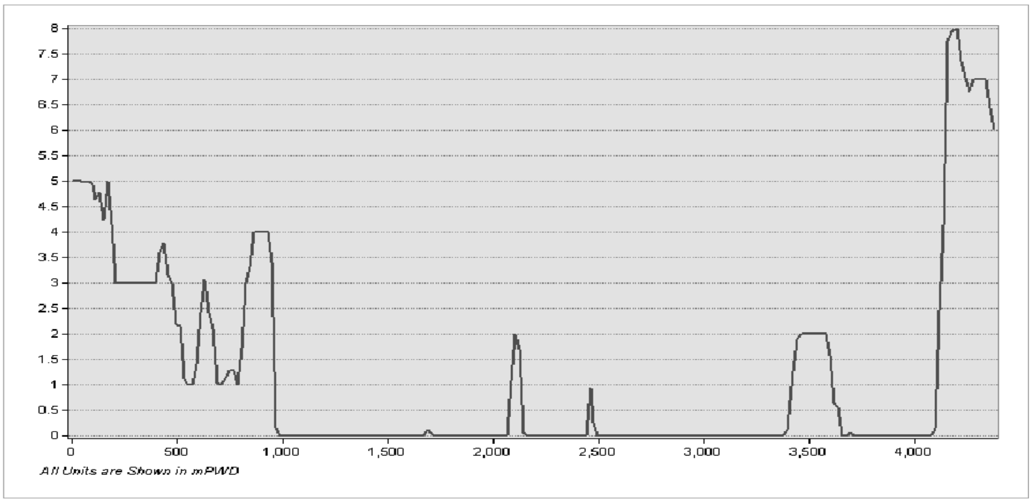


Figure 3.2: Long Profile of Hatirjheel Lake from Sonargaon Crossing to Rampura Bridge

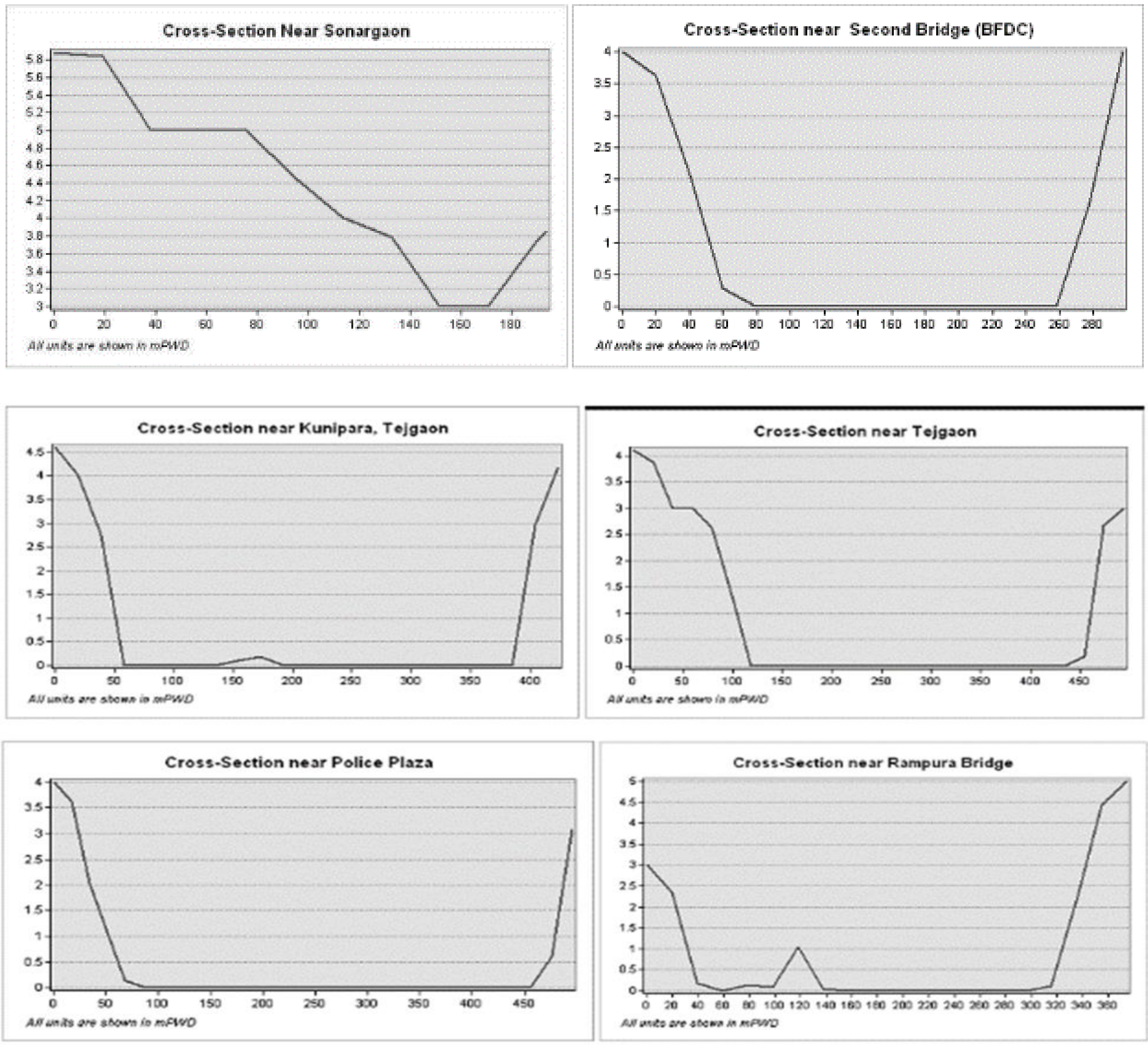


Figure 3.3: Cross-Sections at Different Points of Hatirjheel Lake

One of the main purposes of the Hatirjheel Project is to retain storm water so that a good amount of water can be reserved around the year if needed. During dry reason, the Hatirjheel Lake can hold approximately 3.06 billion liters of water. During the rainy season, the lake can hold approximately 4.81 billion liters of water. This makes Hatirjheel Lake the largest water body inside the capital of Bangladesh [38]. Another source describes that, storage volume for 2 m elevation is 1.24 Million m^3, for 5m elevation storage volume is 3.23 Million m^3, for 7.5 m elevation storage volume is 5.06 Million m^3. The total storage volume is found to be 37.11 Mm^3 for maximum elevation of 7.5 m when the lake is about to get fully stored [13].

At the design phase of the project, the plan was to pass wastewater throughout the pipeline constructed both side of the lake but the plan failed due to sloping problem. There are total four pipe lines (two pipe each in both side) each have 1080 mm dia. Though the diameter of the pipe is insufficient for wastewater, it is limited by the slope of lake with Rampura Lake and Balu River. For this in rainy season every year wastewater in entering the Hatirjheel lake by overflowing the separated wastewater structure. To keep the design height of water in lake, authority is allowing intrusion of wastewater at dry season also. The volume of wastewater entering the lake in dry season is given in Table 3.1.

Table 3.1: Dry Season Discharge in Hatirjheel Lake [45]

Outlet Identification Number	Location	Dry Season discharge (m^3/s)
Q1	Low land behind Sonargaon Hotel	1.73
Q2	East of Tongi Diversion Road	0.28
Q3	Storm sewer coming from Karwan Bazar area and discharging into the lowland behind Sonargaon Hotel at the entrance of BGMEA building	0.20
Q4	Storm sewer coming from Tejgaon area and discharging immediately to the east of Tongi Diversion Road	0.14
Q5	Modhubagh, Nayatola	0.11
Q6	Niketon outfall	1.08
Q7	Outfall on the southern side of Rampura Bridge	0.31
Q8	Storm sewer from Badda	0.48
Q9	Outfall on the northern side of Rampura Bridge	0.11
Total		4.44

In storm water diversion system, there are total 58 Manholes which also overflow during rainy season [39]. In rainy season the discharge is about 258.41 m^3/s [40]. But in this calculation only rainwater is calculated. As most of the municipal waste water is connected to storm sewer of Dhaka city, the calculated discharge is more than the real one.

Other than that, some SSDS are designed for separation of storm swear and rain water but failed. As a part of a major restoration project, Special Sewage Diversion Structures (SSDS) 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 [41].

Unauthorized wastewater line, dumping of solid waste directly by visitors and adjacent resident, decomposition of dead leaves, animals and construction waste are continuously polluting the water.

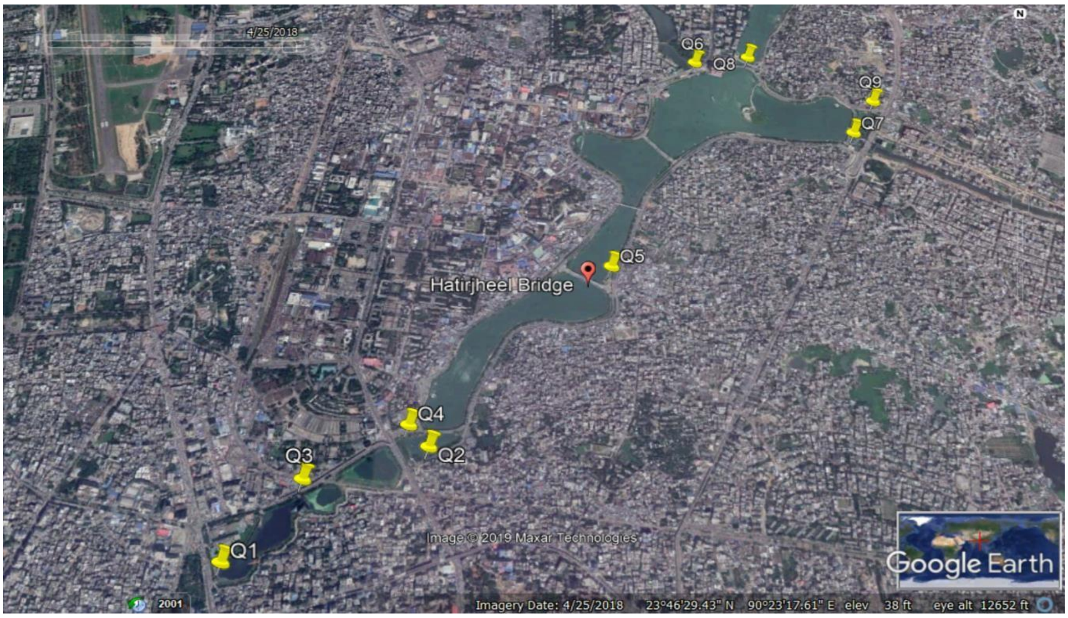


Figure 3.4: Major wastewater intrusion points in Hatirjheel Lake [45]

3.2.3 Positive and Negative Agents on Water Quality

From the water quality sample, it is very much clear that, water quality is varying throughout the longitude of lake. The variation is occurring due to interference of incoming wastewater and some other internal events. Cleaning sludge from bottom, cleaning suspended particles, pumping water, introducing water taxi, vegetation on lake slope etc. has positive influence on lake water quality. On the other hand, direct intrusion of waste water to the lake, uncontrolled rainwater flow, direct waste throwing to lake by visitors etc. has negative influence on the water quality of lake. Negative and positive influencing agents on lake water quality are listed below with their impacts.

3.2.4 Negative Agents

Negative influencing agents are those which have direct or indirect impact on lake water quality degradation. This can be both natural and man-made. Main negative influencing agents in lake water quality is its seasonal intrusion of wastewater (both municipal and chemical) to lake.

3.2.5 Positive Agents

Positive influencing agents are those which have positive direct or indirect impact on lake water quality. This can be both natural and man-made. A list of positive interference is given bellow:

Table 3.2: List of Positive Agents

No.	Name	Interference type	Impact type	Comments
1.	Water Taxi Service	Man Made	High Impact	Increasing DO
2.	Shape of Lake	Natural	Medium Impact	Increasing water residence time to settle sludge
3.	Vegetation on lake shore	Man made	High Impact	Reducing dirt and grit flow directly to lake from rainwater
4.	Aerobic and Anaerobic bacteriological growth	Natural	High Impact	Decomposing the decomposable materials and helps to sediments. And restrict flowing those in whole lake.

3.3 Methodology and Experimental Setup

3.3.1 Introduction

The contribution of constructed wetlands to wastewater treatment are already proven science. But the treatment potentiality efficiency largely depends on different factors including climate, wastewater condition, climate, flow type volume velocity and pattern, geography, types of water body etc. Sometimes used pants, media and shapes are also important parameters to increase or reduce the treatment potential. Plants root zone plays and important role to treat the water for its symbiotic relation with nitrogen fixing bacteria. Especially root zone nodule provide shelter for different nitrogen fixing bacteria specially rhizobia. Besides nodule, the plant has its own treatment capacity and the root zone works as heavy metal and other key component to pollutant intake. Dense root zone also worked as a filtration chamber of suspended and dissolve solids.

Figure 3.5: Nodules in root zone of Plant from the pilot project

(Source: Photo taken on 12 Aug 2018)

3.4 Design of Natural Treatment System

Constructed Floating Wetlands (CFW) are natural treatment technologies that efficiently treat many different types of polluted water. CFWs are engineered systems designed to optimize processes found in natural environments and are therefore, considered environmentally friendly and sustainable options for wastewater treatment. Compared to other wastewater treatment technologies, CFWs have low Operation and Maintenance (O&M) requirements and are robust in that performance is less susceptible to input variations. CFW can effectively treat raw, primary, secondary or tertiary treated sewage and many types of agricultural and industrial wastewater. This volume focuses on domestic wastewater treatment using CFW [42].

3.4.1 Different Types of Natural Treatment Process

Treatment wetlands can be subdivided into surface flow and subsurface flow systems. Although there are many wetland variants in the literature, in this volume a simple approach is adopted, and four treatment wetlands. Subsurface flow treatment wetlands are subdivided into Horizontal Flow (HF) and Vertical Flow (VF) wetlands depending on the direction of water flow. In order to prevent clogging of the porous filter material, HF and VF wetlands are generally used for secondary treatment of wastewater.

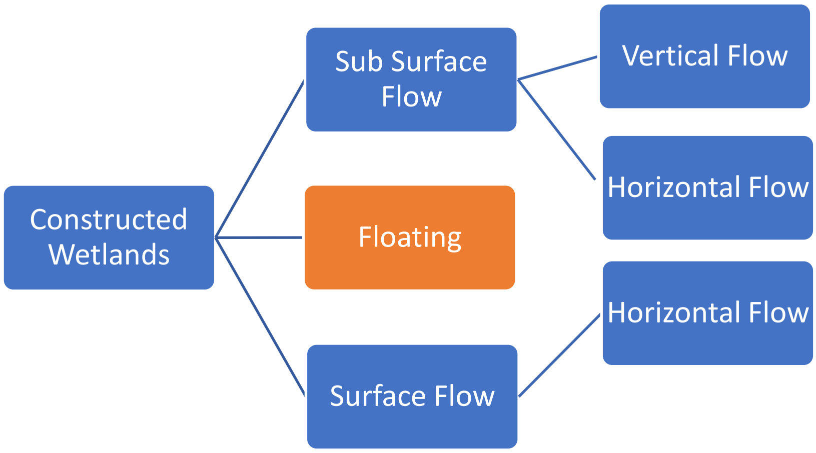


Figure 3.6: Types of Constructed Wetlands [43]

Among those treatment systems, we will use floating wetlands system mainly for our lake water treatment and in some part, we will use vertical flow system for treatment of flowing rainwater with dirt.

3.5 Removal Mechanism

In CFW removal of organic matter is done through aerobic and anaerobic microbial degradation, removal of suspended solid is done by sedimentation and filtration, removal of nitrogen by nitrification and denitrification, plant uptake and adsorption, phosphorous is removed mostly through adsorption and plant uptake. Details of removal process is discussed in subsequent paragraphs:

3.5.1 Ammonia Removal

Ammonification (mineralization) is the process where organic N is biologically converted into ammonia. Ammonia is converted from organic forms through the complex, energy-releasing, multi-step, biochemical process. In some cases, this energy is used by microbes for growth, and ammonia is directly incorporated into microbial biomass. A large fraction (up to 100%) of the organic nitrogen is readily converted to ammonia [44]. The ammonification process is essentially a catabolism of amino acids and presumably includes several types of deamination reactions. The oxidative deamination can be written as [45]:

Amino acids→ Imino acids →Keto acids→NH_3

And may be operative in the oxidized soil layer. On the other hand, the reductive deamination [46] presumably takes place in the reduced soil layer:

Amino acids →Saturated acids→NH_3

Kinetically, ammonification proceeds more rapidly than nitrification [44]. Mineralization rates are fastest in the oxygenated zone, and decrease as mineralization switches from aerobic to facultative anaerobic and obligate anaerobic microflora [47]. Since depth of the aerobic zone in flooded or saturated soils is usually less than1 cm, the contribution of aerobic mineralization to the overall N mineralization would be very small, compared to facultative anaerobic and obligate anaerobic mineralization [48]. Ammonification rates are dependent on temperature, pH, C/N ratio, available nutrients and soil conditions such as texture and structure [49]

3.5.2 Nitrogen Removal

The removal of nitrogen involves a number of processes all which act on different types of wastewater wetlands. These processes include ammonia volatilization, ammonification, nitrification, nitrate ammonification, denitrification, fixation, plant and microbial uptake, ammonia adsorption and organic nitrogen burial. These are the major nitrogen mechanisms some of which occur in different types of wastewater wetlands. The following will go into more detail on these mechanisms and in which types of wetlands the mechanisms are present [18]. As noted before the most important forms of organic nitrogen found in wetlands are ammonium, nitrate, and nitrite. These various forms of nitrogen are required for biological life to function in the wetland. The processes that transform various forms of nitrogen are all necessary for wetlands to function successfully. Ammonia volatilization is the physicochemical process where ammonium is in equilibrium with gas and hydroxyl forms.

3.5.3 Nitrification:

Nitrification is usually defined as the biological oxidation of ammonium to nitrate with nitrite as an inter-mediate in the reaction sequence. This definition has some limitations where heterotrophic microorganisms are involved but is adequate for the autotrophic and dominant species. Nitrification has been typically associated with the chemoautotrophic bacteria, although it is now recognized that heterotrophic nitrification occurs and can be of significance. Nitrification is a chemoautotrophic process. The nitrifying bacteria derive energy from the oxidation of ammonia and/or nitrite and carbon dioxide is used as a carbon source for synthesis of new cells. Paul and Clark pointed out that Warrington, in 1878, at Roth Amsted, United Kingdom, found that nitrification was a two-step process involving two groups of microorganisms. One microbial group ox-idized ammonium-N to nitrite-N and nitrite-N and another oxidized nitrite-N to nitrate-N [50]:

$$NH_4^+ + 1.5O_2\ N \Longrightarrow NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 0.5O_2 \Longrightarrow NO_3^-$$

$$NH_4^+ + 2O_2\ N \Longrightarrow NO_3^- + 2H^+ + H_2O$$

The first step, the oxidation of ammonium to nitrite, is executed by strictly chemo lithotrophic (strictly aerobic) bacteria which are entirely dependent on the oxidation of ammonia for the generation of energy for growth.

3.5.4 Denitrification:

Denitrification is most commonly defined as the process in which nitrate is converted into dinitrogen disintermediates nitrite, nitric oxide and nitrous oxide [51]. From a biochemical viewpoint, denitrification is a bacterial process in which nitrogen oxides (in ionic and gaseous forms) serve as terminal electron acceptors for respiratory electron transport. Electrons are carried from an electron-donating substrate (usually, but not exclusively, organic compounds) through several carrier systems to a more oxidized N form. The resultant free energy is conserved in ATP, following phosphorylation, and is used by the denitrifying organisms to support respiration. Denitrification is illustrated by the following equation:

$$6(CH_2O) + 4NO_3 \Longrightarrow 6CO_2 + 2N_2 + 6H_2O$$

This reaction is irreversible, and occurs in the presence of available organic substrate only under anaerobic or anoxic conditions, where nitrogen is used as an electron acceptor in place of oxygen. More and more evidence is being provided from pure culture studies that nitrate reduction can occur in the presence of oxygen. Hence, in waterlogged soils nitrate reduction may also start before the oxygen is depleted [52]. Gaseous N production during denitrification can also be depicted by

$$6(CH_2O) + 4NO_3 \Longrightarrow 6CO_2 + 2N_2 + 6H_2O$$

$$5(CH_2O) + 4NO_3 \Longrightarrow H_2CO_3 + 4HCO_3 + 2N_2 + 2H_2O$$

Diverse organisms are capable of denitrification. In an array are organotropism, lithographs, phototrophs, and diazotrophs [50]. Most denitrifying bacteria are chemo heterotrophs. They obtain energy solely through chemical reactions and use organic com-pounds as electron donors and as a source of cellular carbon [53]. The genera Bacillus, Micrococcus and Pseudomonas are probably the most important in soils; Pseudomonas, Aeromonads and Vibrio in the aquatic environment [53]. When oxygen is available, these organisms oxidize a carbo-hydrate substrate to CO_2 and H_2O [47]. Aerobic respiration using oxygen as an electron acceptor or anaerobic respiration using nitrogen for this purpose is accomplished by the denitrifies with the same series of electron transport system. This facility to function both as an aerobe and as an anaerobe is of great practical importance because it enables denitrification to proceed at a significant rate soon after the onset of anoxic conditions (redox potential of about 300 mV) without change in microbial population. Because denitrification is carried out almost exclusively by facultative anaerobic heterotrophs that substitute oxidized N forms for O_2 as electron acceptors in re-aspiratory processes, and because these processes follow aerobic biochemical routes, it can be misleading to refer to denitrification as an anaerobic process. It is rather one that takes place under anoxic conditions. It is generally agreed that the actual sequence of biochemical changes from nitrate to elemental gaseous nitrogen is

$$2NO_3 \Longrightarrow 2NO_2 \Longrightarrow 2NO \Longrightarrow N_2O \Longrightarrow N_2$$

Environmental factors known to influence denitrification rates include the absence of O_2, redox potential, soil moisture, temperature, pH value, presence of denitrifies, soil type, organic matter, nitrate concentration and the presence of overlying water [18]. Paul and Clark reported that the optimum pH range lies between pH 6 and 8. Denitrification becomes slow but may still remain significant below pH 5 and denitrification by organotrophs is negligible or absent below pH 4.

3.5.5 Phosphorus Removal

Another important nutrient that causes eutrophication in water is phosphorus. Removal of phosphorus tends not to be as high as nitrogen removal in wastewater wetlands. This is because wetlands do not provide the direct metabolic pathway to remove phosphorus. Wetlands use physical, chemical, and biological means to reduce phosphorus [54]. Phosphorus exists as phosphates as inorganic and organic forms. The predominant form is in the form of orthophosphate which can be used by algae and macrophytes. Inorganic phosphorus can also be found as polyphosphates. Organic forms include phospholipids, nucleic acids, nucleoproteins, and phosphorylated sugars. These forms are primarily known as easily decomposable phosphorus and there other forms called slowly decomposable organic phosphorus which contains phytin [18]. The major phosphorus transformations in wastewater wetlands are done by physical/chemical means and biological means.

3.6 BOD_5

Biochemical Oxygen Demand (BOD_5, also called Biological Oxygen Demand) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD_5 value is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days of incubation at 20°C and is often used as a surrogate of the degree of organic pollution of water [55].

Biochemical oxygen demand test or BOD_5 test is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. It is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. It is most commonly expressed in milligrams of oxygen consumed per liter of sample during 5 days (BOD_5) of incubation at 20°C and is often used as a robust surrogate of the degree of organic pollution of water.

3.7 COD

Chemical Oxygen Demand or COD is a measurement of the oxygen required to oxidize soluble and particulate organic matter in water. A COD test can be used to easily quantify the number of organics in water. The most common application of COD is in quantifying the amount of oxidizable pollutants found in surface water (e.g. lakes and rivers) or wastewater.

The organic matter, present in the water sample is oxidized by potassium dichromate in the presence of sulfuric acid, silver sulfate and mercury sulfate to produce carbon dioxide (CO_2) and water (H_2O). The quantity of potassium dichromate used is calculated by the difference in volumes of ferrous ammonium sulfate consumed in blank and sample titrations. The quantity of potassium dichromate used in the reaction is equivalent to the oxygen (O_2) used to oxidize the organic matter of wastewater.

3.8 Plants Used in this Study

As Cana Indica locally known as Kolaboti and Phragmites Australis locally known as Nol Ghas is mostly available in Hatirjheel Lake area and there was some study on them has done to determine the potentiality to treat different types of wastewater in Bangladesh, we have selected Cana Indica and Phragmites Australis. Though there were some differences among the potentiality of plant species but in this study overall potentiality is counted.

3.9 Experimental Setup

From secondary source and desktop analysis background data of rainfall, evaporation, climate condition, lake geography, flow pattern, flow velocity and volume, existing lake water quality etc are collected and analyzed. Then from background data, residence period for Hatirjheel Lake are calculated and total eight pilot projects are set up. Each pilot project consisted of a water tank of 1.83m x 1.07m x 1.22m. About 300 Liter (±2%) water flows along each pilot project every day and in total 2100 Liter (±2%) in seven days retention period. How much water requires to flow is calculated from collected background data of Hatirjheel Lake. There is a change found at the time of checking background data collected from desktop study of published journal or thesis on Hatirjheel Lake water. The retention time and dry period flow is calculated about 7 days (for Sonargaon inlet to water bus station) and 2.53m^3/s but Hatirjheel authority confirmed that now they are capable to divert more water with pipeline and for construction of some new structure some water are already diverted from upstream as a result dry period residence time increases to 14 day (for Sonargaon inlet to before water bus station). As already our pilot project is adjusted with 7 days retention period, the retention time kept similar and at the time of calculation a relationship between retention time and treatment capacity established.

3.10 Setting up of Pilot Scale Project

Total eight tanks of each 1.83m x 1.07m x 1.22m size were set up parallelly behind the Sonargaon Hotel as shown in figure 4.3. Each two tanks comprised one unit. Three tanks were kept for testing water sample and one unit is kept for monitoring the plant growth, deposition of sediments, natural occurrence etc. Primarily each tank is filled with fully fresh water and floating bed were put in one tank of each unit. Two tanks of each unit are connected with pipes are shown in Figure 4.4. After a week we have changed the full water of all four units and used Hatirjheel lake water and fresh water in 1:1 ratio. After two weeks the ratio was changed to 2:1 and finally after one month all tanks were filled with lake water only showing in figure 4.3. Then with only lake water they were kept closed for four weeks. Total development period took about eight (8) weeks. After development we have started taking inlet and outlet water quality sample for testing. But before selecting this set up, we have tried different types of set up which includes:

a. 100% coverage with plants with only Cana Indica (in two tanks).

b. 100% coverage of Plants with Phragmites Australis (in two tanks).

This set ups were tried just only thumb basis and we have tried out which set up approximately may reduce the most pollutants.

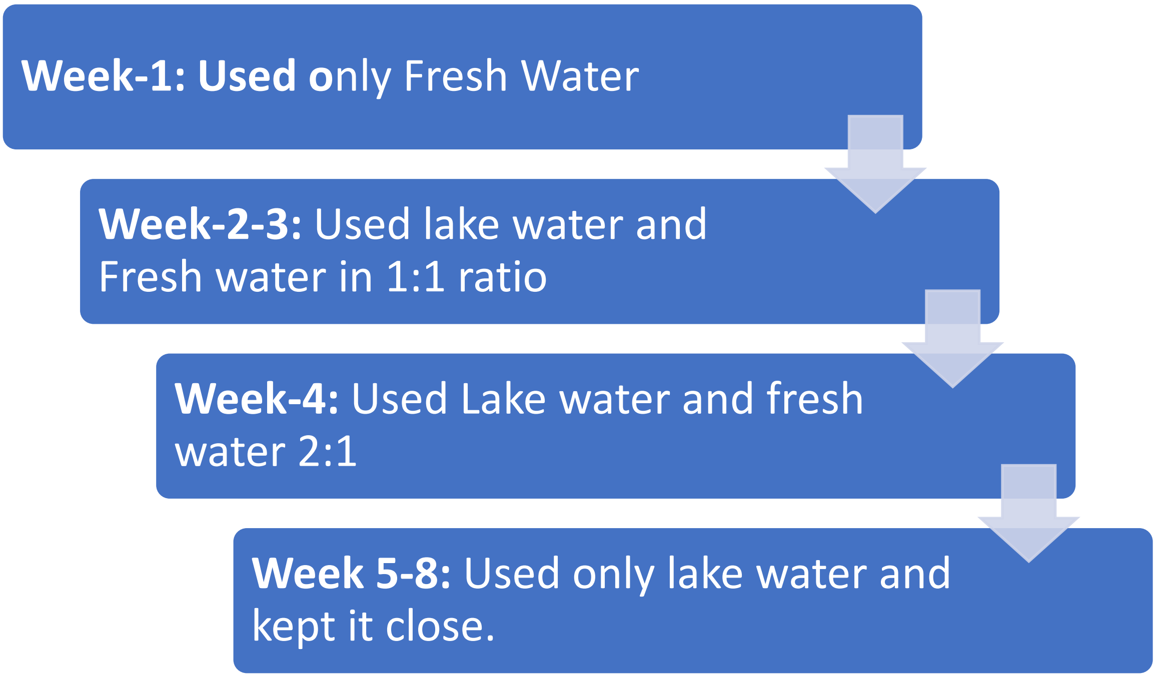


Figure 3.7: Development of Pilot Project

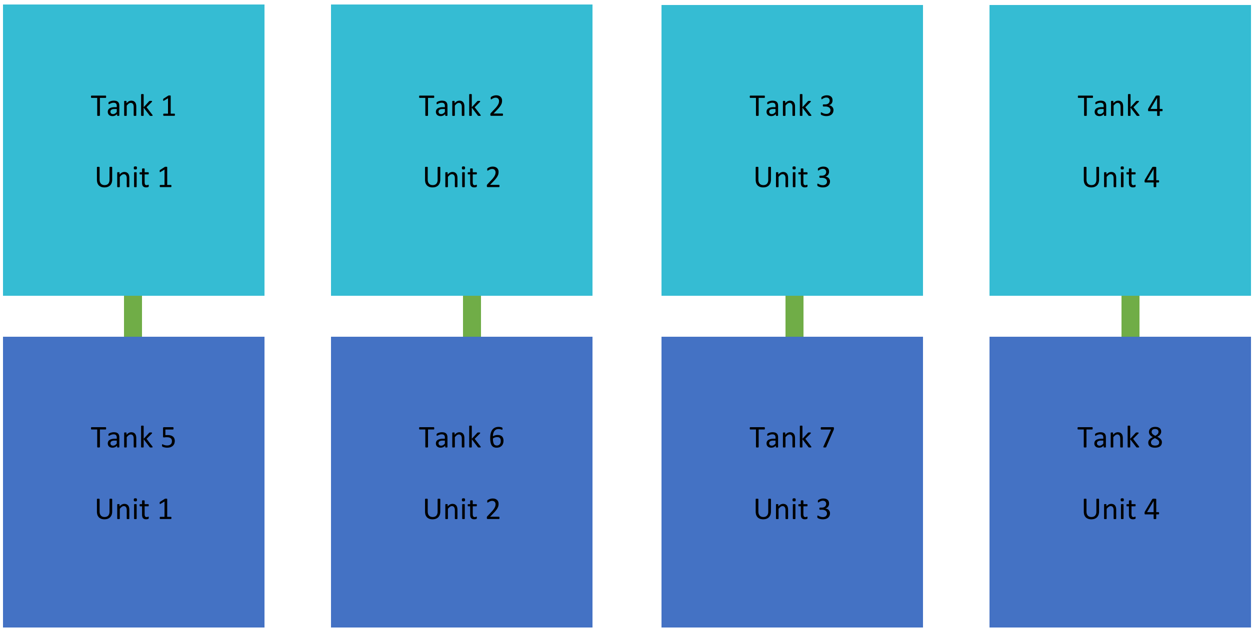


Figure 3.8: Experimental Set Up of tanks

(Source-Prepared by Author)

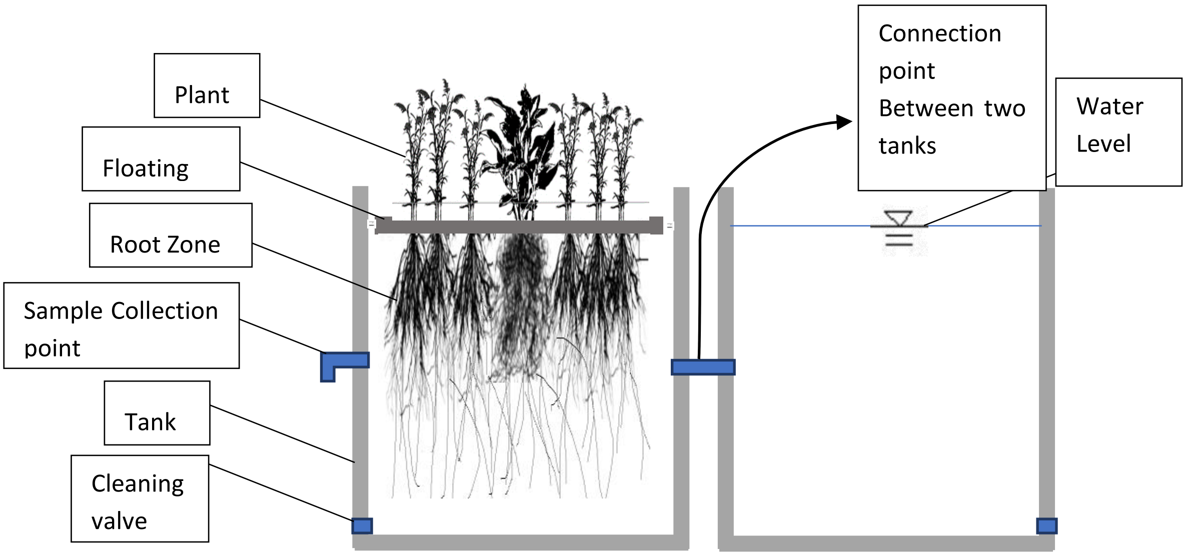


Figure 3.9: Schematic arrangement of one unit

(Source-Prepared by Author)

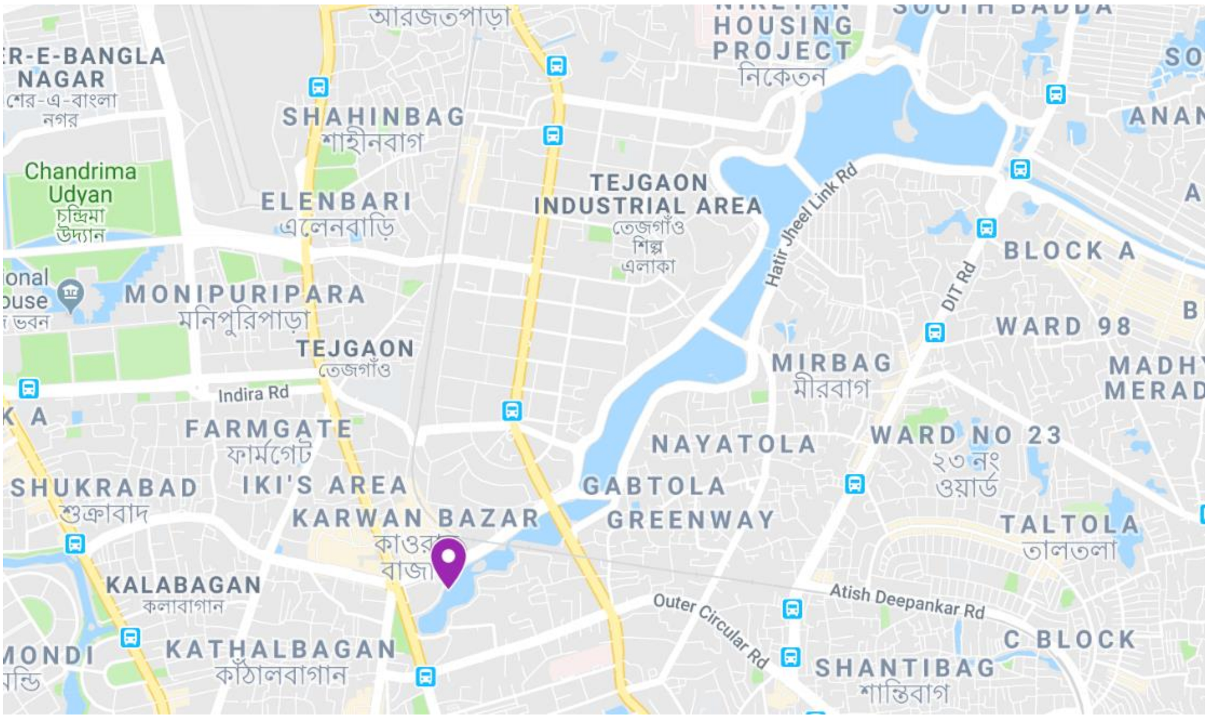


Figure 3.10: Lake Water Collection Point

3.11 Construction of Floating Mat

Floating mat is constructed using four-inch (4”) diameter pipe attaching with elbo with PVC glue. So that no water can enter within the pipe. The pipe frame provides enough buoyant forces for keeping mat floating. A net fastens tightly with the pipe frame and supported with cross bracing to prepare the bed for plant.

Figure 3.11: Selection of Plastic Water Containers

(Source: Photo taken on 10 August 2017)

Figure 3.12: Construction of Floating Mat

(Source: Photo taken on 25 August 2017)

Figure 3.13: Plantation on the Floating Mat kept inside Water Container

(Source: Photo taken on 27 august 2017)

Above this floating mat a thin layer of straw (dry stalks of cereal plants after the grain and chaff have been removed) surrounding the plant is used and then a layer of mud surrounding the plant is used to support the plant. Cana Indica and Phragmites Australis are planted in such a manner that the root can easily grow below the mat passing net. Finally, the mat floated in pilot scale tank and plantation was done. In some planted bed where most of the plants are P. Australis or no water above the mat, we used only some rope to keep plants vertical. The plants intake all kinds of nutrients from water and the role of soil and straw is only to keep plants stand vertical and ensure root zone below the mat.

Figure 3.14: Installation of Floating Mat

(Source: Photo taken on 30 August 2017)

Figure 3.15: Inspection of the Growth of Plants

(Source: Photo taken on 25 October 2017)

Figure 3.16: Experimental Site for collection of lake water

(Source: Photo taken on 25 august 2017)

Figure 3.17: Plant Growth after Development Phase

(Source: Photo taken on 25 October 2017)

Figure 3.18: Growth of Root Zone after development Phase for Cana Indica

(Source: Photo taken on 25 October 2017)

Figure 3.19: Growth of Root Zone after development Phase for Phragmites Australis

(Source: Photo taken on 25 October 2017)

CHAPTER 04: EXPERIMENTAL RESULTS

CHAPTER : 04

EXPERIMENTAL RESULTS

4.1 Introduction

Natural treatments for wastewater are always simple process to implement and requires very less effort and low cost because the treatment process run itself with very minimum effort and human intervention after installation. In our system we are planning to introduce an integrated system led by different types of constructed wetlands for water treatment of Hatirjheel Lake water. Treatment of wastewater through constructed wetlands followed many complex matrices of natural process which depends largely on natural conditions and very much difficult to calculate. The lake is designed to hold water for recreational purpose and separated drainage system is installed beside two banks of lake for municipal wastewater, storm swear and other different types of wastewater. The wastewater from drainage are mixing with lake water regularly. The flow volume, velocity and types and varies highly in dry and rainy season. Again, the lake is about 4 km long and due to human interventions (i.e. infrastructures, water taxi, recreational boat etc.) the water quality is very much diversified.

4.2 Removal Analysis of Constructed Wetland System

Removal analysis of constructed wetland is calculated for floating treatment wetlands. As dry season is the most critical period for pollution in lake, dry period time data is taken for efficiency calculation of floating wetlands. Total three months data are taken from end of October to end of January. In dry period residence time for water in treatment zone (including both primary and secondary) is about 12 days-26 days (taken avg. 14 days). That means water takes 12 days to pass the area of primary and secondary treatment zone. We have constructed and operated our pilot wetlands system for 10 days residence time for primary treatment and 4 (four) days for secondary treatment. Removal analysis of 7 days residence time with area calculation is given below.

4.3 Removal Calculation of Constructed Floating Wetlands

Constructed wetlands are wastewater treatment systems which have a diverse set of pollutant removal pathways from wastewater including pathogens. Unlike other conventional wastewater treatment systems in which removal processes are optimized by a series of separate unit operations designed for a specific purpose, multiple removal pathways simultaneously take place in one or two reactors. Wetland plants play several important roles in treatment wetlands. Primarily, their roots and rhizomes provide attachment sites for microbial biofilms increasing the biological activity per unit area compared to open water systems such as ponds. They diffuse the flow, limiting hydraulic short-circuiting, and can also release small amounts of oxygen and organic carbon compounds into the rooting matrix, fueling both aerobic and anoxic microbial processes. Indeed, a unique feature of TWs is their ability to support a diverse consortium of microbes; obligate aerobic, facultative, and obligate anaerobic microorganisms can be found due to large redox gradients, a factor contributing to the robust performance of a TW. The heterogeneous distribution of redox conditions within a TW is caused by several factors, especially the presence of the macrophyte root system [42]

Figure 4.1: Treated Water (Left) Vs Hatirjheel Water (Right)

(Source: Photo taken on 30 November 2017)

Figure 4.2: Outlets for Water Collection Point

(Source: Photo taken on 25 October 2017)

4.4 BOD$_5$ Analysis

Biochemical Oxygen Demand is a measure of the oxygen consumption capacity of a wastewater i.e. the level of oxygen required, under standard conditions, to stabilize organic wastes by microbial processes. BOD$_5$ removal is the lowering of demand for dissolved oxygen required for biological decomposition processes in the water column; hence, BOD$_5$ removal can be accomplished by biological decomposition in open-water zones and by flocculation and sedimentation in fully vegetated zones. In FWS wetlands, removal of the soluble BOD$_5$ is due to microbial growth attached to plant roots, stems, and leaf litter that have fallen into the water. Because algae are not present with the complete plant coverage, water surface reaeration provides the major sources of oxygen for these reactions in addition to plant translocation of oxygen from the leaves to the rhizosphere (U.S. EPA, 1980). Bacteria attached to plant stems and the humic deposits are the major factor for BOD$_5$ removal.

4.4.1 Analysis of BOD in Dry Season

Total 11 weeks data starting from 20 October 2017 were collected for analysis of BOD$_5$ in Hatirjheel Lake. Two separate samples were collected from the treated water from CFW containing Cana Indica locally known as Kolaboti and treated water from a separate CFW containing Phragmites Australis locally known as Nol Ghas respectively for the study. The first week lake water BOD_5 value is considered as reference for evaluating the performance of CFWs containing Kolaboti and Nol Ghas.

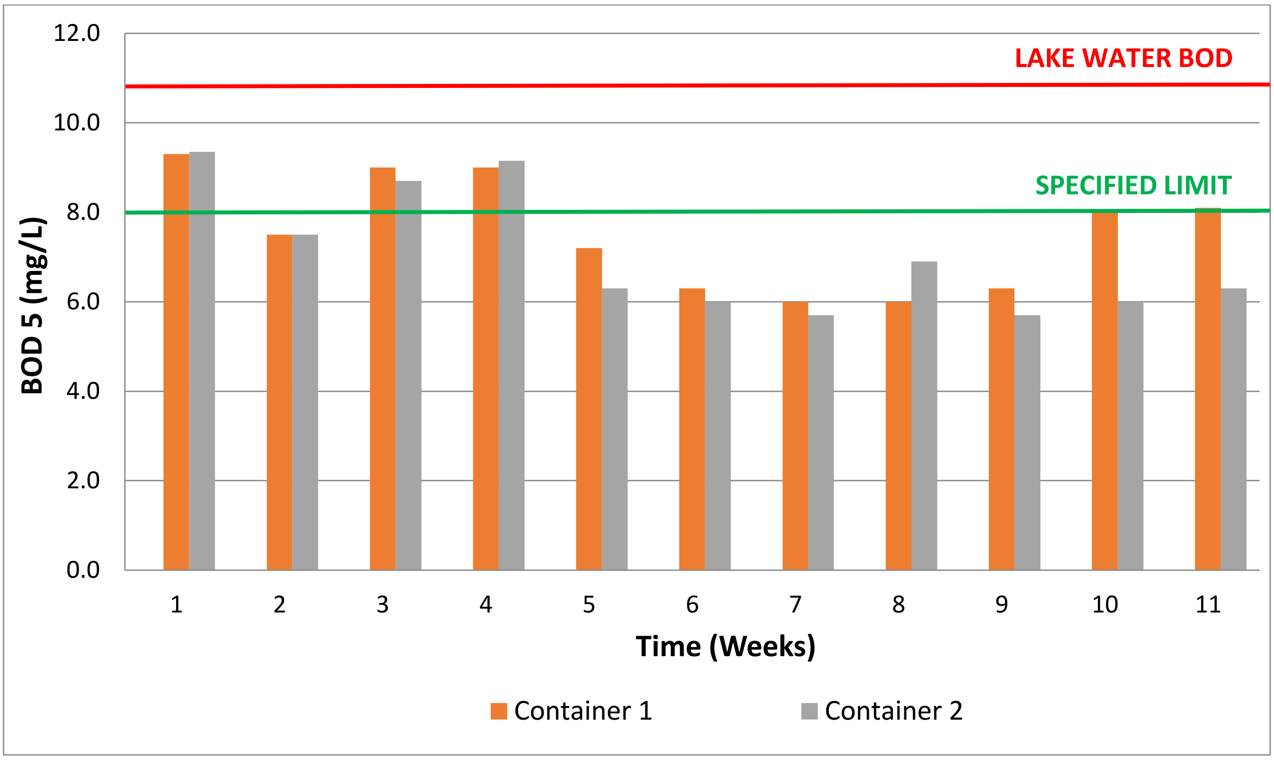


Figure 4.3: BOD_5 Chart for Lake Water (Control) Vs Treated Water (Dry Season)

The first week BOD_5 value of lake water was found 10.86 mg/L which is more than the specified limit i.e. 8 mg/L. It indicates that the lake water of Hatirjheel is severely polluted in terms of BOD_5. Both the CFWs containing Kolaboti and Nola Ghas effectively removed the BOD_5 to a significant amount. For up to 4 weeks during the maturation of system, the BOD_5 of treated water was above 8 mg/L. But after full maturation of system, the BOD_5 of treated water for both the container dropped below the severe limit.

4.4.2 Analysis of BOD_5 in Wet Season

Total 06 weeks data starting from 14 August 2018 were collected for analysis of BOD_5 in wet season. Similar to dry season two separate samples were taken and the first week BOD_5 value of lake water in wet season was taken as reference for evaluation. Unlike dry season only 06 weeks data were collected since the system had already matured fully.

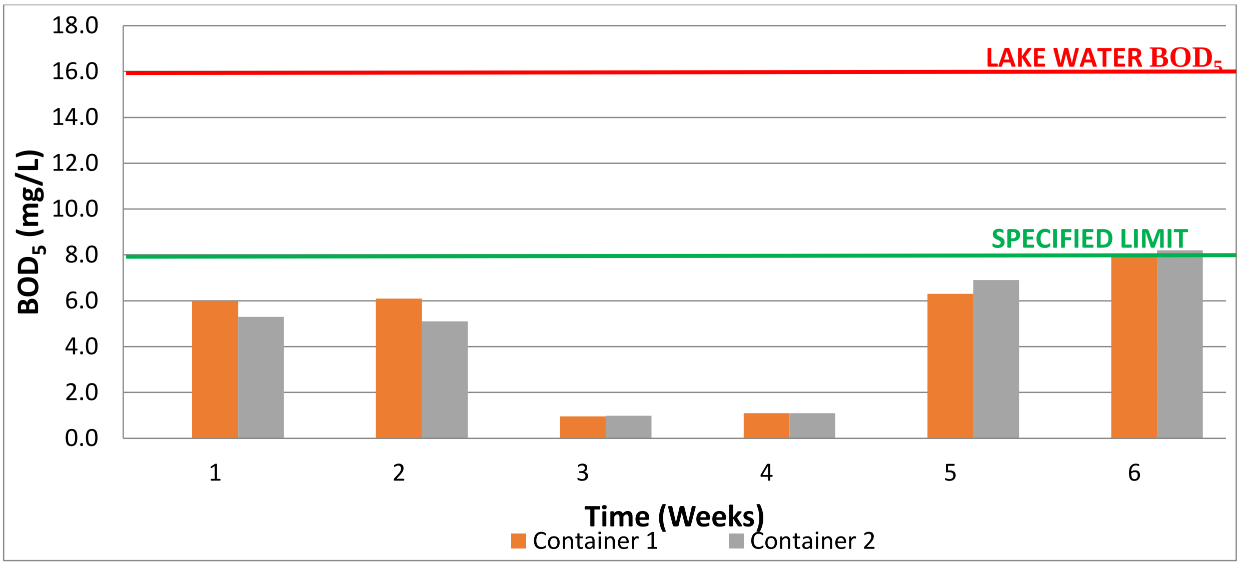
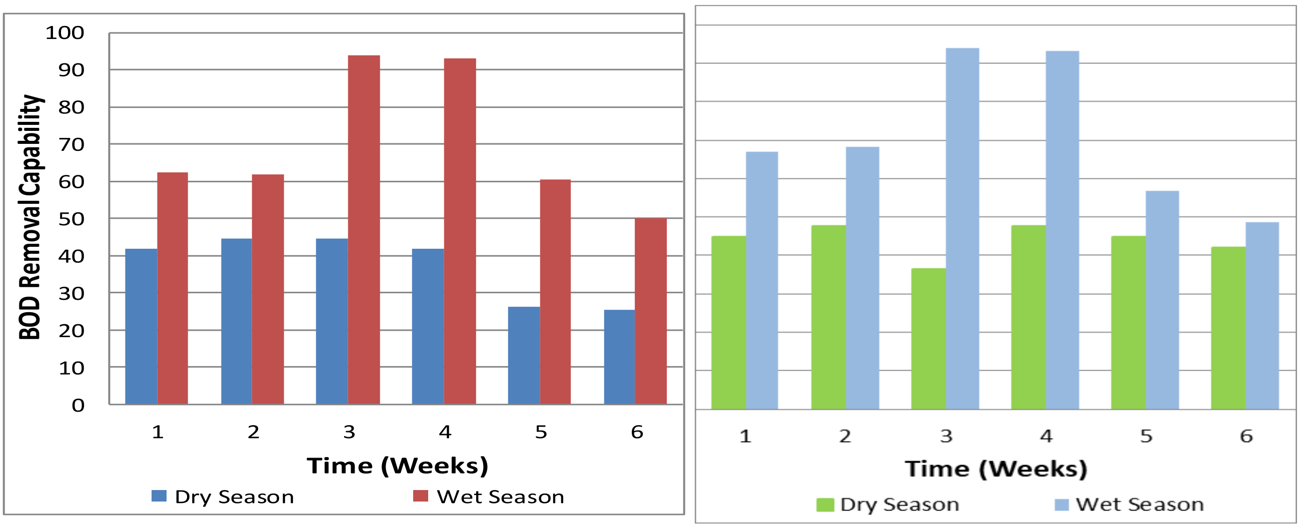


Figure 4.4: BOD_5 Chart for Lake Water (Control) Vs Treated Water (Wet Season)

The BOD_5 of lake water in wet season was also above the severe limit (16 mg/L). Treated water from both the CFWs saw a significant decline in the BOD_5 values which were below the severe limit in all cases.

4.4.3 Effect of Seasonal Variation on BOD_5 Removal

The BOD_5 removal capacity is calculated based on the first week BOD_5 value of lake water and the subsequent values of BOD_5 from the two CFWs. For both CFWs it is seen that the BOD_5 removal capability is higher in wet season compared to dry season for all the weeks. For both the CFWs it is observed that the efficiency is higher after the plants are fully matured and then it slightly reduces in the passing weeks.



(a) (b)

Figure 4.5: BOD_5 Removal in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.5 COD Analysis

Chemical oxygen demand (COD) is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is commonly expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per liter (mg/L). A COD test can be used to easily quantify the number of organics in water. In this lake water COD level is very high due to intrusion of municipal and industrial wastewater. The lake water COD increases from week 1 to week 9 due to dry period. And before tasting in week 10 due to diverting some wastewater with drainage line and for rain the concentration decreases. But we have found that, in our treated water COD level is continuously decreasing. This has occurred due to the growth of root zone of plants. Plants root zone microbial activities are breaking the nutrients and decreasing the COD level. At the same time for plant activity DO is increasing which also affect the COD reduction in treatment unit.

4.5.1 Dry Season

From the experimental data it is seen that the initial COD of lake water is 165 mg/L which is way beyond the specified limit. Influent COD in normal domestic sewage is generally 600 – 900 mg/l and it is then treated to at least 75 -100 mg/l before discharge to minimize pollution potential.

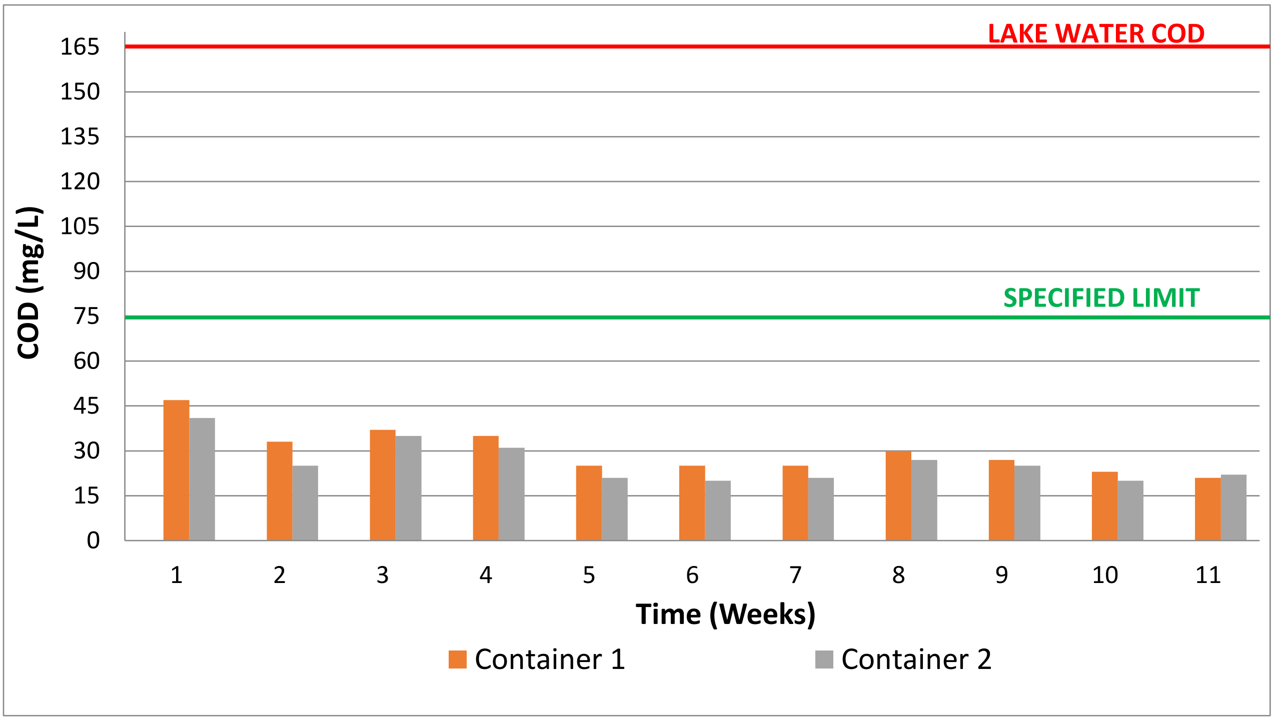


Figure 4.6: COD chart for Lake Water (Control) Vs Treated Water (Dry Season)

Both Kolaboti and Nol Ghas were very effective in removing COD values below the severe limit. The effectiveness increased with each passing week as the plants grew to full maturation.

4.5.2 Wet Season

Total 06 weeks data were collected for analysis of COD in wet season since the system was already in full maturation. The value of lake water COD was more than the severe limit first week of analysis. The COD value of treated water was below the severe limit for all the cases and hence it can be said that both the containers were very effective in removing COD in the wet season also.

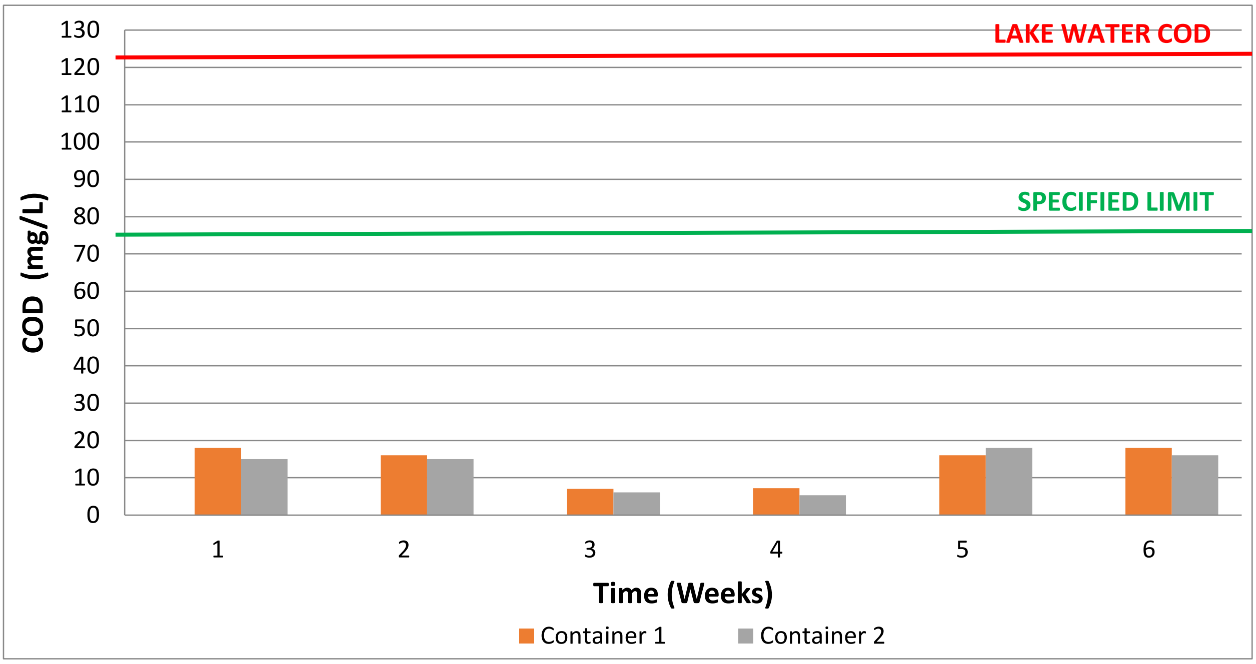
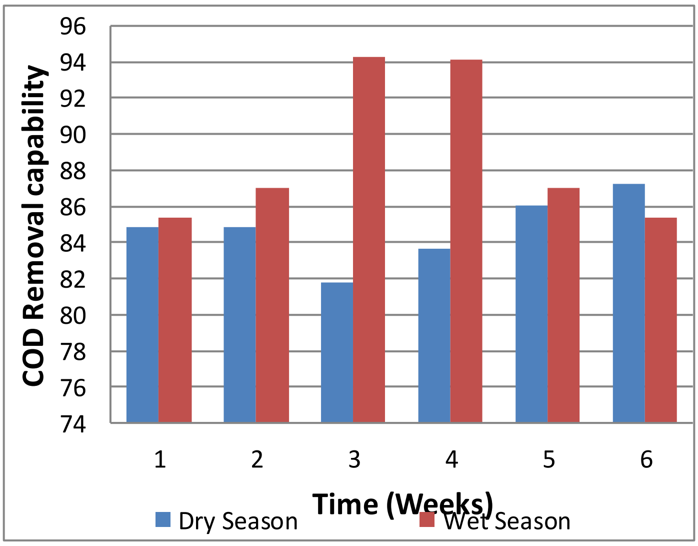


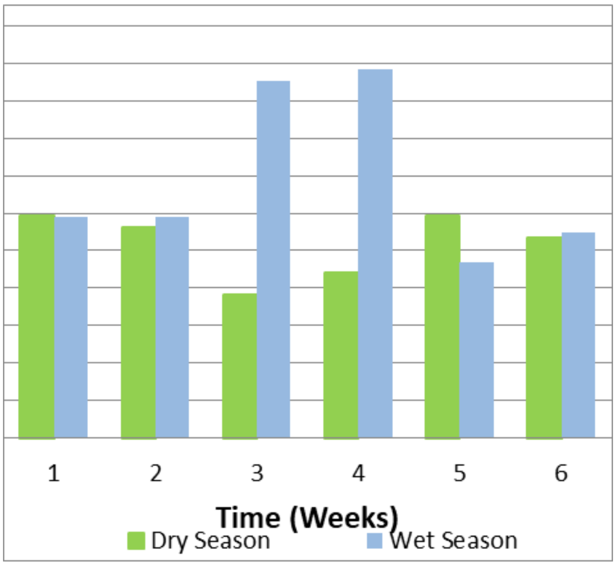
Figure 4.7: COD Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.5.3 Effect of Seasonal Variation on COD Removal

Figure 4.8 shows the effect of seasonal variation in COD removal capability for both the CFWs.



(a)



(b)

Figure 4.8: COD Removal in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

From the graph it is seen that the COD removal capability of Kolaboti was higher in wet season except the last week of analysis. In case of Nol Ghas the capability was higher in dry season in initial weeks but later on it was better in wet season.

4.6 Dissolved Oxygen (DO) Analysis

Dissolved Oxygen (DO) is one of the most important indicators of water quality. It is essential for the survival of fish and other aquatic organisms. Oxygen dissolves in surface water due to the aerating action of winds. Oxygen is also introduced into the water as a byproduct of aquatic plant photosynthesis. When dissolved oxygen becomes too low, fish and other aquatic organisms cannot survive. DO can be expressed as a concentration per unit volume or as a percentage. Healthy water should generally have dissolved oxygen concentrations above 6.5-8 mg/L and between about 80-120 %. However according to ECR 1997, the DO level for recreational and fisheries use should be greater than 5.0 mg/L.

4.6.1 Analysis of DO in Dry Season

From the experiment it was seen that the DO level of lake water in dry season was alarmingly low. It was even below half of the required level for aquatic life. The DO level decreased with time and was found minimum in the final week of analysis. Both the wetlands contributed in increasing the DO level of treated water but failed to attain the standard limit. This is mainly due to the small size of wetland and limited number of plants used in them. But if used in large amount the wetland might prove very effective in raising the DO level to specified limit.

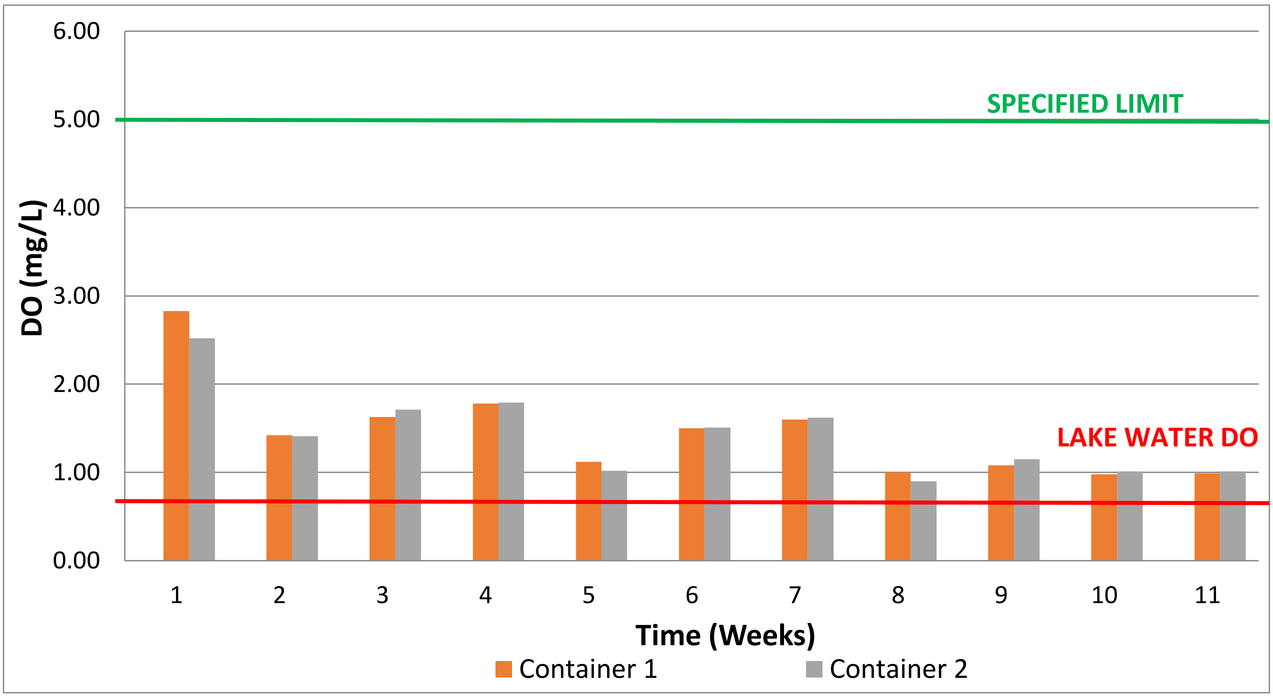


Figure 4.9: DO Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.6.2 Analysis of DO in Wet Season

The DO level of lake water was found alarmingly low in wet season also. It needs immediate attention and treatment for healthy aquatic life. The DO level was even below 1.5 mg/L making it impossible for any aquatic life to survive in the lake. But both the wetlands showed very good potential in increasing the DO level in wet season also.

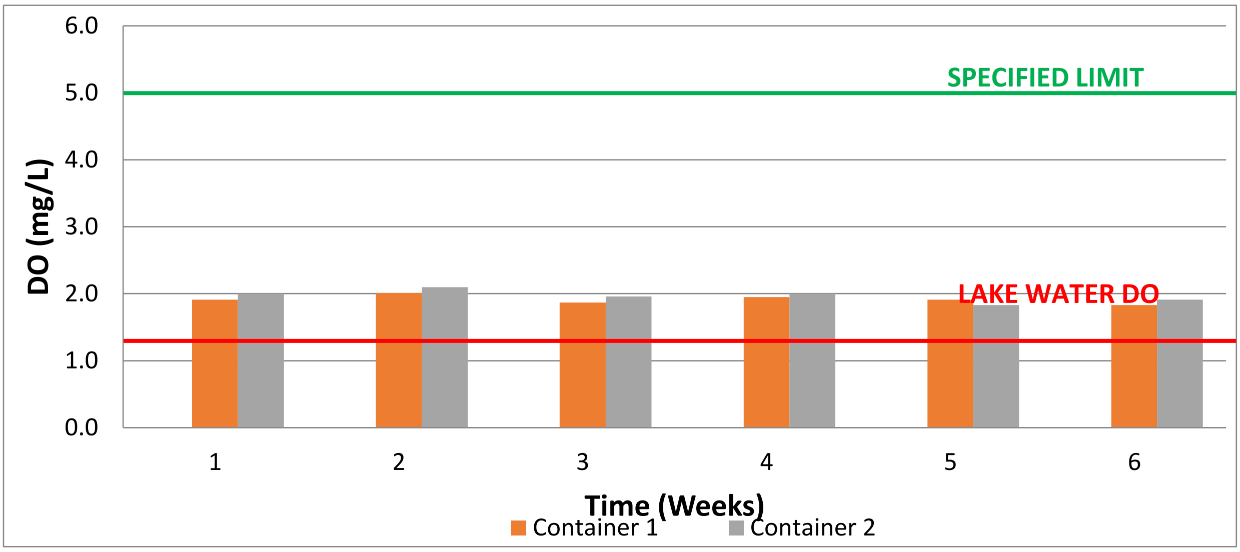
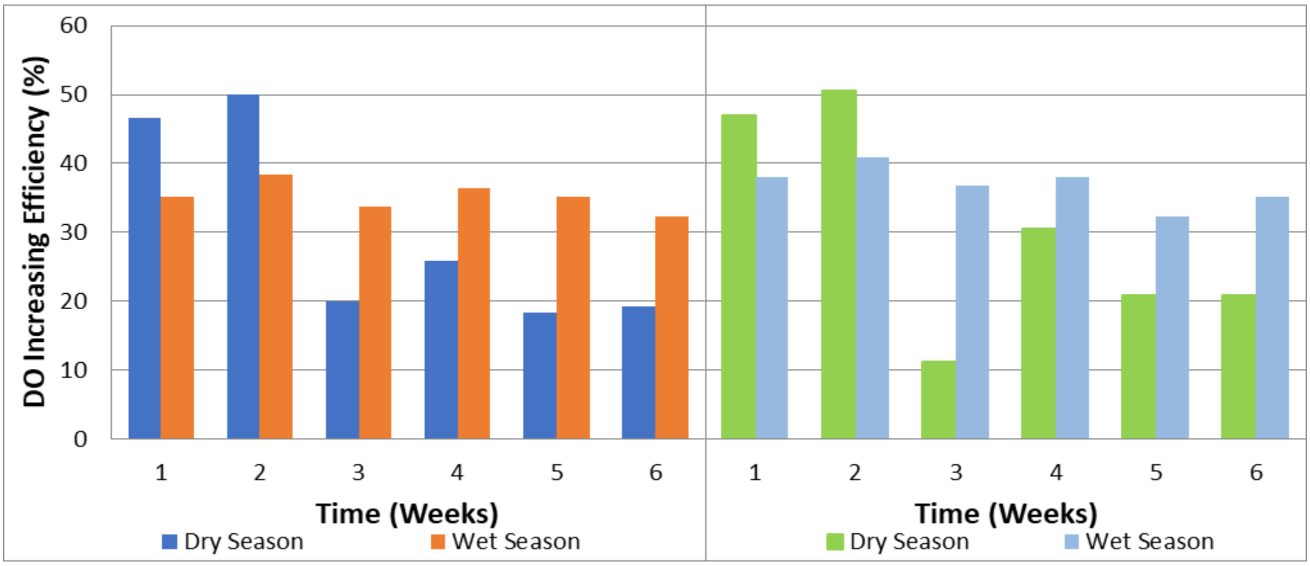


Figure 4.10: DO Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.6.3 Effect of Seasonal Variation on DO Increase

For both the CFW it is seen that the DO increasing ability is higher in the dry season at the start of analysis. But after initial 02 weeks of analysis both the CFW shows better performance in the wet season.



(a) (b)

Figure 4.11: DO Improvement in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.7 Colour Analysis

Colour analysis is any technique by which an unknown color is evaluated in terms of known colours. Colour analysis is important for the monitoring process of liquids and as a measurement of water quality for distribution or discharge. Colour in water or wastewater may result from the presence of metals, organic acids, microbiological matter and/or industrial wastes. Nowadays, the colour scale used for measuring water quality can also be referred to as the Pt-Co (Platinum-Cobalt) / APHA (from American Public Health Association) / HU (Hazen Units) colour scale. It ranges from 0 (clean or distilled water) to 500 (very dark, polluted water).

4.7.1 Analysis of Colour in Dry Season

From the graph it is seen that the colour value of lake water in the initial week was 350 which indicates severe pollution of lake water. But both the CFWs effectively removed the colour value of lake water to satisfactory limit. During the mid-period of analysis the colour value of treated water for both the CFWs dropped significantly due to heavy seasonal rainfall. But it increased slightly during the later period.

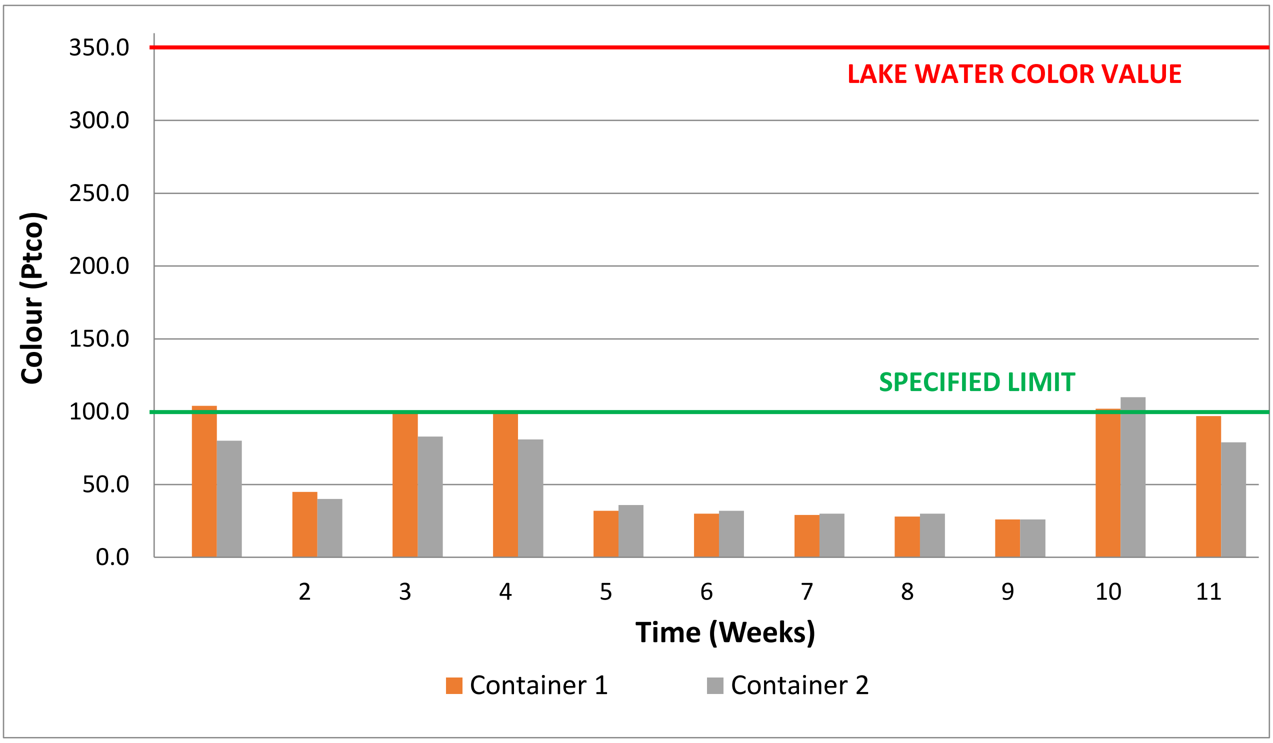


Figure 4.12: Colour Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.7.2 Analysis of Colour in Wet Season

The colour value of lake water was slightly better in wet season compared to dry season because of seasonal rainfall. The colour value was found 220 Ptco in wet season which is in the medium range.

Both the CFWs showed excellent performance in terms of colour removal capability and could effectively bring the colour value under the specified limit for all the weeks during analysis.

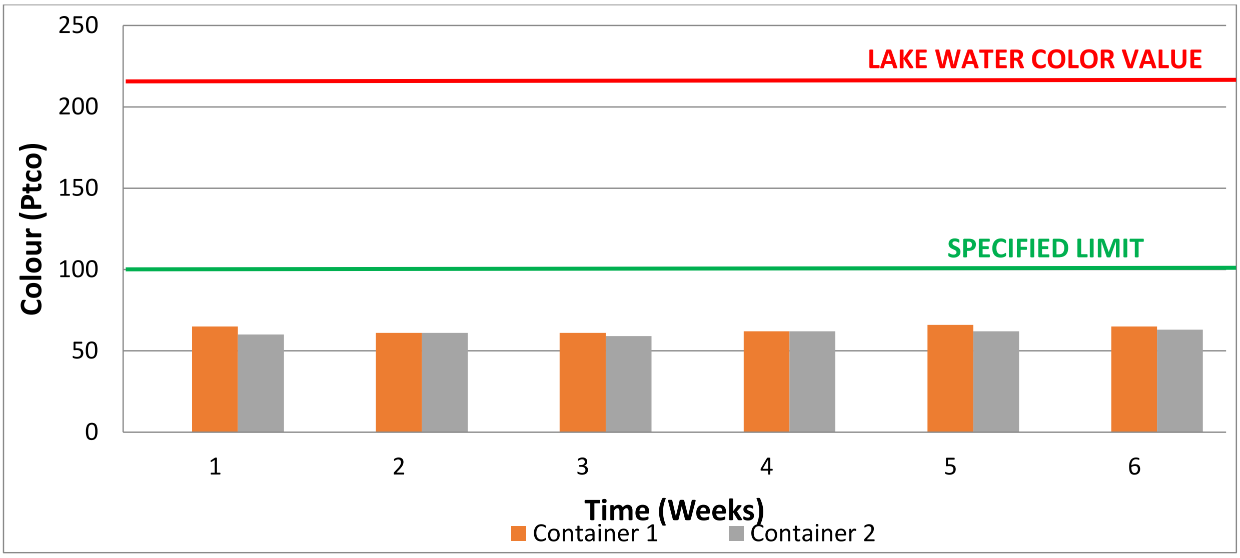
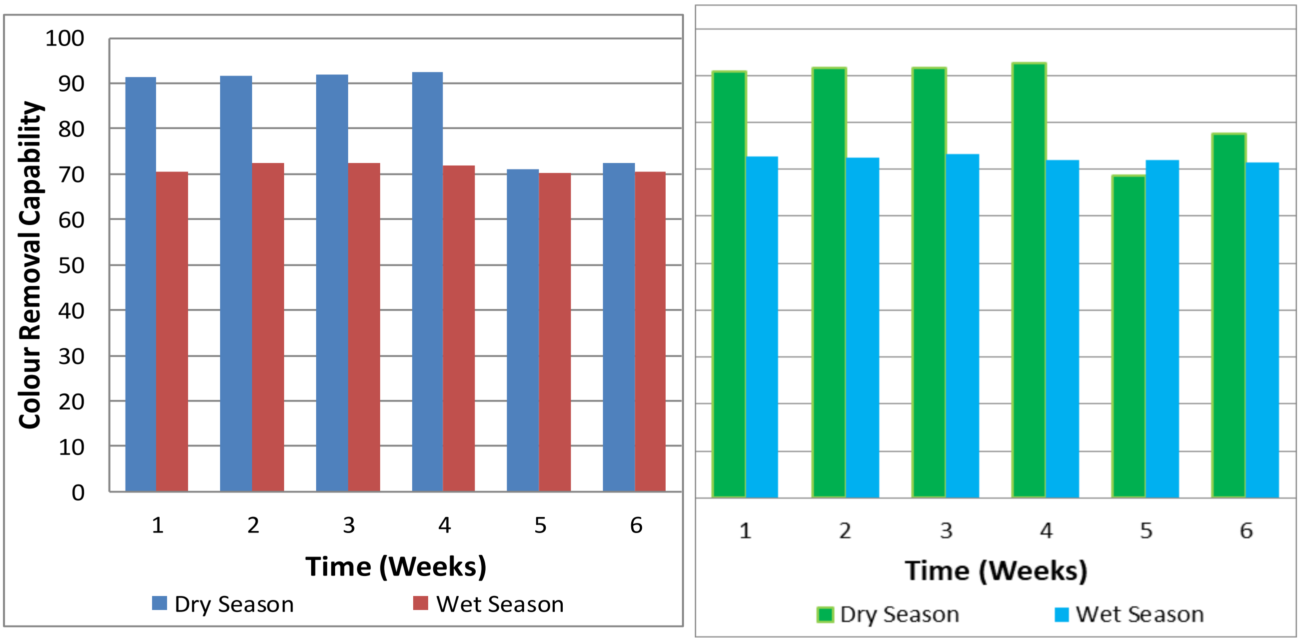


Figure 4.13: Colour Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.7.3 Effect of Seasonal Variation on Colour Removal

For both CFWs it is seen that the Colour removal ability is higher in dry season compared to wet season for all the weeks. For both the CFWs with Kolaboti and Nol Ghas the ability was found much higher in dry season comparing the wet season.



(a) (b)

Figure 4.14: Colour Removal in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.8 TDS Analysis

Total Dissolved Solids (TDS) are solids in water that can pass through a filter. TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. Primary sources for TDS in receiving waters are agricultural runoff and residential (urban) runoff, clay-rich mountain waters, leaching of soil contamination, and point source water pollution discharge from industrial or sewage treatment plants. The most common chemical constituents are calcium, phosphates, nitrates, sodium, potassium, and chloride, which are found in nutrient runoff, general storm water runoff and runoff from snowy climates where road de-icing salts are applied. More exotic and harmful elements of TDS are pesticides arising from surface runoff. The United States has established a secondary water quality standard of 500 mg/l to provide for palatability of drinking water.

4.9 Analysis of Total Dissolved Solids (TDS) in Dry Season

From the experimental data it is seen that the TDS of lake water in dry season is found quite satisfactory and below the specified limit i.e. 500 mg/L. Both the CFWs showed almost identical performance in terms of TDS removal ability. In an average both the CFW could lower the value of TDS by 80 – 100 mg/L.

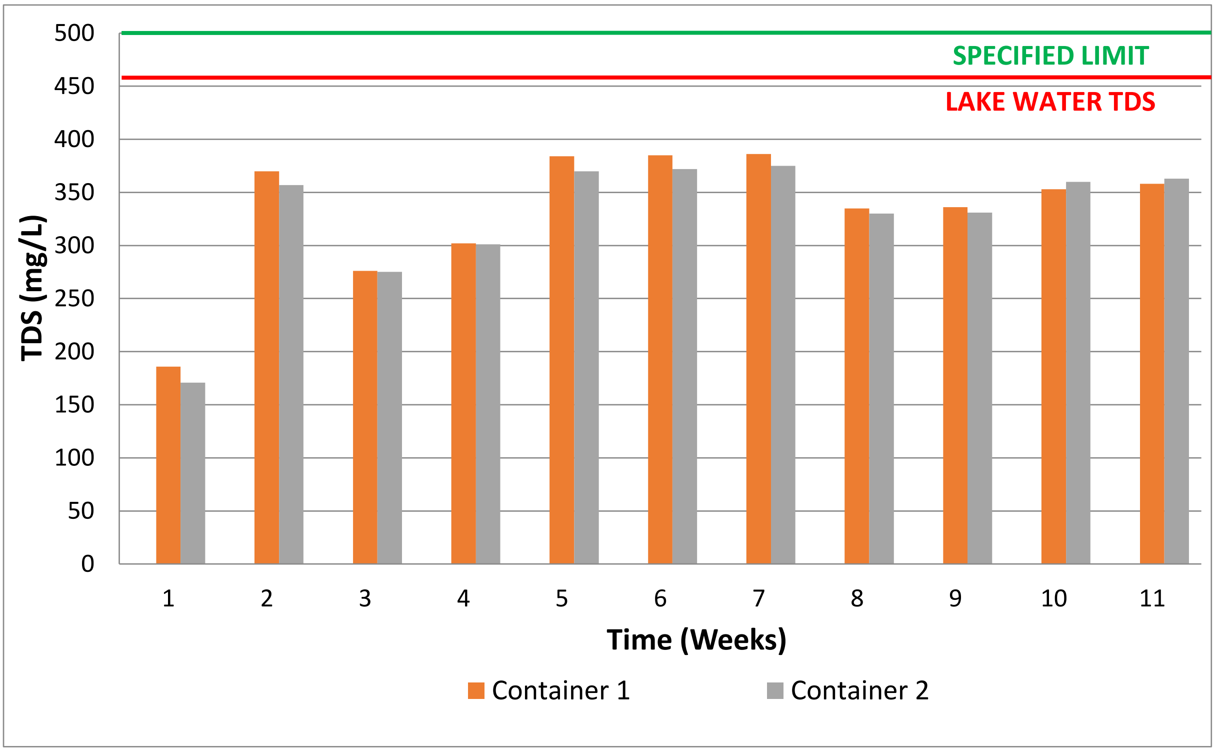


Figure 4.15: TDS Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.9.1 Analysis of TDS in Wet Season

The TDS value of lake water in wet season was also found below the specified limit which indicates that the lake water remains satisfactory in terms of TDS throughout the year. It indicates that the seasonal rain has very little effect on the TDS value of lake water. Both the CFWs could further lower the TDS value successfully by about 200 mg/L. It indicates that the CFWs perform better in wet season compared to dry season. Also CFW containing Kolaboti showed better performance in TDS removal than that of Nol Ghas.

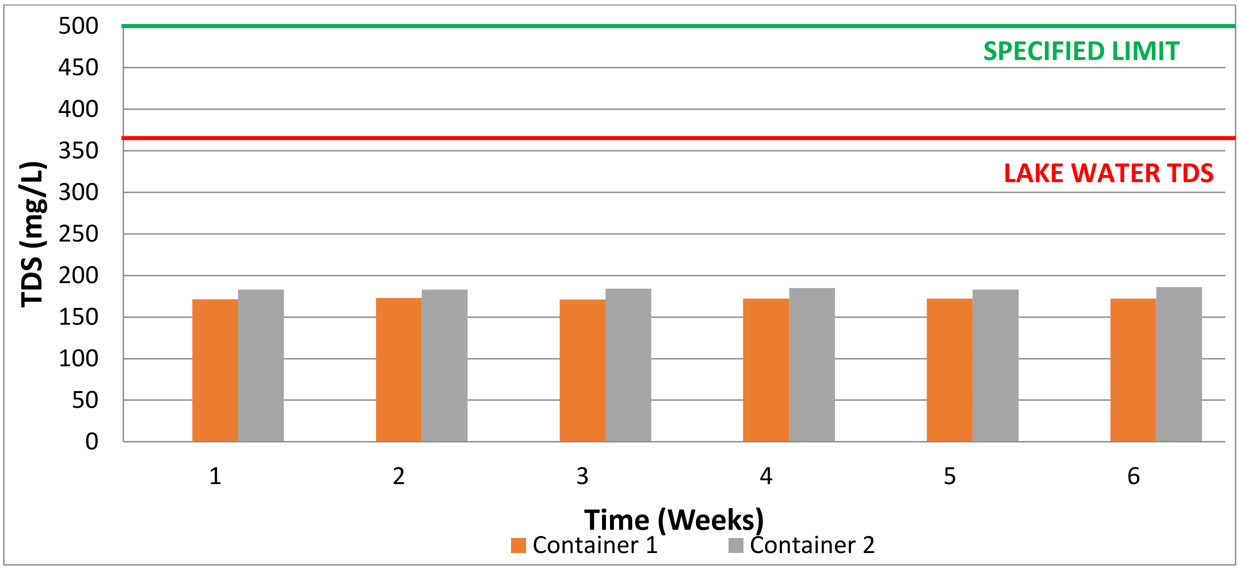


Figure 4.16: TDS Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.9.2 Effect of Seasonal Variation on TDS Removal

For both CFWs it is seen that the TDS removal capability is significantly lower in dry season compared to wet season for all the weeks. However, both the CFWs containing Kolaboti and Nol Ghas have shown almost similar performance trends in both the seasons.

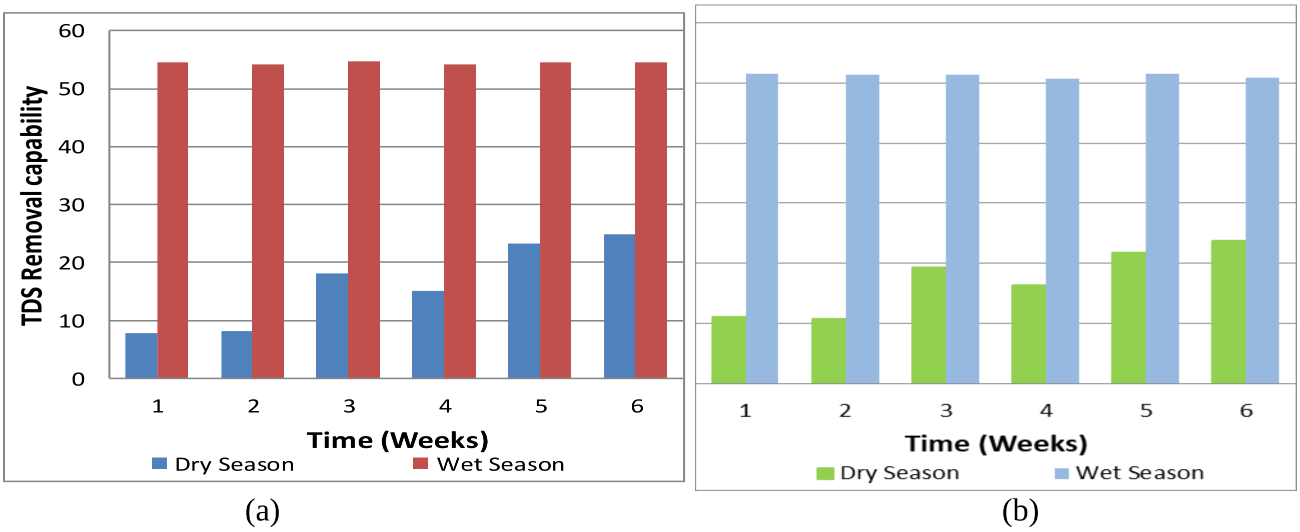


Figure 4.17: TDS Removal in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.10 Total Suspended Solids (TSS) Analysis

Total Suspended Solids (TSS) are the dry-weight of suspended particles that are not dissolved in a sample of water, that can be trapped by a filter and that is analyzed using a filtration apparatus. It is a water quality parameter used to assess the quality of a specimen of any type of water or water body, ocean water for example, or wastewater after treatment in a wastewater treatment plant. Total Dissolved Solids is another parameter acquired through a separate analysis which is also used to determine water quality based on the total substances that are fully dissolved within the water, rather than undissolved suspended particles. Total Dissolved Solids are differentiated from Total Suspended Solids (TSS), in that the later cannot pass through a sieve of 2 micrometers and yet are indefinitely suspended in solution. The term Settleable Solids refers to material of any size that will not remain suspended or dissolved in a holding tank not subject to motion, and excludes both TDS and TSS.

4.10.1 Analysis of TSS in Dry Season

The TSS value of lake water in dry season was also found below the specified limit i.e. 100 mg/L. From the experiment it is seen that both the CFWs exhibit excellent performance in terms of TSS removal ability. In average both the CFW lowered the TSS value by 65- 70 mg/L and the removal capability increased with each passing week. After maturation CFW with Nol Ghas showed slightly better performance than that of Kolaboti.

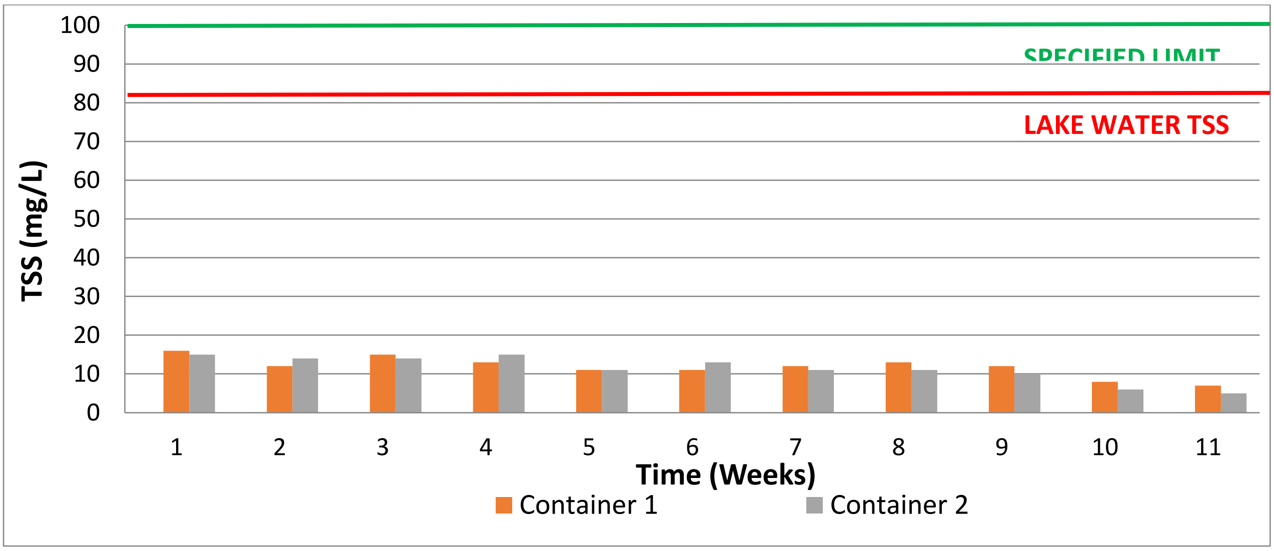


Figure 4.18: TSS Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.10.2 Analysis of TSS in Wet Season

Though the TSS of lake water in dry season was quite satisfactory but in wet season the value of TSS was beyond the specified limit. This is mainly due to deposit of suspended solids in lake water with increased surface runoff in rainy season. The TSS value in wet season was found 230 mg/L during the first week of analysis. The TSS removal capability was found very high from week 01 since the system was in full maturation. Though the removal efficiency of CFW with Kolaboti was slightly lower in initial week but later on it showed better performance than that of CFW with Nol Ghas.

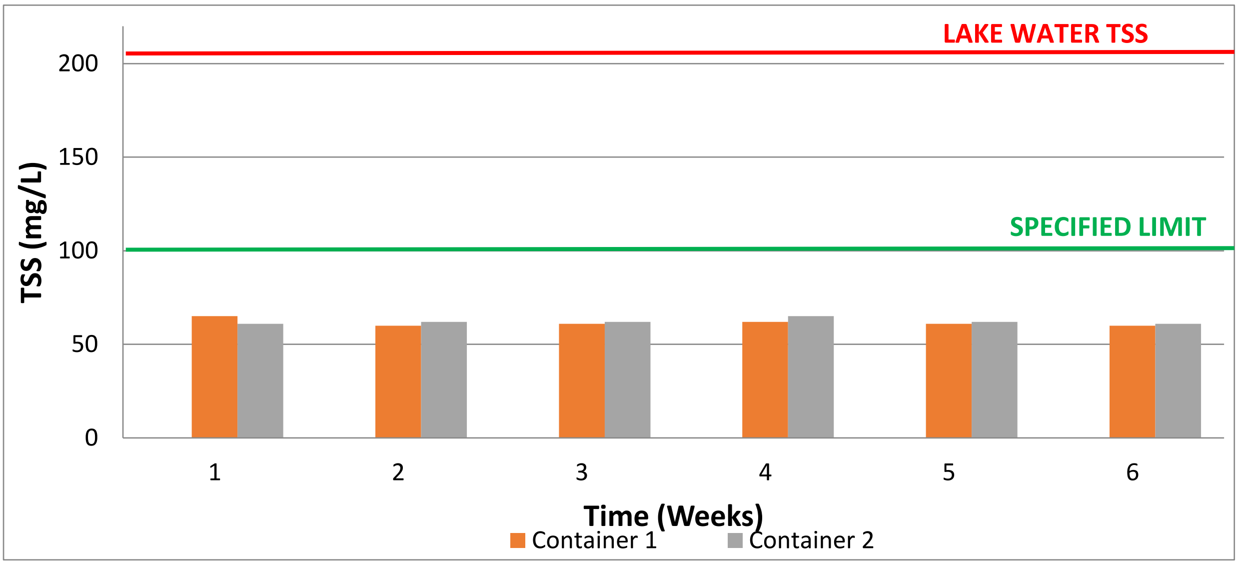


Figure 4.19: TSS Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.10.3 Effect of Seasonal Variation on TSS Removal

For both CFWs it is seen that the TSS removal ability is higher in dry season compared to wet season for all the weeks. The removal efficiency of Nol Ghas increases with each passing week in dry season but remains almost identical in wet season.

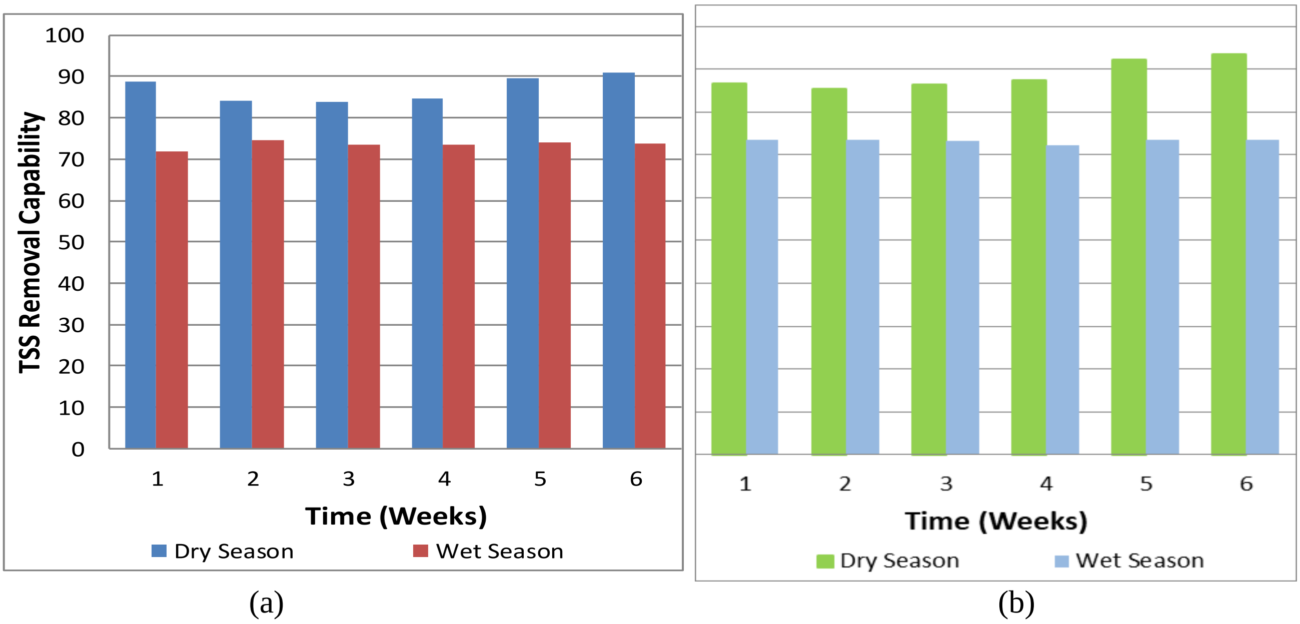


Figure 4.20: TSS Treatment in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.11 Nitrate Analysis

Nitrates are a form of nitrogen, which is found in several different forms in terrestrial and aquatic ecosystems. These forms of nitrogen include ammonia (NH_3), nitrates (NO_3), and nitrites (NO_2). Nitrates are essential plant nutrients, but in excess amounts they can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream. This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/L) or higher) under certain conditions. The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/L); in the effluent of wastewater treatment plants, it can range up to 30 mg/L. Sources of nitrates include wastewater treatment plants, runoff from fertilized lawns and cropland, failing on-site septic systems, runoff from animal manure storage areas, and industrial discharges that contain corrosion inhibitors.

4.11.1 Analysis of Nitrate in Dry Season

The nitrate value of lake water in dry season was found 2.4 mg/L which is beyond the specified limit (1 mg/L). It indicates severe pollution of lake water in terms of nitrate and is very harmful for the organs of fishes and any other living creatures. From the experiment it is seen that the nitrate removal ability varies significantly throughout the season and does not follow any pattern till week 06. The removal capability rises in week 04 and then it suddenly drops in week 05. Afterwards the removal ability gradually raises in week 11 for both the CFWs and they exhibit almost similar pattern in removal of nitrate.

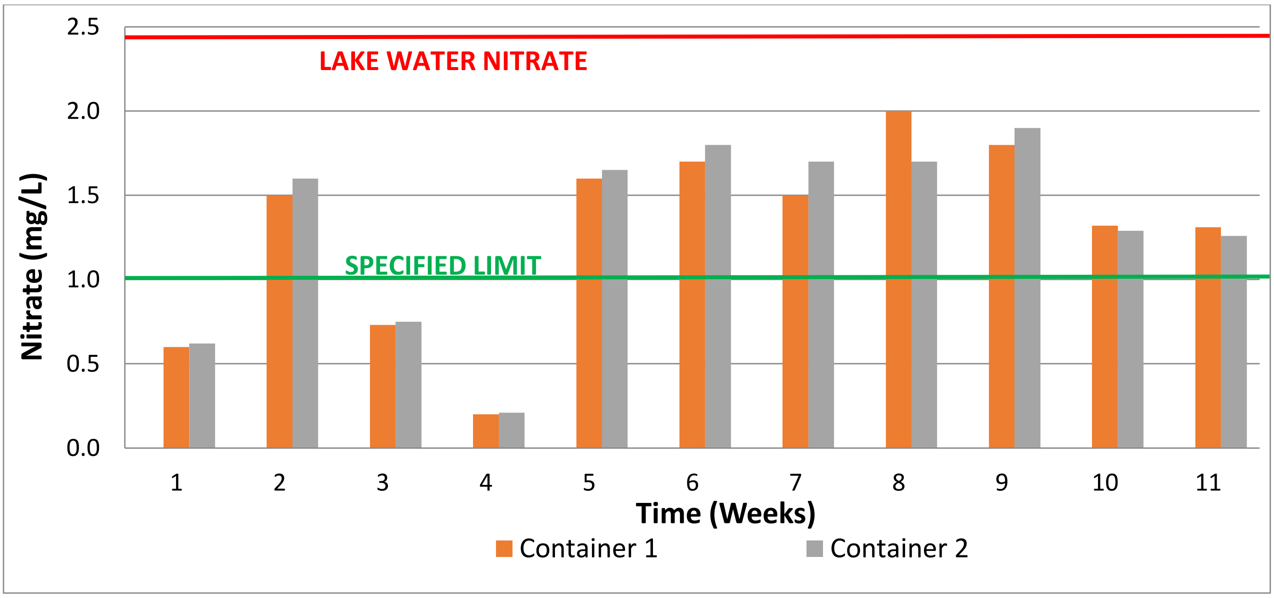


Figure 4.21: Nitrate Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.11.2 Analysis of Nitrate in Wet Season

The nitrate value of lake water was also beyond 1 mg/L in wet season also. In the mid period of analysis time the value was very low and in the range of 0.1 to 0.2 mg/L due to seasonal rainfall. It indicates that rain water significantly decreases the nitrate value. After week 04, the value again jumps.

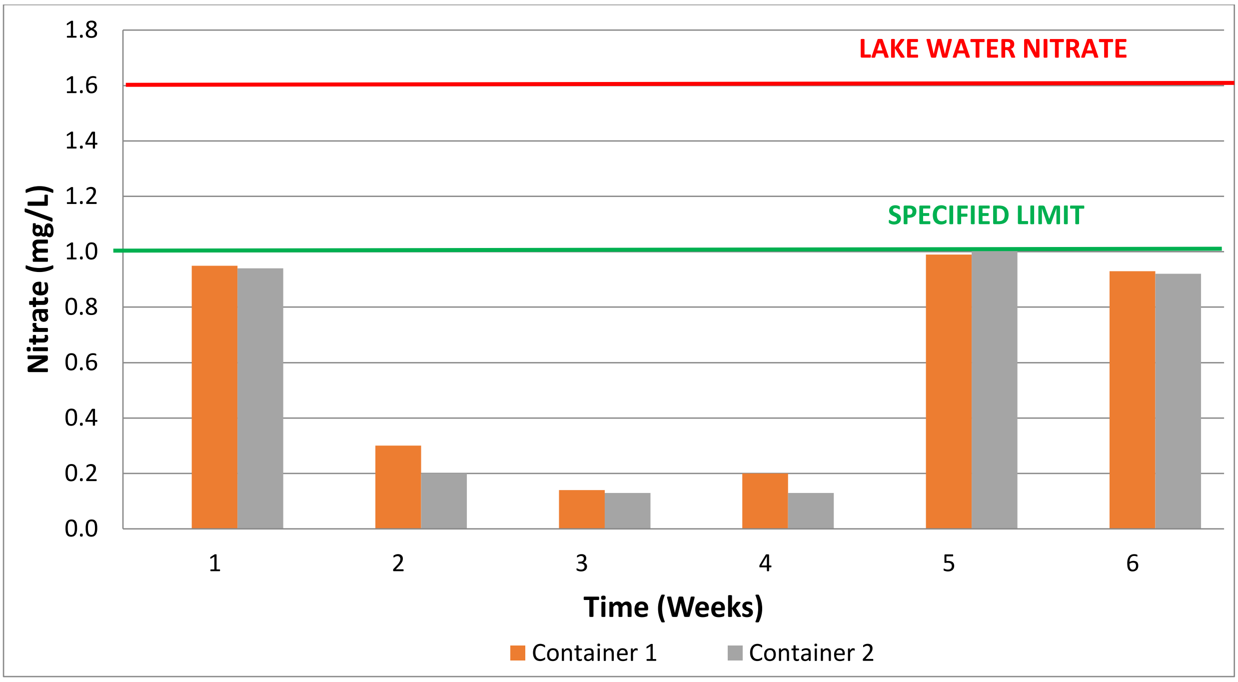
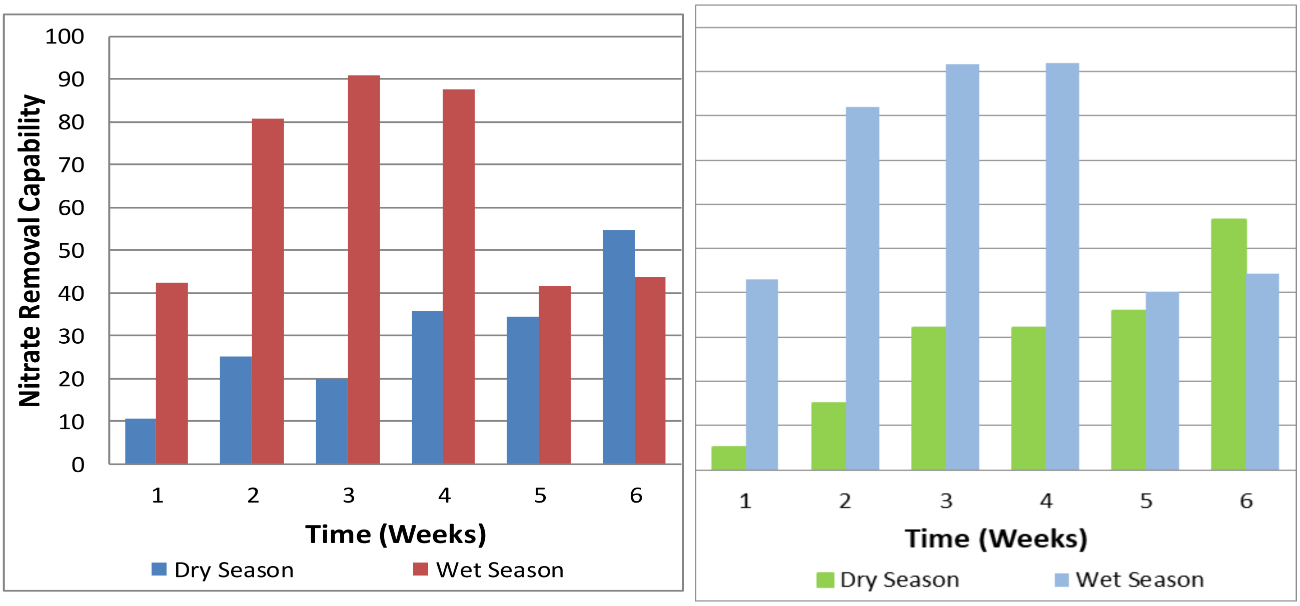


Figure 4.22: Nitrate Chart for Lake Water (Control) Vs Treated Water (Wet Season)

Both the CFWs have shown almost similar pattern in terms of nitrate removal ability in wet season. They could successfully bring the nitrate value below the specified limit throughout the wet season. Almost similar pattern was observed in case of nitrate removal efficiency in wet season when there was rain in week 03 and 04. Therefore, it can be said that the rain water has a marked effect in nitrate removal efficiency for both the CFWs.

4.11.3 Effect of Seasonal Variation on Nitrate Removal

The nitrate removal efficiency was found higher in wet season for both the CFWs except for the last week of analysis. From the graph it is seen that the removal ability in dry season rises gradually for both the CFWs but in wet season it does not follow any definite pattern mostly due to the effect of rainfall on nitrate values.



(a) (b)

Figure 4.23: Nitrate Treatment in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.12 Orthophosphate Analysis

Phosphorus is also an essential nutrient for plant growth in lakes and streams. Phosphorus is generally present in the form of orthophosphate (condensed phosphate or polyphosphate) in natural and waste waters. It commonly originates from human and animal wastes, agricultural runoff and household detergents. The discharge of excessive amount of phosphate ions from wastewater treatment plants may adversely affect the water quality of a receiving body. Domestic wastewater is an important source of inorganic nutrients such as ammoniacal-nitrogen (NH_4-N) and orthophosphate (PO_4-P). Phosphorus was found between the levels of 3–15 mg/L in domestic wastewater; merely about 3 mg/L was formed by the breakdown of protein wastes while the majority came through the usage of detergents. Many countries around the world including the European Union allow 1–2 mg/L as the limit of total phosphorus (TP) for effluent discharge in wastewater treatment plants. However, some regions followed more strict measures of around 0.5–0.8 mg P/L to control eutrophication. Algal blooms can occur if the concentration of PO_4-P exceeds 0.1–0.5 mg/L which cause “eutrophication” in the receiving water, thus phosphate removal is an essential part of domestic wastewater treatment.

4.12.1 Analysis of Orthophosphate in Dry Season

The phosphate content in lake water was found exceedingly high in dry season for all the weeks. Therefore, if not treated properly, the lake may experience algal blooms due to exceeding value of phosphate content. Both the CFWs containing Kolaboti and Nola Ghas effectively removed the orthophosphate to a significant amount. The value dropped below the severe limit from the start of the analysis.

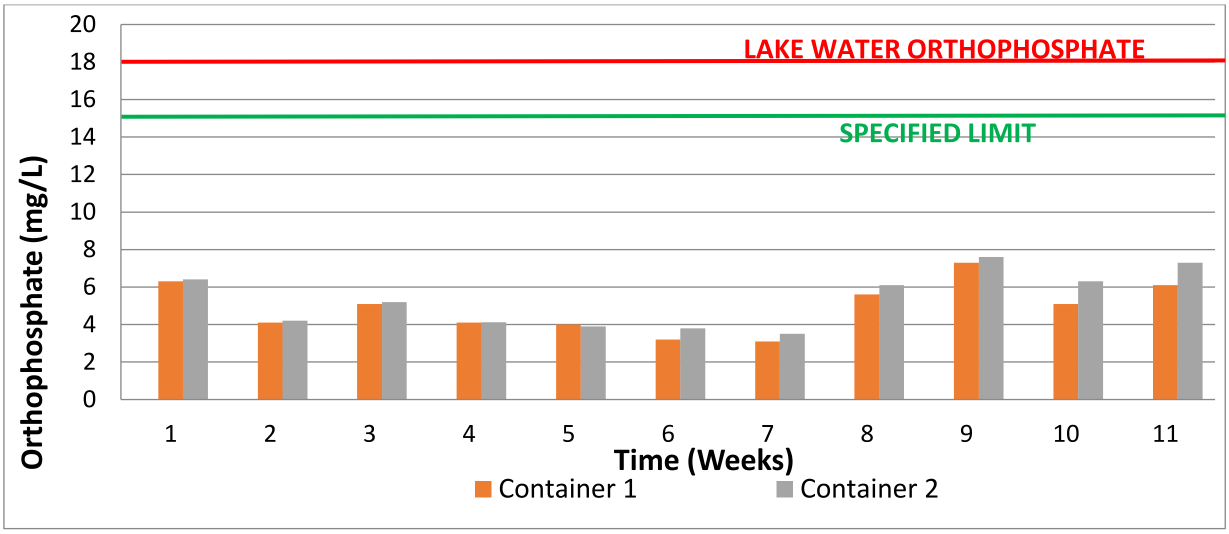


Figure 4.24: Orthophosphate Chart for Lake Water (Control) Vs Treated Water (Dry Season)

From the graph it is seen that the orthophosphate removal efficiency for both the CFW is almost identical throughout the season. The removal efficiency is almost similar upto week 09 and after that the CFW with Kolaboti showed a slightly better performance than that of Nol Ghas.

4.12.2 Analysis of Orthophosphate in Wet Season

Unlike dry season, the phosphate level of lake water in wet season was slightly better even though it was beyond the limit of domestic wastewater. Both the CFW showed excellent performance in treating orthophosphate. The value of treated water was below the severe limit for all the cases. The efficiency dropped significantly in week 03 and 04 due to seasonal heavy rain. Both the wetlands show almost similar pattern in orthophosphate removal efficiency in wet season.

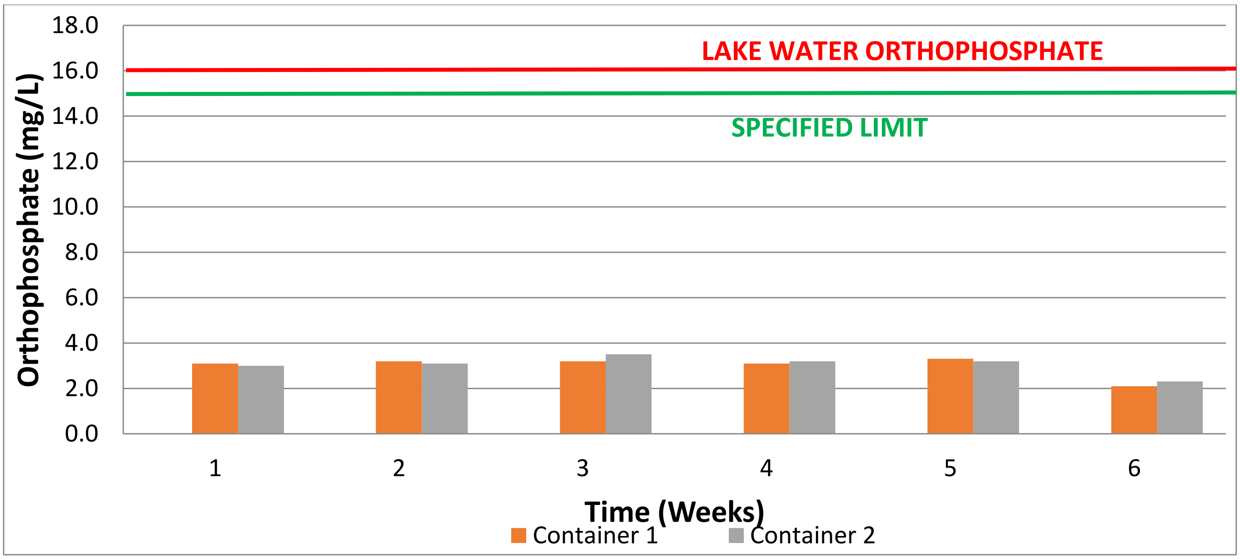
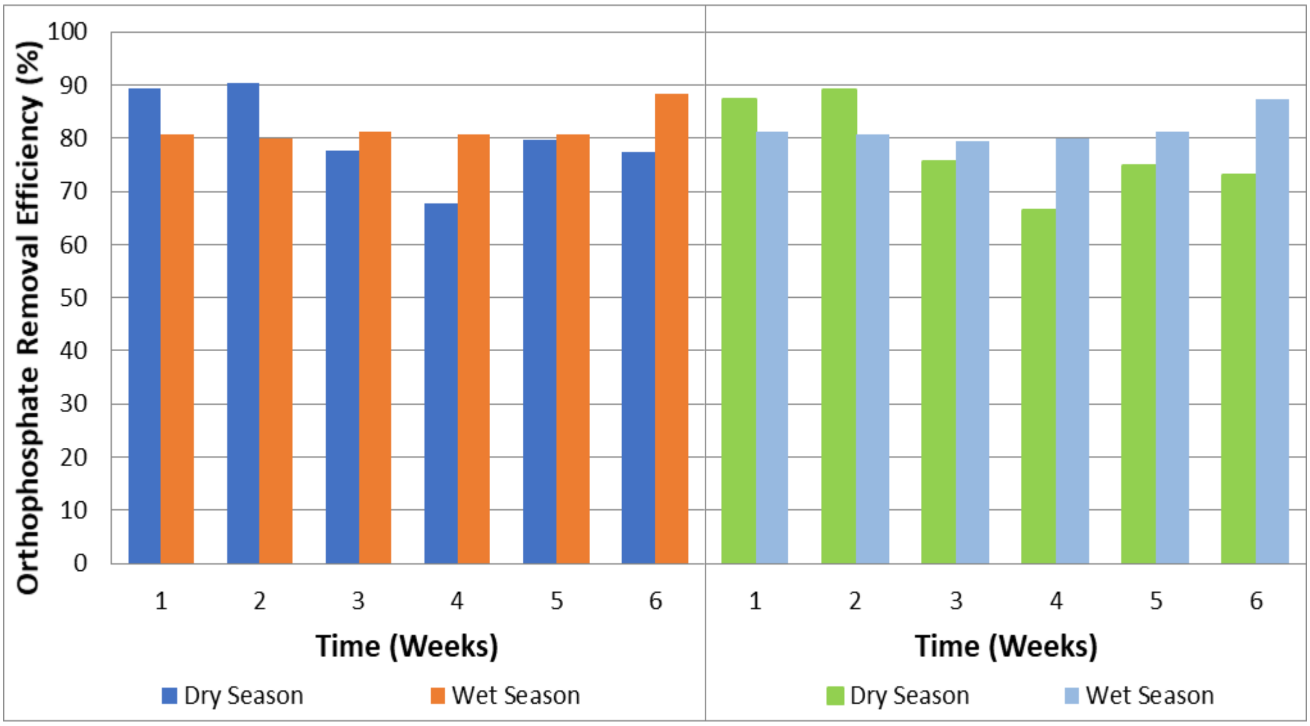


Figure 4.25: Orthophosphate Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.12.3 Effect of Seasonal Variation on Orthophosphate Removal

For both CFWs it is seen that the orthophosphate removal efficiency is higher in dry season compared to wet season up to week 03. Afterwards tboth the wetlands show better performance in wet season on the later stages of analysis.But the efficiency for both the season is almost identical.



(a) (b)

Figure 4.26: Orthophosphate Treatment in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.13 Ammonia Analysis

Ammonium (NH_4^+) — or its uncharged form ammonia (NH_3) — is a form of nitrogen which aquatic plants can absorb and incorporate into proteins, amino acids, and other molecules. High concentrations of ammonium can enhance the growth of algae and aquatic plants. Bacteria can also convert high ammonium to nitrate (NO_3^-) in the process of nitrification, which lowers dissolved oxygen. Ammonia in water is either un-ionized ammonia or the ammonium ion. Typically, the value reported is the sum of both forms and is reported as total ammonia or simply - ammonia. The relative proportion of the two forms present in water is highly affected by pH. Nitrification is the most common way to biologically remove ammonia in wastewater lagoons. In this process, ammonia treatment occurs via bacteria already present in the water. These bacteria break down the ammonia and eventually promote the release of nitrogen gas into the atmosphere. The end result is that your wastewater lagoon ammonia is nitrified, resulting in lower ammonia levels in your lagoon effluent.

4.13.1 Analysis of Ammonia in Dry Season

The level of ammonia of lake water in dry season was found alarmingly high and was recorded 16 mg/L during the first week of analysis. Both the wetlands showed excellent performance in treating the ammonia level of the lake water. From the experiment is seen that the ammonia treatment efficiency was quite high from the very start even before the maturation of the CFWs. Both the wetlands exhibited almost similar pattern in treatment efficiency but CFW with Kolaboti showed better consistency throughout the season. But the treatment efficiency dropped with each passing week. This might be due to variation of lake water ammonia in dry season.

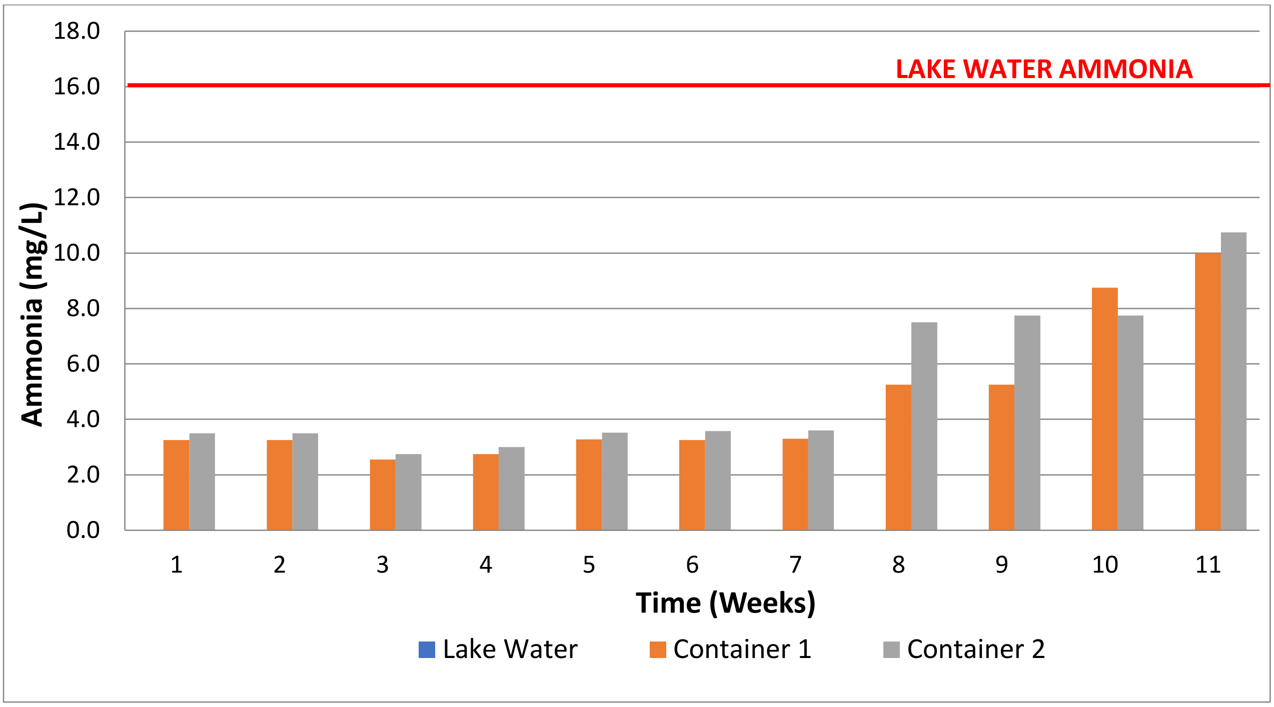


Figure 4.27: Ammonia Chart for Lake Water (Control) Vs Treated Water (Dry Season)

4.13.2 Analysis of Ammonia in Wet Season

The lake water level of ammonia in wet season was also exceedingly high and far beyond the specified limit. Both the CFWs show excellent performance in ammonia treatment efficiency from the very start since the system had already matured. Wetland with Nol Ghas showed better performance and consistency than Nol Ghas.

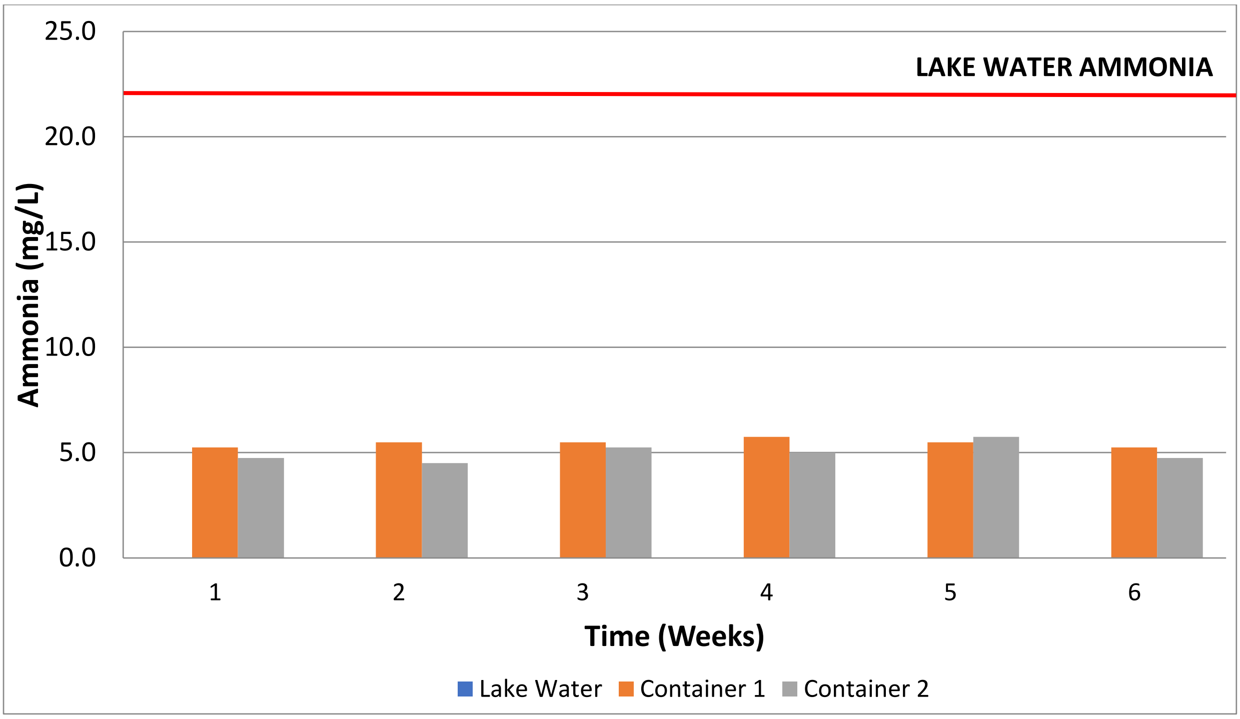


Figure 4.28: Ammonia Chart for Lake Water (Control) Vs Treated Water (Wet Season)

4.13.3 Effect of Seasonal Variation on Ammonia Removal

For both CFWs it is seen that the ammonia removal capability is higher in dry season compared to wet season for all the weeks except the last one.

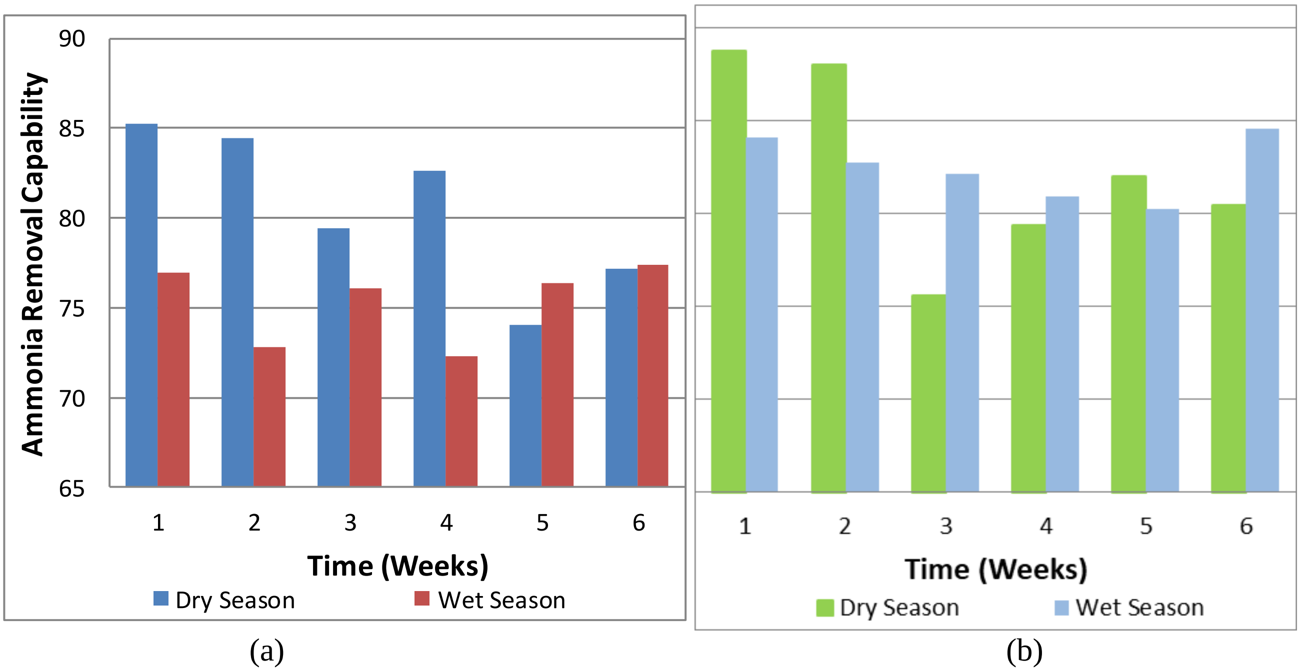


Figure 4.29: Ammonia Removal in Different Season (a) CFW with *Cana Indica* (Kolaboti) (b) CFW with *Phragmites Australis* (Nol Ghas)

4.14 P^{H} Analysis

P^{H} is a measure of how acidic/basic water is. The range goes from 0 to 14, with 7 being neutral. pHs of less than 7 indicate acidity, whereas a pH of greater than 7 indicates a base. pH is really a measure of the relative amount of free hydrogen and hydroxyl ions in the water. Water that has more free hydrogen ions is acidic, whereas water that has more free hydroxyl ions is basic. Since pH can be affected by chemicals in the water, pH is an important indicator of water that is changing chemically. pH is reported in "logarithmic units". Each number represents a 10-fold change in the acidity/basicness of the water. Water with a pH of five is ten times more acidic than water having a pH of six. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon) and heavy metals (lead, copper, cadmium, etc.). For example, in addition to affecting how much and what form of phosphorus is most abundant in the water, pH also determines whether aquatic life can use it. In the case of heavy metals, the degree to which they are soluble determines their toxicity. Metals tend to be more toxic at lower pH because they are more soluble. According to ECR 1997, the P^{H} for recreational and fisheries purpose should be in the range of 6.5 to 8.5.

4.14.1 Analysis of P^{H} in Dry Season

The P^{H} of lake water remains within the specified limit in the dry season. In general the lake water was found acidic in the dry season. Both the CFWs had very insignificant effect in the P^{H} value and they also maintained the P^{H} of treated water within the ECR specified range.

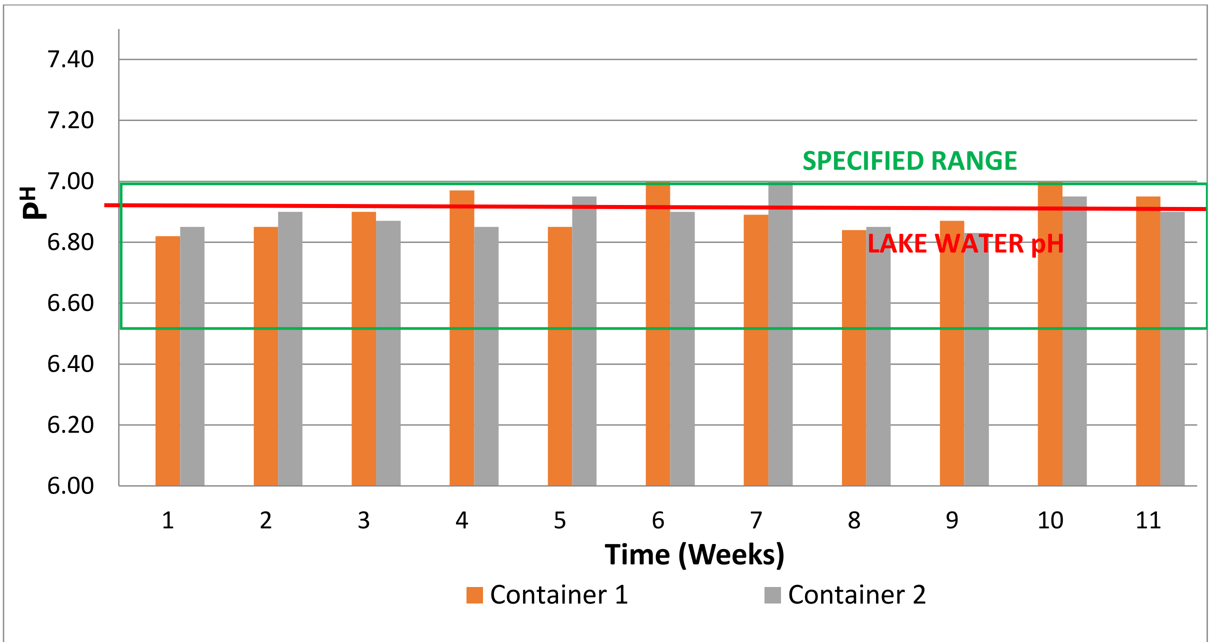


Figure 4.30: Analysis of P^{H} in Dry Season

4.14.2 Analysis of P^H in Wet Season

The P^H value of lake water was found acidic for all the weeks and it was also below the specified range of ECR i.e. below 6.5. But both the wetlands showed excellent performance in increasing the P^H value and keeping it within the range.

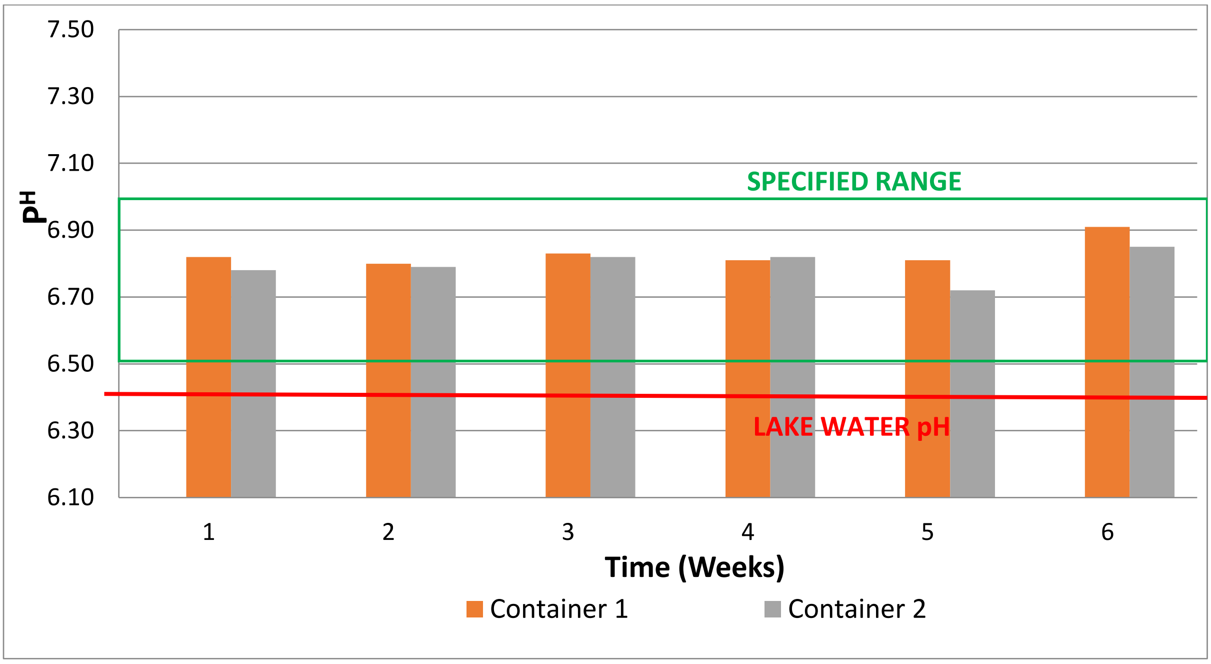
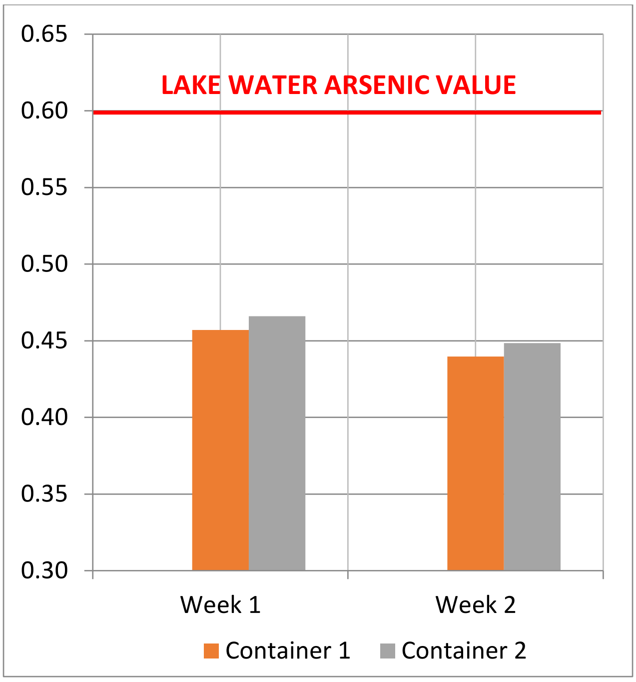


Figure 4.31: Analysis of P^H in Wet Season

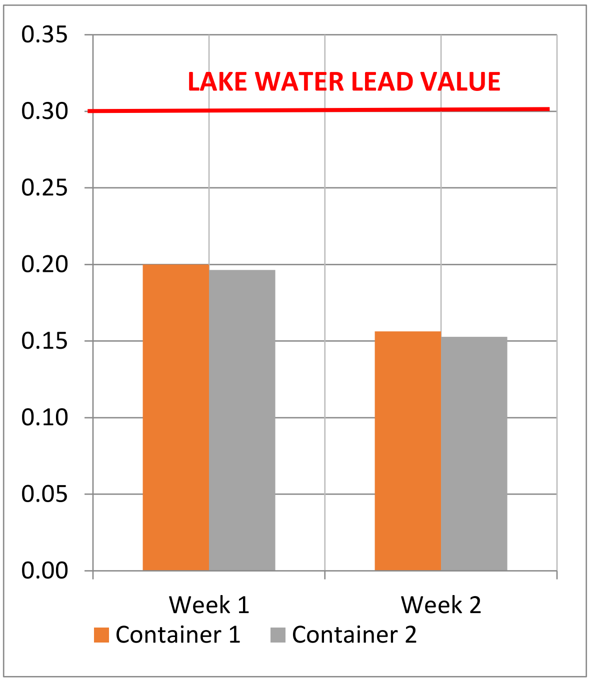
4.15 Analysis of Heavy Metal Removal

Heavy metals are a group of trace elements that include metals and metalloids, such as arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, tin, and zinc. The metal ions are known to contaminate the soil, atmosphere, and water systems and are poisonous even in very low concentrations. There are two main sources of heavy metals in water—natural and anthropogenic. Natural sources comprise volcanic activities, soil erosion, activities of living organisms, and weathering of rocks and minerals, whereas anthropogenic sources include landfills, fuel combustion, street run-offs, sewage, agricultural activities, mining, and industrial pollutants, such as textile dyes. Heavy metals are classified as toxic and carcinogenic, they are capable of accumulating in tissues and cause diseases and disorders.

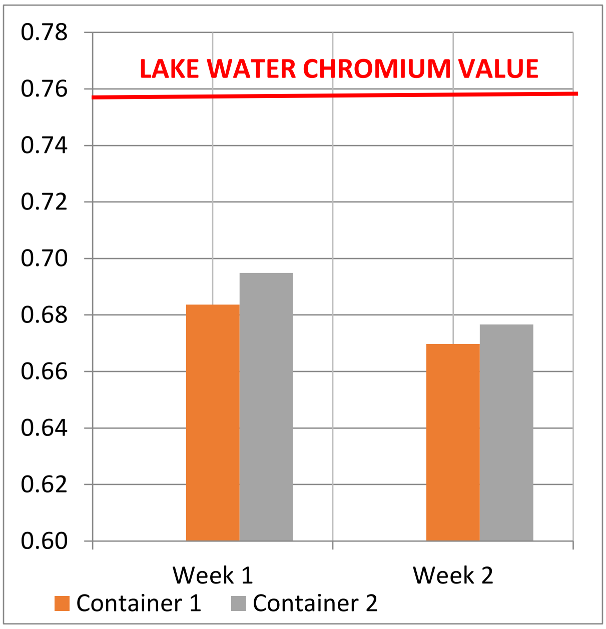
This study had focus in a very limited scale on the removal of Arsenic, Lead, Chromium and Cadmium from the lake water by using constructed floating wetlands. Only two weeks data of the mentioned metals were taken for analysis. Three separate samples were collected similar to water quality parameters from the lake, treated water from CFW containing Cana Indica locally known as Kolaboti and treated water from a separate CFW containing Phragmites Australis locally known as Nol Ghas respectively for the study.



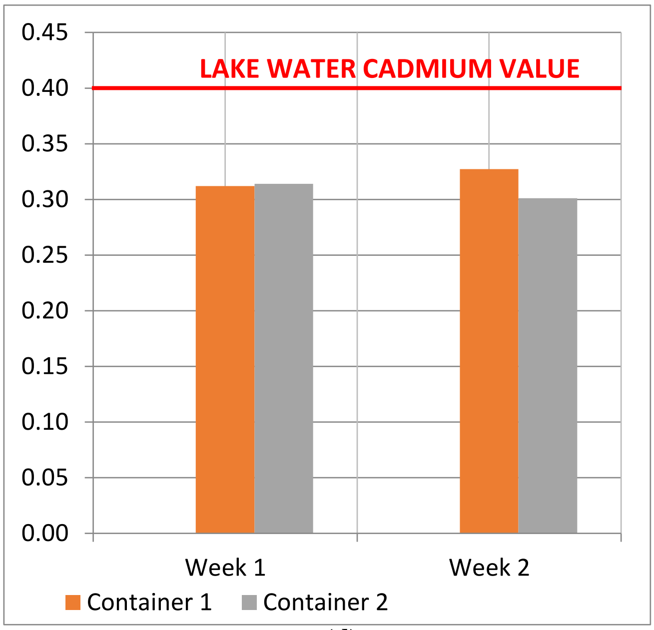
(a)



(b)



(c)



(d)

Figure 4.32: Removal of Heavy Metal with CFW (a) Arsenic (As) (b) Lead (Pb) (c) Chromium (Cr) (d) Cadmium (Cd)

From the above graphs it is seen that both the wetlands showed great potential in terms of heavy metal removal. The heavy metal concentration of treated water was found less than the lake water except for Chromium. But since heavy metal analysis is a vast topic hence further elaborate study can be conducted to evaluate the performance of CFWs in terms of heavy metal removal of waste water.

CHAPTER 05: DISCUSSIONS

CHAPTER : 05

DISCUSSIONS

5.1 Introduction

Constructed Floating Wetland (CFW) is an innovative technology which can be installed on the surface of a storm water retention pond to improve pollutant removal capability. It is composed of a porous floating mat planted with emergent macrophytes. Plant roots grow through the mat and are suspended in the water column underneath. These are suitable for new construction or retrofit installation in existing storm water ponds/lakes.

5.2 Discussion on Results

From the foregoing experiment on removal capacity of Kolabati (Container 1) and Nol Ghas (Container 2) in dry and wet season we can summarize the results through below figure 5.1, 5.2 and table 5.1. In this research the performance of two types of locally available plants Kolabati and Nol Ghas were evaluated in terms of removing nutrients, contaminants and heavy metals from the lake water in both dry and wet season. The removal cability in dry season was found much better than wet season and the cleaning capacity of this system was found surprisingly high for some parameters like (COD 82%, Colour 83%, TSS 85%, Orthophosphate 78%, Ammonium 80%, BOD_5 55%) and moderate performance for other parameters like TDS 50%, Nitrate 62%, DO 32%. The experiment has shown great potentials in terms of removing heavy metals like As, Cd, Cr, and Pb.

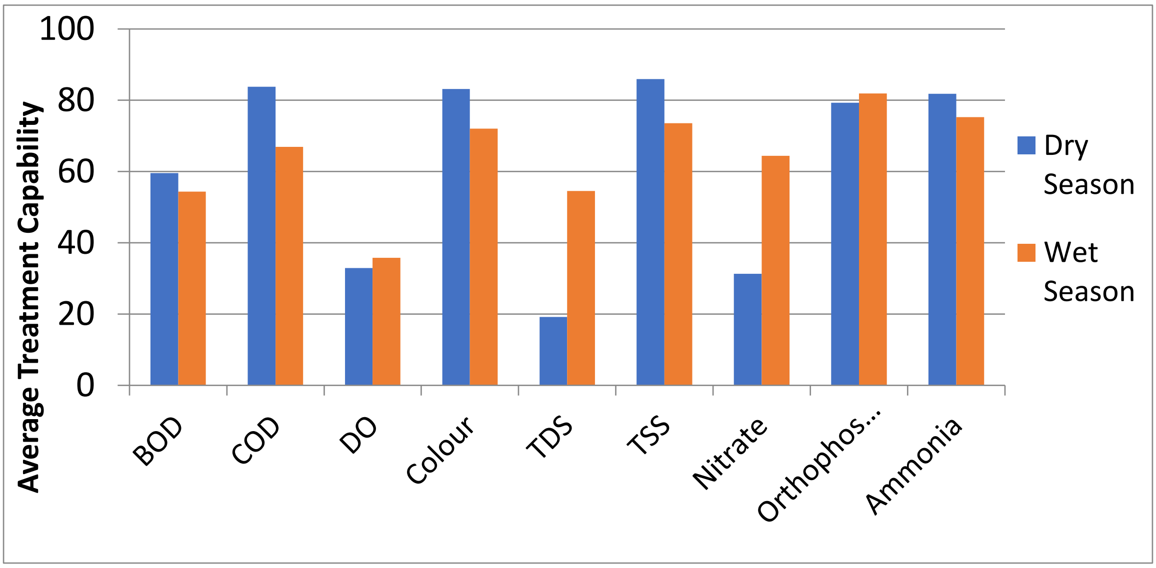


Figure 5.1: Removal using Cana Indica (Kolabati)

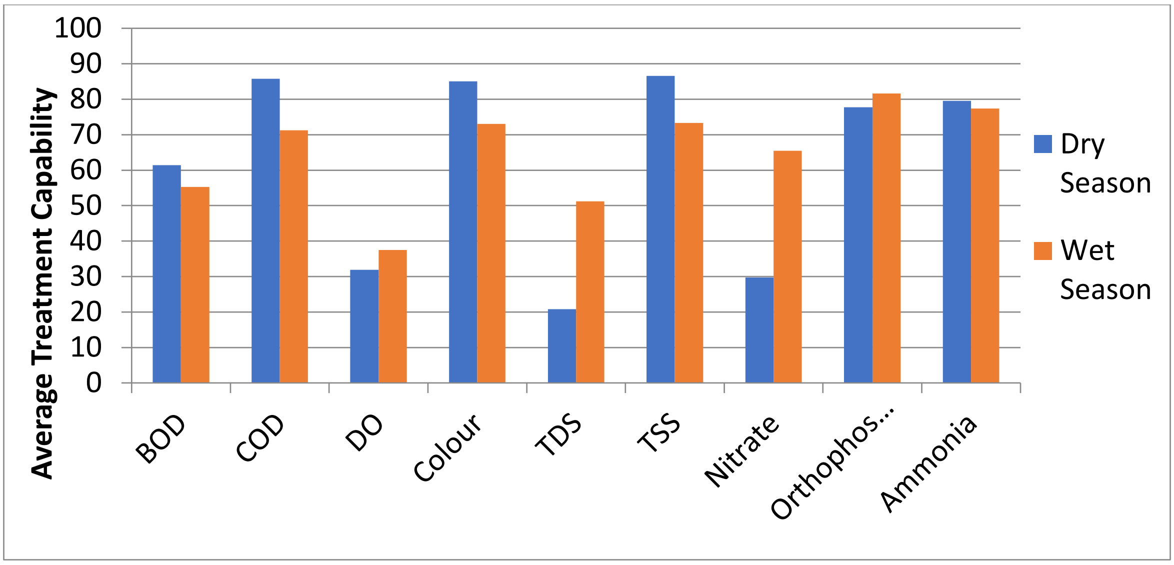


Figure 5.2: Removal using Phragmites Australis (Nol Ghas)

Table 5.1: Removal Analysis - Comparative Statement

Parameters	**AVERAGE TREATMENT CAPABILITY (%)**				
	Cana Indica (Kolaboti)		Phragmites Australis (Nol Ghas)		Performance Analysis
	Dry Season	Wet Season	Dry Season	Wet Season	
BOD	59.6	54.4	61.4	55.3	Satisfactory
COD	83.8	66.9	85.8	71.2	Good
DO	32.9	35.8	31.9	37.5	Moderate
Colour	83.3	72	85	73	Excellent
TDS	19.2	54.5	20.8	51.2	Moderate
TSS	85.9	73.6	86.6	73.2	Excellent
Nitrate	31.3	64.4	29.7	65.5	Moderate in Dry Season
Orthophosphate	79.3	81.9	77.7	81.6	Excellent
Ammonia	81.8	75.3	79.5	77.5	Excellent

a. Both the CFWs containing Kolabati and Nol Ghas showed almost similar pattern in wastewater treatment.

b. Both the CFWs showed excellent performance for treatment of all the water quality parameters except DO, TDS and Nitrate treatment.

c. Overall, Phragmites Australis (Nol Ghas) showed slightly better performance than Cana Indica (Kolaboti).

d. Based on the study, the CFWs may be recommended as a sustainable and nature-based solution to treat the water of Hatirjheel lake or other similar lakes containing waste water.

e. Considering the aesthetic value Cana Indica (Kolaboti) may be recommended as a suitable option to construct the CFW, which will add value to the attraction of Hatirjhhel Lake.

Despite of many limitations, this study can be called the first application of CFWs to treat lake water. Due to limitations on various field conditions like less experienced personnel involved in monitoring growth and applying dosing, taking various measurements etc desired datas could not be taken elaborately, and many scopes like monitoring root zone growth, sludge deposition and other natural phenomenon were excluded from the study. All in all it can be said that this is the first initiative to show out the path how to use green technology for treating wastewater or lake water.

CHAPTER 06: CONCLUSION AND RECOMMENDATIONS

CHAPTER : 06

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Study on constructed wetlands concept in Bangladesh is very new and started in 2011. Though in BUET there were some study on constructed wetlands which started before 2000 but not completed properly. Most of the lakes and canals in and around Dhaka City is polluted with different types of wastewater from municipality, factory, tannery etc. and Constructed Wetlands is capable to treat about all types of wastewater. There are many researches in cold climate-based area for constructed wetlands but adopting them directly may not be effective for our climate condition. To get more efficient and optimum level of design more Bangladesh based study is recommended. As a whole the system was found to be effective as an environment friendly, low cost technology for enhancing the water quality of Hatirjheel Lake and this can be applied in other lakes and waterbodies in Dhaka City and elsewhere in Bangladesh.

6.2 Recommendations

a. Floating wetlands bed may be placed around the inlet water points of Hatirjheel Lake in such a way that, a root barrier is created around the wastewater inlet path.

b. Rotation of floating wetlands bed unit should be done regularly after construction from high polluted area to less polluted area.

c. Study with different arrangement and combinations of plant may be carried out.

d. Further detail study may be carried out to check the heavy metal removal capability by application of CFWs.

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Table A1: Water Quality Parameter (P^H, Color) of Water Lake, container 1 & 2 in Dry Season

Date	P^H			Color (Ptco)		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
20 Oct 2017	7.030	6.820	6.850	352.000	104.000	80.000
05 Nov 2017	7.200	7.300	7.220	380.000	45.000	40.000
15 Nov 2017	7.020	7.100	7.000	360.000	100.000	83.000
20 Nov 2017	7.000	7.120	7.050	365.000	99.000	81.000
11 Dec 2017	7.420	7.410	7.410	397.000	32.000	36.000
17 Dec 2017	6.950	7.010	7.120	390.000	30.000	32.000
24 Dec 2017	6.750	6.890	7.000	402.000	29.000	30.000
31 Dec 2017	6.790	6.840	6.850	406.000	28.000	30.000
07 Jan 2018	6.850	6.870	6.830	403.000	26.000	26.000
14 Jan 2018	6.860	7.000	7.010	396.000	102.000	110.000
21 Jan 2018	6.880	7.040	7.050	382.000	97.000	79.000
Avg	6.977	7.036	7.035	384.818	62.909	57.000
Max	7.420	7.410	7.410	406.000	104.000	110.000
Min	6.750	6.820	6.830	352.000	26.000	26.000
Std Dev	0.194	0.189	0.172	18.686	36.259	29.746

Table A2: Water Quality Parameter (TDS, TSS) of Water Lake, container 1 & 2 in Dry Season

Date	TDS (mg/L)			TSS (mg/L)		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
20 Oct 2017	348.000	185.900	170.900	75.000	16.000	15.000
05 Nov 2017	410.000	370.000	357.000	70.000	12.000	14.000
15 Nov 2017	380.000	276.000	275.100	79.000	15.000	14.000
20 Nov 2017	388.000	302.000	301.000	76.000	13.000	15.000
11 Dec 2017	418.000	384.000	370.000	72.000	11.000	11.000
17 Dec 2017	418.000	385.000	372.000	72.000	11.000	13.000
24 Dec 2017	420.000	386.000	375.000	75.000	12.000	11.000
31 Dec 2017	409.000	335.000	330.000	81.000	13.000	11.000
07 Jan 2018	396.000	336.000	331.000	79.000	12.000	10.000
14 Jan 2018	460.000	353.000	360.000	76.000	8.000	6.000
21 Jan 2018	476.000	358.000	363.000	77.000	7.000	5.000
Avg	411.182	333.718	327.727	75.636	11.818	11.364
Max	476.000	386.000	375.000	81.000	16.000	15.000
Min	348.000	185.900	170.900	70.000	7.000	5.000
Std Dev	35.346	60.302	61.007	3.355	2.639	3.384

Table A3: Water Quality Parameter (Nitrate, Orthophosphate) of Water Lake, container 1 & 2 in Dry Season

Date	Nitrate(mg/L)			Orthophosphate(mg/L)		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
20 Oct 2017	0.700	1.300	1.200	18.000	6.300	6.400
05 Nov 2017	1.700	1.500	1.700	25.000	4.100	4.200
15 Nov 2017	1.200	0.730	0.750	20.000	5.100	5.200
20 Nov 2017	1.600	0.200	0.210	22.000	4.110	4.120
11 Dec 2017	1.800	1.600	1.900	27.000	4.000	3.900
17 Dec 2017	1.900	1.700	1.800	30.000	3.200	3.800
24 Dec 2017	2.000	1.500	1.700	32.000	3.100	3.500
31 Dec 2017	2.500	2.000	1.700	25.100	5.600	6.100
07 Jan 2018	2.800	1.800	1.900	22.700	7.300	7.600
14 Jan 2018	2.010	1.320	1.290	25.000	5.100	6.300
21 Jan 2018	2.900	1.310	1.260	27.000	6.100	7.300
Avg	1.919	1.360	1.401	24.891	4.910	5.311
Max	2.900	2.000	1.900	32.000	7.300	7.600
Min	0.700	0.200	0.210	18.000	3.100	3.500
Std Dev	0.653	0.507	0.533	4.125	1.339	1.490

Table A4: Water Quality Parameter (DO, BOD_5) of Water Lake, container 1 & 2 in Dry Season

Date	DO			BOD_5		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
20 Oct 2017	2.260	2.830	1.600	(4.57-0.95)x3	(4.90-1.80)x3	(5.21-1.15)x3
05 Nov 2017	1.020	1.420	1.410	6.2x3	2.5x3	2.5x3
15 Nov 2017	1.150	1.630	1.710	5.1x3	3x3	2.9x3
20 Nov 2017	1.560	1.780	1.790	4.9x3	3.00X3	3.05X3
11 Dec 2017	0.590	1.120	1.020	6.9x3	2.4x3	2.1x3
17 Dec 2017	0.790	1.500	1.510	7x3	2.1x3	2.0x3
24 Dec 2017	0.710	1.600	1.620	7.5x3	2.0x3	1.9x3
31 Dec 2017	0.780	1.000	0.900	8x3	2x3	2.3x3
07 Jan 2018	0.900	1.080	1.150	8.3x3	2.1x3	1.9x3
14 Jan 2018	0.610	0.980	1.010	28.000	8.000	6.000
21 Jan 2018	0.540	0.990	1.010	29.000	8.100	6.300
Avg	0.992	1.448	1.339	28.500	8.050	6.150
Max	2.260	2.830	1.790	29.000	8.100	6.300
Min	0.540	0.980	0.900	28.000	8.000	6.000
Std Dev	0.514	0.543	0.327	0.707	0.071	0.212

Table A5: Water Quality Parameter (COD, Ammonia) of Water Lake, container 1 & 2 in Dry Season

Date	COD (mg/L)			Ammonia (mg/L)		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
20 Oct 2017	165.000	47.000	41.000	0.64x25	0.13x25	0.14x25
05 Nov 2017	180.000	33.000	25.000	0.80x25	0.13x25	0.14x25
15 Nov 2017	175.000	37.000	35.000	68x25	0.102x25	0.110x25
20 Nov 2017	180.000	35.000	31.000	0.7X2.5	0.11X25	0.12X25
11 Dec 2017	188.000	25.000	21.000	0.82x25	0.131x25	0.141x25
17 Dec 2017	190.000	25.000	20.000	0.88x25	0.13x25	0.143x25
24 Dec 2017	200.000	25.000	21.000	0.85x25	0.132x25	0.144x25
31 Dec 2017	187.000	30.000	27.000	1.02x15	0.21x25	0.30x25
07 Jan 2018	201.000	27.000	25.000	1.21x25	0.21x25	0.31x25
14 Jan 2018	199.000	23.000	20.000	1.35x25	0.35x25	0.31x25
21 Jan 2018	203.000	21.000	22.000	1.75x25	0.40x25	0.43x25
Avg	188.000	29.818	26.182	#DIV/0!	#DIV/0!	#DIV/0!
Max	203.000	47.000	41.000	0.000	0.000	0.000
Min	165.000	21.000	20.000	0.000	0.000	0.000
Std Dev	12.207	7.653	6.868	#DIV/0!	#DIV/0!	#DIV/0!

Table A6: Water Quality Parameter (P^H, Color & TDS) of Water Lake, container 1 & 2 in Rainy Season

Date	P^H			Color (Ptco)			TDS (mg/L)		
	Water Lake	Container 1	Container 2	Water Lake	Container 1	Container 2	Water Lake	Container 1	Container 2
14 Aug 2018	6.430	6.820	6.780	221.000	65.000	60.000	377.100	171.500	183.000
20 Aug 2018	6.470	6.800	6.790	223.000	61.000	61.000	377.000	173.000	183.100
28 Aug 2018	6.410	6.830	6.820	223.000	61.000	59.000	378.000	171.000	184.000
04 Sep 2018	6.420	6.810	6.820	230.000	62.000	62.000	376.000	172.000	185.000
12 Sep 2018	6.410	6.810	6.720	225.000	66.000	62.000	378.000	172.000	183.000
20 Sep 2018	6.510	6.910	6.850	236.000	65.000	63.000	378.600	172.000	186.000
Avg	6.442	6.830	6.797	226.333	63.333	61.167	377.450	171.917	184.017
Max	6.510	6.910	6.850	236.000	66.000	63.000	378.600	173.000	186.000
Min	6.410	6.800	6.720	221.000	61.000	59.000	376.000	171.000	183.000
Std Dev	0.040	0.040	0.045	5.645	2.251	1.472	0.933	0.665	1.250

Table A7: Water Quality Parameter (TSS, Nitrate) of Water Lake, container 1 & 2 in Rainy Season

Date	TSS (mg/L)			Nitrate(mg/L)		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
14 Aug 2018	230.000	65.000	61.000	1.6500	0.9500	0.9400
20 Aug 2018	235.000	60.000	62.000	0.1550	0.9300	0.9100
28 Aug 2018	231.000	61.000	62.000	0.1550	0.0140	0.0130
04 Sep 2018	235.000	62.000	65.000	0.1610	0.0200	0.0130
12 Sep 2018	235.000	61.000	62.000	1.6900	0.9900	1.0100
20 Sep 2018	230.000	60.000	61.000	1.6500	0.9300	0.9200
Avg	232.667	61.500	62.167	0.9102	0.6390	0.6343
Max	235.000	65.000	65.000	1.6900	0.9900	1.0100
Min	230.000	60.000	61.000	0.1550	0.0140	0.0130
Std Dev	2.582	1.871	1.472	0.8252	0.4823	0.4825

Table A8: Water Quality Parameter (Orthophosphate, DO) of Water Lake, container 1 & 2 in Rainy Season

Date	Orthophosphate(mg/L)			DO		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
14 Aug 2018	16.0000	3.1000	3.0000	1.240	1.910	2.000
20 Aug 2018	16.0000	3.2000	3.1000	1.250	2.010	2.100
28 Aug 2018	17.0000	3.2000	3.5000	1.200	1.870	1.960
04 Sep 2018	16.0000	3.1000	3.2000	1.210	1.950	2.000
12 Sep 2018	17.0000	3.3000	3.2000	1.210	1.910	1.830
20 Sep 2018	18.0000	2.1000	2.3000	1.250	1.830	1.910
Avg	16.6667	3.0000	3.0500	1.227	1.913	1.967
Max	18.0000	3.3000	3.5000	1.250	2.010	2.100
Min	16.0000	2.1000	2.3000	1.200	1.830	1.830
Std Dev	0.8165	0.4472	0.4037	0.023	0.063	0.092

Table A9: Water Quality Parameter (BOD_5, COD & Ammonia) of Water Lake, container 1 & 2 in Rainy Season

Date	BOD_5			COD (mg/L)			Ammonia (mg/L)		
	Water Lake	Container1	Container2	Water Lake	Container 1	Container2	Water Lake	Container1	Container2
14 Aug 2018	16.000	6.000	5.300	123.000	18.000	15.000	0.91x25	0.21x25	0.19x25
20 Aug 2018	15.000	6.100	5.100	124.000	16.000	15.000	0.81x25	0.22x25	0.18x25
28 Aug 2018	1.660	0.960	0.990	20.000	7.000	6.100	0.92x25	0.22x25	0.21x25
04 Sep 2018	1.620	1.100	1.100	19.000	7.200	5.300	0.83X25	0.23X25	0.20X25
12 Sep 2018	20.000	6.300	6.900	131.000	16.000	18.000	0.93x25	0.22x25	0.23x25
20 Sep 2018	21.000	8.000	8.200	21.000	18.000	16.000	0.93x25	0.21x25	0.19x25
Avg	12.547	4.743	4.598	73.000	13.700	12.567	#DIV/0!	#DIV/0!	#DIV/0!
Max	21.000	8.000	8.200	131.000	18.000	18.000	0	0	0
Min	1.620	0.960	0.990	19.000	7.000	5.300	0	0	0
Std Dev	8.751	2.968	2.976	58.127	5.190	5.436	#DIV/0!	#DIV/0!	#DIV/0!

Table A10: Heavy Metal Concentration (As & Pb) of Water Lake, container 1 & 2

Week	As			Pb		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
1st week	0.6066	0.4571	0.4659	0.2836	0.2000	0.1964
2nd week	0.5099	0.4396	0.4484	0.2764	0.1564	0.1527

Table A11: Heavy Metal Concentration (Cr & Cd) of Water Lake, container 1 & 2

Week	Cr			Cd		
	Water Lake	Container1	Container2	Water Lake	Container1	Container2
1st week	0.7549	0.6837	0.6949	0.3912	0.3120	0.3140
2nd week	0.6537	0.6698	0.6767	0.3810	0.3272	0.3012