WASTEWATER TREATMENT IN CONSTRUCTED WETLAND

- A Lysimeter Study

By

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DECLARATION

The work described in this thesis was carried out by me at the Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya under the supervision of Dr. M.I.M. Mowjood, Dr. B.F.A. Basnayake and Mr. Nishantha. A report on this has not been submitted to any other university for another degree.

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**DEDICATED
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ABSTRACT

The wastewater generated from the domestic, industrial and commercial consumption is commonly discharged into the environment. This makes severe damage to the existing environment. Therefore in order to prevent the impact of wastewater discharge, there is an increasing demand for treatment of wastewater prior to disposal.

Constructed wetland have the potential to provide cost – effective low maintenance treatment systems to improve the discharge quality of wastewater, compared to conventional systems.

The purpose of this study was to find out how constructed wetland systems can be used as an effective mechanism for wastewater treatment and to study the contribution of *Typha latifolia* (Cattail) plant in wastewater treatment in constructed wetland system.

Two-laboratory scale wetland lysimeters were constructed at the Meewathura Farm, University of Peradeniya. The first lysimeter was planted with *Typha latifolia* while the second was left void of plants. Tests were conducted using wastewater with high and low organic loads in two operating systems, Free Water Surface (FWS) and Subsurface Flow System (SFS). Effluents from Lysimeter at both FWS and SFS were analyzed for five-day Biochemical Oxygen Demand at 20°C (BOD_5), Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Dissolved Oxygen (DO), pH and temperature.

Treatment efficiencies were compared to determine the best operating system. Treatment levels are compared for planted and non-planted wetlands operated at low organic load wastewater. The results showed that the treatment by the planted system in FWS was higher than that of non-planted system. Rate of removal efficiency for TSS, TDS, EC, and BOD_5 was 83.26%, 58.99%, 59.11% and 23.91% respectively.

The SFS in planted wetland failed to meet performance of standards. This may be due to the short period of time that was allowed for the establishment of plants in the lysimeter.

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ABBREVIATIONS

FWS - Free Water Surface

SFS - Subsurface Flow System

BOD_5 - Five day Biochemical Oxygen Demand

DO - Dissolved Oxygen

TDS -Total Dissolved Solids

TSS -Total Suspended Solids

EC -Electrical Conductivity

CEA -Central Environmental Authority

CHAPTER 1
INTRODUCTION

Water is one of the essential requirements of life. Without it neither individual nor the community can survive. Unlike many other raw materials, there is no substitute for water in many of its uses. Modern industrial development would not have been possible without an adequate supply of water. Therefore water has occupied an important position in the civilization of human.

Rapid industrialization, urbanization and population growth in many countries resulted in the generation of large quantities of waste materials, which may be toxic, carcinogenic or mutagenic and cause problems to the environment. The waste generated from the domestic, industrial and commercial consumption is commonly discharged into the environment. This makes severe damage to the existing environment especially to water bodies. The quality of water in natural water bodies goes down and reduces the aesthetic value of the environment as a result of eutrophication. Therefore in order to prevent the impact of wastewater discharge, there is an increasing demand for treatment of wastewater prior to disposal. The watercourses can assimilate certain portion of the pollution load without affecting seriously to water quality and the environment. But the recent trend in the generation of wastewater in terms of quality and quantity has reduced the assimilative capacity of water bodies and the potential for natural purification.

Waste treatment aims at the removal of unwanted components in wastewater for safe discharge onto the environment. This can be achieved by using physical, chemical and biological methods either alone or in combination. A complete treatment or 100% removal of the pollution load is uneconomical and never aimed at any waste treatment plant.

Wetlands are a major feature of the landscape in almost all parts of the world. They are basically habitats with permanent or temporary accumulation of water for flora and fauna communities. So far the wetlands have been regarded as wasteland and indiscriminately exploited for residential industrial and commercial purposes without understanding the role it plays in the environment. It is also used as dumping ground for solid waste. Many wetlands are under threat in Sri Lanka.

However, during the last two decades, the multiple functions and values of wetlands have been recognized. The importance of wetlands expressed in the significance of pertaining functions, products and attributes. The functions of water quality enhancement by wetland have recently been incorporated to treat wastewater. Therefore the preservation, restoration, function and use of wetland have become important issues of concern throughout the world particularly in Sri Lanka.

The application of constructed wetland technology for the treatment of wastewater has received increasing attention in recent years. Natural and constructed wetlands are relatively simple system in term of operation and maintenance. They are extremely energy efficient when compared to mechanical systems, while being habitat for variety of wild life and enhance the aesthetic value of area. Therefore, searching of the most practical and cost effective approach to treat wastewater, considerable attention has been directed towards the artificial or natural wetlands to treat municipal and industrial wastewater.

The scientific studies of wastewater treatment with constructed wetland in Sri Lanka are not cited.

Objectives

(I) To identify how wetlands can be used as an effective mechanism for wastewater treatment with plant and without plant.

(ii) Examine the contribution of Common Cattail (*Typha latifolia*) in wastewater treatment in constructed wetland.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Characterization of Wastewater

Characterization and monitoring of wastewater is essential in providing the necessary information for the design and operation of wastewater treatment plants. It is also necessary to monitor the treated wastewater discharged into the environment to ensure that compliance with the appropriate effluent discharged is attained.

2.1.1 Physical Characteristics

(a) Temperature

Temperature is an important parameter to measure in the monitoring of the wastewater, as the rates of the different types of treatment processes are strongly dependent on temperature (Sastry et al., 1995).

(b) Colour

Though the pure water is colourless; it has a pale green blue tint in large volumes. It is necessary to differentiate between true color due to material in solution and apparent colour due to suspended matter (Tebbutt, 1983).

(c) Solids (TDS/TSS)

These may be present in suspension and / or in solution and they can be organic or inorganic matters.

Total Dissolved Solids (TDS) are due to soluble materials whereas the total Suspended Solids (TSS) are discrete particles (Tebbutt, 1983).

(d) Turbidity

The presence of colloidal solids gives liquid, a cloudy appearance, which is aesthetically not acceptable and may be harmful. Turbidity in water may be due to clay and silt particles, discharge of sewage or industrial wastes, or to the presence of large number of microorganisms (Tebbutt, 1983).

2.1.2 Chemical Characteristics

(a) pH

pH is another important parameter affecting the treatment process of the wastewater. The intensity of acidity or alkalinity of a sample can be measured on the pH scale which actually shows the concentration of hydrogen ions in the water (Tebbutt, 1983).

(b) Dissolved Oxygen (DO)

Oxygen is most important element in water quality control. Its presence is essential to maintain the higher forms of biological life (Tebbutt, 1983).

(c) Oxygen Demand

Organic compounds are generally unstable and may be oxidized biologically or chemically to stable, relatively inert, end products such as CO_2, NO_2, H_2O. An indication of the organic content of a waste can be obtained by measuring the amount of oxygen required for its stabilization (Tebbutt, 1983).

(i) Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand is by definition the quantity of oxygen utilized by a mixed population of microorganisms in aerobic oxidation under controlled conditions. The oxygen up taxes for five days of incubation at a temperature of 20°C is determined as the standard BOD. This value is denoted as BOD_5 (Tebbutt, 1983).

(II) Chemical Oxygen Demand (COD)

Chemical Oxygen Demand is used to characterize the organic strength of wastewater and pollution of natural waters. The test measures the amount of oxygen required for chemical oxidation of organic matter in the sample to carbon dioxide and water (Tebbutt, 1983).

(d) Nitrogen

This is an important element since biological reactions can only proceed in the presence of sufficient nitrogen. Nitrogen exists in four main forms (Tebbutt, 1983).

(I) Organic Nitrogen

Nitrogen in the form of proteins, amino acids and urea

(II) Ammonia Nitrogen

Nitrogen as ammonium salts, e.g. $(NH_4)_2CO_3$, or as free ammonia.

(III) Nitrite Nitrogen

An intermediate oxidation stage not normally presents in large amounts.

(iv) Nitrate Nitrogen

Final oxidation product of nitrogen.

2.1.3 Biological Characteristics

Almost all-organic wastes contain large number of microorganisms. Sewage contains over 10^6/ml, but the actual numbers present are not often determined. After conventional sewage treatment the effluent still contain large number of microorganisms, as do many natural surface waters (Tebbutt, 1983).

2.2 National Standards for Treated Water

The following table shows the Sri Lankan standards of the effluent that can be discharged into water bodies.

Table 2.2 – General standards for discharge of effluent into inland surface water.

NO	Determinant	Tolerance limit
1	Appearance	Colorless
2	Temperature	Lower than 40 °C
3	pH values at ambient temperature	6.0 to 8.5
4	Total Suspended Solids (TSS)	50 (mg/l)
5	Chemical Oxygen Demand (COD)	250 (mg/l)
6	Biochemical Oxygen Demand (BOD_5)	30 (mg/l)

Source – Pollution Control Guideline Series, Central Environmental Authority

2.3 Wastewater Treatment Methods

2.3.1 Aerobic Biological Wastewater Treatment

Aerobic treatment processes utilize a mixed population of microorganisms which convert dissolved organic material mainly to new cellular material in the presence of oxygen. Many different types of organisms, including bacteria, fungi, protozoa, rotifers and other higher forms of life can be found in the system at any particular time (Sastry et al., 1995).

The main aerobic biological treatment units include:

(a) Activated Sludge Processes (ASP)

ASP is aerobic biological process that can be used to treat many types of waste, mainly sewage. In the ASP, wastewater is treated in an aeration basin together with high concentration of biological sludge.

(b) Trickling Filter

In trickling filters, wastewater is distributed over a fixed bed of packing materials covered with a biological slim layer. Trickling filters are aerobic oxidation units, which absorb and oxidize organic matter in the wastes passing over the filter media.

(c) Rotating Biological Discs

In rotating biological discs, discs of packing materials with a layer of microorganisms rotate in the wastewater. The rotating discs serve to provide support of a fixed biological growth, contact of growth with the wastewater and aeration of the wastewater.

(d) Aerated Lagoon

Aerated lagoon is a wastewater treatment lagoon having mechanical aeration device to supply the oxygen needed by the bacteria for waste stabilization.

(e) Facultative Lagoon

Facultative lagoon is a waste treatment lagoon where the upper part is aerobic and the lower section is under anaerobic condition.

(f) Oxidation Pond

Oxidation pond utilizes bacteria algae symbiosis and sedimentation for treatment.

2.3.2 Anaerobic Wastewater Treatment

Anaerobic treatment technologies are used throughout the world for the effective treatment of municipal wastewater, sludge and industrial wastewater. This technology is particularly attractive, as the energy required for operating the process is minimal as compared to that for aerobic processes (Sastry et al., 1995).

2.3.3 Physical and Chemical Treatment

Physical – chemical treatment is more expensive than biological treatment. Less land is required and the physical – chemical systems is generally more easily controlled than a biological process (Sastry et al., 1995).

(a) Disinfection

The purpose of disinfection is to reduce total bacterial concentration and to eliminate the pathogenic bacteria in water. There are number of chemicals and methods that can be used for disinfection such as chlorine, iodine, ozone, quaternary ammonium compounds and ultraviolet light.

(b) Chemical Precipitation

The addition of chemicals to wastewater offers opportunities to precipitate particulate and colloidal material.

(c) Sedimentation

Sedimentation is the process most commonly used to remove settleable solids from sewage and industrial wastes in wastewater treatment.

(d) Flotation

Dissolved air flotation is a process, which increase the rate of removal of suspended matter from liquid wastes. The process achieves solids – liquid separation by attachment of gas bubbles to suspended particles, reducing the effective specific gravity.

2.4 Definition of Wetland

Areas of marsh, fen, peat land or water whether natural or artificial, permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters (CEA, 1994).

2.5 Types of Wetlands

According to the Ramsar definitions for wetlands many parts of Sri Lanka can be consider as wetlands. More than 20 different types can be distinguished in the country, but for convenience, surface waters nave been divided in three main groups: freshwater, saltwater and man made wetlands. These groups have been sub divided in 10 general wetland types (CEA, 1994).

Freshwater wetlands

- Streams and rivers
- Lakes
- Freshwater marshes

Saltwater wetlands

- Deltas and estuaries
- Lagoons
- Marine wetlands

Man made wetlands

- Tanks
- Agricultural
- Salt ponds
- Aquaculture

2.6 Wetland Functions and Values

The physical, chemical and biological interactions within wetlands are often collectively referred to as wetland functions. Representative biological functions include providing habitat for reproduction, feeding, and resting. Physical functions include flood attenuation, groundwater recharge and sediment entrapment. Chemical functions include nutrient removal and toxics decontamination.

The characteristics of wetlands that are beneficial to society are considered as wetland values, for example, source of natural products, water supply and transportation, energy production, recreation and tourism.

The role of wetlands in terms of water quality functions has become inextricably linked in recent years to the interest in using wetlands for small-scale sewage treatment as well as storm water retention or treatment basins (Kent, i995).

2.7 Constructed Wetland

Constructed wetlands are a technology designed to mimic processes found in natural wetland ecosystems. These systems utilize wetland plants, soils and their associated microorganisms to remove contaminants from wastewater, as well as other sources, As with other natural biological treatment technologies, wetlands treatment systems are capable of providing additional benefits. The reuse, or reclamation, of wastewater using constructed wetland technology also provides an opportunity to create or restore valuable wetland habitat for wildlife and environmental enhancement.

The application of constructed wetland technology for the treatment of wastewater has received increasing attention in recent years.

In Kentucky, nearly 2000 on- site constructed wetland systems have been installed. The inlet is fed septic tank effluent. Emergent macrophytes are planted and their metabolism and that of their symbiosis contribute to nutrient and pathogen removal. Results from this and the previous study indicated that systems generally have good fecal coliform bacteria reduction potential (overall 95%).

Studies were conducted in New Zealand for the treatment of dairy farm wastewater using gravel bed constructed wetlands. Treatment levels achieved over a 20-month period were compared for planted and plant free wetlands operated at four wastewater loading rates, corresponding to nominal retention times of 2,3,5.5, and 7 days. Mean annual removals of TSS were recorded in the range of 75 to 85%, irrespective of loading rate or the presence of plants. In the planted wetlands, mean annual mass removal of (BOD increased from 76 – 90% total BOD (carbonaceous + nitrogenous BOD) From 50 –80%, fecal coliforms from 95 to over 99%, TN from 48 to 75% and TP from 37 to 74% as wetland retention time increased. The non-planted wetlands generally showed similar performance to the planted wetlands at long retention times, but poor BOD, nitrogen and phosphorus removal at short retention times (Campbell, 1995).

Treatment of agricultural wastes using constructed wetlands was tested in Canadian farms province. Research project was conducted to determine the effectiveness of constructed wetland for the treatment of barnyard runoff under Ontario's soil and climate conditions. A total of 10 experimental systems were installed and monitored across southern Ontario. Designs incorporate a variety of components including runoff holding ponds, vegetated marsh treatment cells, and water quality polishing cells. These experimental systems used for an assessment of treatment effectiveness, management requirements and economic benefits for Ontario farms. The result of this research is subjected to further the development of low cost alternatives for the farm community to protect water quality (Campbell, 1995).

2.8 Typical Classification of Constructed Wetlands for Wastewater Treatment

Constructed wetlands for wastewater treatment may be Free Water Surface (FWS) wetland with wastewater flowing over land through and constructed marsh or Subsurface Flow wetlands with wastewater flowing through a high hydraulic conductivity substrate such as gravel.

Both systems incorporate emergent aquatic plants to provide a rhizophere for bacterial attachment and oxygen transfer.

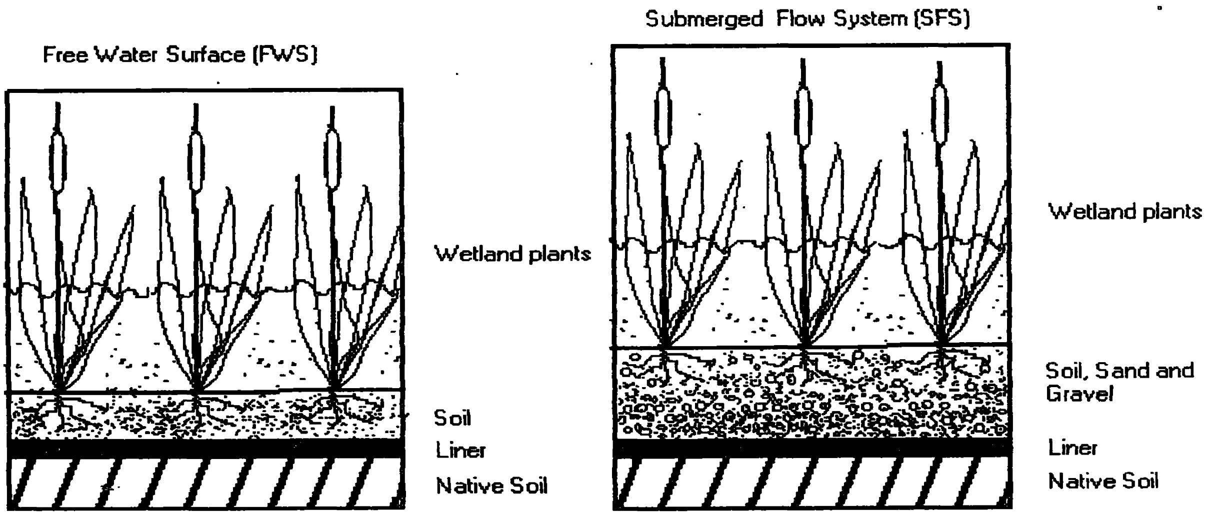


Figure 2.8: Typical classification of constructed wetland for wastewater treatment

A free water surface flow constructed wetland was installed at the Auburn University Poultry unit in Auburn, Alabama to treat effluent from an anaerobic poultry waste lagoon. These constructed wetlands have shown the capability of providing treatment to dilute poultry wastewater within the first year of operation. However, the vegetated systems should show increased level of treatment, as they become better establishment. The effect of plant presence on wastewater treatment during the cold winter month was difficult to determine due to the variation of influent quality (Campbell, 1995).

The concept of treating wastewater in constructed wetlands with subsurface flow was developed in Germany in the seventies. The design consists typically of a bed planter with the common reed and underlain by and impermeable membrane to prevent seepage. The medium in the bed may be soil or gravel. During the passage of the wastewater through the rhizophere of the reeds, organic matter is decomposed microbiologically, nitrogen is denitrified and phosphorous and heavy metals should is fixed in the soil, The quantitative significance of the uptake of nutrients in the plant tissue is negligible as the amount of nutrients taken up during a growing season constituents only a few percent of the total content introduced with the wastewater. Moreover, the nutrients bound in the plant tissue are recycled in the system upon decay of the plant material.

Subsurface flow wetland systems were built in 1990 – 1991 to serve three small rural communities in Oklahoma the towns of Binger, Maysville and Colbert respectively. But the three subsurface flow wetlands failed to meet performance standards. The cause of the failure were not conclusively identified (Campbell, 1995).

2.9 The Treatment Processes of Constructed Wetland

(a) Biochemical Oxygen Demand

Biological metabolism is the primary process for removal of BOD in a wetland system. The diverse microbial populations in the water column consume the soluble organic waste products. In the soil and sediment layer, the organic are adsorbed in the soil, and later, biologically oxidized into stable end products. Also, sedimentation in FWS systems, and filtration in SFS systems are processes that remove BOD associated with suspended organic materials (Kent, 1995).

(b) Suspended Solids

Settleable suspended solids are readily removed in the early stages of a FWS by gravity settling in quiescent, shallow areas downstream of the system inlet. In the case of wastewater receiving little pretreatment, the distributed in flow design will safeguard against development of adverse and detrimental conditions from sludge buildups. In the SFS wetland, settleable solids are removed by filtration as the wastewater moves through the underdrain system (Kent, 1995).

(c) Nutrients

Constructed wetlands are an effective means to control the discharge of nutrients such as nitrogen and phosphorus. The mechanisms for nutrient removal in a wetland system are(Kent, 1995)

- Direct plant uptake
- Chemical precipitation
- Uptake by algae and bacteria
- Soil sorption
- Denitrification
- Loss by insect and fish uptake

(d) Metals

The mechanisms for metal removal in wetland systems are chemical oxidation or reduction, resulting in precipitation, sorption by plants or soil, and simple filtration or sedimentation (Kent, 1995).

2.10 Plant Selection

Many plant species are available, and have been used, for wetland wastewater treatment systems. The two principal groups are free floating plants such as hyacinths and duckweed, and rooted macrophytes such as cattails and reeds. Cattail and bulrushes are among the most researched plant species for wetlands treatment systems (Kent, 1995).

For instance, two stage lagoon systems are commonly used in the dairy industry for treatment of wastewater generated by the washing of feedlots, at the Louisiana State University, Louisiana. It presents the preliminary result of a demonstration/ research project that is using several types of aquatic plant systems as tertiary treatment units for improvement of lagoon effluent quality. It focuses on two of the systems in the project.

A pond with black willow *Salix niger* and duckweed Spiraled sp. and a pond with water hyacinth *Eichhornia crassipes*. Each of these systems was effective in removal of TSS, BOD5, and fecal coliforms (Campbell, 1995).

2.11 Design and Working Principal

(a) The Role of Macrophytes

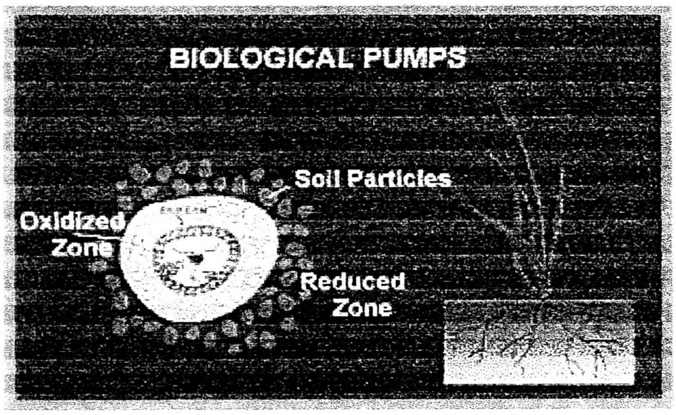


Figure 2.11 Simplified representation of the redox-condition around roots of wetland plant

The macrophytes have a key role in the functioning of root – zone treatment plants. The wetland plants do two important functions:

(a) To supply oxygen to the hetertophic microorganisms in the rhizophere.
(b) To increase /stabilize the hydraulic conductivity of the soil.

The roots and rhizomes, however, leak oxygen in to the substrate thereby creating oxidized microzones in an otherwise reduced substrate. The presence of these oxidized and anoxic zones around the roots create a favourable environment for aerobic and facultative anaerobic microorganisms in the rhizophere.

(c) The Role of Microorganisms

The degradation of organic matter and the denitrification of nitrogen in a root – zone of plant is mediated by microorganisms. The leakage of oxygen from the roots of the macrophytes creates oxidized zones around the roots. Most of the organic content in the wastewater is decomposed to carbondioxide and water in these zones using oxygen as the terminal electron acceptor.

(d) The Role of Soil

The soil in a root – zone treatment plant provides a stable surface area for microbial attachment, a solid substrate for plant growth, and functions directly in the purification of the wastewater through physical and chemical processes. Soils are very effective in removing suspended solids, pathogenic bacteria and viruses by filtration and sorption. Nutrients are removed from water flowing through soil in several ways. Ion exchange can remove significant amounts of positively charged ions and anions and may be adsorbed onto charged surface of humic substances.

CHAPTER 3
MATERIALS AND METHODS

3.1 Construction and Preparation of Wetland Lysimeters

Two field scale wetlands lysimeters were constructed at the Meewathura farm, University of Peradeniya.

Cylindrical cement tanks with three feet (3ft) in diameter and two feet (2ft) in height were constructed. Their outlets were arranged at both top and bottom of each tank, while inlets were kept top of the lysimeters. During the construction, concrete was used to line the bottom of the lysimeters to eliminate the seepage.

The bottoms of the lysimeters were filled with gravel up to 10 cm in height. Then soil was filled up to the height of 30 cm. The soil was mixed with sand and gravels. In this case the original soil at the site was used (Figure 3.1.1).

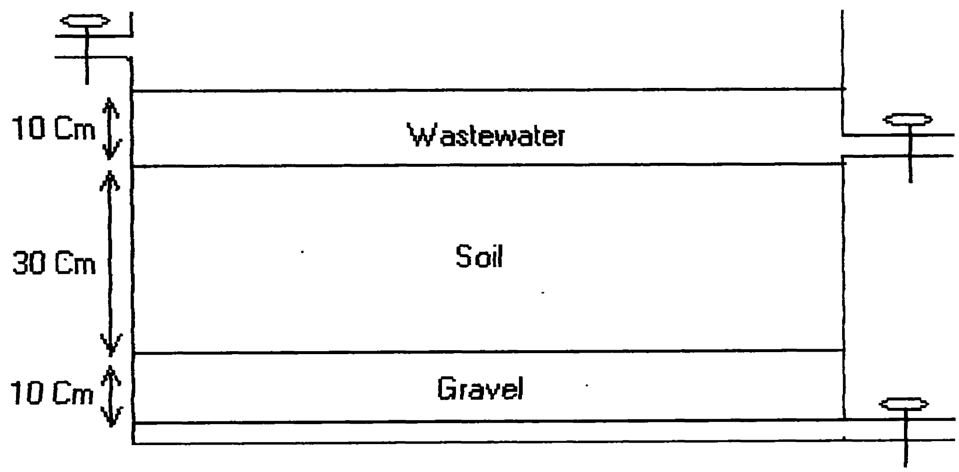


Figure 3.1.1: Cross section of non - planted lysimeter

Each lysimeters was used as FWS and SFS for treatment of wastewater. *Typha lattifolia* was planted in one lysimeter while the second was left void of plants. The planting was done on November 9th, 2001 and left for the establishment during the November with regulated water levels and no wastewater applied to the system (Figure 3.1.2).

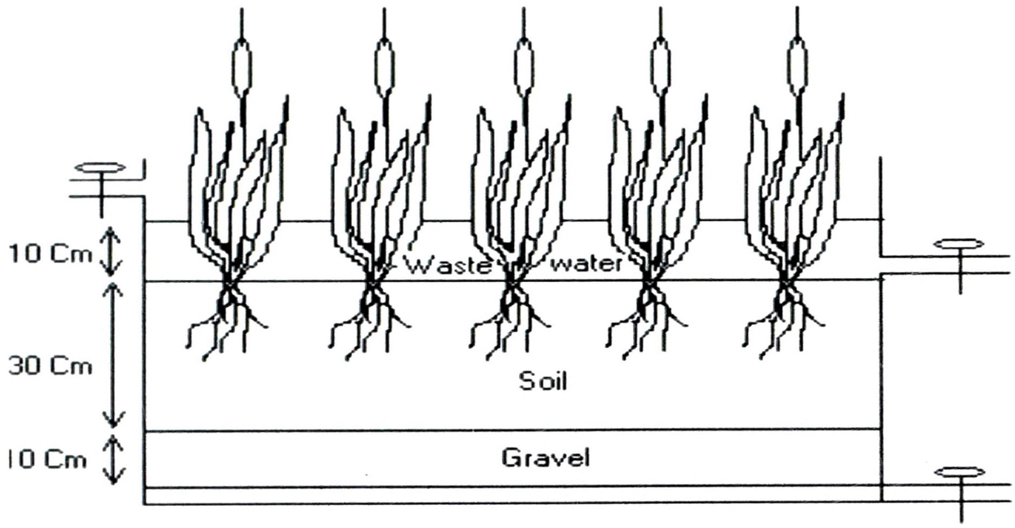


Figure 3.1.2 : Cross section of lysimeter planted with *Typha latifolia*

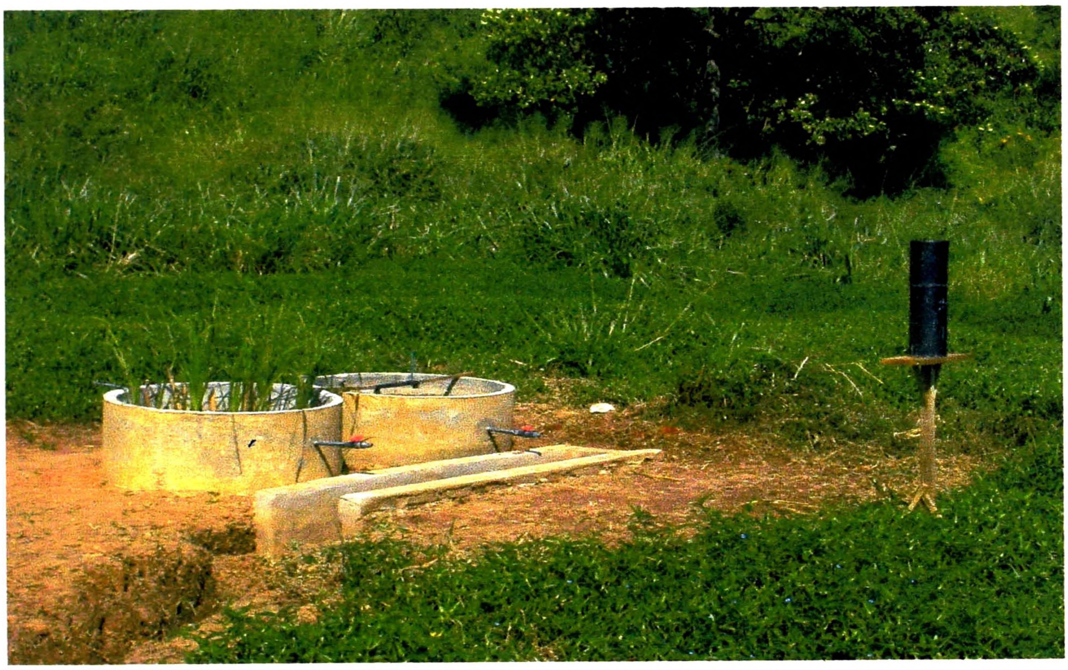


Figure 3.1.3 Laboratory scale constructed wetland lysimeters installed at the Meewathura farm

3.2 Identification of Wastewater

The wastewater collected from two different locations was analyzed for BOD_5, TDS, TSS, EC, and pH. Samples, which showed a higher BOD_5 value more than 1000, were classified as high organic load of wastewater and that with lower value were grouped as low organic load of wastewater.

3.3 Introduction of Wastewater to the Lysimeters and Sampling

Figure 3.3 shows the application of wastewater to the constructed wetland lysimeters.

3.3.1 Introduction of Wastewater with High Organic Load to the Non-planted Lysimeter

The high organic load of wastewater was introduced to the non-vegetated lysimeter (without plant) on 22nd of November 2001, two weeks after construction. The experiment was conducted as a batch processing for both SFS and FWS. The lysimeter was operated with wastewater up to the depth of 10 cm.

The effluent from both top (FWS) and bottom (SFS) of the lysimeter were sampled in three days intervals and analyzed in the laboratory between 22nd of November and 4th of December 2001. The retention time of the wastewater was 12 days.

3.3.2 Introduction of Wastewater with Low Organic Load to the Both Planted and Non-planted Lysimeters

The low organic loads of wastewater were introduced to the both planted and non-planted lysimeters simultaneously on 12th of December. Wastewater was fed into lysimeters approximately 10 cm in height as a batch processing system. There were 10 plants when experiment was conducted.

The effluent of each wetland lysimeters from the top (FWS) and bottom (SFS) were sampled in three days intervals between 12th of December and 26th of December 2001. The retention time of wastewater was 14 days.

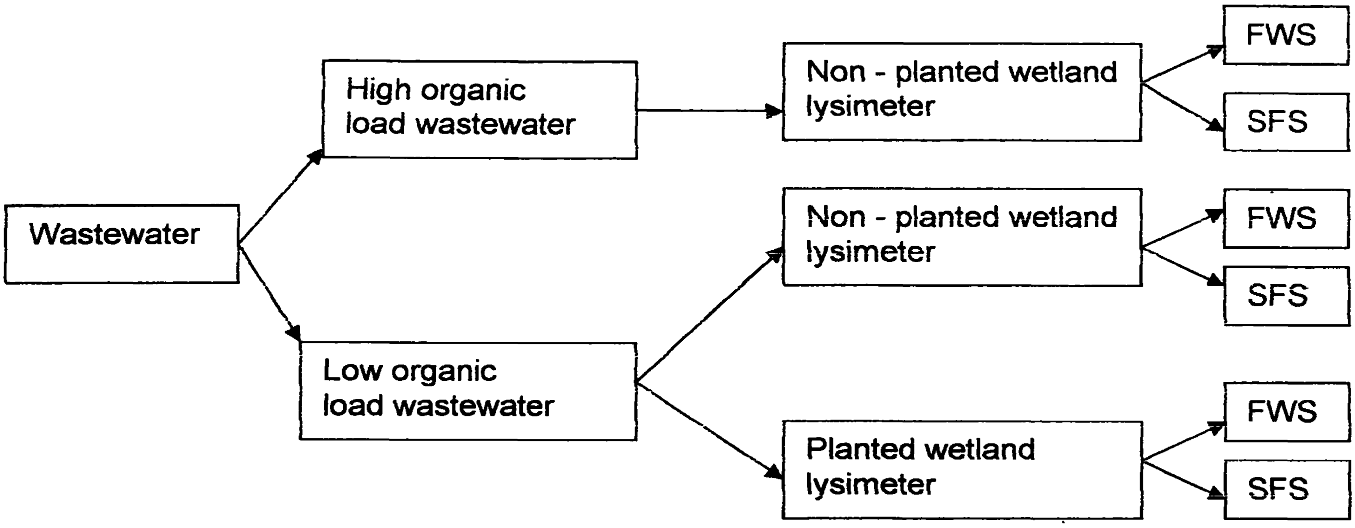


Figure 3.3 The flow diagram of application of wastewater to the constructed wetland lysimeters.

3.3.3 Sampling Equipment

Samples were collected in clean plastic bottles having capacity of 400ml. The sample was taken between 8.00 to 9.00 am and transported to the lab as soon as possible for the analysis.

3.4 Determination of Water Quality Parameters

Wetland treatment performance was determined through water quality parameter tests. Five day Biochemical Oxygen Demand at 20°C (BOD_5), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Suspended Solids (TSS), Dissolved Oxygen (DO), pH were monitored to determine treatment efficiency. Rainfall, Evaporation and temperature also measured in the field to determine the water balance for the lysimeters.

Sample was analyzed using standard methods (Water Analysis user-friendly Field/Laboratory Manual 1996 and Standard Method For The Examination of Water and Wastewater 1992) in the laboratory of the Agricultural Engineering Department at the University of Peradeniya.

3.4.1 Temperature

Temperatures of the water in the lysimeters were taken at the site of sampling using the mercury thermometer, which was recorded in Celsius.

Sample was collected in clean plastic bottles. The Thermometer was dipped into the water for nearly one minutes and recorded the temperature at the site of sampling. Reading was taken from the instrument directly in terms of Celsius.

3.4.2 pH

pH was measured using a calibrated pH meter (Model 407A,Oron Research Incorporated USA). A glass electrode in conjunction with a reference electrode is used for pH measurement. The glass electrode consists of a special glass membrane, which is sensitive to H+ ions in solution.

pH meter was calibrated using buffer standards pH=4.0, pH=7.0 and pH=9.0. Then the electrode probe was dipped into the water for nearly one minutes and recorded the pH value. pH meters display reading directly in pH units.

3.4.3 Dissolved Oxygen (DO)

Dissolved Oxygen in water sample was measured using Winkler titration method as follows.

Apparatus;

a) BOD incubation bottles (300ml)
b) Pipettes (10ml) graduated in 0.1ml
c) Burettes, graduated in 0.1ml
d) Measuring cylinders
e) Conical flasks
f) Volumetric flasks
g) Dropper
h) Funnels
i) Stand

Preparation of standards and Reagents;

1) $MnSO_4$ Solution

120g of $MnSO_4$ was dissolved in distilled water and diluted to 250ml.

2) Alkali - iodide – azide solution

175g of Sodium Hydroxide (NaOH) and 37.5g of Sodium Iodide (NaI) were dissolved in a small amount of distilled water. 2.5g of NaN_3 was dissolved in small amount of distilled water separately. Two solutions were mixed and diluted up to 250ml.

3) Starch solution

1g of starch was dissolved in 100ml hot distilled water and then cooled. 0.1g of Salicylic acid was added as a preservative.

4) Standard Thiosulphate solution (0.025N $Na_2S_2O_3.5H_2O$)

3.10g of $Na_2S_2O_3.5H_2O$ was dissolved in distilled water and diluted it up to 250ml.

Procedure;

1. Water sample was collected in a 300ml bottle. Care was taken when pouring sample directly into the BOD bottle not to entrain the air bubbles in water.
2. 2ml of $MnSO_4$ Solution was added and immediately followed by 2ml of alkali – azide solution.
3. The stopper was placed carefully to exclude any air bubbles and mixed by inverting the bottles a few times.
4. 2ml of Conc. H_2SO_4 were added to dissolve precipitate (MnO_2).
5. The solution was titrated with standard Thiosulphate solution. Starch was used as an indicator.

Calculation;

DO concentration was calculated using the following equation.

$$DO = af * \frac{1000}{V-1} * 0.2 \text{ (mg/l)}$$

Where,

a – titration reading for iodine

f – factor of $Na_2S_2O_3.5H_2O$ solution

v – Volume of the sample

3.4.4 Biochemical Oxygen Demand (BOD_5)

Biochemical oxygen demand was measured using incubation method.

Apparatus;

a) Incubator (temperature 20 $\pm$ 0.5 °C)
b) BOD incubation bottles
c) Pipettes (10ml) graduated 0.1ml
d) Beakers
e) Burettes, graduated 0.1ml
f) Measuring cylinders
g) Conical flasks
h) Volumetric flasks
i) Dropper

Preparation of Standards and reagents;

1. Ferric Chloride solution

0.0625g of Ferric Chloride Hexahydrate ($FeCl_3.6H_2O$) was dissolved in distilled water and diluted up to 250ml.

2. Calcium Chloride solution

6.875g of Calcium Chloride was dissolved in distilled water and diluted to 250ml in volumetric flask.

3. Magnesium Sulphate solution

5.625g of Magnesium Sulphate Heptahydrate ($MgSO_4.7H_2O$) was dissolved in distilled water and diluted to 250ml.

4. Phosphate buffer solution

Following salts was dissolved in distilled water and diluted to 250ml. Solution was at pH 7.2.

Potassium Dihydrogen Phosphate (KH_2PO_4)	= 2.125g
Potassium Hydrogen Phosphate (K_2HPO_4)	= 5.348g
Disodium Hydrogen Phosphate ($Na_2HPO_4.7H_2O$)	= 8.35g
Ammonium Chloride (Na_4Cl)	= 0.425g

Procedure;

1. A liter of distilled water was aerated nearly 30 minutes.
2. A liter of aerated dilution water solution was prepared by adding
   1 ml of Ferric Chloride solution
   1 ml of Calcium Chloride solution
   1 ml of Magnesium Sulphate solution and
   1 ml of Phosphate buffer solution
3. Blank was determined for aerated dilution water.
4. The dilution water was used to dilute 1ml of wastewater in to 600ml (1:600 dilution factor) and 1ml of wastewater into 300ml (1:300 dilution factor).
5. Care was taken when pouring water directly into the BOD bottles not to entrain the air bubbles in water.
6. The initial DO concentration was measured in one sample by using Winkler method, which was mentioned, in section 3.4.2.3.
7. BOD bottles were tightly stopered, covered with aluminum foil and placed in an incubator for incubating five-day period at 20°C.
8. Final DO was measured using above method.

Calculations;

Whenever, seeding was not required, BOD could be obtained from following equation.

$$\text{BOD} = \frac{\text{Initial DO in mg/l} - \text{Final DO in mg/l}}{\dfrac{\text{Effluent in mg}}{\text{Volume of BOD bottle in mg}}}$$

Let,

DO concentration (mg/l) in sample before incubation – D_1

DO concentration (mg/l) in sample after incubation – D_2

DO concentration (mg/l) in blank before incubation – B_1

DO concentration (mg/l) in blank after incubation – B_2

Fraction of Sample in incubation – P

Ratio of seed in diluted sample to seed in blank – (1-P)

Then,

$$BOD_5\ (mg/l) = \frac{(D_1 - D_2) - (B_1 - B_2)(1-P)}{P}$$

Where,

P – decimal fraction of effluent sample used $= \dfrac{\text{Volume of effluent}}{\text{Volume of dilution water plus effluent}}$

3.4.5 Total Suspended Solids (TSS)

The total suspended solid was determined by oven dry method.

Apparatus;

(a) Electrical oven (temperature $105 \pm 5°C$)
(b) Top loading balance
(c) Desicator
(d) Filter papers
(e) Measuring cylinders
(f) Funnels

Procedure;

1. Dried filter papers were weighed.
2. 50 ml of sample was measured and filtered through filter papers.
3. Filter paper with the remaining parts was kept in an oven for 1hr at 105°C.
4. Then filter papers was cooled in a desicator and weighed.

Calculation:

$$\text{Total Suspended Solids (mg/l)} = \frac{(W_2 - W_1)*1000}{50 \text{ ml}}$$

Where,

Weight of the filter paper - W_1 mg

Weight of filter paper + residues - W_2 mg

3.4.6 Electrical Conductivity (EC)

EC was measured with the help of a Conductivity meter (Thermo Orion, model 145).

The conductivity cell was placed in the sample and slightly agitated the cell to remove any air bubbles. It was allowed the reading to stabilize.

Reading was taken from the instrument directly. The conductivity reading was recorded in ms (mili siemens/cm) or µs (µicro siemens/cm).

3.4.7 Total Dissolved Solids (TDS)

TDS was measured with the help of a Conductivity meter. (Thermo Orion, model 145).

The conductivity cell was placed in the sample and slightly agitated the cell to remove any air bubbles. The MODE key was pressed until the TDS mode indicator is displayed and waited until the reading stabilize.

Reading was taken from the instrument directly. The unit is mg/l.

3.4.8 Rainfall

Rainfall was measured with help of the non-recording rain gauge installed at the site of experiment daily in the field. The area of rains gauge was 122.768 cm^2.

3.4.9 Evaporation

Evaporation in the lysimeters was measured with help of the hook gauge daily.

3.5 Analysis of Data

Both absolute levels of parameters and relative removal efficiency were compared between planted and non-planted lysimteres. Relative removal efficiency for a given parameter was computed by dividing influent and effluent difference levels by influent levels and expressed as a percentage.

$$\text{Removal efficiency} = \frac{(\text{influent level} - \text{effluent level}) * 100}{\text{Influent level}}$$

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Identification of Wastewater

Table 4.1 shows the level of pollutant in wastewater collected from two different locations for this study.

Table : 4.1 Level of pollutant in two locations for selected water quality parameters.

Water Quality Parameters	Level of Pollutant	
	Location i	**Location ii**
TDS	366 (mg/l)	140 (mg/l)
TSS	1460 (mg/l)	480 (mg/l)
EC	763 (μs/cm)	294 (μs/cm)
BOD_5	4251.49 (mg/l)	690 (mg/)l
DO	0 (mg/l)	1.2 (mg/l)
pH	6.8	6.8

According to the BOD_5 values the wastewater was classified as a high and low organic load. Because the BOD_5 gives the amount of oxygen required to degradation of organic matter present in the wastewater by microbes.

4.2 Treatment Efficiency of Wastewater in Constructed Wetland Lysimeters

4.2.1 Treatment Efficiency of High Organic Load Wastewater in Non-planted Lysimeter.

The water quality of FWS and SFS with retention time is shown in table 4.2.1.1 and table 4.2.1.2 respectively.

Table 4.2.1.1 : Treated effluent water quality from FWS system

Retention time (days)	TDS (mg/l)	TSS (mg/l)	EC (μs/cm)	BOD_5 (mg/l)	DO (mg/l)	pH
0	366	1460	763	4251.49	0	6.5
03	337	540	702	4251.49	7.2	7.3
06	305	380	635	4251.49	7.5	8.0
09	298	400	621		7.4	8.0
12	289	380	605		7.5	8.0

Table 4.2.1.2 : Treated effluent water quality from SFS

Retention time (days)	TDS (mg/l)	TSS (mg/l)	EC (μs/cm)	BOD_5 (mg/l)	DO (mg/l)	pH (mg/l)
0	366	1460	763	4251.49	0	6.5
03	358	420	746	4251.49	0.2	6.8
06	357	160	744	4251.49	0.1	6.9
09	360	120	750		0.1	6.8
12	362	60	754		0.1	7.0

Water balance was computed with rainfall and evaporation data during the sample collection period (table 4.2.1).

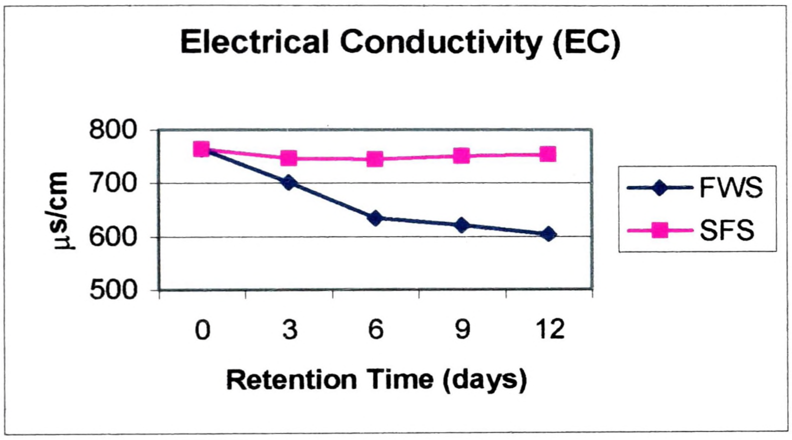
Table 4.2.1.3:Rainfall and evaporation data

Date	Rainfall (mm)	Evaporation (mm)
2001/11/22	-	-
2001/11/23	63.54	1
2001/11/24	-	1
2001/11/25	-	5
2001/11/26	-	4
2001/11/27	-	5
2001/11/28	-	5

2001/11/29	-	5
2001/11/30	-	5
2001/12/01	-	5
2001/12/02	-	5
2001/12/03	0.8	1
2001/12/04	9.28	1

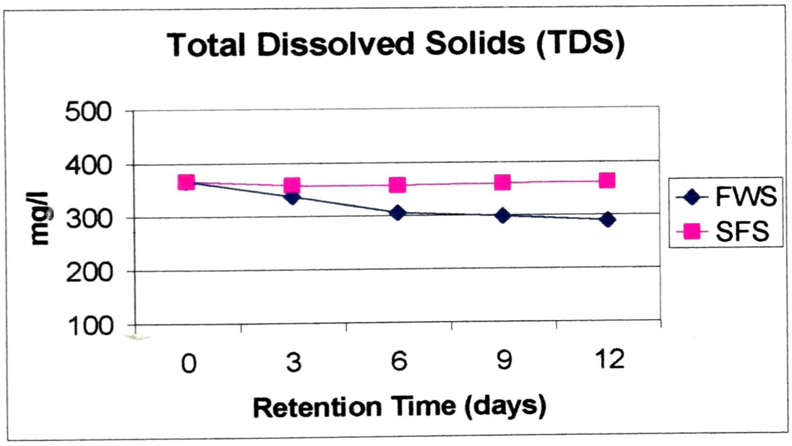
The treatment levels for both high organic load of wastewater are compared for SFS and FWS in non-planted wetland lysimeter.

4.2.1.1 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)



Removal Efficiency of EC
FWS 20.70%
SFS 1.17%

Figure 4.2.1.1.1:Comparison between SFS and FWS for EC changes



Removal Efficiency of TDS
FWS 21.03%
SFS 1.09%

Figure 4.2.1.1.2. Comparison between SFS and FWS for TDS changes

The rate of removal efficiency for TDS and EC in FWS is higher than that of SFS. This is probably due to filtration of dissolve organic substances by the soil. In the FWS system, the diverse microbial populations in the water column consume the soluble organic waste products.

4.2.1.2 Dissolved Oxygen (DO)

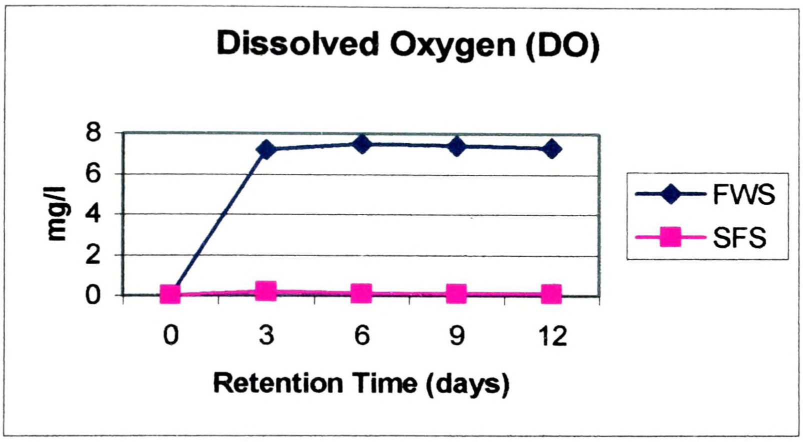
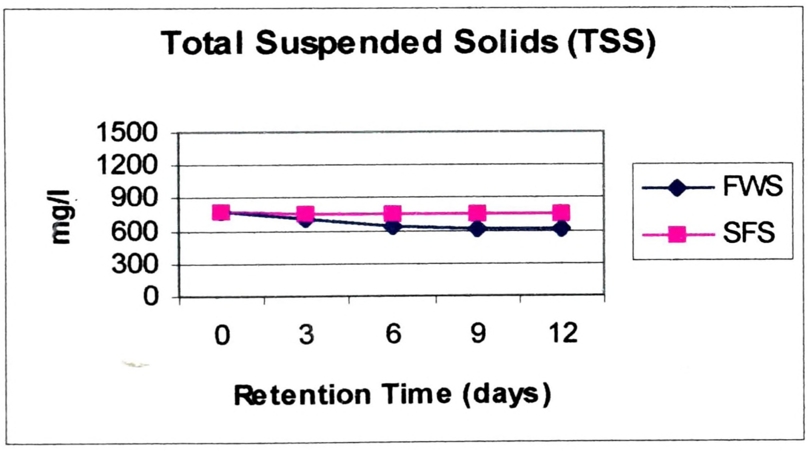


Figure 4.2.1.2: Comparison between FWS and SFS for DO changes

The FWS system had greater dissolved oxygen concentration resulting from photosynthesis of algae and greater oxygen diffusion across the open water surface. It shows that greater algae production occurs in FWS. In SFS the availability of DO concentration was limited.

4.2.1.3 Total Suspended Solids (TSS)



Removal Efficiency of TSS
FWS 73.97%
SFS 95.89%

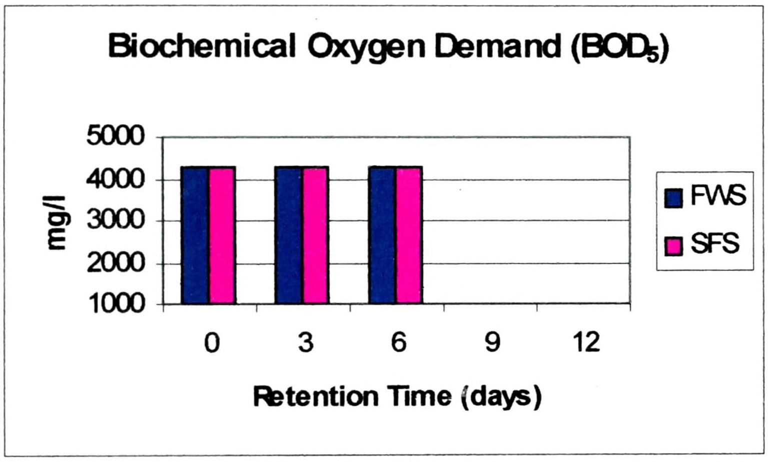
Figure 4.2.1.3: Comparison between FWS and SFS for TSS changes

Both systems provide good reduction in TSS (FWS – 73.97%, SFS – 95.89%). The rate of removal of TSS in the SFS was higher than that of FWS system.

Settleable suspended solids are readily removed in the early stages of FWS by gravity settling in quiescent water. In the SFS, settleable solids are removed by filtration as the wastewater moves through the soil particle.

For colloidal suspended solids, the primary removal mechanism is bacterial metabolism in both types of wetland treatment system. Some filtration and sorption may occur in SFS system.

4.2.1.4 Biochemical Oxygen Demand (BOD_5)



Removal Efficiency of BOD_5
FWS 0%
SFS 0%

Figure 4.2.1.4: Comparison between FWS and SFS for BOD_5 changes

There was no change in BOD_5 reduction in both two-treatment systems. The applied BOD_5 levels is much higher (4251.49 mg/l), therefore the area of the lysimeter may not be enough to reduce the BOD_5 significantly Hence the area of wetland lysimeter could be enlarged or the higher organic load effluent should undergo for primary treatment before introducing into the wetlands.

4.2.1.5 pH

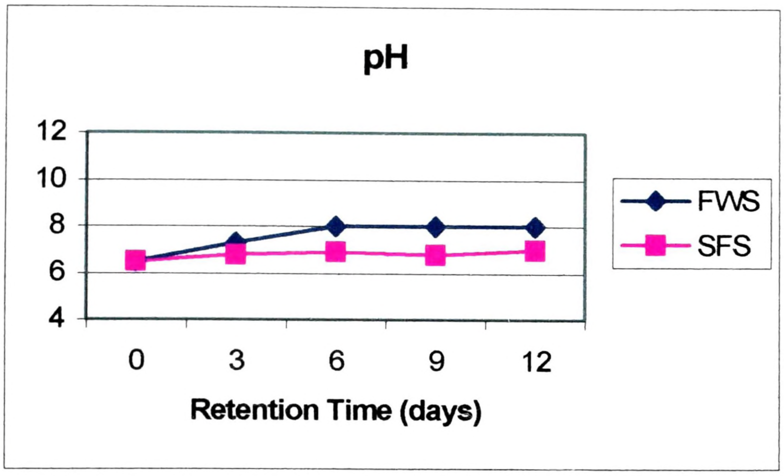


Figure 4.2.1.5: Comparison between FWS and SFS for pH changes

The pH increased slightly in both systems and it was relatively stable between 6.5 to 8.0

4.2.2. Treatment Efficiency of Low Organic Load Wastewater in Planted and Non-planted Lysimeters

Tables 4.2.2.1 and 4.2.2.2 show the water quality parameter of treated effluent from FWS in the non-planted lysimeter and planted lysimeter, respectively.

Table 4.2.2.1: Treated effluent from FWS system in non-planted lysimeter

Retention time (days)	**TDS (mg/l)**	**TSS (mg/l)**	**EC (μs/cm)**	**BOD5 (mg/l)**	**DO (mg/l)**	**pH (mg/l)**
0	140	480	294	690	1.2	6.7
03	132	200	277	660	6.7	7.1
06	124	160	261	630	7.2	7.3
09	80	120	168	585	7.5	7.3
14	72	120	150	585	7.6	7.3

Table 4.2.2.2 : Treated effluent from FWS system in planted lysimeter

Retention time (days)	TDS (mg/l)	TSS (mg/l)	EC (μs/cm)	BOD5 (mg/l)	DO (mg/l)	pH
0	140	480	294	690	1.2	6.7
03	126	190	265	675	6.2	7.0
06	119	120	251	570	7.0	7.0
09	62	80	130.8	540	7.4	7.2
14	57	80	119.8	525	7.5	7.2

The water quality of treated effluent from SFS in non-planted and planted lysimeters are shown in table 4.2.2.3 and 4.2.2.4, respectively.

Table 4.2.2.3: Treated effluent from SFS in non-planted lysimeter

Retention time (days)	TDS (mg/l)	TSS (mg/l)	EC (μs/cm)	BOD5 (mg/l)	DO (mg/l)	pH (mg/l)
0	140	480	294	690	1.2	6.7
03	138	160	289	690	0.5	7.0
06	136	60	286	675	0.1	7.0
09	137	40	288	690	0.1	7.1
14	136	40	286	690	0.1	7.1

Table 4.2.2.4: Treated effluent from SFS in planted lysimeter

Retention time (days)	TDS (mg/l)	TSS (mg/l)	EC (μs/cm)	BOD5 (mg/l)	DO (mg/l)	pH (mg/l)
0	140	480	294	690	1.2	6.7
03	139	160	293	675	0.6	7.1
06	137	80	288	660	0.3	7.2
09	138	40	289	675	0.2	7.0
14	137	40	288	675	0.2	7.1

Water balance was computed with rainfall and evaporation data during the sample collection period (table 4.2.2).

Table 4.2.2.5:Rainfall and evaporation data

Date	Rainfall (mm)	Evaporation (mm)
2001/12/12	-	-
2001/12/13	-	1
2001/12/14	-	2
2001/12/15	-	2
2001/12/16	-	4
2001/12/17	-	3
2001/12/18	0.8	3
2001/12/19	7.49	1
2001/12/20	17.1	1.5
2001/12/21	61.09	1
2001/12/22	36.65	1
2001/12/23	21.34	2
2001/12/24	21.42	2
2001/12/25	15.64	2
2001/12/26	8.14	2

The treatment level in the vegetated levels was compared to the treatment level in a physically similar system without plants.

The treatment efficiency of low organic load wastewater is compared for planted and plant free wetlands operated as FWS system and SFS.

4.2.2.1 Dissolved Oxygen (DO)

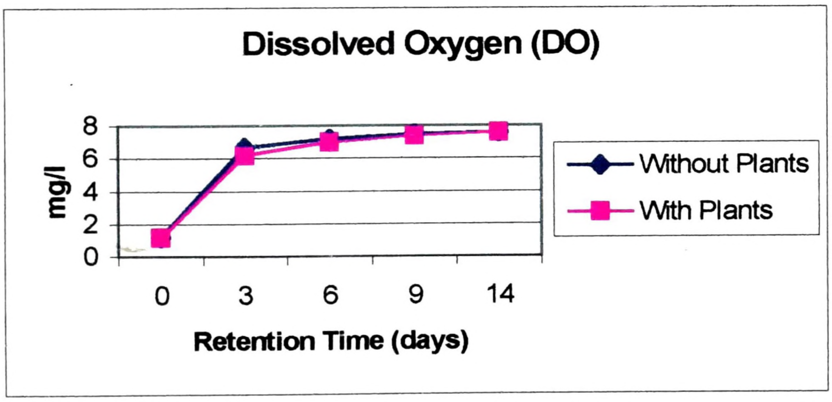


Figure 4.2.2.1.1: Comparison between with plants and without plants of FWS system for DO

Both lysimeters of free water surface system had greater dissolved oxygen concentrations resulting from the photosynthesis of algae and oxygen diffusion across the open water surface.

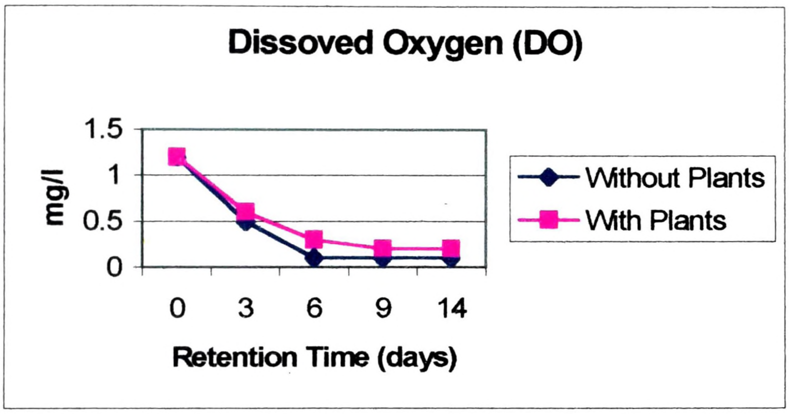


Figure 4.2.2.1.2: Comparison between with plants and without plants of SFS system for DO

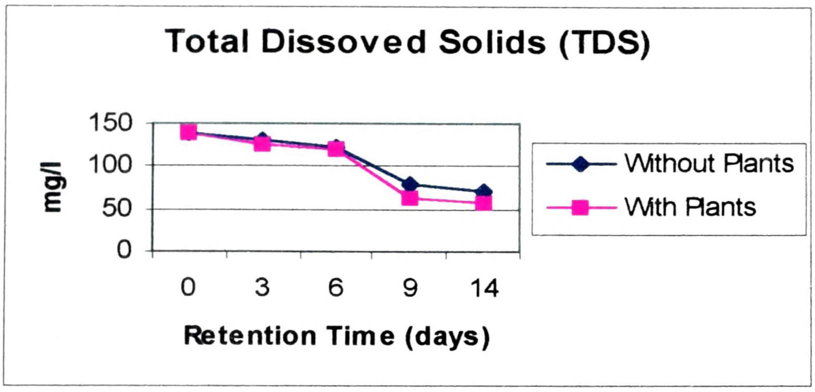
Dissolved oxygen concentration on SFS wetland treatment systems is less than that of FWS due to the limited supply of oxygen.

The availability DO concentration in non-planted lysimeter of SFS had minimum, rather than that of planted wetland. This confirms that the oxygen supply is limited in the soil layer in non-planted lysimeter.

The DO concentration in the SFS of planted system was expected to be higher. It was not happened in this case. It is suggested that the system constructed in this study is not established yet for the best function.

The literature review shows an establishment period is required to achieve full operability and treatment performances of a constructed wetland system. The establishment period may vary from a few months to years. Rooted plants require eight to sixteen months to full establishment (Kent, 1995).

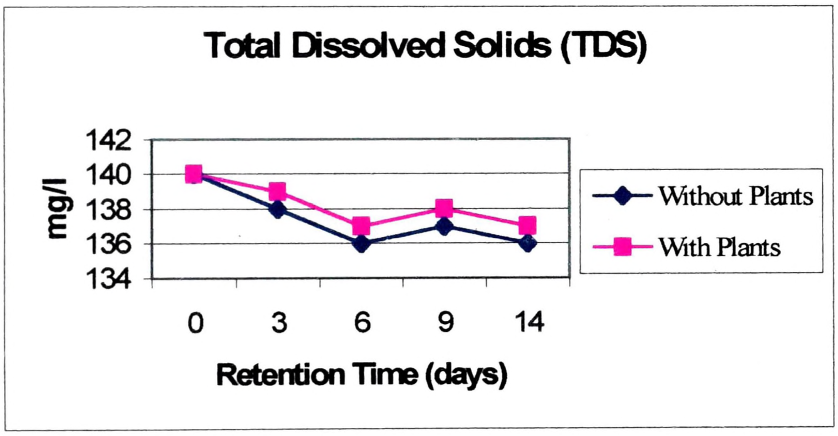
4.2.2.2 Total Dissolved Solid (TDS)



Removal Efficiency of TDS
Without Plants 48.57%
With Plants 59.28%

Figure 4.2.2.2.1:Comparison between with plants and without plants of FWS system for TDS

The removal efficiency of TDS in FWS of non-planted lysimeter (48.57%) is less than that of planted lysimeter (59.28%).

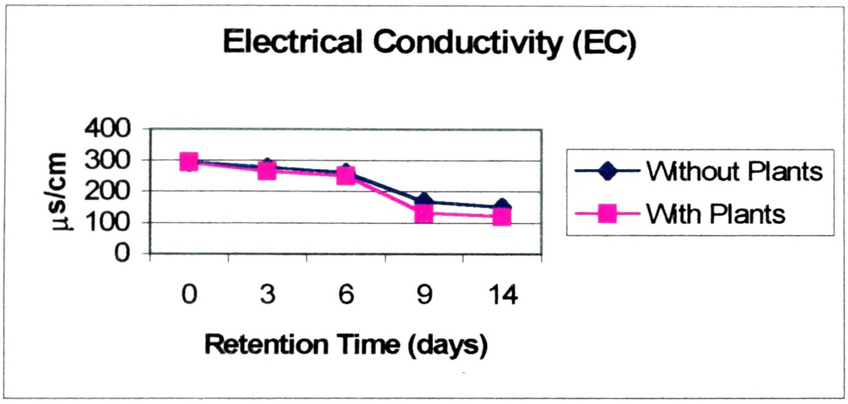


Removal Efficiency of TDS
Without Plants 2.8%
With Plants 2.14%

Figure 4.2.2.2.2: Comparison between with plants and without plants of SFS system for TDS

The removal efficiency of TDS in SFS of both planted (2.14%) and non-planted lysimeters (2.8%) were minimal and much lower than that of FWS. This probably resulted from dissolved organic substance in the soil and the limited supply of oxygen in SFS.

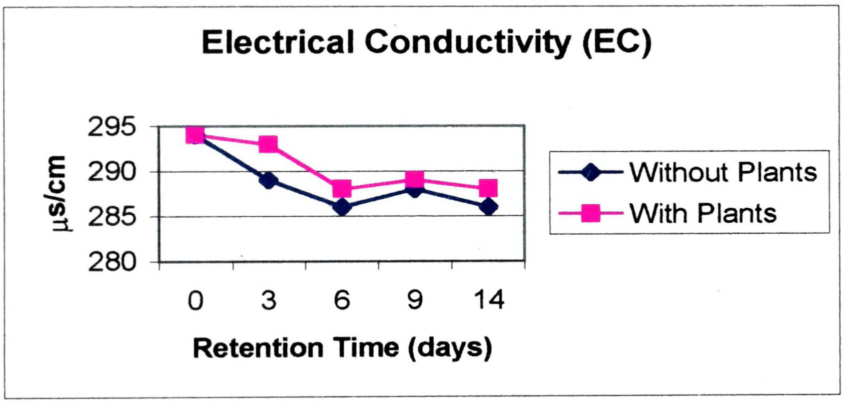
4.2.2.3 Electrical Conductivity (EC)



Removal Efficiency of EC
Without Plants 48.97%
With Plants 59.25%

Figure 4.2.2.3.1: Comparison between with plant and without plant of FWS system for EC.

The rate of removal of EC in FWS of non-planted cell (48.97%) is less than planted cell (59.25%).

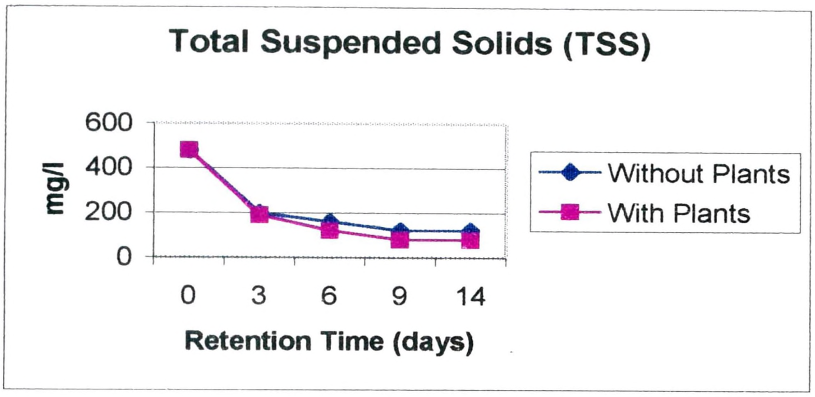


Removal Efficiency of EC
Without Plants 2.72%
With Plants 2.04%

Figure 4.2.2.3.2: Comparison between with plants and without plants of SFS system for EC.

It is clear that rate of removal of EC in FWS is higher than SFS in both planted and non-planted wetland lysimeters. EC on the water column depend on the TDS of the system.

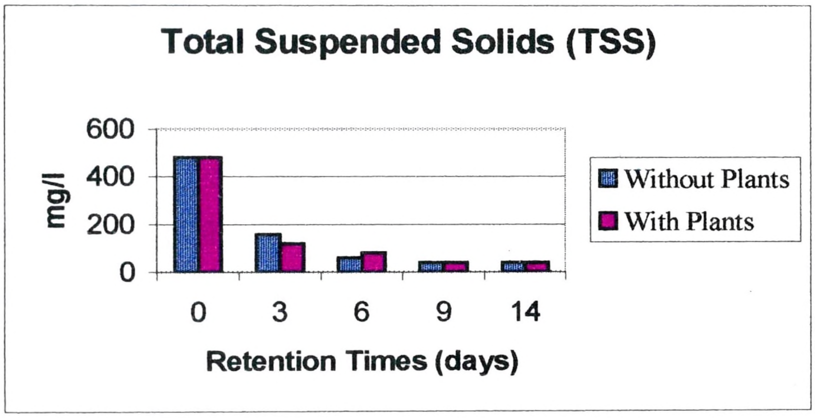
4.2.2.4 Total Suspended Solids (TSS)



Removal Efficiency of TSS
Without Plants 75%
With Plants 83.33%

Figure 4.2.2.4.1:Comparison between with plants and without plants of FWS system for TSS

All treatments provide great reduction in TSS. The TSS removal efficiency in FWS of non-planted cell (75%) is less than that of planted cell (83.33%).



Removal Efficiency of TSS
Without Plants 91.66%
With Plants 91.66%

Figure 4.2.2.4.2: Comparison between with plants and without plants of SFS system for TSS

In the SFS both wetland lysimeter provide same reduction efficiency of TSS (91.66%).It is clear that rate of removal efficiency of TSS is greater in SFS than FWS due to algal growth within the water column in FWS. TSS tested filter papers were bright green with algae filtered from samples, a condition not noted from SFS.

4.2.2.4 pH

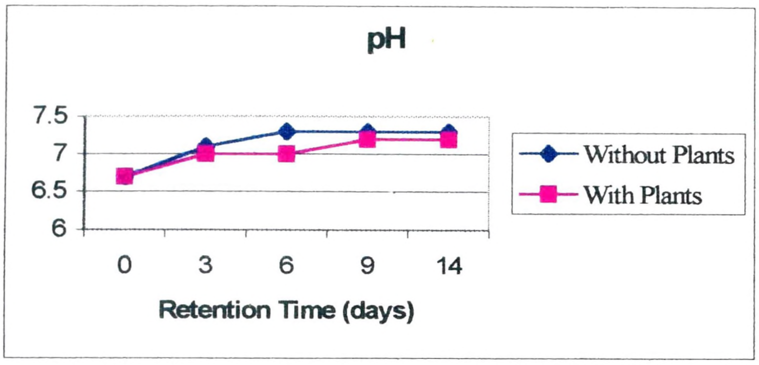


Figure 4.2.2.4.1: Comparison between with plants and without plants of FWS system for pH

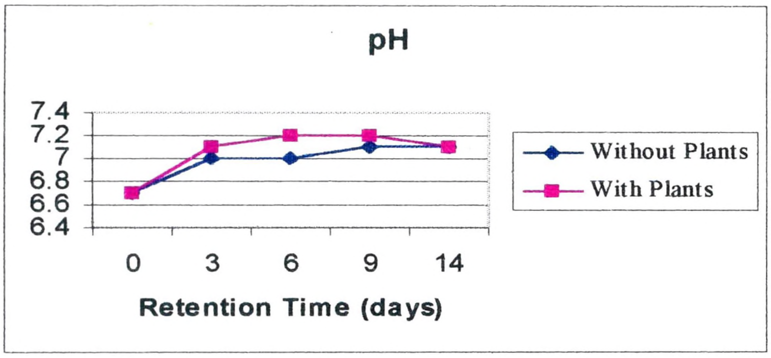
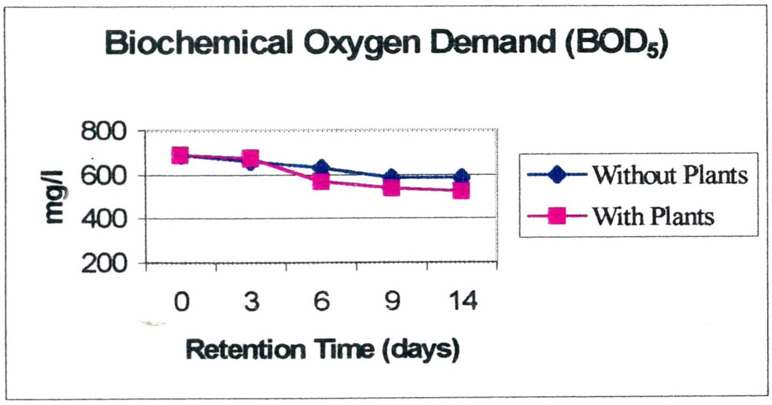


Figure 4.2.2.4.2: Comparison between with plants and without plants of SFS system for pH

The pH of the all treatment systems was relatively stable at 6.5 to 8.0.

4.2.2.5 Biochemical Oxygen Demand (BOD_5)



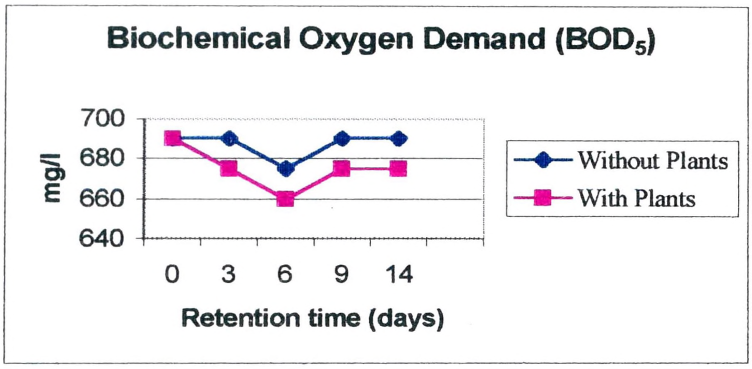
Removal Efficiency of BOD_5

Without Plants	15.21%
With Plants	23.91%

Figure 4.2.2.5.1: Comparison between with plants and without plants of FWS system for BOD_5.

The non-planted wetland of FWS system showed poorer removal of BOD_5 (15.21%) than the planted wetland (23.91%) with loading rate of 690 mg/l. This probably result of the biological activity in the FWS is from algae and bacteria where microbial growth is attached to structures such as plant stem and soil surface in the wetland.

The removal rate of BOD_5 is not much higher in the FWS of planted lysimeter. Reasons, which may have contributed for not gaining the expected higher removal rate, may be the area of the lysimeter, the higher BOD value of applied wastewater and plant establishment period.



Removal Efficiency of BOD5
Without Plants 0%
With Plants 2.17%

Figure 4.2.2.5.2:Comparison between with plants and without plants of SFS system for BOD_5

The BOD_5 removal in SFS in non-planted lysimeter was negligible (zero) and the planted lysimeter was 2.17%. The rates of removal of both wetland lysimeters of SFS are minimal and much less. It may happen because the system of planted lysimeter is not well established during the sampling period. Hence oxygen release from roots of *typha latifolia* is far less than the amount required for aerobic degradation of the oxygen containing substances in wastewater.

The initial expectation was for the planted FWS and SFS systems to perform high removal rate of BOD_5. This however did not observed. The experiment should be repeated once again after the planted lysimeter is fully established.

Like most biological system constructed wetlands require a period of time to become established. Treatment levels should increase as the constructed wetlands get older and the plants spread to fill in void areas. As the system matures, a wider variety of microorganisms and plants will become established and it can be expected better treatment level of wastewater.

CHAPTER 5
CONCLUSION

According to the rate of removal efficiency, the Free Water Surfaces system in planted lysimeter with *Typha latifolia* shown the capability of providing treatment for low organic load of wastewater. In this system removal efficiency of TSS, TDS, EC and BOD_5 was 83.26%, 58.99%, 59.11%and 23.91% respectively. The lysimeter was operated with water depth of 10 cm and Retention time was 14 days as batch processing system.

The overall treatment level in the planted lysimeter was not much greater than in the non-planted lysimeter. However the vegetated system should show increased level of treatment as they established well because, the treatment is mainly due to root system of plant. Each of every wetland treatment system was effective in the removal of total suspended solid. The treatment of wastewater in SFS wetland system performed well in terms of removing TSS.

The SFS in vegetated wetland failed to meet performance standards. It should be stated that as constructed wetlands are biological system, a period of time is required for the ponds to become fully established. It is suggested that higher treatment can be obtained once with vegetation is well established.

High organic load wastewater could not be treated effectively in non-planted lysimeter. It is believed that constructed wetland system is suitable for secondary treatment of wastewater and also the area of the lysimeter should be enlarged to achieve good treatment level.

FURTHER STUDIES AND RECOMMENDATION

Further studies are necessary to

- Identify how FWS and SFS constructed wetland (with best establishment) may be used as an effective mechanism for secondary or tertiary treatment of wastewater with replications.
- Identify suitable plant variety for wastewater treatment.
- Study whether a constructed wetland could effectively remove phosphorous and nitrogen from the wastewater.

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APPENDIX 1

Removal Efficiency for High Organic Load Wastewater in Non-planted Lysimeter

Constructed Wetland Systems	Parameters			
	TDS (mg/l)	TSS (mg/l)	EC (µs/cm)	BOD_5 (mg/l)
Free Water Surface	21.03%	73.97%	20.70%	0%
Subsurface Flow System	1.09%	95.89%	1.17%	0%

Removal Efficiency of Low Organic Load Wastewater in Free Water Surface System (FWS).

Constructed Wetland Systmes	Parameters			
	TDS (mg/l)	TSS (mg/l)	EC (µs/cm)	BOD_5 (mg/l)
Without Plant	48.57%	75%	48.97%	15.21%
With Plant	59.28%	83.33%	59.25%	23.91%

Removal Efficiency of Low Organic Load Wastewater in Subsurface Flow System (SFS).

Constructed Wetland Systems	Parameters			
	TDS (mg/l)	TSS (mg/l)	EC (µs/cm)	BOD_5 (mg/l)
Without Plant	2.8%	91.66%	2.72%	0%
With Plant	2.14%	91.66%	2.04%	2.17%

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