Wastewater Treatment in a Sub-Surface Flow Constructed Wetland: Nutrient Removal Analysis

By

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This thesis is dedicated to my parents and late grandmother for their love and support

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All praise to Almighty Allah, Who bestowed man with intelligence and knowledge as well as the sight to observe and the mind to think and judge. Peace and blessings of Allah be upon the Holy Prophet, Muhammad (pearl of my eyes), who exhorted his followers to seek knowledge from cradle to grave.

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Maham Ayesha

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LIST OF ABBREVIATIONS

COD	Chemical Oxygen Demand
CW	Constructed Wetland
EPA	Environmental Protection Agency
FWS	Free Water Surface
HFCW	Horizontal Flow Constructed Wetland
HFS	Horizontal Flow System
PNEQS	Pakistan National Environmental Quality Standards
SFS	Subsurface Flow System
SS	Suspended Solids
TDS	Total Dissolved Solids
TN	Total Nitrogen
TSS	Total Suspended Solids
VFCW	Vertical Flow Constructed Wetland
Pi	Inorganic Phosphorus
PO	Phosphates
VFS	Vertical Flow System
UV	Ultra Violet

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ABSTRACT

Constructed Wetlands (CWs) treating the wastewater and minimizing the environmental degradation is a very economical and eco-friendly technique. In order to understand the treatment efficiency of these engineered systems, a six month study (December 2014-May 2015) was carried out. The objective of this investigation was to evaluate the removal efficiency of contaminants from municipal wastewater by two main phytoremediation plants i.e. *Lammncea* and *Typha lattifolia*. Targeted wetland was located in NUST (National University of Science and Technology) Sector H-12 Islamabad Pakistan, having the capacity for receiving municipal wastewater from a population of 6000, generating 0.2 MGD wastewater. The water quality parameters were studied at four units pilot scale unit, lab scale unit, parallel unit and control unit. The evaluated parameters were; Chemical oxygen demand (COD), Total suspended solids (TSS), Total dissolved solids (TDS), Electric conductivity (EC), pH, Total phosphates (TP), Dissolved oxygen (DO), Temperature, *Total coliforms*, *Fecal Coliform* and nutrients (ammonia, nitrate and orthophosphate). Control unit running as reference showed no removal efficiency which strengthened the fact that plants were responsible for treatment of waste water. In all the cases parallel unit, comparatively showed the maximum removal efficiency due to more retention of wastewater. For both the plants typha and duckweed most significant removal efficiencies were recorded as, TSS (63 and 72%), DO (46 and 49%), TDS (40.61 and 34.9%), COD (69 and 62%), TP (64 and 81%), *fecal coliform* (97 and 98%) and *total coliforms* (98 and 97%). Removal percentage for nutrient parameters (ammonia, orthophosphate, and nitrate) were higher at lab scale than that of pilot scale because of controlled lab conditions. Results generated for six months studies depicts that seasonal fluctuation played a major role in contaminant removal , it was high in summers due to improved plant growth.

Chapter 1

INTRODUCTION

1.1 Background

Water is amongst the most imperative substances on earth. All plants and creatures must have water to survive. Every living organism need water but the water with disintegrated or suspended solids, released from homes, business foundations, industries, and commercial ventures is of no use for most of the living organisms. Such type of water is called wastewater, although 71 % of this planet is covered by water but only 2-3 % is fresh water which could be used by human beings. Fresh water resources are depleting at a very rapid rate, whereas amount of wastewater being generated is increasing day by day. Water is an asset that is turning out to be progressively rare and should be managed, internationally and locally. The accessibility of fresh water is amongst the most major issues being faced by billions of individuals today, it has been assessed that 1.2 billion individuals have no water within of 400 m of their home. Governments and associations everywhere throughout the world have understood that fresh water and wastewater administration is very fundamental.

Domestic sewage is mainly utilized water from residential areas it is also called grey sewage. The wastewater that is created by every family is artificially treated and discharged into the ocean. The sewage water carries harmful microbes and chemicals that can bring wellbeing issues. There are several pathogens that are typical water toxin, the sewers of urban areas contain several microorganisms that could cause diseases. Microorganisms in water are reason for some deadly infections. On other hand domestic wastewater may turn into the reproducing ground for different animals that could act as the carrier of some infectious diseases.

1.2 Domestic Wastewater in Pakistan

In Pakistan, there is no arrangement for the treatment of municipal waste water and it is released direct to a sewer or water body, near a field or in an internal septic tank. Mainly, city wastewater is not subjected to any treatment and none of the urban territories have any treatment system beside Islamabad and Karachi. Urban regions only treat a little amount of their wastewater before dumping, considering that all the presented treatment plants are working at full their full potential It is evaluated that around 8% of urban wastewater is probably treated in local treatment plants. Wastewater is directly dumped in open streams. The whole scenario of wastewater treatment is not viable. Most of the water went on untreated, only some of its percentage gets some sort of treatment which includes sedimentation. Mostly secondary and tertiary level treatment is out of question. Most of the time, only few numbers of treatment plants have the facility of secondary or tertiary level treatment, as there is only few of them thus the work load on them is always more than their capacity.

Table 1.1: Composition of Wastewater

Sr no.	**Contaminants**	**Unit**	**Weak**	**Medium**	**Strong**
1.	Total solids (TS)	mg L^{-1}	350	720	1200
2.	Total dissolved solids (TDS)	mg L^{-1}	250	500	850
3.	Suspended solids (SS)	mg L^{-1}	100	220	350
4.	Total organic carbon (TOC)	mg L^{-1}	80	160	290
5.	Chemical oxygen demand (COD)	mg L^{-1}	250	500	1000
6.	Nitrogen (total as N)	mg L^{-1}	20	40	85

Sewage is marginally more than 99.9 % unadulterated water by weight. The rest, under 0.1 percent, contains a wide mixed bag of disintegrated and suspended debasements. Adding up to a little division of the sewage the properties of these contaminations and the extensive amount of sewage in which they are passed make transmission of local wastewater a noteworthy specialized issue. The important contaminates are putrescible natural materials and plant nutrients. However, household sewage is additionally contain illness causing microorganisms.

1.3 Methods for Wastewater Treatment

For the maintenance of a sound environment, it is necessary to treat the wastewater effluents as it would reduce the risk of downstream water contamination. Impressive advances have been made in the field of wastewater filtration and without further ado it envelops a scope of low tech. and innovative arrangements. But in third world countries still these facilities are very less in number, new innovations are beyond their reach (mostly due to their high prices) along with the other various reasons, which includes excessive treatment procedures, absence of successful ecological contamination control laws and poor usage of the said laws.

1.3.1 Conventional Treatment System

A wide range of treatment methods including stabilization pond systems, septic tanks, activated sludge's, in developing countries trickling filters, anaerobic systems and land application systems are used (Canter *et al*., 1982). The expense of establishment and working of wastewater treatment plants that perform extensive treatment as far as further BOD_5 or nitrogen removal is high in comparison with the expense of essential and optional treatment. The goal for a less expensive methodology for cleaning and for removing nutrients has created enthusiasm for area application and wetlands utilization of effluents produced by conventional wastewater treatment plants.

1.3.2 Constructed Wetland

Constructed wetlands, rather than natural wetlands, are man-made frameworks or designed systems that are outlined, manufactured and worked to imitate elements of natural wetland. It is constructed at a non-wetland environment or a previous physical environment, fundamentally with the end goal of contaminant or poison removal from wastewater. The developed wetland frameworks are marshes. Swamps are shallow water districts commanded by distinguished herbaceous vegetation including cattails, bulrushes, surges and reeds**.**

1.4 Present Study

Present study was done to evaluate the treatment efficiency of a constructed wetland established at National University of Sciences and Technology (NUST) along with this pilot scale wetland, a lab scale set up was also established .Samples for physcio-chemical analysis from both field scale and lab scale setup were collected.

1.5 Aims and Objectives

1. Physcio-chemical analysis and microbial analysis of treatment system
2. Comparative study of nutrient removal between lab and pilot scale treatment system
3. Measuring uptake efficiency of plants

Chapter 2

LITERATURE REVIEW

2.1 Wastewater Treatment Overview

Wastewater treatment is categorized by the nature of the treatment process operation being used; for example Physical Methods, Chemical Methods and Biological.

A complete treatment system may consist of a number of physical, chemical and biological processes to the wastewater.

2.1.1 Physical Methods

Physical systems involve procedures where no biological or chemical changes are done and entirely physical phenomenon is utilized for the enhancement or treatment of the wastewater. It could be coarse screening to evacuate bigger articles or sedimentation.

With the time spent sedimentation, physical phenomena relating to the settling of solids by gravity, is allowed to work. For the most part this contains essentially holding wastewater for a brief time in a tank under conditions, allowing the heavier solids to settle, and emptying the "cleared up "effluents. Sedimentation for solids is a to a great degree typical methodology and is routinely used toward the begin and toward the end of wastewater treatment operations. While sedimentation is amongst the most surely understood physical treatment shapes used to fulfil treatment, another physical treatment methodology is air dissemination which incorporates air, typically to offer oxygen to the wastewater. Other physical phenomena which are used as a part of treatment is filtration. Here wastewater adheres to a medium to disengaged solids. Another method would be the usage of sand channels to encourage remove emanating solids from a treated wastewater, permitting oils, for example to buoy to the surface and skimming or physically ousting them from the wastewaters is often done as an element of the general treatment process.

2.1.2 Chemical Treatment

Chemical treatment involves usage of some substance reactions to upgrade the water quality. The best used compound system is chlorination. Chlorine is used to wipe out microorganisms and to diminish the rate of crumbling of the wastewater. Bacterial evacuation is proficient when vital characteristic strategies are impacted by the chlorine. Another strong oxidizing operators that has moreover been used as an oxidizing disinfectant is ozone. A compound process for the most part used as a part of various mechanical wastewater treatment operations is balance. Balance includes expansion of corrosive or base to change pH levels back. Since lime is a base, it is once in a while used as a part of the balance of destructive squanders. Coagulation involves the expansion of an exacerbate that, through a synthetic reaction delivers an insoluble completed thing that serves to oust substances from the wastewater. Polyvalent metals are normally used as coagulating chemicals as a major aspect of wastewater treatment and common coagulants would join lime (that can in like manner be used as a component of balance), certain iron containing blends, (for instance, ferric chloride or ferric sulfate) and alum (aluminum, sulfate). Certain strategies may be both physical and synthetic in nature. The usage of carbon to "adsorb" or evacuate organics, for occurrence, incorporates both compound and physical systems.

2.1.3 Biological Treatment

Phytoremediation is the combination of Greek word "phyton" (plant), with the Latin word "remediare" (to cure) to portray a framework whereby certain plants can change contaminants into safe or less harmful materials. Whilst the innovation has truly been connected to soil clean-up, it can likewise be connected to the treatment of wastewater. Phytoremediation uses green plants to free soils and wastewater from metals and metalloids. It can be characterized as the clean-up of contaminations basically done by photosynthetic plants.

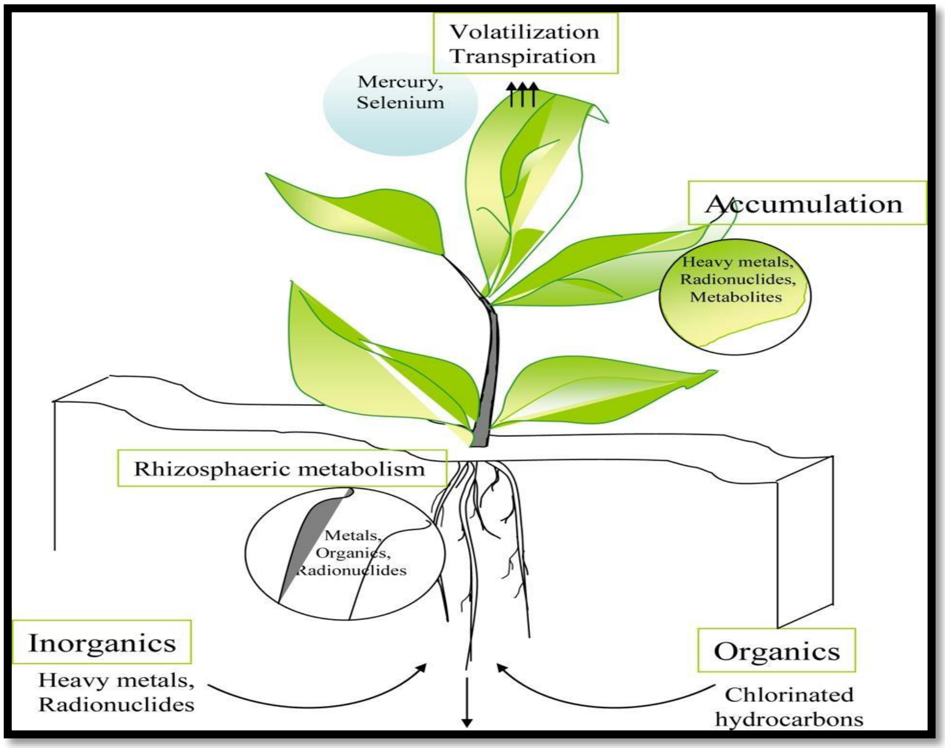

Figure 2.1: Phytoremediation Processes

These plants and their microbially-dynamic rhizosphere (root zone) can change poisons and nutrient nitrogen into biomass, with the remaining water removed by means of transpiration. The scope of natural medications for ecological issues, as portrayed by the term phytoremediation, really comprises of a few particular procedures:

Phytoextraction: Uptake of substances from nature, with capacity in the plant.

Phytostabilisation: Sinking the development or movement of substances in the earth. Case in point, constraining the filtration of substances degrading the soil.

Phytostimulation: Enrichment of microbial movement for the degradation of contaminants, normally around plant roots.

Phytotransformation: Uptake of substances from the earth, with degradation happening inside of the plant (phytodegradation).

Phytovolatilisation: Removal of substances from dirt or water with discharge into the air, conceivably after degradation.

Rhizofiltration: The removal of poisonous metals from groundwater.

Phytoremediation use the nutrient usage procedures of the plant to take in water and nutrients through roots, water through leaves. On the other hand, they may ingest lethal follow components, including substantial metals, for example, lead, cadmium and selenium. Phytoremediation is an innovation that is most helpful when contaminants are inside of the root zone of the plants (best three to six feet of the dirt). With pollution spread over the substantial range, phytoremediation may be a financially practical innovation.

2.2 Introduction to Constructed Wetland Systems

Natural wetlands or constructed wetland both type of wetlands, are economical and novel technology for wastewater treatment. Wetlands which are constructed and designed by man are known as **'Constructed Wetland Treatment System' (CWTS).** Previously in past no such type of system was designed for the treatment of wastewater but know the scenario have been changed. Interest in better water quality, recovery of water and then its reuse, leads to the increase usage of CWTS throughout the world. Like many other natural systems natural wetlands are also destroyed, so constructed wetlands being imitation of natural wetlands would try to play the same role. Natural factors play similar role in CWTS (vegetation development) as that in natural wetlands to carry out the task of water treatment. During previous couple of years it has been observed that usage of CWs has been increased similar trend could be seen in western countries like US, Australia and New Zealand where use of CWs is increasing. In these countries CWs are mostly surface flow system and less quantity of nutrients and suspended solids are being removed.in some other countries, local sewage is mostly treated with the wetlands. However in on other hand in some regions usage of Constructed Wetlands is restricted to the treatment of town wastewater.

2.2.1 Pollutant Removal Processes in Constructed Wetlands

There are several basic procedures which help in decontamination of wastewater in CWs. These procedure are precipitation, adsorption, microbial activities macrophyte uptake and sedimentation (Vymazal, 2001). Still, various elements influence the decontamination procedures and contaminants are largely removed as a result of a few interconnected procedures, however the evacuation mechanisms in CWs remain a dynamic exploration region for researchers (Gottschall *et al*., 2007). The removal processes in wetlands are extremely complex. So, more learning about how vegetation and water stream influences decontamination may help in designing an inexpensive but efficient CWs for wastewater treatment. The two main factors which effects the removal of Nitrogen from CWs are oxygen level and temperature. It is normally observed that removal of Phosphate is achieved through physical processes. These processes are sedimentation and precipitation. They are not effected by temperature but quantity of oxygen in CWs largely effects the removal of phosphate (Wallace and Knight, 2009). Additionally on a conventional level, dissimilarities in the abstraction of Phosphate may be visually perceived because of higher Phosphate uptake by vegetation in summer and lower in fall and winter. A large quantity of phosphate is released during winters due to the decomposition of plants may keep the balance of increase uptake by plants during summers.

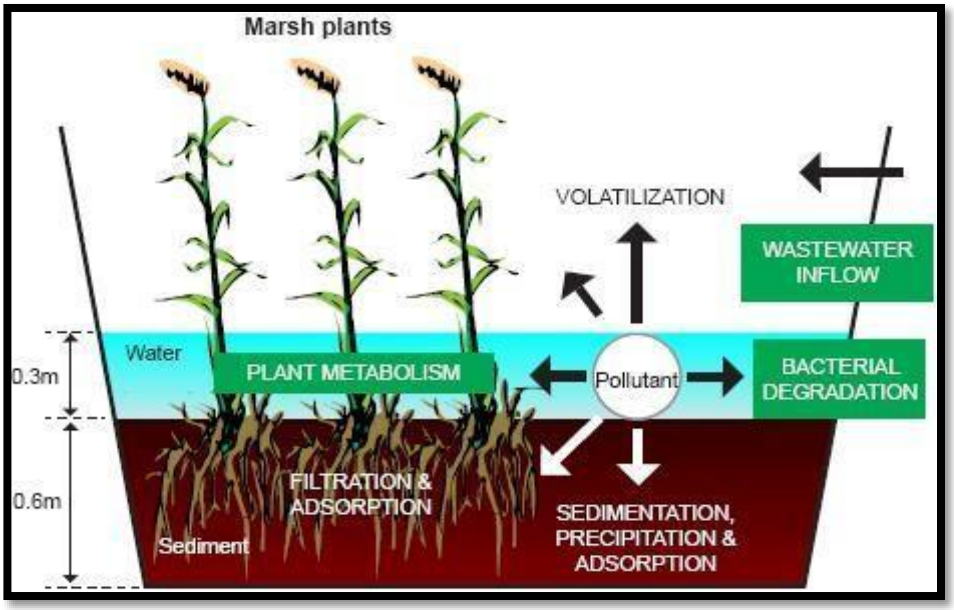

Figure 2.2: Processes of Pollutant Removal in a Constructed Wetland System

2.2.2 Types of Constructed Wetland Treatment Systems

Mainly there are two types of constructed wetlands: **Horizontal Flow System (HFS)** and **Vertical Flow System (VFS):** There are further two categorize of HFS, first type is Surface Flow (SF) while second is Sub-surface Flow (SSF). HFS is type of system in which water flow horizontally .it enters from inlet and then after flowing through every bed it reach outlet. Whereas on other hand in case of VFS flow of water is irregular and wastewater channels present in beds vertically drains it.

a. Surface Flow (SF): in North America SF type of wetlands are broadly used. Such type is used for the treatment of urban wastewater mainly for nutrient evacuation. The SF framework has a tendency to be fairly vast in size with just a couple systems being used. Most of the constructed wetland treatment plants are Surface-Flow or Free-Water surface (SF).

In these types of wetlands water usually flows over the basins having vegetation, and water is noticeable at a shallow depth over the surface of the substrate materials. The materials used as substrate are mostly local soils and dirt or non-penetrable geotechnical materials that prevent seepage. Inlet devices are introduced to boost sheet flow of wastewater through the wetland, to the outlet. Regularly, depth of the bed is around 0.4 m.

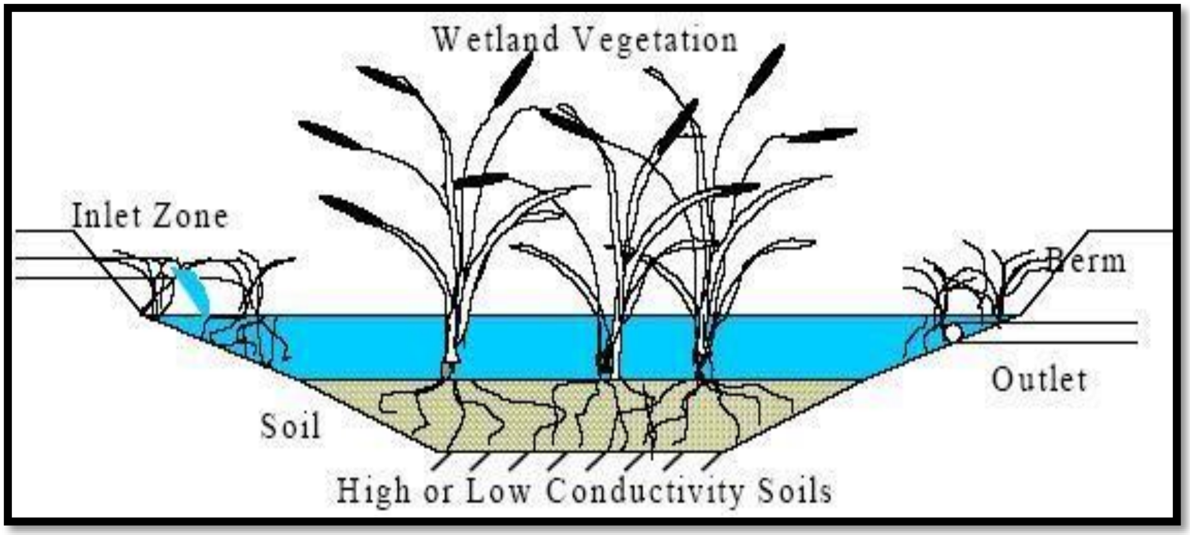

Figure 2.3: Free Surface Flow Constructed Wetland

b. Sub-surface Flow (SSF) framework

In a vegetated Sub-surface Flow (SSF) framework, water flows from one end to the next end through penetrable substrates which is made of a blend of soil and rock or crushed rock. The substrate will boost the growth of vegetation. It is likewise called "Root-Zone Method" or "Rock-Reed-Filter" or "Emergent Vegetation Bed System". The depth of media is 0.6 m and the base is a dirt layer to prevent underground drainage. Media size for most rock substrate extended from 5 to 230 mm with 13 to 76 mm being average. The base of the bed is slanted to minimize the overland flow of water. Wastewater flows by the action of gravity evenly throughout the root zone of vegetation around the 100-150 mm surface beneath the rock. Numerous micro and macro life forms occupy the substrates. Free water is not noticeable. The delta zone has a buried channel to evenly distribute water through the treatment zone. Treated water is gathered at outlets at the base of the media, normally 0.3 to 0.6 m underneath bed surface.

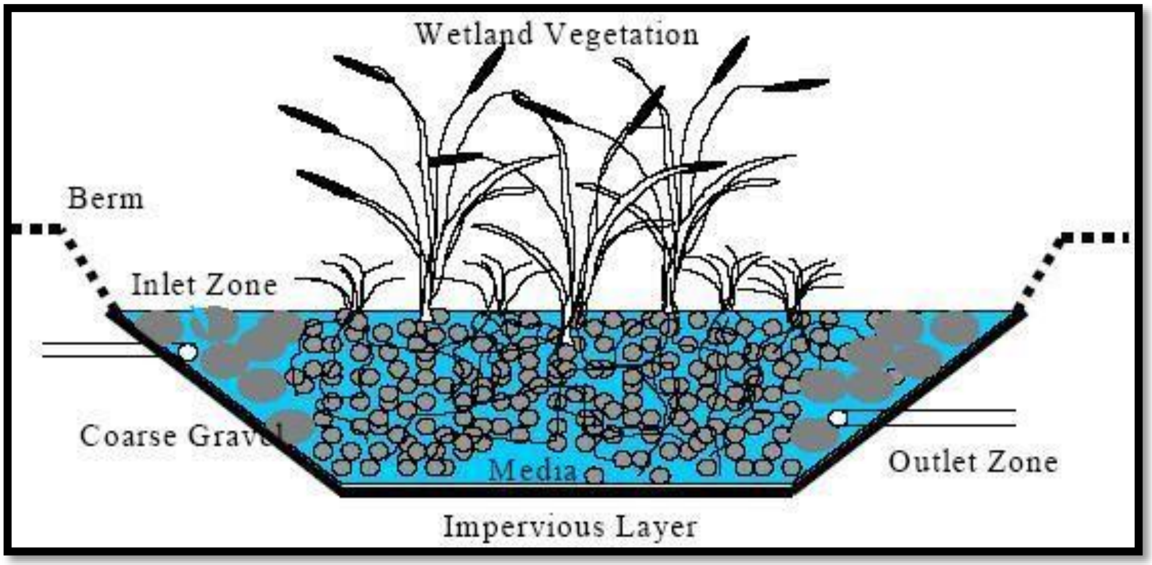

Figure 2.4: Subsurface Flow Constructed Wetland

2.2.3 Roles of Wetlands Plants in Wastewater Treatment

Physical impacts are the critical functions which are brought by the presence of the plants in relation to decontamination of wastewater. Massive area for the growth and production of microorganisms is provided by the plants. Roots of the plants stabilized the surface of bed, moderate the water flow and in this manner help with sedimentation. Wetland plants assume an essential part in the elimination and conservation of nutrients and help in keeping up the process of eutrophication in wetlands. There are number of plants which have capability to treat wastewater. The Common Reed Phragmites and Cattail Typha angustifolia are some of the marsh species that viably uptake nutrients. These plants have an extensive biomass both above (leaves) and beneath (underground stem and roots) the surface of the substrate. The sub-surface plant tissues grows horizontally and vertically, and make a broad framework, that ties the dirt particles and makes an extensive surface zone for the uptake of nutrients and particles. Empty vessels in the plant tissues empower oxygen to be transported from the leaves to the root zone and to the surrounding soil. This facilities the microbial decay process and the uptake of toxins from the water system.

2.2.4 Selection of Wetland Plants

a. Water Lettuce and Duckweed

Both the plants Water lettuce and Duckweed endophytic plants and have shown their capability of removing of BOD, TSS and Total Phosphorus and Total Nitrogen. It is necessary to remove these plants on regular intervals of time period as their long time presences could affect water quality. A huge mat would be created at the upper surface by these plants and that mat would not allow the penetration of sunlight to the lower layers of wetland. Constructed wetlands have to be monitored strictly to avoid attack from any invasive macrophyte species. On other hand, if plant cover is decreases it would disturb the treatment of wastewater. Constructed wetlands containing floating plants have high maintenance budgets. Biomass of dead Plants have to be collected regularly to avoid eutrophication. Plant development should be additionally kept up at an ideal rate to keep up treatment effectiveness.

b. Typha

The Common Reed (*Phragmites* sp.) and Cattail (*Typha* sp.) are emergent species that are utilized as a part of constructed wetland treatment frameworks. These developing plants have a fundamental role in the removal and maintenance of nutrients in a wetland. Although these macrophytes are less effective at bringing down nitrogen and phosphorus substances by direct uptake because of their lower development rates (contrasted with floating and submerged plants), their capacity to uptake nitrogen and phosphorus from sediment sources through rhizomes is higher than that of water.

2.3 Water Quality Monitoring

Water quality data is a good indication of wetland performance. Water quality should be monitored through assessment of inflow and outflow water quality parameters. Some important water quality parameters to be monitored include:

a. Dissolved Oxygen

Oxygen is the measure of vaporous oxygen (O_2) disintegrated in the water. Oxygen enters the water by direct assimilation from air, by fast development, or as a waste product of plant photosynthesis. Water temperature and the volume of moving water may influence dissolved oxygen levels. Less oxygen is dissolved in cooler water than hotter water. The oxygen of water will diminish when there will be an increase in nutrients and organic materials from wastewater, sewage releases, and spill over from the area. Excessive plant and algae development and decay because of expanding nutrients can altogether influence the measure of available DO. Sufficient DO is critical for good water quality and important to all types of life. DO levels that drop underneath 5.0 mg/L reason may cause stress to amphibian life. Lower fixations cause more prominent stress. Oxygen levels that go beneath 1-2 mg/L for a couple of hours may bring about fish death.

b. Temperature: Wastewater temperatures ordinarily range somewhere around 100 and 20 ^{0} C, the temperature of wastewater will be higher than that of the water supply. This is a result of the addition of warm water from family units warming inside the plumbing system. Temperature of wastewater is dependent upon the geographic area and varies according to area. The temperature of water is a critical parameter in view of its impact on chemical responses and response rates, aquatic life, and the suitability of the water for different uses. High temperature, for instance, may bring about a change in the types of fish that may exist in the water body. Likewise, oxygen is less dissolved in warm water than in cold water. The increment in the rate of biochemical responses that goes with an increment in temperature, joined with the reduction in the amount of oxygen present in surface waters may frequently bring about genuine collapse in DO fixations in the late spring months. Ideal temperatures for bacterial action range from around 25 to 35 ^{o}C. Oxygen consuming absorption and nitrification processes stop when the temperature ascends to 50 ^{O}C. At the point when the temperature drops to around 15 ^{O}C, methane-delivering microscopic organisms turn out to be very dormant, and at around 5 ^{O}C, the autotrophic-nitrifying microbes basically stop working.

c. pH value: pH refers to the acidity of the effluent. Domestic wastewater before treatment typically has a pH of 6.5 to 8.5, but a final effluent of 7.0-7.2.

d. Total Suspended Solids (TSS)

These are the solids that stay in suspension as opposed to settling out of wastewater. These solids give the turbidity that is dangerous in waters of wastewater effluent. It raises the temperature of the water and obstructs the sunlight supply to oxygen-delivering plants and green growth, hence lessening the DO of the water.

e. Chemical Oxygen Demand (COD): The COD demonstrates the quantity of oxygen which is needed for the oxidation of every single organic substance in water in mg/L or g/m^3. Quantity of COD (Chemical Oxygen Demand) is measured with the standard method named Dichromate-Method. With the help of this technique the chemical oxygen requirement is measured during chromic acid digestion of organic loads in waste water. COD is turned into a normally utilized whole parameter as a part of wastewater investigation.

f. Mechanism of Bacterial Removal

Significant concerns associated with wastewater wetlands include their capacity to remove pathogens of helminths, protozoans, bacteria's and viruses. There have been reports that wetlands lessened total coliforms by 57 %, and *fecal coliforms* by 62%. Silt of wetlands has a tendency to collect coliforms. It has been found that waterway mud contains 100-1000 times more *fecal coliforms* than the surface water. These dregs give some microscopic organisms the capacity to survive longer. Another approach to remove bacteria is thought to be through the root structure of plants in wastewater wetlands. Some studies show that sedimentation plays a noteworthy part in decreasing bacteria in wetlands. The connection to the root structure has bigger influence with *fecal coliforms*. A multispecies wetland demonstrated 73 and 58 % evacuation of *fecal coliforms* and a duckweed wetland demonstrated 98 and 89 % tentatively (Karim *et al*., 2004).

2.4 Nutrient Removal in Constructed Wetlands

Domestic wastewater contains loads of nutrients. Nutrient evacuation is vital for aquaculture wastewater treatment to shield waters from eutrophication and for potential reuse of the treated water. Wetlands lessen nutrients by promising sedimentation (Schlosser *et al*., 2012), sorbing nutrients to silt, taking up nutrients in plant biomass (Lee *et al*., 2004) and improving denitrification. While the confirmation for this emerges from various separate studies, a few studies demonstrate that wetlands can be inadequate for decreasing nutrient loadings.

2.4.1 Removal of Nitrogen in Constructed Wetlands

From CWs, there are various pathways through which nitrogen can be evacuated, the first process could be the deterioration of normal nitrogen in wastewater by heterotrophic microorganisms and to ammonium (NH_4^+), and this method is called ammonification. Ammonification happens very quickly during aerobic conditions. Processes of adsorption is another factor which might help in the removal of ammonia. Due to the alterations in water science or hydrology bounded $NH4^+$can release back to the water through departure of NH_4^+ in CWs. This processes could be further strengthened by another highly energetic system which is called nitrification. In the processes of nitrification in NH_4^+ is oxidized to nitrite (NO_2^-) and further to nitrate (NO_3^-) by organisms. There are some factors which could accelerate the rates of nitrification in a CW. These factors are presence of inorganic carbon and ammonium, along with the temperature from 30–40 °C and pH perusing and 7.5–8. Some of the studies have demonstrated that level of oxygen could be lessen removal of NH_4^+ in CWs due to lower rates of nitrification. Smelling salts volatilization is a type of method through which NH_4^+ may be accumulated to the earth in the form of soluble base gas (NH_3). In CWs when pH is under 8 volatilization is not considered as an important process for removal of NH_4^+. Microorganisms helps in changing the nitrates to nitrogen gas (N_2), this process is called denitrification. That nitrogen gas than diffuses from the water surface of CW and in this way finally nitrogen returns to the environment. Those microscopic organisms which helps in denitrifying are mostly present in epiphytic biofilms. These biofilms coats the submerged CW surfaces. This surface is made up of sediments, litter and parts of plant (Bastviken *et al.,* 2003). Anoxic conditions favours the process of denitrification is because availability of carbon, along with the high temperatures which is ideally 60–75 °C and pH 6–8.5 (Reddy *et al.,* 1984). Nitrogen fixation is a type of procedure which happens when di-nitrogen gas exchanges with nitrogen with the help of bacteria's. Osmosis of nitrogen, i.e. uptake of inorganic nitrogen and change to natural nitrogen in living cells and tissues of plants, algae and microorganisms are thought to be irrelevant in high-stack wetland macrophytes that support NH_4^+-N as the nutrient type of nitrogen since they are more proficient as a building stone for amino acids, proteins and different nitrogenous natural atoms. Still, macrophytes can likewise take up NO_3^-, yet the absorption rate is controlled by the NH_4^+-N accessibility in the CW (Martin and Reddy, 1997). In any case, when vegetation passes on, significant measures of N are come back to the water and soil of the CW through deterioration.

2.4.2 Phosphorus Removal in Constructed Wetlands

The key Phosphorus present in wastewater coming to CW is particulate phosphorus (PP) and dissolved phosphorus, together called all out Phosphate (TP). Dissolved P, as phosphate-phosphorus (PO_4^3-P) is accessible for the utilization of living beings while PP for the most part needs a few alterations to get to be available and further changes to regular P (OP). Both abiotic and biotic systems control the relative P part sizes and change the rates of P shaping inside the CW water and residue/soil. Abiotic techniques join sedimentation, precipitation, and the overlying water portion. Biotic methods join ingestion by vegetation, minuscule fish, periphyton and microorganisms. Various experts consider progressive expansion, i.e. the making of new stable residuals, as the major whole deal P stockpiling process in wetlands. The continuous expansion system is the whole of P precipitation, adsorption and accumulating of waste in the CW sedimentation/soil.

As wastewater enters CW, organic and inorganic particles and P starts to form another deposit layer through the accumulation of a low thickness material called floc. The P content in the floc in CWs depends upon the wastewater, which normally contains 3 mg P L^{-1} represents around 0.1–

0.4% for each dry weight (DW). Still, the thickness of the floc layer can be 20–30 cm and can hold 3–50 g P m-2 CW. The flocs might be removed from the CW by method for vacuuming or other suitable framework. Still, if left untouched with time, the flocs separate and form another soil layer, and in this way join the P that has entered the CW through wastewater. Regardless, under particular conditions P collected in the CW floc or soil can resuspend back to the water portion as PP and later desorb to DP. The key systems that deal with the P content in the floc or the CW deposit are adsorption/desorption and precipitation/solubilisation. The previous procedure incorporates intermolecular alluring forces between PO_4^3-P, inorganic and normal particles in the CW residue. The second process is the formation of structures between PO_4^3-P and metal minerals presented on edges of inorganic and characteristic particles or free inscriptions in the water area. The bonds in a P mineral complex are less reversible than the adsorption bonds between P and inorganic or organic particles. Definitely, these P portions might be caught in the CW soil through the continuous expansion process. Still, PO_4^3-P departure by CWs might depend on upon the P centre in the pore (water filled voids between soil particles) (Reddy *et al.*, 1999).

Moreover, adsorption/desorption and precipitation/solubilisation are controlled by variables such as pH, redox potential and the measure of P and metal minerals in the silt. In CW situation with $6 < pH < 8$, PO_4^3-P can be adsorbed to, with minerals of iron and aluminium in the CW soil. Still, for iron rich residue, high-effect conditions are required for the P precipitation to happen. The complex between PO_4^3-P and calcium is not delicate to anoxic conditions yet requires CW conditions with $pH > 8$ for the precipitation to happen and stays stable (Nichols, 1999).

Studies have reported that P evacuation by CWs diminishes with time and this could be because of the immersion of the greater part of the sorption destinations. This behaviour might be considered as the "developing marvels" in wetlands. As a result of the "maturing phenomna" the silt/soil can start to discharge P. Of course, spillage of P from recently CWs has furthermore been seen in view of lower P in water. In like manner, a change from harmful to overwhelmingly anoxic conditions in the CW can realize solubilisation of P bound to iron minerals in the wetland soil. Hence, adsorption and precipitation of P by CW residue/soils is steady, but instead reversible. The primary method to inevitably remove P from the CW is through burrowing of the residue/soil for exchange (Stowell *et al.,* 2001) or by procuring the CW macrophytes. Of course, (Lindstrom and White, 2011) suggested that aluminum sulfate (alum) extension could be a more common framework to enhance P removal in CWs. Still, contemplates have prescribed that P precipitation with aluminum chemicals is of low manure esteem if connected to cultivating fields, achieving P ingestion in soil which could make potential ecological dangers (Ippolito *et al*., 2005).Phosphorus is a restricting component for development of macrophyte in CWs, and hence, these organic entities acclimatize P from wastewater present in CWs. On the other hand, a piece of the acclimatized P comes back to the water stage upon senescence and succeeding. The net impact of macrophytes on the water stage P fixation may rely upon macrophyte age and climatic conditions, additionally on the CW operation and maintenance. Literature demonstrates that FWS CWs with new vegetation treating wastewater with inlet concentration in the range of 3.7–24 mg TP L^{-1} accomplishes relative removal of inlet concentration in order of 9–62% and absolute removal extending between 0.02–2.14 g.

2.4.3 Removal of Ammonia from Constructed Wetland

Ammonia and ammonium removal in wetlands is most efficient in subsurface flow wetlands when nitrification is taking place. The factors which limit the nitrification in wetlands are DO (dissolved oxygen), temperature and detention time. It has been observed that increased BOD levels also lessen nitrification rates in wetlands because of competition for dissolved oxygen. Existing CWS utilizing bulrush types of plant have demonstrated the best nitrification rates among all plant species, with Calculations indicating translocation of 120 mg/L O_2 in the wetland and evacuation rates up to 98 % of TN. The expansion of a gravel trickling filter to the outlet of a current wetland was a powerful alteration that expanded air circulation and enhanced ammonium removal. CWS show extraordinary accomplishment because of plant cover and algal control. But subsurface stream wetlands serve well for little scale facilities because of the expense of materials and area size needed to accomplish the correct detainment time. If DO levels increase, results would be promising, yet operational and support expenses would be still high.

2.4.4 Nitrate Removal

The principle removal component of nitrate in runoff has been a subject of open discussion. On separate events, both microbial denitrification and plant uptake have been recognized as a significant evacuation system. Microbial denitrification needs energy for the change of nitrate into nitrogen gas (as N_2, N_2O, or NO). For complete oxidation of nitrates to happen, the oxygen particle must be available as the last electron acceptor. The chemical nitrate reductase (or nitrite reductase) permits particular microscopic organisms to utilize the oxygen from nitrate as last electron acceptor, changing NO_X to nitrogen gas. Denitrification can just happen when a satisfactory carbon source is available for microbial interest. The source of this carbon can be methanol, acetic acid derivation, glucose, plant litter. Plants don’t just give a carbon source to denitrification, but also give a surface to the denitrifying microscopic organisms. These microorganisms are more efficient in treatment of wetlands than in natural wetlands. Since denitrification is a microbial procedure, it reduces at frosty temperatures and increase as water temperature increases. Despite the fact that plants do take up nitrates, ammonia is the favoured nitrogen structure. Ammonia uptake requires less energy than nitrate uptake, bringing about full plant development potential it has been found that in ammonia containing water, plants some do not make the nitrate-diminishing protein. On the other hand, if the water is rich in nitrates, plants will take them up and change them to unstable structures.

Chapter 3

METHODOLOGY

In this chapter the methodology adopted for complying with the research objectives has been detailed. The first section describes the experimental design and approach used in this study followed by the second section that provides detailed information on constructed wetlands (CW). The final section describes the procedures used for monitoring and analysis of water quality and wetland nutrient removal. The study was conducted to assess the effectiveness of phytoremediation plant installed at National University of Sciences and Technology H-12, having the capacity to treat a sewerage line which is around 0.1 Million.

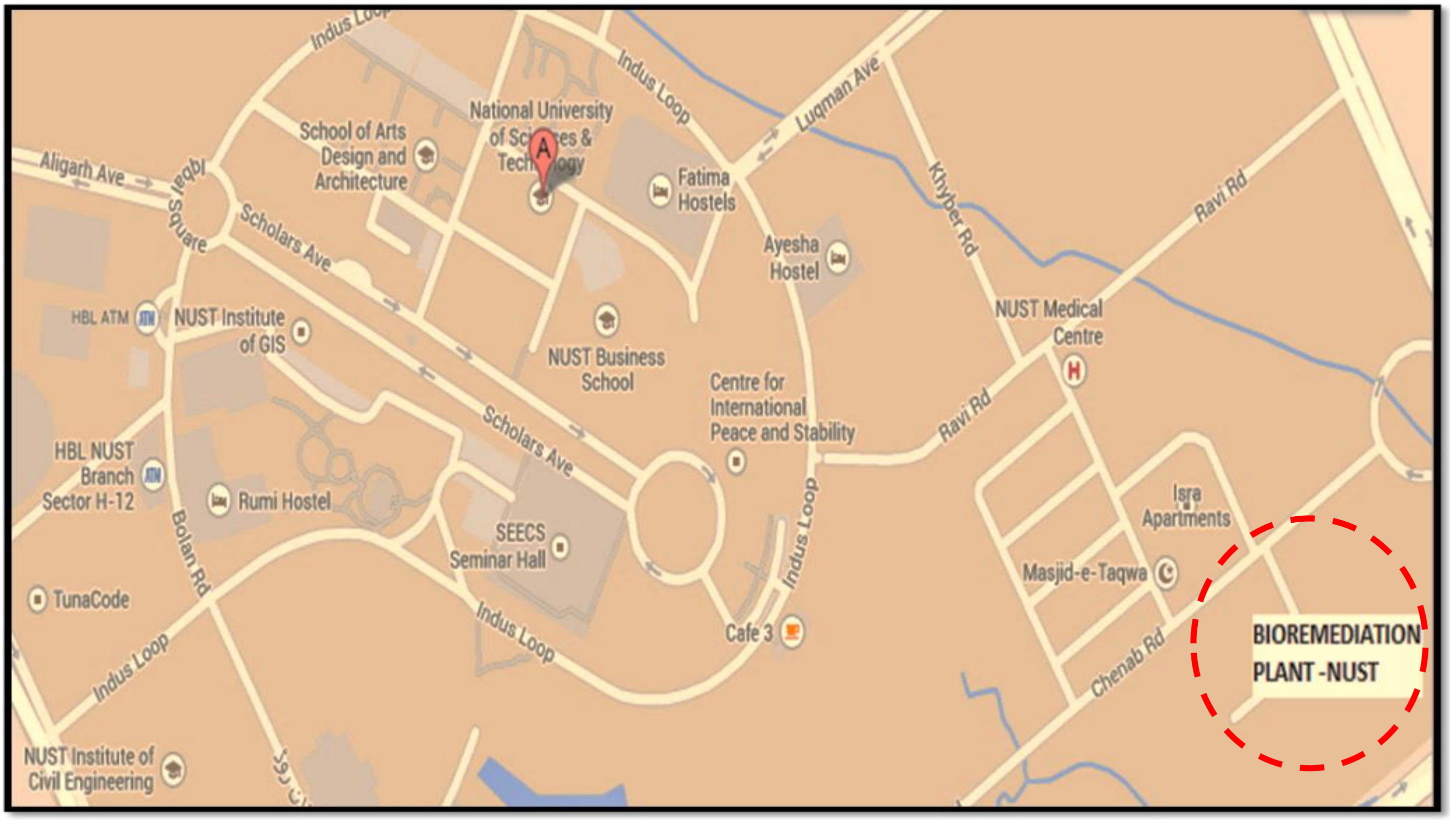

Figure 3.1: Layout of NUST (Encircled point indicates study site)

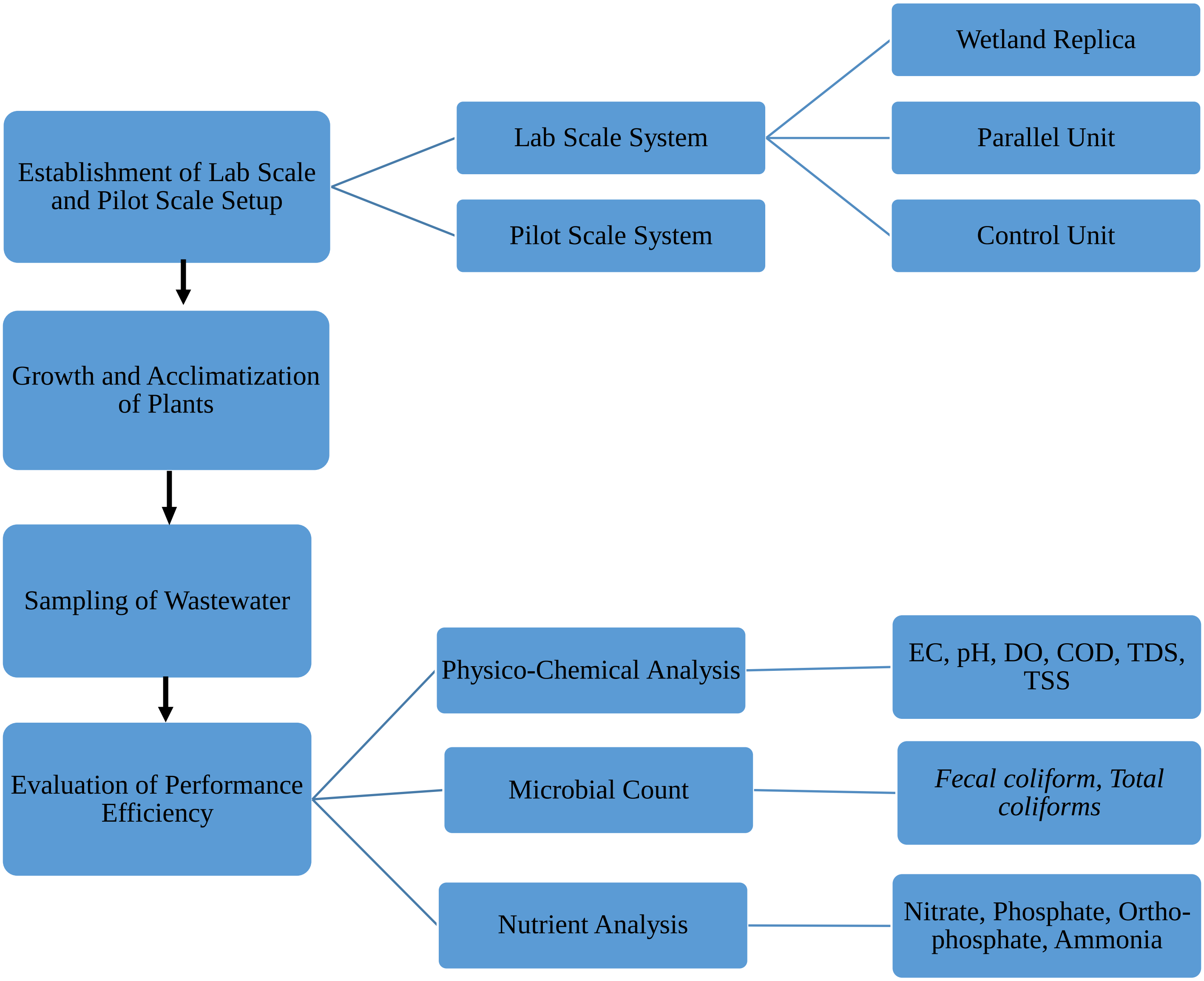

Figure 3.2: Processes Flow Chart

3.1 Experimental Set Up

3.1.1 Pilot Scale Unit

The study site was located in the National University of Sciences and Technology (latitude 12°42’ N, longitude 80° 02’ E) campus Islamabad, capital of Pakistan. The Pilot scale unit installed at the facility received the wastewater from the faculty residence, offices and student hostels. It consists of eight interconnected tanks. The beds of the ponds were coated with plastic sheet to avoid seepage. Four plants (Typha, duck weed, penny wort, and water lettuce) have been planted in the ponds numbered 1 to 8. 1st pond was cultivated with *Typha latifola* (Bulrush) which was supported through gravel and soil. Pond number 2nd and 3rd contained water lettuce which does not require additional support for its growth. *Centella asiatica* (Pennywort) was cultivated in pond number 4th and 5th, both sustained by thermocol sheet to support roots and organic soil, whereas pond number 6th and 7th contained duckweed. The last pond was served as an outlet for the system.

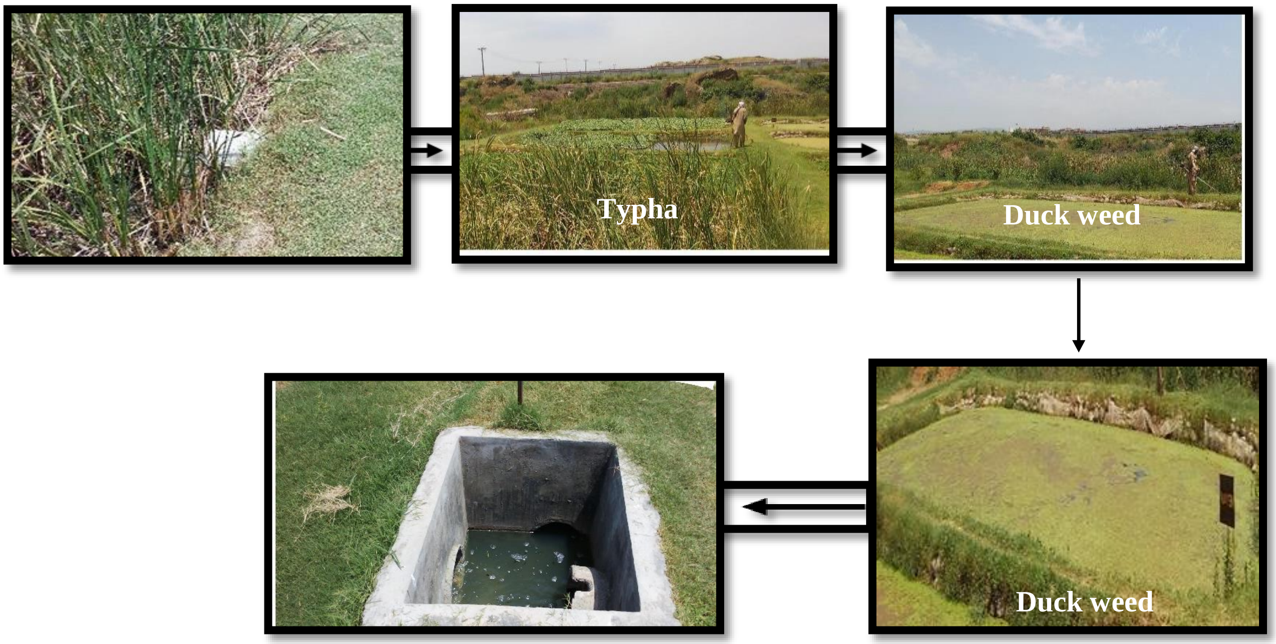

Figure 3.3: Schematic Layout of Pilot Scale Constructed Wetland

3.1.2 Replica Lab Scale Set Up

A replica of pilot scale was established at the lab for establishing a comparison between the treatment efficiencies of pilot scale and lab scale. Plastic tubes were interconnected like that of wetland ponds with the steel pipe 1ft. in size. The length and width of the tubs used was 13 inches by 2 ft. Plastic tubes were used to ensure no leakage. Setup was built at an open air place so that sunlight could be available to the plants. Wastewater, supporting material and order of plants grown was same as that of pilot scale unit.

Figure 3.4: Design of Lab Scale Wetland Replica

3.1.3 Parallel Scale Unit

The design of this unit was like that of the replica unit except that tubs were not interconnected with each other. The purpose behind the establishment of this unit was to measure the individual uptake efficiency of plants without their dependence on each other. Plants in this unit were same as those in pilot and replica scale unit**.**

Figure 3.5: Parallel Scale Unit

3.1.4 Control Unit

Control unit consisted of four tubs containing wastewater without plants to ensure that phytoremediation was the only process playing a key role in the treatment facility. The reason behind the establishment of this unit was to confirm the involvement of physical processes in wastewater treatment.

3.2 Wastewater Analysis

3.2.1 Wastewater Sample Handling

Samples were collected in sterilized 250 mL schott (glass) sampling bottles from the inlet and outlet of each selected plant on weekly basis. For parallel system samples were collected from each of the two tubs while for the control unit sample were collected from inlet and outlet. Bacterial count analysis for both lab scale and pilot scale units was carried out at the Environmental Microbiology teaching Lab at Institute of Environmental Sciences and Engineering (IESE).

Table 3.1: Methods and Instruments for Physio-Chemical Parameters (APHA, 2012)

Sr No.	Parameters	Method Of Analysis	Equipment Used	Units
1	Temperature	Laboratory Method	HACH Session 1	(^{O}C)
2	Conductivity	Potentiometric Method	Conductivity Meter	(µS/cm)
3	Total Dissolved Solids (TDS)	Potentiometric Method	Conductivity Meter	(mg/L)
4	Total Suspended Solids (TSS)	Gravimetric Dried Method	Analytical Mass Balance	(mg/L)
5	Chemical Oxygen Demand (COD)	The Closed Reflux Method	Through Titration	(mg/L)
6	pH	HACH 156	pH meter	--------
7	Dissolved oxygen (DO)	Crison Oxi 45	DO meter	(mg/L)

3.2.2 Microbial Analysis of Wastewater

Membrane filtration (MF) technique was adopted for microbial analysis of collected wastewater.

3.2.2.1 Membrane Filtration Technique

Preparation of Media

Eosin methylene blue (EMB) agar was prepared and poured on dried autoclaved petri plates. After solidification, media plates were placed in incubator for 24 hours in order to check sterility.

Serial Dilution Technique

Ten Flasks, each filled with 90 ml distilled water were autoclaved. 10 ml sample was introduced in first flask and shaked, then 10 ml from this was introduced to the second flask. Same procedure was repeated in the series of ten flasks and 10 ml from last one was discarded in order to make equal volume in all flasks.

Coliforms Enumeration

Sample from each flask was filtered using 0.45µ/m filter paper. Residue on each filter paper was placed oon EMB plates and incubated at 37 C for 24 hours and observed on next day. Ccolonies grown on plates were counted using colony counter and documented as CFU/100.

Table 3.2: Bacterial Parameters and Technique Used (APHA, 2012)

Sr no.	Parameters	Technique Used	Media Used	Measured Units
1.	Total Coliforms	Membrane Filtration (MF)	Eosin Methylene Blue Agar	CFU/100 mL
2.	Fecal Coliforms	Membrane Filtration (MF)	Eosin Methylene Blue Agar	CFU/100mL

3.3 Analysis of Nutrients in Wastewater

Nutrient analysis of collected wastewater samples was performed on weekly basis. Table 3.3 indicates nutrient parameters that were analysed along with their methods (Grag *et al*., 2008).

Table 3.3: Methods for the Nutrient Analysis in Water

Sr no.	Parameters	Methods	Units
1.	Nitrite-N (No_2-N)	Sulphanilamide Spectrophotometric Method	mg/L
2.	Nitrate-N (No_3-N)	Phenol Sulphanilamide Spectrophotometric Method	mg/L
3.	Ammonia-N (NH_3-N)	Phenate Method	mg/L
4.	Phosphate	Per chloric Acid Method	mg/L
5.	Orthophosphate	Ammonium Molybadate	mg/L

3.3.1 Nitrate Analysis in Water (NO_3)

- **Preparation of reagents**

Reagent A: Phenol disulphonic acid

Reagent B: 168.2 g of Potassium hydroxide (KOH) was dissolved in a small quantity of distilled water and then the volume was made upto 250 mL.

Standard stock solution: 3.61 g of potassium nitrate was dissolved in distilled water and the volume of the solution was made upto 500 mL (1000 mg/L). 1 mL of the solution was taken in a flask and then the volume was made upto 1000 mL by adding distilled water this giving 1 mg/L.

Procedure: Reagent A (0.5 mL) was added to 25 mL water sample and allowed to reach dry state on hot. When sample was about to dry reagent B (0.5 ml) was introduced, shacked and appearance of yellow colour was observed. Same procedure was repeated for blank sample.

A series of standards containing 0, 0.2, 0.4, 0.6, 0.8, 1 mg/L nitrate respectively were prepared. Absorbance of the blank, standards, and samples were taken at wavelength of 410 nm through spectrophotometer. A calibration curve was drawn for standards by plotting absorbance vs. nitrate concentration. The concentration of nitrate for the unknown samples was estimated by using the calibration curve.

3.3.2 Ammonia (NH_4) Analysis in Water

- **Preparation of reagents**

Reagent A: Rochelle salt solution was prepared by dissolving 50 g of potassium sodium titrate hydrate ($K\text{-}NAC_4 H_4O_6.4H_2O$) in 100 mL distilled water.

Reagent B: Nessler's reagent was prepared by dissolving (a) 100 g of HgI_2 and 70 g of KI in distilled water (b) 160 g of NaoH in a dissolved in a small quantity of distilled water, and made the volume 1 L by adding distilled water.

Standard stock solution: 0.831 g of anhydrous NH_4CL was dissolved in 100 mL distilled water and the volume was made up to 1 L. 5 mL from this solution was taken in a volumetric flask and the volume was made upto 500 mL by adding distilled water.

Procedure: 50 mL of filtered water sample was taken in a flask, added with regent A (0.2 ml) and reagent B (2 mL) and observed after 20 minutes until the blue colour appeared. Same procedure was repeated with blank.

Series of standard stock solutions were prepared containing 0, 0.5, 1, 1.5, 2 concentrations of ammonia. Absorbance of the sample, blank and standard was measured thorough a spectrophotometer at the wavelength 425 nm. A calibration curve was prepared for standards, plotting absorbance against respective ammonia concentration. The ammonia concentration for the unknown samples was estimated by using the calibration curve.

3.3.3 Orthophosphate Analysis in Water

- **Preparation of reagents**

Reagent A: (a) 5 g of ammonium molybedate $(NH_4)_6\,MO_3O_{24}.4H_2O)$ was dissolved in 35mL of distilled water. (b) 35 mL of concentrated H_2SO_4 was added in 80mL of distilled water. Both solutions were mixed at room temperature and volume was made upto 200 mL by adding distilled water.

Reagent B: Stannous chloride used as reagent B was made by dissolving 0.5 g of $Sncl_2\,.2H_2O$ in 2mL of HCL and solution was made upto 20 mL with distilled water.

Standard stock solution: 21.95 mg of anhydrous KH_2PO_4 was dissolved in 1 L distilled water. 10 mL of this solution was taken in a separate flask and the volume was made upto 500 mL by adding distilled water.

Procedure: Reagent A (1 mL) and reagent B (0.3 mL) was added to 1.25 mL of water sample taken in a conical flask and appearance of blue colour was observed. Same procedure was repeated for blank sample.

Blank sample along with a series of standard stock solutions containing 0, 0.5, 1, 1.5, 2 concentration of orthophosphate was prepared. Absorbance of the sample solution, blank and standard was observed on spectrophotometer at 690 nm. The concentration of orthophosphate in the sample was calculated by using a calibration curve.

3.3.4 Phosphate Analysis in Water

- **Preparation of reagents**

Reagent A: Per chloric acid (AR GRADE)

Reagent B: Phenolphthalein Indicator

Reagent C: 8 g of NaoH dissolved in 100 mL of distilled water (sodium hydroxide 8%)

Procedure: 25 mL of water sample was evaporated in a conical flask and left to cool at room temperature and 1 mL of per chloric acid was added in order to allow digestion. Sample was heated again until it become colourless. After cooling at room temperature, 100 mL of distilled along with a drop of phenolphthalein indicator was added. Solution was then titrated against 8 % NaoH until the colour faded away. Standard curves prepared for orthophosphate was used for total phosphate analysis as well.

Chapter 4

RESULTS AND DISSCUSSION

4.1 Evaluating performance efficiency of *Typha latifolia* and *Lammancea* at Lab, Pilot and Parallel scale

Pilot scale system is a series unit that means ponds are connected with one another. *Typha latifolia* was planted in 1st pond whereas *lammancea* (duckweed) was planted in 4th pond. Inlet and outlet concentration of designed parameters were measured for both plants. Lab scale unit was the replica of wetland unit (series unit) and designed parameters were measured both at inlet and outlet. While parallel unit was designed to check the removal efficiency of individual plant.

4.1.1 Removal of Total Suspended Solids at Pilot Scale

Typha and duckweed both plants have shown the greater tendency of TSS removal during the summer season as compared to winter season. In winter, gradual decrease in temperature led to the growth retardation of plants due to which TSS removal was also decreased. Even amount of TSS was also high at inlet in winter as compared to the summers due to the organic debris of decomposed plants. Maximum removal efficiency was observed during month of May for both plants which was 72 for typha and 60 % for duck weed at pilot scale. Table 4.1 shows the variations in TSS removal by both plants.

Table 4.1: Average Removal of TSS by Typha and Duckweed at Pilot Scale

	Months	Dec	Jan	Feb	Mar	Apr	May
Typha	**Inlet (mg/L)**	38 (34-41)	41.9 (38-44.2)	55.0 (51-58)	30.6 (25-35)	22 (18-26)	15.5 (12-18)
	Outlet (mg/L)	19 (16-21)	22 (19-25)	35 (31-38)	12 (10-14)	8 (6-10)	4.5 (2-6)
	%Efficiency	**50.2**	**46.3**	**35.6**	**60.1**	**64.8**	**72**
Duckweed	**Inlet (mg/L)**	36 (32-38)	40.9 (35-44)	42.0 (39-45)	34.6 (32-38)	25.4 (21-29)	23.5 (21-25)
	Outlet (mg/L)	21 (19-23)	28 (24-33)	29.46 (26-32)	15 (12-18)	10.46 (8-12)	9.28 (7-11.2)
	%Efficiency	**41**	**31**	**30**	**50**	**58**	**60**

***Brackets contains the minimum and maximum values**

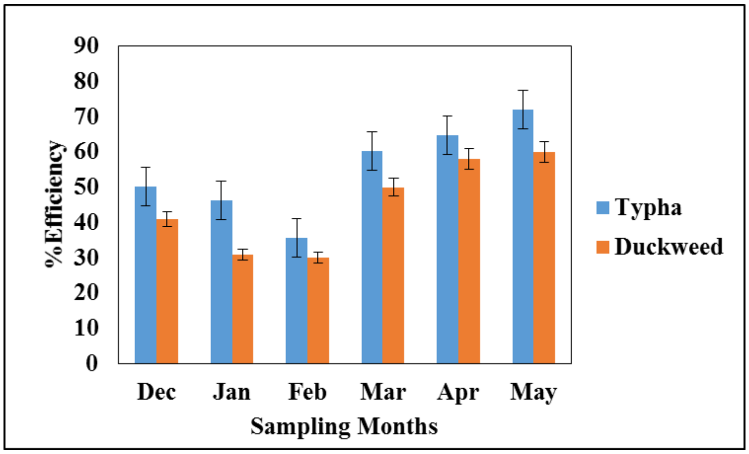

Figure 4.1: Removal (%) of TSS by Typha and Duckweed at Pilot Scale

4.1.2 Removal of Total Suspended Solids at Lab Scale

During winters, removal concentration of total suspended solids (TSS) were very low (26 - 46%) for duckweed and (40 – 49%) for typha while in summer, total suspended solids removal efficiency values increased upto a maximum of 70 for typha and 55% by duckweed. Consequently, the variations in the influent and effluent of total suspended solids (TSS) values (Table 4.2) can be related to the growth and widespread root system developed by plants. Removal percentage was enhanced by giving a larger surface area, decreasing the water velocity and supporting settling and filtration in the root network.

Table 4.2: Average Removal of TSS by Typha and Duckweed at Lab Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	41 (39-43.7)	46.93 (43-51)	52.02 (48-56.9)	34.66 (32-38)	17 (15-19)	13.53 (12-15)
	Outlet (mg/L)	20 (18-22.5)	25.5 (22-30)	30.4 (27-34)	14 (10-18.5)	5.4 (3-8)	4 (1.7-6)
	%Efficiency	**49.83**	**46.52**	**40**	**60.2**	**68.32**	**70**
Duckweed	**Inlet (mg/L)**	40.75 (37.8-43)	42 (40-43)	56 (51-62)	26 (24-28.5)	28 (22-32)	26.8 (25-30)
	Outlet (mg/L)	22 (18-26)	26 (22-31)	41.5 (37-46)	15 (12-18)	14 (11.9-16.8)	12 (11-13)
	%Efficiency	**46**	**38**	**26**	**42**	**49**	**55**

***Brackets contains the minimum and maximum values**

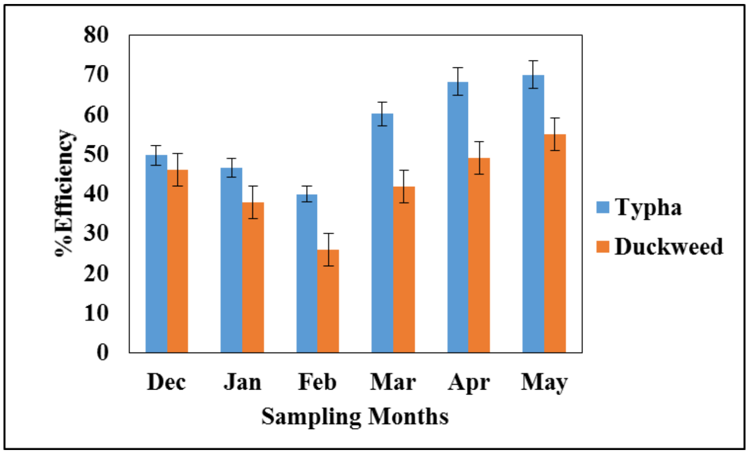

Figure 4.2: Removal (%) of TSS by Typha and Duckweed at Lab Scale

4.1.3 Removal of Total Suspended Solids at Parallel Scale

Total suspended solids removal percentage of the parallel system ranged between 47–72% for typha and 41-63% for duckweed as presented in Figure 4.3. Generally, through the monitoring period, effluent total suspended solids concentration of system was below the National

Environmental Quality Standards of Pakistan, which is 150 mg L^{-1} for treated domestic wastewater.

Table 4.3: Average Removal of TSS by Typha and Duckweed at Parallel Scale

Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Inlet (mg/L)	41.04 (38-44)	46.93 (44-48)	60.02 (57-63)	34.66 (32-36)	25.4 (22-28)	23.55 (20-25)
Typha (mg/L)	12 (10-14)	22.1 (20-24)	32.1 (30-34)	13.96 (11-15)	9.12 (8-11)	6.57 (5-7)
%Efficiency	**68.01**	**52.21**	**47.39**	**60.17**	**64.08**	**72.19**
Duckweed (mg/L)	24 (22-26)	32 (30-34)	42 (40-44)	17 (15-20)	10.46 (8-12)	8 (6-12)
%Efficiency	**41**	**31**	**30**	**50**	**58**	**63**

***Brackets contains the minimum and maximum value**

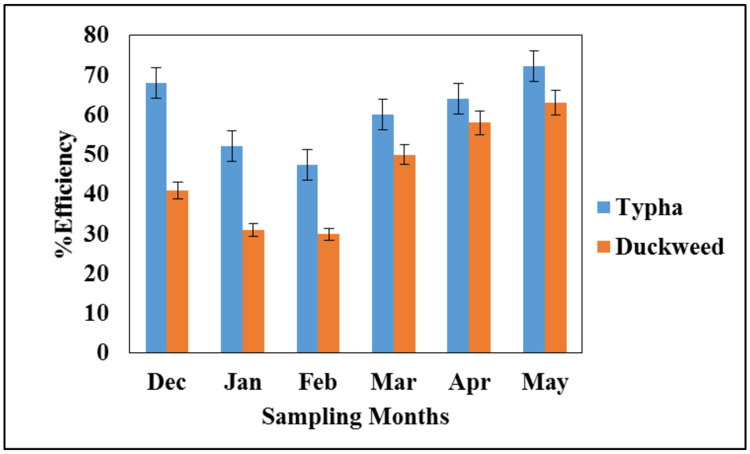

Figure 4.3:Removal (%) of TSS by Typha and Duckweed at Parallel Scale

4.1.4 Removal of Chemical Oxygen Demand at Pilot Scale

Chemical oxygen demand removal was achieved by a combination of physical and microbial mechanisms in CWs. The SFCW system has two important features which make wetlands efficient at removing chemical oxygen demand under heavy loads. Firstly, due to the physical separation mechanism, organic solids could settle out and retained in the wetland cell for a longer time, thereby allowing improved hydrolysis of organic solids for biodegradation to proceed easily. Further, coarse gravel media placed inside the wetland cell allow accumulation of immense amounts of attached bacteria, which may be very helpful in rapidly catalysing chemical reactions to affect the treatment. That removal efficiency by typha was 24.81 and 16.3% was by duckweed.

Table 4.4: Average Removal of COD by Typha and Duckweed at Pilot Scale

	Months	Dec	Jan	Feb	Mar	Apr	May
Typha	**Inlet (mg/L)**	558.7 (552-560)	503.3 (549-505)	501.6 (547-505)	301.0 (295-305)	254.6 (250-258)	129.4 (125-132)
	Outlet (mg/L)	442.7 (440-445)	400.5 (395-405)	450.6 (445-455)	250.0 (245-255)	197.8 (195-200)	97.3 (95-100)
	%Efficiency	**20.76**	**20.42**	**10.16**	**16.94**	**22.32**	**24.81**
Duckweed	**Inlet (mg/L)**	613 (610-615)	623 (620-625)	620 (615-625)	413 (410-415)	319 (315-325)	250 (245-255)
	Outlet (mg/L)	544 (540-550)	577 (570-580)	577 (570-580)	383 (380-385)	290 (285-295)	209 (205-215)
	%Efficiency	**11.30**	**7.5**	**6.93**	**7.38**	**8.90**	**16.38**

***Brackets contains the minimum and maximum values**

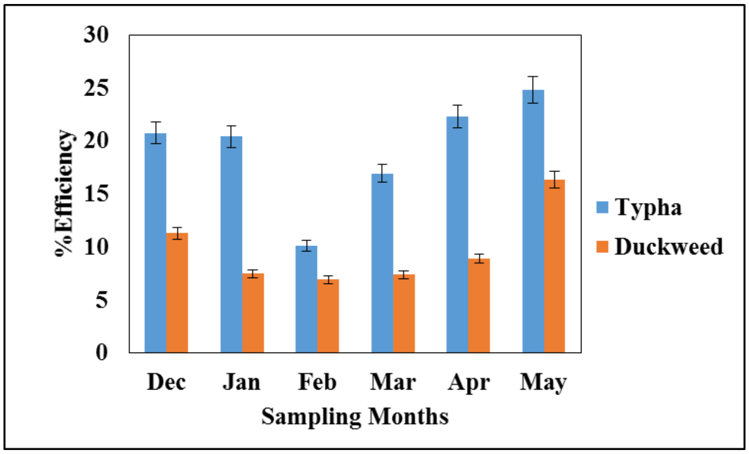

Figure 4.4: Removal (%) of COD by Typha and Duckweed at Pilot Scale

4.1.5: Removal of Chemical Oxygen demand at Lab Scale

The efficiency of organic pollutant removal is indicated by the change in chemical oxygen demand of the effluent treated through the system planted with typha and duckweed. The observed chemical oxygen demand removal efficiencies could be related mostly to quiescent conditions by deposition and filtration, under which organic compounds had undergone both aerobic and anaerobic degradation by the heterotrophic micro-organisms in the system arising from the oxygen concentration in the bed. The present study shows that chemical oxygen demand removal percentage was high during summers and low during winters. It was found to be about 47 for typha and 29% for duckweed during summers. Whereas it was only 13% for typha and 10.8% for duckweed during winters.

Table 4.5: Average Removal of COD by Typha and Duckweed at Lab Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	585.5 (580-590)	526.15 (520-530)	384.5 (380-390)	334.66 (330-340)	256.14 (250-260)	245.9 (240-250)
	Outlet(mg/L)	505.7 (500-510)	469 (465-475)	345.9 (340-350)	257 (255-260)	136.4 (130-140)	129.4 (125-135)
	%Efficiency	**13.62**	**10.80**	**10.02**	**23.21**	**46.73**	**47.37**
Duckweed	**Inlet (mg/L)**	524.0 (520-530)	473.2 (470-479)	426.7 (420-430)	383.9 (380-387)	245.3 (242-247)	250.3 (245-253)
	Outlet(mg/L)	467.2 (465-470)	441.4 (438-443)	405.4 (402-407)	279.3 (276-282)	178.3 (173-182)	176.3 (172-180)
	%Efficiency	**10.8**	**6.7**	**5.0**	**27.2**	**27.3**	**29.5**

***Brackets contains the minimum and maximum values**

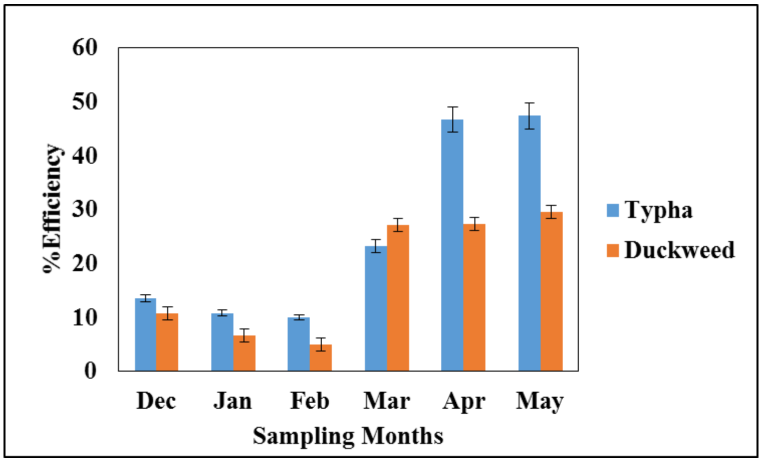

Figure 4.5: Removal (%) of COD by Typha and Duckweed at Lab Scale

4.1.6 Removal of Chemical Oxygen demand at Parallel Scale

COD removal values for typha and duckweed were examined. Lowest removal efficiencies measured were for month of February was recorded as 31.81% for typha and 41.68% for duckweed. Maximum efficiency for typha was recorded as 62%. For duckweed it was 69% at the parallel scale during month of May.

Table 4.6: Average Removal of COD by Typha and Duckweed at Parallel Scale

Months	Dec	Jan	Feb	Mar	Apr	May
Inlet(mg/L)	520 (515-523)	543 (540-545)	515 (509-518)	349 (345-352)	225 (220-230)	195 (190-200)
Typha(mg/L)	204 (200-209)	256 (250-260)	351.19 (345-354)	166.66 (162-169)	79 (75-81)	59 (56-62)
%Efficiency	**60.77**	**52.85**	**31.81**	**52.25**	**65.0**	**69.0**
Duckweed(mg/L)	278.74 (272-284)	306 (302-310)	300.37 (298-304)	181.07 (179-184)	102 (98-105)	72 (70-74)
%Efficiency	**46.40**	**43.00**	**41.68**	**48.12**	**54.67**	**62.0**

***Brackets contains the minimum and maximum values**

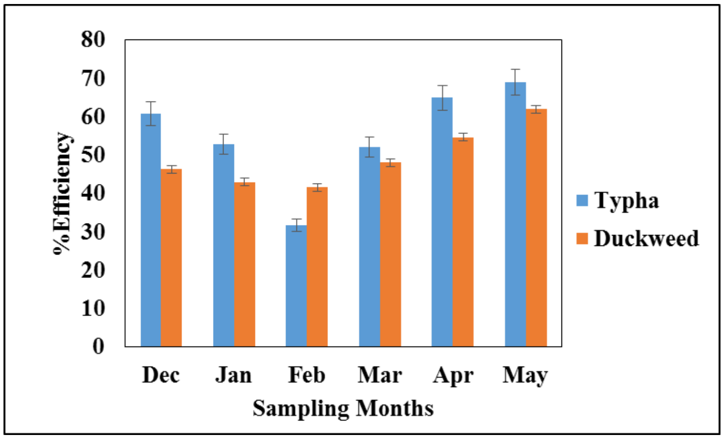

Figure 4.6: Removal (%) of COD by Typha and Duckweed at Parallel Scale

4.1.7 Removal of Electric Conductivity and Total Dissolved Solids at Pilot Scale

The term TDS stands for total dissolved solids in water. The TDS and electrical conductivity are closely related. The more solid are dissolved in the water, the higher is the value of electric conductivity. Majority of solids, which remain in the water are dissolved ions. Sodium chloride for example is found in water as Na^+ and Cl^-. The water temperature affects the electric conductivity so that its value increases from 2 to 3 % per 1 degree Celsius that was the reason for higher EC and TDS values at inlet during summer. While both plants typha and duckweed showed their least removal values during month of February as 3.91 and 7.71 % respectively for EC and TDS.

Table 4.7: Average Removal of EC by Typha and Duckweed at Pilot Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (μs/cm)**	621 (615-625)	554.5 (550-560)	486 (483-490)	1132 (1130-1135)	1319 (1315-1325)	1219.5 (1214-1224)
	Outlet (μs/cm)	556 (550-560)	525 (520-530)	467 (465-472)	1029 (1025-1034)	1207 (1205-1212)	1037 (1035-1040)
	%Efficiency	**10.47**	**5.32**	**3.91**	**9.10**	**8.49**	**14.97**
Duckweed	**Inlet (μs/cm)**	868.00 (865-872)	783.40 (780-786)	747.90 (745-750)	715.00 (710-719)	1145.20 (1140-1152)	1145.48 (1139-1150)
	Outlet (μs/cm)	753.00 (750-758)	690.00 (685-693)	690.25 (683-691)	610.00 (607-612)	1000.00 (998-1004)	901.17 (897-903)
	%Efficiency	**13.25**	**11.92**	**7.71**	**14.69**	**17.68**	**21.33**

***Brackets contains the minimum and maximum values**

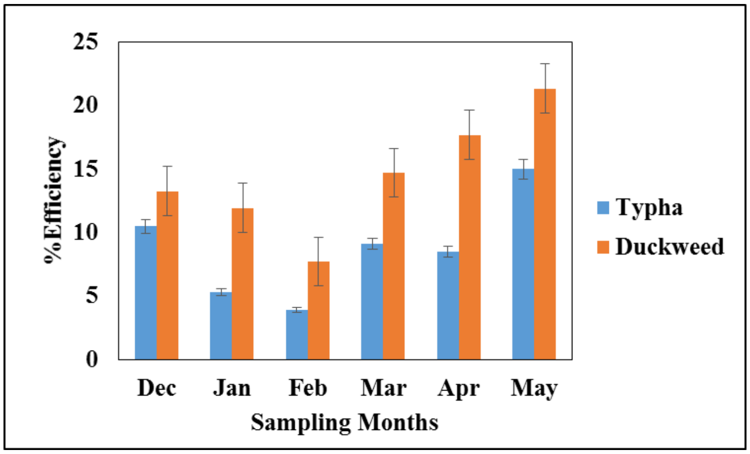

Figure 4.7: Removal (%) of EC by Typha and Duckweed at Pilot Scale

Table 4.8: Average Removal of TDS by Typha and Duckweed at Pilot Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	529 (526-532)	325.25 (323-330)	312.9 (310-316)	550.5 (545-553)	657.5 (655-660)	658 (654-662)
	Outlet(mg/L)	471 (469-473)	307 (305-311)	301 (297-303)	499 (496-502)	604 (601-608)	560.7 (555-565)
	%Efficiency	**10.47**	**5.32**	**3.91**	**9.10**	**8.49**	**14.97**
Duckweed	**Inlet (mg/L)**	351 (347-353)	288 (285-291)	145.2 (142-151)	459 (453-462)	583.4 (580-585)	647.9 (645-652)
	Outlet (mg/L)	304 (298-306)	253.6 (248-258)	135 (130-140)	392 (390-395)	509 (503-512)	508 (503-510)
	%Efficiency	**13.25**	**11.92**	**7.71**	**14.69**	**17.68**	**21.33**

***Brackets contains the minimum and maximum values**

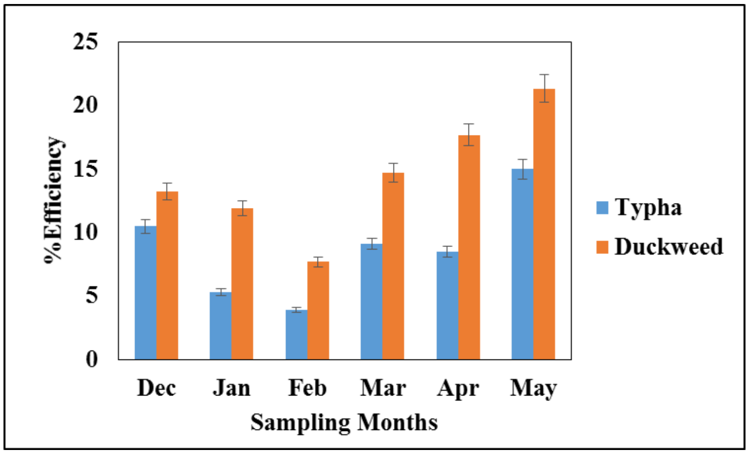

Figure 4.8: Removal (%) of TDS by Typha and Duckweed at Pilot Scale

4.1.8 Removal of Electric Conductivity and Total Dissolved Solids at Lab Scale

Both the plants typha and duckweed showed least removal percentage during months of February 2.73 for typha and 1.92% for duckweed and highest during the month of May 11.62 by typha and 10.97% for duckweed. Table 4.9 gives average decrease in EC by typha and duckweed while table 4.10 gives details about the average removal of TDS by typha and duckweed.

Table 4.9: Average Removal of TDS by Typha and Duckweed at Lab Scale

	Months	Dec	Jan	Feb	Mar	Apr	May
Typha	**Inlet (mg/L)**	1125 (1120-1129)	951 (945-954)	734 (730-739)	1125 (1122-1128)	1268 (1262-1272)	1257 (1255-1261)
	Outlet (mg/L)	1076 (1072-1080)	915.6 (911-918)	715 (712-719)	1036 (1032-1039)	1146 (1143-1149)	1112 (1110-1114)
	%Efficiency	**4.76**	**3.34**	**2.73**	**7.93**	**9.69**	**11.62**
Duckweed	**Inlet (mg/L)**	1081 (1078-1083)	934 (930-939)	699 (695-703)	1127.3 (1125-1130)	1233 (1230-1238)	1277 (1275-1279)
	Outlet (mg/L)	987.5 (985-990)	885.3 (880-889)	683 (680-685)	1068.1 (1065-1070)	1109.5 (1105-1113)	1111.1 (1106-1114)
	%Efficiency	**8.65**	**5.21**	**2.29**	**5.25**	**10.02**	**13.01**

***Brackets contains the minimum and maximum values**

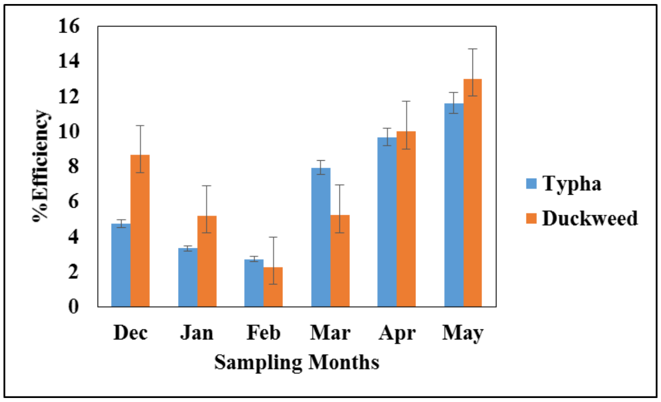

Figure 4.9: Removal (%) of EC by Typha and Duckweed at Lab Scale

Table 4.10: Average Removal of EC by Typha and Duckweed at Lab Scale

	Months	Dec	Jan	Feb	Mar	Apr	May
Typha	**Inlet (µs/cm)**	462 (460-465)	367 (365-370)	306 (302-308)	561 (556-565)	576 (572-580)	617 (615-621)
	Outlet (µs/cm)	440.5 (438-442)	355 (353-357)	298 (295-300)	516 (512-521)	520 (517-522)	545 (542-549)
	%Efficiency	**4.76**	**3.34**	**2.73**	**7.93**	**9.69**	**11.62**
Duckweed	**Inlet (µs/cm)**	524 (521-527)	457 (455-460)	313 (310-315)	413 (409-417)	557 (552-563)	625 (620-629)
	Outlet (µs/cm)	479 (475-484)	433 (430-437)	304 (297-310)	391 (387-395)	500 (495-505)	539 (535-543)
	%Efficiency	**8.65**	**5.21**	**2.29**	**5.25**	**10.02**	**13.01**

***Brackets contains the minimum and maximum values**

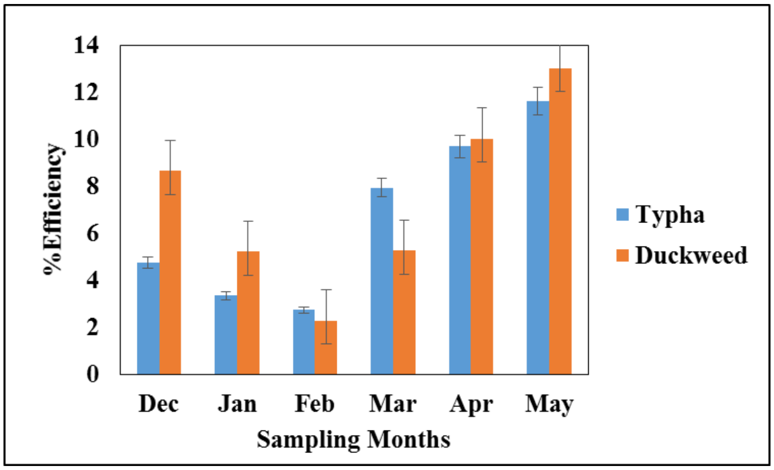

Figure 4.10: Removal (%) of TDS by Typha and Duckweed at Lab Scale

4.1.9 Removal of Electric Conductivity and Total Dissolved Solids at Parallel Scale

Conductivity and TDS were measured for parallel scale unit. Lowest efficiency values of EC and TDS for typha were observed during month of February which were 7.08 % for both parameters. In case of duckweed lowest removal efficiencies for EC and TDS were 7.04 %. Maximum efficiencies were achieved in month of May for both plants with EC and TDS values for typha as 40.61 and for duckweed as 34.9%.

Table 4.11: Average Removal of TDS by Typha and Duckweed at Parallel Scale

Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Inlet (mg/L)	623 (620-626)	540.5 (535-545)	369 (367-372)	500.62 (495-505)	547.52 (545-549)	616.5 (612-618)
Typha(mg/L)	578.5 (575-581)	476.75 (472-478)	335.5 (330-340)	367.12 (365-369)	382.37 (380-384)	366.16 (362-368)
% Efficiency	**9.14**	**11.79**	**7.08**	**26.67**	**30.16**	**40.61**
Duckweed(mg/L)	556 (552-558)	421 (419-423)	341 (339-343)	362 (360-364)	388 (386-390)	399 (397-401)
% Efficiency	**10.75**	**22.11**	**7.45**	**27.03**	**28.34**	**34.92**

***Brackets contains the minimum and maximum values**

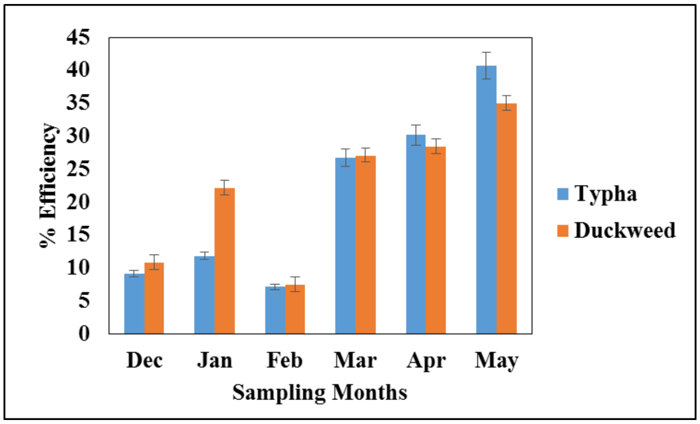

Figure 4.11: Removal (%) of EC by Typha and Duckweed at Parallel Scale

Table 4.12: Average Removal of EC by Typha and Duckweed at Parallel Scale

Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Inlet (μs/cm)	1146 (1142-1148)	981 (979-983)	738 (736-742)	1033 (1030-1036)	1148.5 (1146-1150)	1233 (1230-1236)
Typha(μs/cm)	1063 (1060-1066)	866 (863-869)	671 (669-673)	809.33 (806-811)	801.5 (799-804)	737.33 (735-739)
%Efficiency	**9.14**	**11.79**	**7.08**	**26.67**	**30.16**	**40.61**
Duckweed (μs/cm)	1023 (1020-1027)	765 (760-771)	682 (680-685)	745 (742-751)	824 (820-829)	797 (795-801)
% Efficiency	**10.75**	**22.11**	**7.45**	**27.03**	**28.34**	**34.92**

***Brackets contains the minimum and maximum values**

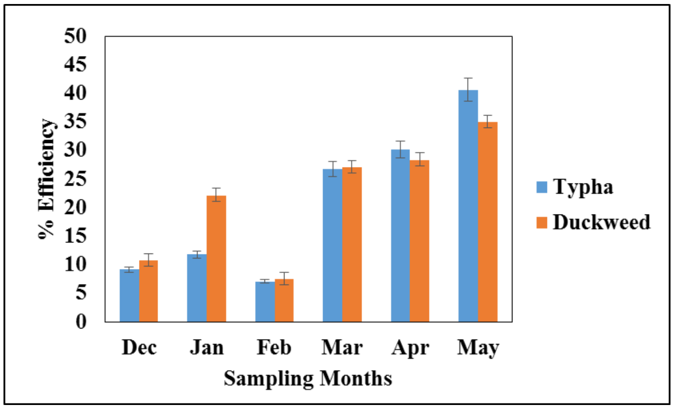

Figure 4.12: Removal (%) of TDS by Typha and Duckweed at Parallel Scale

4.1.10: Dissolved Oxygen at Pilot Scale

The DO concentration varied significantly with the type of plant, depth from the water surface and the time of the day. DO was measured on site using a portable DO meter because change in temperature adversely effects the DO concentration Table 4.13 indicates average increase in dissolved oxygen by Typha and duck weed respectively

Table 4.13: Average Increase of DO by Typha and Duckweed at Pilot Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	6.8 (6.2-7.3)	5.8 (5.6-6.2)	4.7 (4.3-4.11)	3.3 (3.05-3.7)	3.2 (1.75-4.1)	2.2 (1.8-2.8)
	Outlet (mg/L)	7.2 (6.8-7.12)	6.12 (5.85-6.38)	4.95 (4.5-5.33)	3.54 (2.87-3.96)	3.52 (2.84-3.92)	2.52 (1.3-2.13)
	%Efficiency	**6**	**5.7**	**5.5**	**7.1**	**10**	**14**
Duckweed	**Inlet (mg/L)**	4.0 (3.75-4.32)	5.8 (5.66-5.94)	6.11 (5.69-6.55)	6.57 (5.81-7.34)	3.79 ((3.78-3.81)	2.7 (2.5-2.9)
	Outlet (mg/L)	4.35 (4.05-4.82)	6.5 (5.81-7.34)	6.45 (5.79-7.12)	7.14 (6.19-7.88)	4.05 (3.96-4.13)	3.3 (3.05-3.75)
	%Efficiency	**15**	**12**	**6**	**10**	**13**	**22**

***Brackets contains the minimum and maximum values**

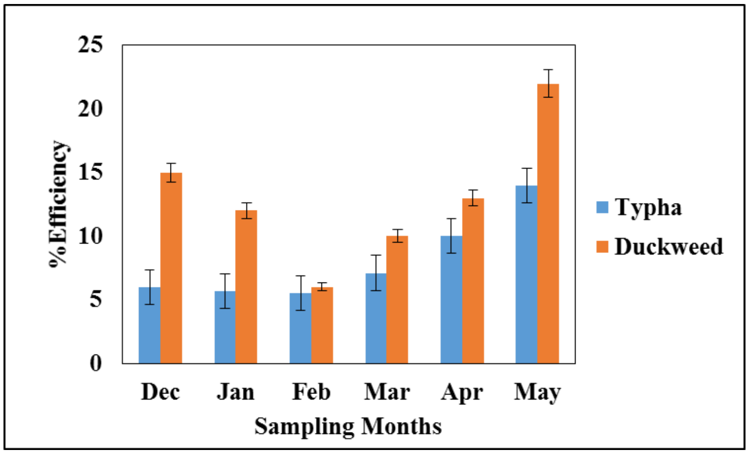

Figure 4.13: Increase (%) of DO by Typha and Duckweed at Pilot Scale

Lowest efficiency of plants in DO measurement was achieved in month of February with a percentage of 5.5 for typha and 6 % for duck weed. Maximum efficiency was achieved in month of May, 14 for typha and 22 % for duckweed .Cold water has the capability of holding more oxygen than warm water due to which DO was higher at the inlet during winter as compared to summer. The relation of density of water with temperature is inversely proportional, so cold water descends to the bottom of a pond and is separated from the source of oxygen (the atmosphere). Warmer water have less density, floats at the top of a pond where mixing with the atmosphere keeps the upper water aerated. The difference in water density results in distinct layers of different temperatures and different DO in a system.

4.1.11 Dissolved Oxygen at Lab Scale

In case of lab scale unit DO was measured immediately after collection of sample as it fluctuates rapidly with time. Table 4.14 indicates average increase in dissolved oxygen by typha and duckweed respectively. For DO lowest efficiency of plants was achieved in month of February with efficiency of 21.1 for typha and 7% for duckweed and maximum efficiency was achieved in month of May 24 for typha and 20 % for duckweed.

Table 4.14: Average Increase of DO by Typha and Duckweed at Lab Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	4.82 (4.67-4.97)	5.93 (5.76-6.1)	6.8 (5.81-7.8)	4.95 (4.46-5.51)	5 (4.46-5.41)	2.63 (2.08-3.19)
	Outlet (mg/L)	5.72 (5.07-6.37)	6.93 (6.56-7.31)	7.67 (6.15-9.12)	5.76 (5.577-6.13)	6.19 (5.97-6.42)	3.2 (1.75-4.1)
	%Efficiency	**20**	**17.3**	**12.1**	**16.5**	**21.6**	**24.3**
Duckweed	**Inlet (mg/L)**	4.95 (4.46-5.51)	5.8 (5.66-5.94)	6.91 (6.04-7.85)	4.94 (4.52-5.28)	5 (4.46-5.41)	2.63 (2.03-3.3)
	Outlet (mg/L)	5.4 (4.735-6.17)	5.35 (4.825-5.88)	7.23 (7.19-7.28)	5.74 (5.58-5.95)	5.75 (5.577-6.13)	3.16 (1.79-4.5)
	%Efficiency	**12**	**10**	**7**	**16**	**15**	**20**

***Brackets contains the minimum and maximum values**

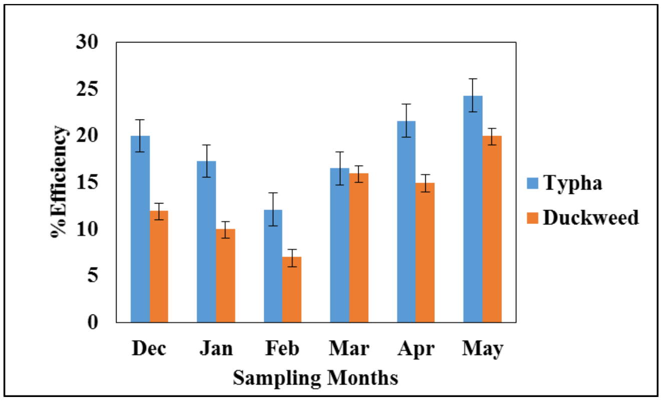

Figure 4.14: Increase (%) of DO by Typha and Duckweed at Lab Scale

4.1.12 Dissolved Oxygen at Parallel Scale

Lowest increased in DO values measured by both plants was observed in month of February which was 11% typha and 13.6 % for duck weed. Maximum increase in DO was calculated in month of May which was 46 % for typha and 49.7 % for duck weed.

Table 4.15: Average Increase of DO by Typha and Duckweed at Parallel Scale

Samples	Dec	Jan	Feb	Mar	Apr	May
Inlet(mg/L)	4.82 (4.67-4.975)	5.95 (5.71-6.25)	6.8 (5.81-7.8)	4.95 (4.52-5.28)	5 (4.46-5.41)	2.63 (2.49-2.84)
Typha(mg/L)	5.75 (5.15-6.37)	6.86 (6.32-7.05)	7.55 (6.14-8.95)	6.89 (6.2-7.39)	7.25 (7.19-7.31)	3.79 (3.78-3.81)
%Efficiency	**19.0**	**15.2**	**11.0**	**39.0**	**45**	**46**
Duckweed(mg/L)	5.8 (5.66-5.94)	6.98 (6.16-7.83)	7.7 (6.15-9.12)	7.06 (6.19-7.88)	7.4 (6.14-8.95)	3.76 (3.15-4.37)
%Efficiency	**20**	**17**	**13.6**	**42.63**	**48**	**49.70**

***Brackets contains the minimum and maximum values**

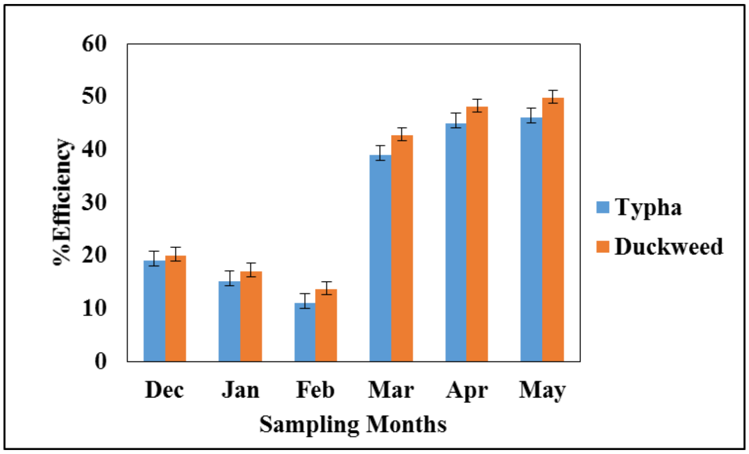

Figure 4.15: Increase (%) of DO by Typha and Duckweed at Parallel Scale

4.1.13 pH of wastewater at Pilot Scale

Shift in pH can be seen in Fig 4.16 where lowest shift could be seen in month of February while highest was observed during the month of May at the pilot scale .Wetland cells containing typha shows 1.90 % change in pH during month of February while 4.95 % during month of May, whereas duckweed containing cell was showing 1% shift in pH during February and 6.6% during May. The probable reason behind such pattern was condition of vegetation during these months. During the winter season due to decrease in temperature plants growth was restarted which decreased their role in treatment whereas during the summer’s season plants were at their full bloom playing key role in water treatment.

Table 4.16: Average Shift in ph by Typha and Duckweed at Pilot Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet**	7.5 (7.43-7.54)	6.93 (6.72-7.17)	6.6 (6.22-7.09)	7.5 (7.14-7.85)	7.6 (7.16-7.89)	7.5 (6.93-7.95)
	Outlet	7.27 (7.01-7.5)	6.78 (6.51-7.05)	6.5 (5.92-7.18)	7.28 (7.15-7.43)	7.25 (7.19-7.30)	7.15 (7.03-7.28)
	%Efficiency	**3.49**	**3.03**	**1.90**	**2.90**	**4.56**	**4.95**
Duckweed	**Inlet**	7.37 (7.21-7.56)	7.3 (7.29-7.39)	7.1 (7.04-7.14)	7.12 (7.1-7.14)	7.0 (6.98-7.09)	7.04 (6.86-7.3)
	Outlet	7 (6.9-7.12)	7.1 (7.07-7.13)	6.99 (6.75-7.20)	6.84 (6.70-7.15)	6.7 (6.19-7.16)	6.58 (5.9-7.1)
	%Efficiency	**5.02**	**2.98**	**1.02**	**3.68**	**4.42**	**6.06**

***Brackets contains the minimum and maximum values**

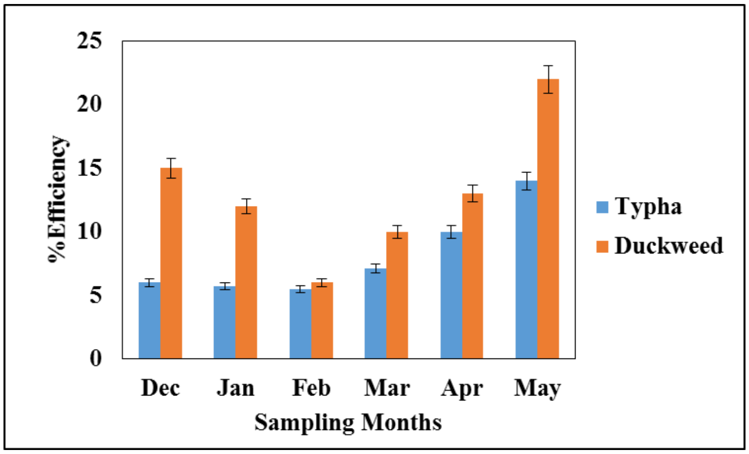

Figure 4.16: (%) Shift in pH by Typha and Duck weed at Pilot Scale

4.1.14 pH of wastewater at Lab Scale

Lowest efficiencies for pH shift were recorded for month of February as 1.38 for typha and 1.09% for duckweed. Highest efficiencies for pH shift were recorded as 13.10 and 2.51% by typha and duckweed respectively during month of May. Table 4.17 and Figure 4.17 shows average shift in pH by typha and duckweed at the lab scale.

Table 4.17: Average Shift in pH by Typha and Duckweed at Lab Scale

	Months	Dec	Jan	Feb	Mar	Apr	May
Typha	**Inlet**	7.01 (6.9-7.12)	6.9 (6.85-7.05)	7.22 (7.09-7.35)	7.36 (7.21-7.51)	7.26 (7.13-7.39)	7.33 (7.04-7.53)
	Outlet	6.55 (5.92-7.18)	6.78 (6.51-7.05)	7.1 (7.07-7.13)	6.85 (6.60-7.11)	6.54 (5.90-7.16)	6.35 (6.1-6.45)
	%Efficiency	**6.65**	**2.11**	**1.38**	**6.11**	**9.28**	**13.10**
Duckweed	**Inlet**	6.9 (6.67-7.11)	7.4 (7.21-7.56)	7.2 (7.06-7.29)	7.3 (7.30-7.45)	7.34 (7.21-7.5)	7.2 (7.20-7.31)
	Outlet	6.75 (6.51-7.05)	7.3 (7.23-7.47)	7.11 (7.04-7.19)	7.24 (7.24-7.38)	7.14 (7.05-7.23)	7.07 (6.94-7.20)
	%Efficiency	**2.11**	**1.28**	**1.09**	**1.84**	**2.20**	**2.51**

***Brackets contains the minimum and maximum values**

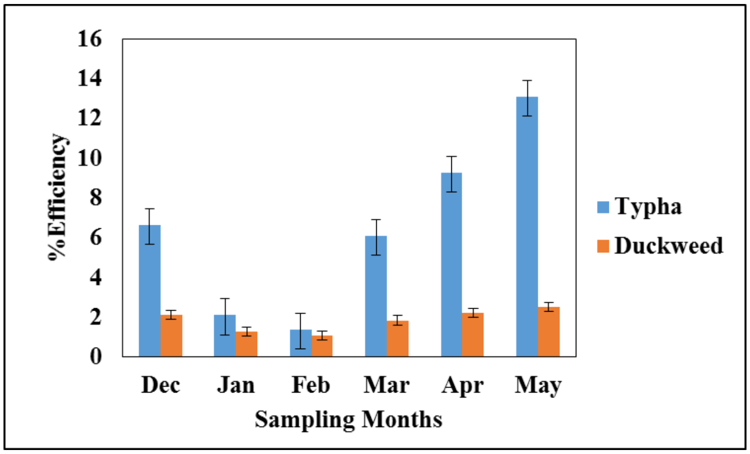

Figure 4.17: (%) Shift in pH by Typha and Duck weed at Lab Scale

4.1.15 pH of wastewater at Parallel Scale

Average shift in pH can be seen in lowest shift could be seen in month of February 0.27 and 0.97% for typha and duckweed respectively, while highest was observed during the month of May 4.83 and 4.54 % for duckweed and typha respectively.

Table 4.18: Average Shift in pH by Typha and Duckweed at Parallel Scale

Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Inlet	7.12 (7.09-7.19)	7.1 (7.10-7.12)	7.32 (7.23-7.47)	7.3 (7.29-7.39)	7.32 (7.23-7.47)	7.25 (7.2-7.305)
Typha	6.89 (6.67-7.11)	7 (6.7-7.10)	7.3 (7.23-7.47)	7.2 (7.11-7.21)	7 (6.98-7.07)	6.94 (6.93-6.96)
%Efficiency	**3.09**	**1.41**	**0.27**	**1.37**	**4.37**	**4.83**
Duckweed	7.04 (6.98-7.07)	7.02 (7.01-7.04)	7.25 (7.2-7.305)	7.19 (7.13-7.29)	7.07 (7.04-7.11)	6.92 (6.72-7.17)
%Efficiency	**1.69**	**1.41**	**0.96**	**1.50**	**3.45**	**4.54**

***Brackets contains the minimum and maximum values**

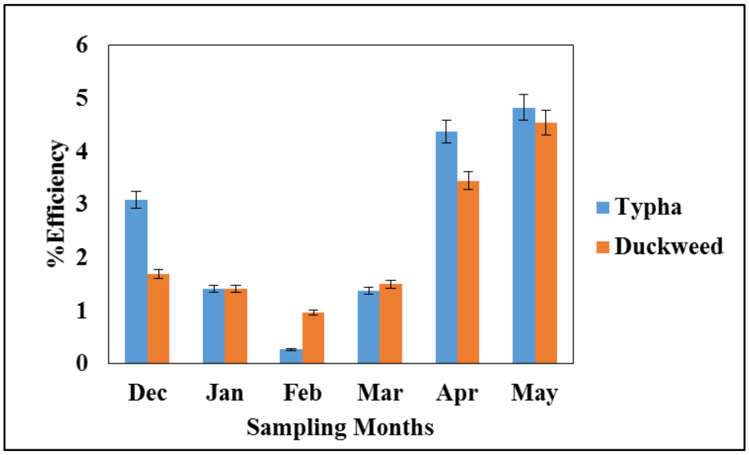

Figure 4.18: (%) Shift in pH by Typha and Duck weed at Parallel Scale

4.1.16 *Coliforms* at Pilot Scale

Samples were taken from inlet of typha and outlet of duckweed for total coliforms. Lowest efficiency achieved was in month of February as 81.4% and for *fecal coliforms* lowest efficiency was 84% in February. Highest efficiencies for total and *fecal coliforms* were achieved in month of May as 96 and 99 % respectively. One of the FWS analysis demonstrated the most noteworthy removal rated for pathogenic microorganisms, around 97% removal rate efficiency for TC and FC (Tsihrintzis *et al.*, 2007). Out of all three systems based on the case studies, the system was the only designed to have high potential for removal of pathogenic microorganisms. The other constructed wetland systems confirmed for TC, FC, and enterococcus removal showed low removal rate (El Hamouri *et al*., 2006; Amaral *et al.*, 2013).

Table 4.19: Average Removal of *Total Coliforms* and *Fecal Coliforms* at Pilot Scale

	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Fecal Coliforms	**Inlet (CFU/100ml)**	6 (4-8)	6.9 (5-12)	6.6 (3-11)	6.6 (5-7.9)	8.0 (4-12)	8.2 (6-10)
	Outlet (CFU/100ml)	5.2 (3-7)	5 (4-7)	4.6 (3-7)	4.2 (2-9)	5.30 (1-9)	4.3 (3.4-5.3)
	%Efficiency	**87**	**85**	**84**	**97**	**97.3**	**99**
Total Coliform	**Inlet (CFU/100ml)**	6.34 (4-8.7)	6.2 (5-7)	6.1 (5.8-6.5)	5.9 (5-6.6)	6.4 (4-8)	6.7 (5-9)
	Outlet (CFU/100ml)	5.2 (4-6)	5.3 (5-5.7)	5.45 (3-6.9)	5.5 (5-6)	4.9 (4.4-5.6)	5.3 (3-8)
	%Efficiency	**86.42**	**82.62**	**81.5**	**92.28**	**94.39**	**96.25**

***Brackets contains the minimum and maximum values**

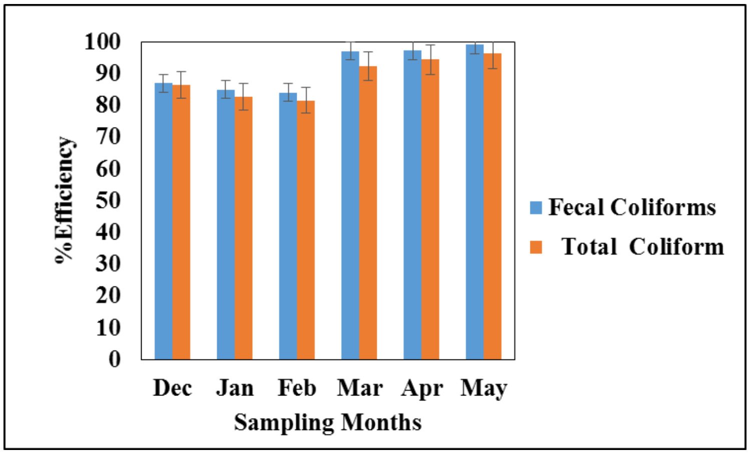

Figure 4.19: Removal (%) of *Total Coliforms* and *Fecal Coliforms*

4.1.17 *Coliforms* at Lab Scale

For total coliforms lowest efficiency achieved was in month of February as 81.4% and for *fecal coliforms* lowest efficiency was 84% in February. Highest efficiencies for total and *fecal coliforms* were achieved in month of May as 96 and 99 % respectively.

Table 4.20: Average Removal of *Total Coliforms* and *Fecal Coliforms* at Lab Scale

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	Months	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Fecal Coliforms	**Inlet (CFU/100ml)**	6.3 (4.7-7.5)	7.3 (5-9)	7 (5.9-8.2)	6.3 (4-8)	7.3 (6.2-8.1)	7.1 (4-9)
	Outlet (CFU/100ml)	5.3 (5-6.3)	5.1 (4.5-6.3)	5.5 (2.98-6.9)	4.9 (3.4-7.2)	4.9 (2.75-5.98)	5.4 (4.1-6.7)
	%Efficiency	**88.42**	**85.62**	**84.5**	**94.28**	**97.39**	**99.25**
Total Coliform	**Inlet (CFU/100ml)**	6.1 (5-7)	5.8 (4.7-6.9)	5.1 (3-7)	5.4 (5-6.1)	6.1 (5-6.9)	6.2 (5.8-7.2)
	Outlet (CFU/100ml)	5 (3-7)	6.0 (5.7-7.9)	5.6 (2-7)	6.2 (5-8)	5.6 (5.2-5.8)	5.3 (5.1-5.9)
	%Efficiency	**89**	**87**	**86.66**	**96**	**98.3**	**99.8**

***Brackets contains the minimum and maximum values**

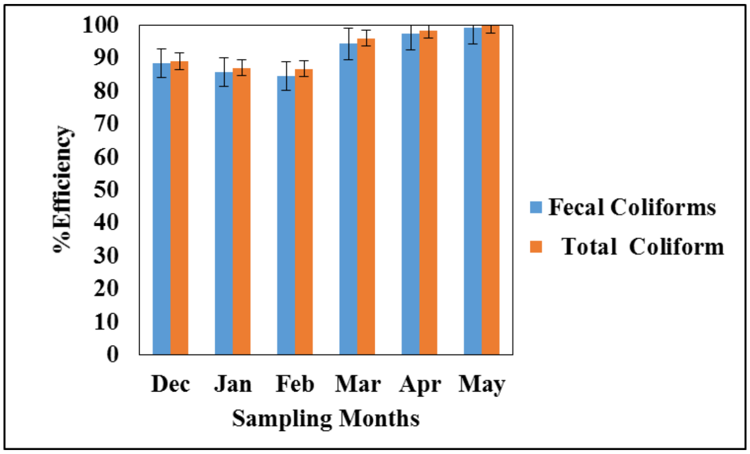


Figure 4.20: Removal (%) of *Total coliforms* and *Fecal Coliforms*

4.1.18 *Coliforms* at Parallel Scale

For *total coliforms* lowest efficiency achieved was in month of February as 81.4% and for *fecal coliforms* lowest efficiency was 84% in February. Highest efficiencies for *total* and *fecal coliforms* were achieved in month of May as 98 and 98.7 % respectively.

Table 4.21: Average Removal of *Total Coliforms* at Parallel Scale

Months	Dec	Jan	Feb	Mar	April	May
Inlet(CFU/100ml)	6.2 (5-8)	6.2 (5.1-7.3)	5.9 (5.1-6.98)	6.17 (5.6-7.3)	6.4 (5.0-7.6)	6.5 (4-8)
Typha(CFU/100ml)	5.1 (3-7)	5.1 (4.7-6.3)	4.9 (3.5-5.6)	4.4 (3-5.7)	5.5 (4.7-7.3)	5.04 (4.2-7.5)
%Efficiency	**90**	**89**	**87.6**	**97**	**97.8**	**98**
Duckweed (CFU/100ml)	5 (4-8)	5.9 (4.7-6.9)	5.3 (5-6.7)	5.66 (4-7)	6.07 (4-8)	5.7 (3-7.9)
%Efficiency	**92**	**90**	**89**	**98.08**	**97**	**98.4**

***Brackets contains the minimum and maximum values**

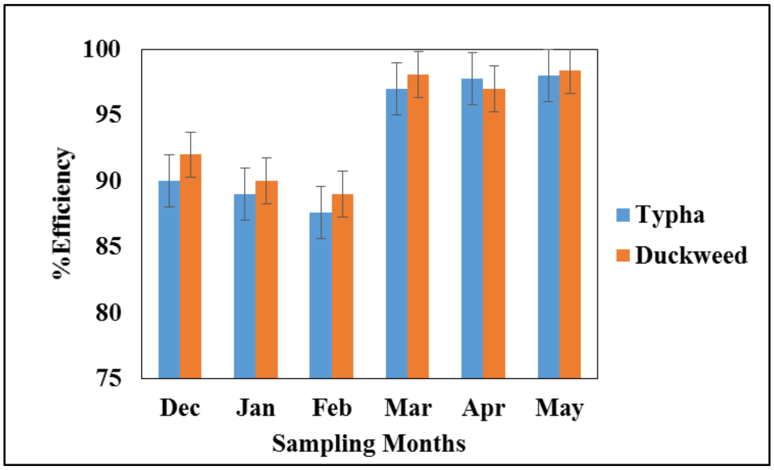


Figure 4.21: Removal (%) of *Total Coliforms* by Typha and Duckweed

Table 4.22: Average Removal of *Fecal Coliforms* at Parallel Scale

Months	Dec	Jan	Feb	Mar	April	May
Inlet (CFU/100ml)	6 (3-9)	5.9 (5-6.5)	5.7 (5.2-6.7)	5.6 (4-7.6)	6.0 (4-8)	6.1 (4.78-6.9)
Typha (CFU/100ml)	4.8 (4-5.8)	4.7 (3-5)	5 (3.7-6.4)	5.0 (4.3-6)	4.7 (4.1-5.9)	4.6 (3.7-5.8)
% Efficiency	**91**	**90**	**84**	**94**	**97**	**97.2**
Duckweed(CFU/100ml)	4.6 (4.1-5.2)	4.9 (4-6.5)	4.7 (4.3-5.3)	4.6 (4-6)	4.4 (3.7-5)	4.3 (4-5.2
% Efficiency	**89**	**87**	**86.5**	**92**	**96**	**98.7**

***Brackets contains the minimum and maximum values**

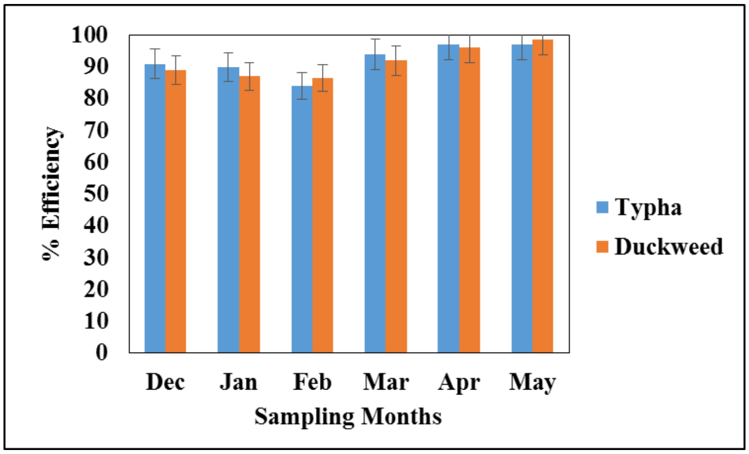
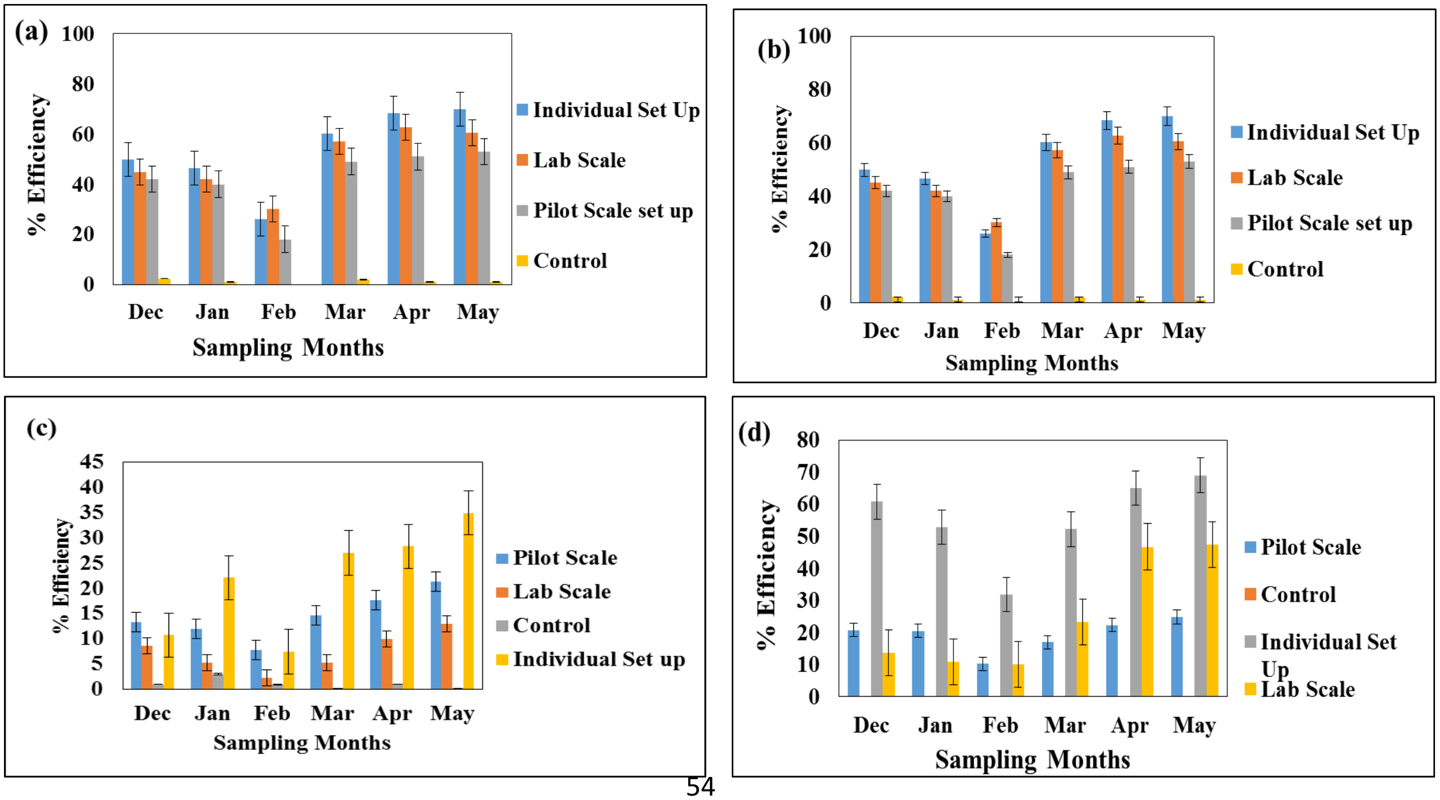


Figure 4.22: Removal (%) of *Fecal Coliforms* by Typha and Duckweed

4.1.19 Comparative Removal Efficiency of Typha and Duckweed Analysis at Pilot Scale, Lab Scale, Parallel Scale and Control Unit

Removal efficiency of typha and duckweed was compared and this helped in better understanding of macrophytes and how their performance differ in different units in Figure 4.20 (a) to (f) which depicts comparative removal efficiency of typha in series unit (Pilot scale unit, Lab scale replica), individual unit and control unit while Figure 4.21 (a) to (f) depicts comparative removal efficiency of duckweed in series unit (Pilot scale unit, Lab scale replica) individual unit and control unit.



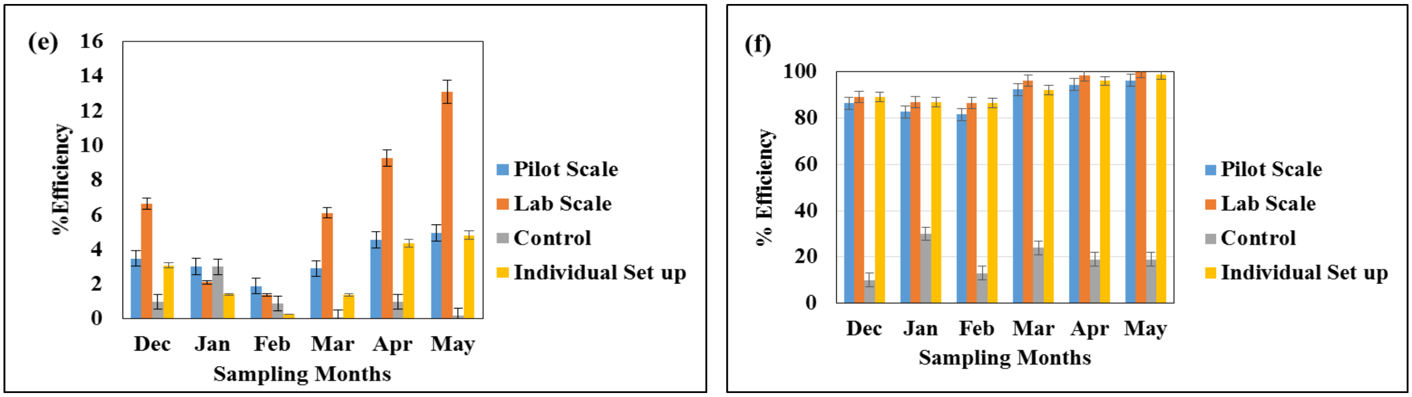


Figure 4.23: Efficiency Comparison of Typha at the All Four Units (A) DO (B) TSS (C) TDS (D) COD (E) pH (F) *Coliforms*

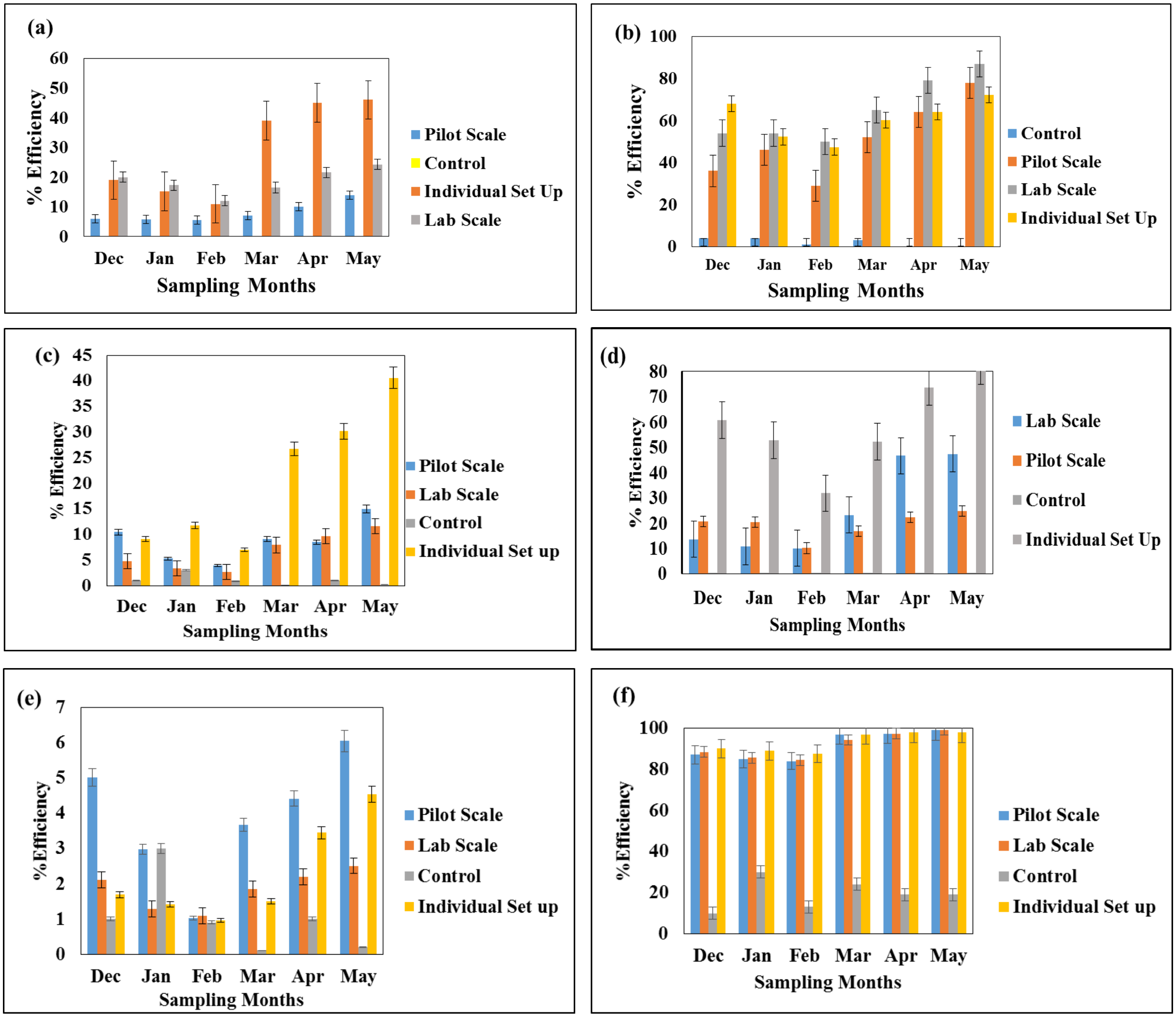


Figure 4.24: Efficiency Comparison of Duckweed at the All Four Units (A) DO (B) TSS (C) TDS (D) COD (E) pH (F) *Coliforms*

4.2 Nutrient Removal Analysis by Typha latifolia and Lammancea at Lab and Pilot Scale

4.2.1 Removal of Ammonia by Typha and Duckweed at Pilot Scale

The removal percentages show that the wetland cells planted with typha were removing an average of 79% at pilot scale whereas wetland cells planted with the duck weed was removing from 50 to 69% of the influent ammonia. It was expected for the effluent concentrations to increase as temperature decreases; however, the reverse was observed for some of the wetland cells. It was concluded that water temperature does not play a role in ammonia removal in aerated, subsurface flow wetlands, at least under the condition studied here. A subsurface flow system with a gravel base (Sikora, *et al*, 1995) produced ammonia removal rates ranging up to 90%. An increase in required detention time occurred as ambient temperature declined from 26 °C to 14 °C.

Table 4.23: Average Removal of Ammonia by Typha and Duckweed at Pilot Scale

Typha	**Months**	**Feb**	**Mar**	**Apr**	**May**
	Inlet (mg/L)	8.91 (5-13)	7.83 (6-12)	7 (5-9.8)	7.25 (3.75-11)
	Outlet (mg/L)	1.8 (0.4-2.4)	2.4 (1.8-2.8)	2 (1.6-2.4)	1.5 (0.7-2.3)
	%Efficiency	**62**	**69**	**71**	**79**
Duckweed	**Inlet (mg/L)**	5.3 (3-7.5)	4.9 (2.8-7)	6.2 (3-9)	5.75 (3.5-10)
	Outlet (mg/L)	2.45 (2-2.9)	2.1 (1.8-2.6)	2.3 (2.1-2.5)	1.8 (0.6-2.2)
	%Efficiency	**54**	**58**	**63**	**69**

*Brackets contains the minimum and maximum values

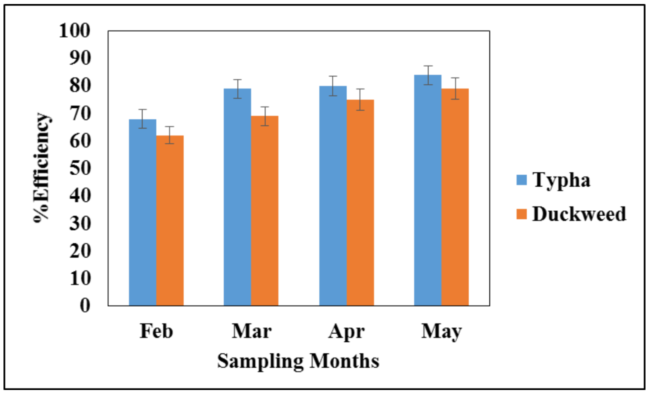


Figure 4.25: Removal (%) of Ammonia by Typha and Duckweed at Pilot Scale

4.2.2 Removal of Ammonia by Typha and Duckweed at Lab Scale

At the lab scale sampling was done for four months and the highest values recorded for typha were 84 while for duckweed it was 79% during the month of May. It was observed that with the increases in temperature removal efficiency of ammonia was also increased. The possible assumed explanation behind this trend was the growth pattern of plants in summer (plants at their full bloom).

Table 4.24: Average Removal of Ammonia by Typha and Duckweed at Lab Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	7.1 (3-11)	5.2 (1.2-7.5)	5.7 (2-9)	7.6 (5.7-9.3)
	Outlet (mg/L)	2.2 (0.2-2.12)	1.0 (0.5-1.7)	1.1 (0.3-1.9)	1.1 (0.5-1.9)
	%Efficiency	**68**	**79**	**80**	**84**
Duckweed	**Inlet (mg/L)**	6.76 (2.7-11)	7.3 (3.2-12)	7.4 (3.5-11.5)	7.25 (5-9)
	Outlet (mg/L)	2.6 (0.4-3)	2.2 (1-3.5)	1.8 (1.6-2.4)	1.5 (1.3-2)
	%Efficiency	**62**	**69**	**75**	**79**

***Brackets contains the minimum and maximum values**

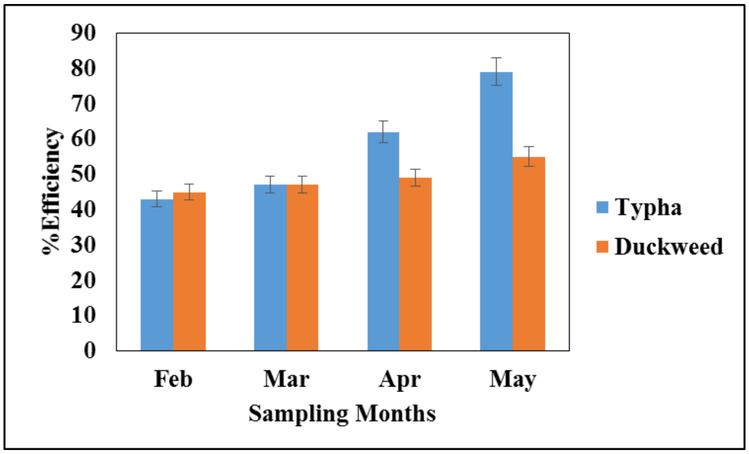


Figure 4.26: Removal (%) of Ammonia by Typha and Duckweed at Lab Scale

4.2.3 Removal of Nitrate by Typha and Duckweed at Pilot Scale

At the pilot scale highest removal efficiency of typha and duckweed was measured 79 and 55% during the month of May whereas during month of Feb lowest efficiency for both the plants was recorded. According to a study, (Behrends *et al.*,2011) Typha latifolia in a wetland contained gravel substrates removed nitrate to a level less than 10 mg/L within 4 days. Collins *et al.*, 2013 reported 17 % reduction in nitrates. Denitrification is considered to be the chief NO_3^- removal process in constructed wetlands, mainly in those established temporally with an accumulated base of organic matter supplying carbon for this process. Plant uptake is also a factor in nitrate removal processes.

Table 4.25: Average Removal of Nitrate by Typha and Duckweed at Pilot Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	60.7 (56.8-67.7)	44.6 (42-47)	41.1 (39-43)	40 (38-42.7)
	Outlet (mg/L)	32 (26-42)	23.6 (20.5-27)	15.1 (13-18)	9.4 (5-14)
	%Efficiency	**43**	**47**	**62**	**79**
Duckweed	**Inlet (mg/L)**	56.6 (45-77)	52.1 (48-57)	44.6 (41-49)	53.6 (50-57)
	Outlet (mg/L)	31.1 (29-33)	27.1 (23-32)	22.5 (20-26)	9 (7-11)
	%Efficiency	**45**	**47**	**49**	**55**

***Brackets contains the minimum and maximum values**

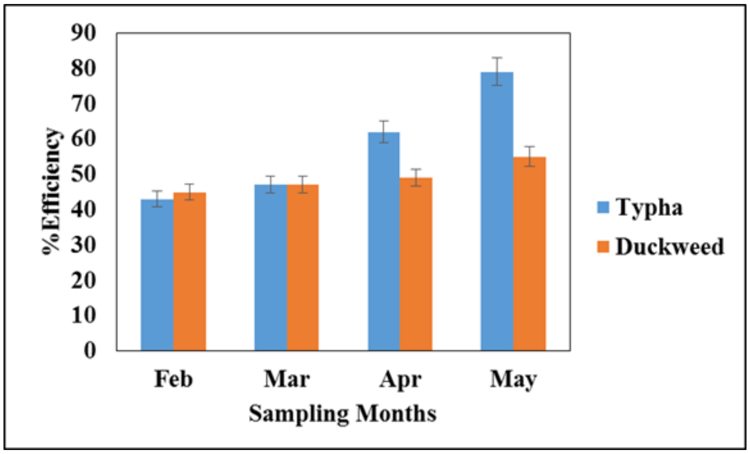


Figure 4.27: Removal (%) of Nitrate by Typha and Duckweed at Pilot Scale

4.2.4 Removal of Nitrate by Typha and Duckweed at Lab Scale

It was observed that concentration of nitrate was higher at inlet during winter as compared to summer due to dead organic matter of plants that organic matter contributes to the concentration of the nitrite at inlet during the winter while during the summer plant growth became rapid and vegetation starts playing its role in the treatment so higher removal efficiency was observed during the summers. Maximum efficiency was recorded during the month of May 75 by typha and 69% by duckweed.

Table 4.26: Average Removal of Nitrate by Typha and Duckweed at Lab Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	52 (48-56.8)	43.6 (40-46)	45.1 (42-49)	37 (33-41)
	Outlet (mg/L)	10 (7-13)	10 (5-11)	6 (3-10)	7 (3-11)
	%Efficiency	**42**	**54**	**64**	**75**
Duckweed	**Inlet (mg/L)**	51.1 (43-61)	45.1 (43-47.7)	42.5 (38-46)	39.4 (36-42)
	Outlet (mg/L)	21.5 (18-26)	19 (17-22)	15 (13-17)	12 (8-16)
	%Efficiency	**57**	**57**	**64**	**69**

***Brackets contains the minimum and maximum values**

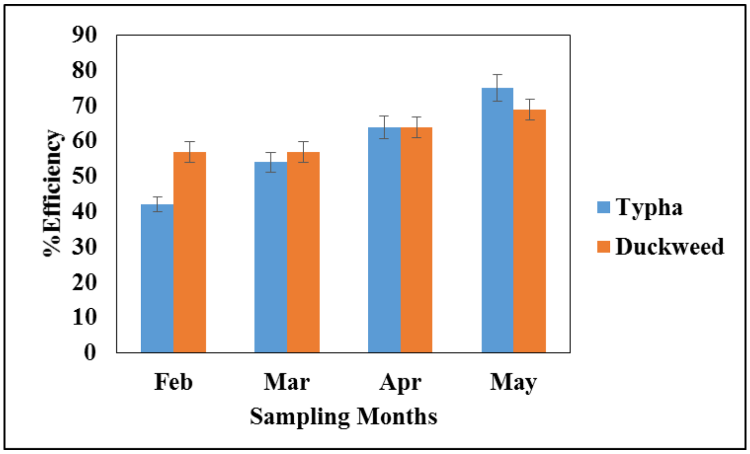


Figure 4.28: Removal (%) of Nitrate by Typha and Duckweed at Lab Scale

4.2.5 Removal of Orthophosphate by Typha and Duckweed at Pilot Scale

The removal percentages showed that the wetland cells containing typha and duckweed are removing, on average, greater than 47 % and 36 % respectively at pilot scale. Phosphorus is present in wastewaters as orthophosphate. Free orthophosphate is the main type of phosphorus being used specifically by macrophytes.

Table 4.27: Average Removal of Orthophosphate by Typha and Duckweed at Pilot Scale

	Months	Feb	Mar	Apr	May
Typha	**Inlet (mg/L)**	11.00 (6.3-13.7)	11.2 (9-13)	18.8 (15.5-22)	21 (14.4-32.9)
	Outlet (mg/L)	9.30 (3-17)	6 (3-9)	5.83 (1-7.9)	5.3 (0.6-8.8)
	%Efficiency	**15.45**	**43.75**	**45.03**	**47**
Duckweed	**Inlet (mg/L)**	12.5 (8-15)	15 (11-19)	16.73 (14-19)	21 (15-30)
	Outlet (mg/L)	9 (5-13)	9 (7-11)	8 (4-12)	7 (3.5-12)
	%Efficiency	**15**	**27**	**34**	**36**

***Brackets contains the minimum and maximum values**

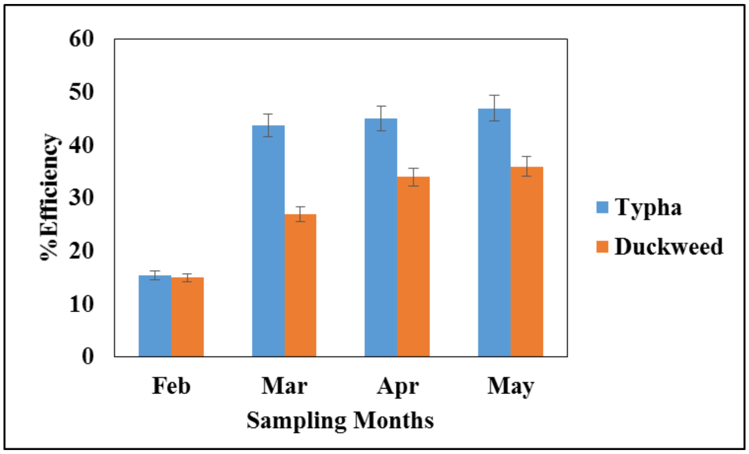


Figure 4.29: Removal (%) of Orthophosphate by Typha and Duckweed at Pilot Scale

4.2.6 Removal of Orthophosphate by Typha and Duckweed at Lab Scale

At the lab scale removal percentages showed that the wetland cells containing typha and duckweed are removing, on average, greater than 50% and 35% respectively. As orthophosphate is only nutrient which is supposed to be directly taken up by macrophytes, during dormient growth seasons of plants during winter’s. The removal percentages of orthophosphate was quite low as compared to summer season when plants were flourishing. Typha was only removing 13% while duckweed was showing the removal efficiency of only 14% during winters.

Table 4.28: Average Removal of Orthophosphate by Typha and Duckweed at Lab Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	11.90 (8-16)	12.81 (8.9-17.8)	21 (17-26)	20.0 (18-24)
	Outlet (mg/L)	9.95 (7.9-11.7)	7.5 (3.5-11)	10 (6-14)	10.25 (4-16)
	%Efficiency	**13**	**37.6**	**50**	**50**
Duckweed	**Inlet (mg/L)**	11 (7-15)	23.79 (13-33)	27.5 (25-30)	32 (15-46)
	Outlet (mg/L)	9.23 (5-13)	10.1 (4-20)	9.3 (5-13)	8 (4-12)
	%Efficiency	**14**	**28**	**31**	**35**

***Brackets contains the minimum and maximum values**

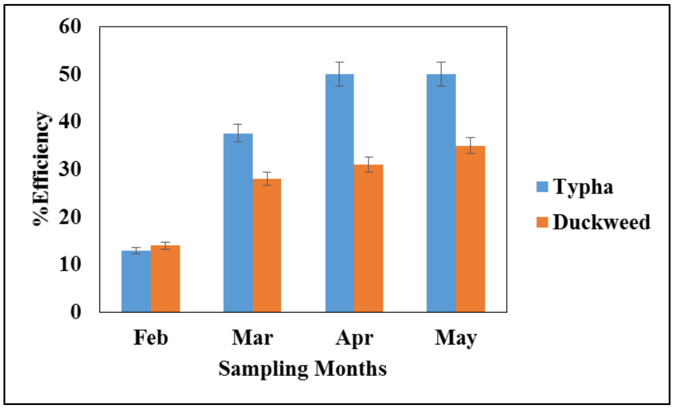


Figure 4.30: Removal (%) of Orthophosphate by Typha and Duckweed at Lab Scale

4.2.7 Removal of Total Phosphates by Typha and Duckweed at Pilot Scale

Total phosphates were measured at inlet and outlet. Lowest efficiencies were recorded as 72% and 69% for typha and duckweed at pilot scale, while highest efficiencies for phosphate removal were 80 and 76% for typha and duckweed at pilot scale respectively. Most of the products which are used for cleaning purposes contains phosphate so usage of such products increases during the summer which was the reason of high phosphate values at the inlet during hot weather.

Table 4.29: Average Removal of Phosphate by Typha and Duckweed at Pilot Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	33.75 (24.5-38.5)	39.62 (39-42.5)	37.41 (36.15-38.5)	30.33 (24.5-38.5)
	Outlet (mg/L)	12.25 (8-15)	10.95 (4-20)	7.33 (5-9)	5.91 (5.9-6.3)
	%Efficiency	**63.7**	**72.34**	**80.40**	**80.49**
Duckweed	**Inlet (mg/L)**	29.4 (15-40)	32.62 (26-42)	33.91 (24.5-38.5)	36.5 (30.15-40.67)
	Outlet (mg/L)	12.5 (8-15)	9.3 (7-11)	7.3 (5.5-9.5)	8.59 (3-17)
	%Efficiency	**66.52**	**69.50**	**75.75**	**76**

***Brackets contains the minimum and maximum values**

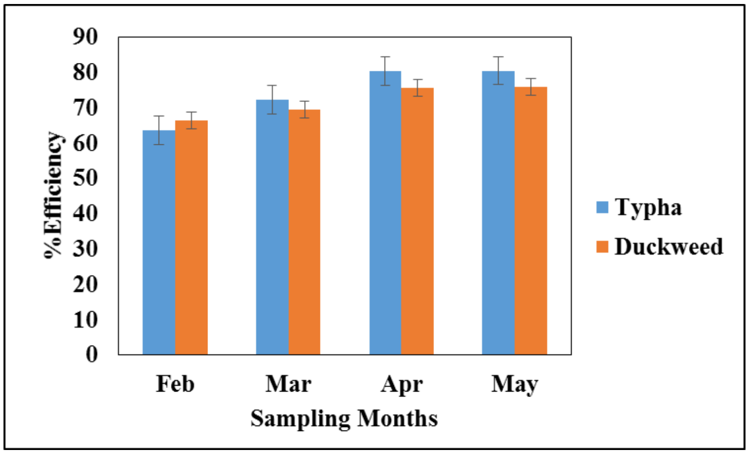


Figure 4.31: Removal (%) of Phosphate by Typha and Duckweed at Pilot Scale

4.2.8 Removal of Total Phosphates by Typha and Duckweed at Lab Scale

Total phosphates were measured at inlet and outlet. Lowest efficiencies were recorded as 54% and 50% for typha and duckweed at lab scale respectively while highest efficiencies for phosphate removal were 80 and 79% for typha and duckweed at lab scale respectively.

Table 4.30: Average Removal of Phosphate by Typha and Duckweed at Lab Scale

	Months	**Feb**	**Mar**	**Apr**	**May**
Typha	**Inlet (mg/L)**	29 (27-31.5)	22 (20-25)	21 (19-23)	27 (25-29.5)
	Outlet (mg/L)	19 (17-21)	8.7 (3-17)	6.3 (2.5-9.5)	7 (5-9)
	%Efficiency	**54**	**57**	**78**	**80**
Duckweed	**Inlet (mg/L)**	29 (23-35)	28 (26-32)	27.4 (25-30)	30 (27-33)
	Outlet (mg/L)	11.2 (8-15)	13.95 (7.6-17.35)	6 (2.5-9.5)	5.9 (5.5-6.3)
	%Efficiency	**50**	**60**	**74**	**79**

***Brackets contains the minimum and maximum values**

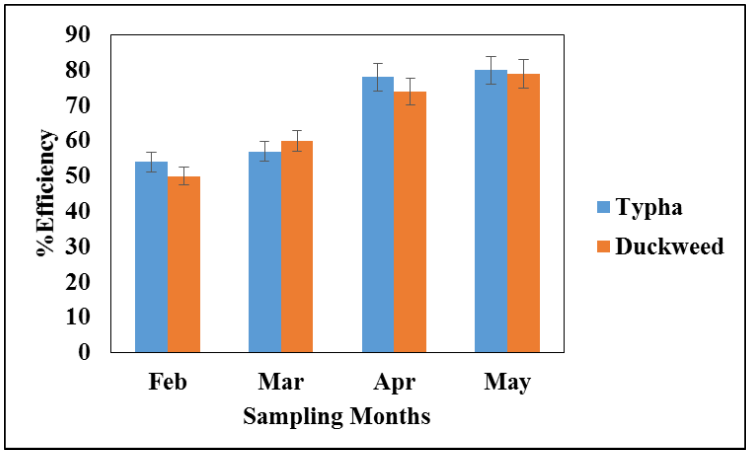


Figure 4.32: Removal (%) of Phosphate by Typha and Duckweed at Lab Scale

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusion were drawn from current study:

1. Efficiency of typha and duckweed to treat wastewater was evaluated at three different levels; pilot scale system and its lab scale replica (series unit) and individual scale system (parallel unit). At all the three units' plants showed maximum removal efficiency during summers (plants with maximum growth) as compared to winters (retarded plant growth).
2. In case of both macrophytes removal efficiency of parallel unit was more than that of series unit due to less retention time of water which leads to less contact of plants with water. In parallel unit for typha and duckweed removal efficiencies recorded as, for TSS (63 and 72%), DO (46 and 49%), TDS (COD (69 and 62%), TP (64 and 81%), *fecal coliform* (97 and 98%) and total coliforms (98 and 97%).
3. Removal percentage for nutrient parameters (ammonia, orthophosphate, and nitrate) were higher at lab scale than that of pilot scale because of controlled lab conditions Typha showed comparatively good removal efficiency than duckweed due to: its temperature resistivity, fast growth and deep root system.

5.2 Recommendations

1. Detailed analysis of plants and sediments need to be done to devise ecofriendly disposal of accumulated contaminants.
2. Degradation pathways of contaminants may be studied for better understanding of degradation processes.

3. Role of micro-organism needs to be monitored in the accumulation of contaminants.

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