Constructed Wetland System for Peat Soil Ecosystem Restoration and Water Quality Analysis

by

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Dissertation submitted in partial fulfilment of
the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

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(Ts. Dr. Lavania Baloo)

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January 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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MUHAMMAD ZUL IRFAN BIN UMAT LOKMAN

ABSTRACT

Peat soil is accumulation of soil with partially decayed organic matter and vegetation and can be located in various parts of the world. Peat soil has little usage within the industry as their soil characteristics can be troublesome to work with. In this study, vertical flow constructed wetland system is used to improve peat soil management. Beyond that, the performance of constructed wetland as a system to treat stormwater while also maintaining peat soil ecosystem for agricultural purposes was also examined. Laboratory scale constructed wetlands were built and cultivated with Eichhornia crassipes, which is a floating plant. The wetlands have a different height of peat soil medium of 10 cm, 20 cm, and 25 cm, respectively. These wetlands consist of mixtures of peat soil and black gardening soil while another one was setup by using only 25 cm of peat soil and serves as the control. The stormwater was collected from UTP lake and duration of treatment was 3 weeks period.. The characterization of stormwater was conducted, and values of Total Phosphorous, Total Nitrogen, nitrate, COD, and turbidity were 7.83, 115, 432, and 65 respectively. Findings show that TP, turbidity, nitrate, and COD had mean removal efficiencies of 44%, 43%, 53%, and 58%. Nitrogen had a 530% mean increase in effluent concentrations after duration of treatment. Peat soil characterization findings also showed a mean moisture content of 379% and organic matter content of 69%. The offshoot growth of the *Eichhornia crassipes* showed mean growth of 27 shoots during the study. Although the peat soil was not capable of treating all the nutrients in constructed wetland, the results show that the peat soil is still capable of sustaining an environment for healthy plant growth. Peat soil medium has potential for stormwater treatment in constructed wetland. Further research on the combining soil medium and different plants would be needed to further understand peat soil capabilities as a constructed wetland medium.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of study

Peat soils are a type of organic soil developed through accumulation of both undecomposed and partially decomposed plant residues (Osman, 2018). The material is also sometimes known as turf. An area of land that consists of majorly peat soil and peat performing organic matter is called a peatland. It forms part of a natural occurring areas including bogs and muskegs. The formation of these peatlands can occur for an excessive period of time, with estimates of more than 10,000 years. The rapid decomposition process of organic matter is not possible due to consequent anaerobic condition and permanent water saturation to the soil. It is estimated that 400 million hectares of peat land covers the land surface of the earth, equivalent to 3% of the total surface area (Veloo et al., 2014). They are naturally more widespread in temperate and cold zones of the Northern Hemisphere. This organic soil has a low bulk density as the soil has less compaction allowing the soil to have a high level of porosity. There are several different types of peat soil that can be found such as moss peat, forest peat and swamp forest peat. Moss peat is peat that consist of sphagnum plants. They have a wide practical of use from insulation to soil conditioner. Forest peats consist of tropical moist forests where waterlogged soil prevents organic matter form fully decomposing. They naturally contain huge amounts of carbon as soil organic matter. Swamp forest peat naturally occur alongside forest peat, where lowland rainforests surround saltwater mangrove forests near the coast.

Peat soil has a lot of uses that are proven to be beneficial to several industries. Peat soil is very good at retaining water when dry and preventing excess water from destroying plants which makes it very suitable for the agricultural industry. The peat soil provides for the largest readily available area for potential agricultural use without previous cultivation being made to the area (Adon et al., 2013). Examples of planting that were successfully grown in peat soils are oil palm trees where the land can be reused for second- and third-time replants. Other than that, peat soil is also good for growing valuable timber, with research showing that there is an abundance of timber in peat swamps at Malaysia. Furthermore, peat is also used for other farming purposes that suits farmers. For instance, farmers in Pontian, Malaysia used peat soil for their pineapple plantations. The organic content in peat soil reduces cost for artificial fertilization and increases the quality of the plantation. Beyond that, peat is also used in horticulture. The use of peat soil in a lightly soil medium improves the water retention and allows for better drainage for the plants. It is also free of weeds and pollutants. Peat soil can also be used as the principal soil medium for the plants or as an additional amendment.

Other than that, peat soil is also used in freshwater aquaria. Most of the peat used is in river systems that mimic the freshwater river basin and soft water. The soft texture of the peat soil is very suitable for bottom dwelling fish species as it does not harm them from the dangers of hard textured soil. Other than that, peat also helps to improve the water quality of the water by reducing the pH of the water. (McKay, 2008) stated that peat will act as an ion exchanger and absorbs the minerals from the water. This process softens the water and help maintain the pH content. Beyond that, peat also naturally contains minerals that are good for growth of plants and increase the health quality of the fishes.

Peatlands are also a type of wetland that are abundant on this earth. A wetland is a distinct ecosystem that is flooded by water where it can occupy the place seasonally or even decades long. The flooding of this environment will cause for oxygen-free processes to happen as it only allows anaerobic conditions to occur. The process for a wetland to appear is by flooding of an area of land due to flooding of water that can be caused by rainstorms. Other than that, they also distinguish themselves from other plots of land based on the water level and the types of living things that inhabited them. Generally, wetlands can support aquatic p2lants inside them. The presence of aquatic plants in wetland systems not only provides a great amount of food for wildlife but can also accommodate the animals that inhabit the wetland. A recent study by Bassi et al., (2014) stated that the freshwater ecosystems in western Ghats, southern India contains 608 species of aquatic plants that supports about 290 species of fish. The richness of the ecosystem supported by the wetland enables it to support a plethora of animals and aquatic plants that thrive from the ecosystem. Other than that, it also provides a huge opportunity for humans to take advantage of the ecosystem by means of activities such as fishing.

Constructed wetlands are a type of wetland that copies the functions of natural wetlands. These man-made environments are mainly used for the treatment of wastewater where they rely on natural biological and chemical processes for the treatment of wastewater using flooded plains of land (Shin et al., 2013). These artificial systems have proven to be very reliable in treating domestic and municipal wastewater. Other than that, Sultana et al. (2015) also stated that constructed wetland can also tolerate high pollutant loads and still have good pollutant removal rates. This has proven that constructed wetland can be used for treatment of wastewater supported by the fact that its usage has been tracked to as early as 1967 in the Netherlands (Vyzamal 2010). The aim of this study is to use constructed wetland for peat soil management and to investigate the nutrients removal efficiencies.

1.2 Problem Statement

Even though peat soil has a few characteristics that can be proven useful for specific uses, the nature of the peat soil itself makes it not viable to be used in a lot of industries. Its natural state is very soft and is not suitable for usage in the construction industry as it will not support the foundations of buildings. Furthermore, even if a structure is managed to be built on peat soil foundation, the structure is vulnerable to structural collapse as a load increase will cause soil settlement and reduce the integrity of the structure it supports (Kolay et al., 2011). Other than that, peat soil is naturally a very unstable soil for agricultural purposes. These problems that arise when implementing the usage of peat soil has refrained the industry from using peat soil even though the soil is very abundant in tropical countries such as Malaysia.

Therefore, the proposed solution for this problem is to use peat soil in constructed wetland. The constructed wetland can take advantage of peat soil characteristics to grow the ecosystem needed to support the constructed wetland. Generally, these constructed wetlands treat wastewater with the aid of aquatic plants to trap and filter sediments that comes from the wastewater. The microorganisms that are present in the wetland ecosystem will breakdown the biodegradable substances during the decomposition process. The nutrients that are present in the peat soil will create an ecosystem that not only provides reliable wastewater treatment for the industry but also has minimal operation costs to run it. Furthermore, this type of wastewater treatment system has been implemented before in the country and has shown that it can also serve as an added recreational value to the place it was constructed. The aim of this study is to use constructed wetland that will allow for better management of peat soil and further increase its usage. Then, the ecosystem created in the wetland will be monitored so that it can be used for agricultural purposes while also evaluating the water quality from the constructed wetland.

1.3 Objectives

The objectives of this study are as follows:

1. To construct wetland system with mixture of different depths of peat soil and gardening soil.

2. To evaluate the nutrient removal efficiencies of the constructed wetland system and plant growth rate.

1.4 Research Questions

1. How to improve the performance of peat soil and integration with constructed wetland?
2. How does peat soil improve the water quality and maintain the ecosystem of the constructed wetland?

1.5 Scope of Study

1. Different designs of constructed wetlands

Each type constructed wetlands will be explored and details of their systems and compatibility will be discussed with a focus towards vertical wetland systems as the chosen system of constructed wetland for this study.

2. Physical properties of peat soil

Physical properties including texture, colour, porosity, density, and structure will be studied alongside their importance to an ecosystem.

3. Nutrient properties of soil

The importance of nutrient properties such as nitrogen and phosphorus are discussed alongside their role in the soil.

4. Domestic and industrial wastewater

The characteristics of industrial wastewater and domestic wastewater and their suitability for treatment using constructed wetland system.

5. Types of macrophytes and their differences

Macrophytes such as emergent, floating and submerged with their implementation into constructed wetland system and their roles in that system

6. Removal process of nutrients and organic matter from wastewater

Water quality parameters such Total Nitrogen, Total Phosphorous, Nitrate, COD and turbidity from effluent were carried out to determine the overall water quality of stormwater sample and treated effluent sample. Characterization of peat soil was also carried out to determine the moisture content, porosity, and organic carbon content of peat soil alongside the characterization of macrophyte used for the project.

CHAPTER 2
LITERATURE REVIEW

2.1 Characterization of Peat Soil

Peat soil has a lot of characteristics that make it suitable to be used as a medium for the use of aquatic plants. The properties of peat soil can be affected by a few different components based on the physical properties, mineral content, and organic content of the soil. These components can be controlled depending on the location of the peat soil to better acclimatise it to serve its purpose. One of the key components of peat soil is that it has a very good water retention under certain conditions. A study conducted by Boelter (1968) based on Figure 2.1 shows the water retention for different types of peat soil. It shows that different types of peat soil have varying ranges of water content. For instance, undecomposed Sphagnum moss peat begins decomposing, the total porosity gradually decreases.

Apart from that, it is also stated that porosity decreases with ongoing decomposition, as the pore sizes and structure of decomposed peat soils differ from amorphous peat (Dettmann et al., 2021). This indicates that the peat soil retains water very well and is suitable for submerged conditions until it reaches a certain threshold. It also shows that different types of peat soil have varying ranges of water content and water retention capacity. Furthermore, peat soils have also been stated to have differing values according to the depth of peat soil sample used. Baird et al. (2017) measured the hydraulic conductivity of peat soil obtained from tropical peatlands in Panama. The data that were analysed from the study ranged from 8.7 x 10^(-5) ms^(-1) for deep peat to 5.462 x 10^(-3) ms^(-1) for hardwood forest peat. Statistical examination of the study's data revealed that deeper peat had much lower hydraulic conductivity than shallower peat. The differences in shallow-peat hydraulic conductivity concentration between the various zones were less obvious. There are also other studies that have suggested that tropical peatlands have similar values of hydraulic conductivity data. Sayok et al. (2007) reported mean values of 3.9 x 10^(-4) ms^(-1) for hydraulic conductivity in Malaysian swamp forest, as determined by slug testing in auger holes. This indicates that peat soils have a very high permeability state. The peat soils need to be used with an impermeable material that will reduce permeability of soil if it is to be applied in constructed wetland systems (Department of Irrigation and Drainage (DID) Malaysia, 2012, p. 11-9).

Peat soil has a lot of characteristics that make it suitable to be used as a medium for the use of aquatic plants. The properties of peat soil can be affected by a few different components based on the physical properties, mineral content, and organic content of the soil. These components can be controlled depending on the location of the peat soil to better acclimatise it to serve its purpose. One of the key components of peat soil is that it has a very good water retention under certain conditions. A study conducted by Boelter (1968) based on Figure 1 2.1 shows that when undecomposed Sphagnum moss peat begins decomposing, the total porosity gradually decreases. This indicates that the peat soil in question retains water very well and is suitable for submerged conditions until it reaches a certain threshold. However, peat soils have also been stated to have differing values according to the depth of peat soil sample used. Baird et al. (2017) measured the hydraulic conductivity of peat soil obtained from tropical peatlands in Panama.

The data that were analysed from the study ranged from 8.7 x 10^{-5} ms^{-1} for deep peat to 5.462 x 10^{-3} ms^{-1} for hardwood forest peat. Statistical examination of the study's data revealed that deeper peat had much lower hydraulic conductivity than shallower peat. The differences in shallow-peat hydraulic conductivity concentrations between the various zones were less obvious. There are also other studies that have suggested that tropical peatlands have similar values of hydraulic conductivity data. Sayok et al. (2007) reported mean values of 3.9 x 10^{-4} ms^{-1} for hydraulic conductivity in Malaysian swamp forest, as determined by slug testing in auger holes. This indicates that peat soils have a very high permeability state. The peat soils need to be used with an impermeable material that will reduce permeability of soil if it is to be applied in constructed wetland systems (Government of Malaysia, Department of Irrigation and Drainage, 2012, p. 11-9).

Even though the peat soil has an increase in porosity value, altering the amount of peat soil used will alter modify the characteristics of the soil and make it usable for its usage in wetland systems. Therefore, the soil's hydraulic conductivity can be modified for the usage in wetlands. Boelter (1968) also stated that dense peat materials have shown lower hydraulic conductivities than other soils such as clay. This characteristic is important as it will affect the runoff characteristic of peat soil and effect its physical properties. Beyond that, it also effects the rate of nutrient leaching from the soil which may affect the ecosystem that it houses.

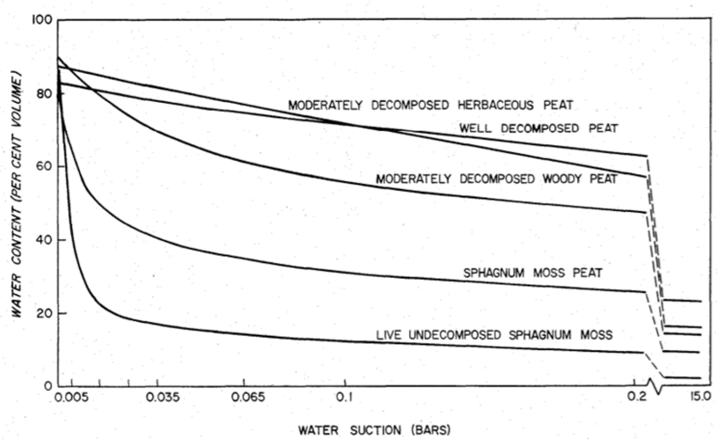

Figure 2.1: Water Retention for peat soil (Boelter, 1968)

2.1.1 Nutrients Content of Peat Soil

Peat soil has ability for an accumulation of nutrients that will aid in the processes that will keep the ecosystem moving. The nutrients will aid in the growth of plants, decomposition of plants and support the function of the ecosystem. The peat soil provides a medium for the nutrients to be recycled and reused. Wang et al. (2015) conducted a study to determine the amount of nutrients that are stored in northern peatlands and the amount of nutrients that were accumulated over time. The result from the study shows that the peat stoichiometry increases within swamp peat compositions as seen in Figure 2.2 where it shows the nutrient ratio of different nutrients with increase in depth of peat soil for bog, fern, and swamp peat.

The nutrients such as P, Ca and Mg had different ratio accumulation as deeper peat soil was analysed. This shows that over time, the nutrients will be recycled into the soil where vegetation can use the nutrients for cultivation before decomposing. The repeated process will eventually accumulate the amount of nutrients in the peat soil thus sustaining the ecosystem of the peat soil. Peat also has a large amount of carbon stored, with estimations of nearly 20% of the Earth's global carbon storage is located in peatlands (Upton et al., 2018). This indicates the suitability for different types of peat to maintain a healthy nutrient content for the growth of plants. However, certain types of peat soil may better sustain an environment compared to others depending on the nutrient content. Therefore, the selection of peat soil for different uses will largely depend on the system that it may be incorporated with.

2.1.2 Organic Matter Content of Peat Soil

Moreover, natural peat soil is very suitable for wastewater treatment as it has high percentage of organic content. Depending on the environment of the peat soil, the decomposition of plant remains may results in organic matter such as fine fibres and woody coarse fibres. Furthermore, the presence of microorganisms can affect the rate of decomposition in the peat soil environment (Afip & Jusoff, 2019). These microorganisms will break down the organic matter and in turn releasing the nutrients from the organic matter. The activities that happen in the ecosystem of peat allows for good plant growth on peat soil. It also provides peat soil with great erosion control measures in the ecosystem. These characteristics that can be strengthen with organic matter content allows peat soil to be applied in various areas such as wastewater treatment. The texture of peat soil can be determined by using the von Post test. The test is conducted by squeezing wet peat sample before conducting assessment on the remaining peat sample. The degree of decomposition or humification can be determined by using ten different categories (H1 – H10). Table 2.1 shows the description of each category of peat according to their respective level of decomposition and fibre content.

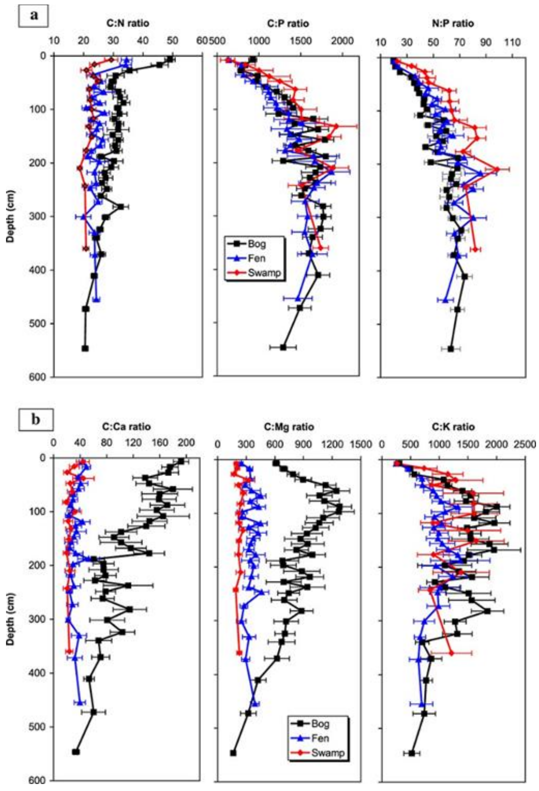

Figure 2.2: Nutrient Ratio as Depth of Peat Increases (Wang et al., 2015)

Table 2.1: The Von Post Classification System

Symbol	Description
H1	Completely undecomposed peat which, when squeezed, releases almost clear water. Plant remains are easily identifiable. No amorphous material is observed to be present
H2	Almost entirely undecomposed peat which, when squeezed, releases clear or yellowish water. Plant remains are still easily identifiable. No amorphous material present
H3	Very slightly decomposed peat which, when squeezed, releases muddy brown water, but from which no peat passes between the fingers. Plant remains are still identifiable, and no amorphous material present
H4	Slightly decomposed peat which, when squeezed, releases very muddy dark water. No peat is passed between the fingers, but the plant remains are slightly pasty and have lost some of their identifiable features
H5	Moderately decomposed peat which, when squeezed, releases very muddy water with a very small amount of amorphous granular peat escaping between the fingers. The structure of the plant remains is quite indistinct although it is still possible to recognize certain features. The residue is very pasty
H6	Moderately highly decomposed peat with a very indistinct plant structure. When squeezed, about one-third of the peat escapes between the fingers. The residue is very pasty but shows the plant structure more distinctly than before squeezing
H7	Highly decomposed peat. Contains a lot of amorphous material with very faintly recognizable plant structure. When squeezed, about one-half of the peat escapes between the fingers. The water, if any is released, is very dark and almost pasty
H8	Very highly decomposed peat with a large quantity of amorphous material and a very indistinct plant structure. When squeezed, about two-thirds of the peat escapes between the fingers. A small quantity of pasty water may be released. The plant material remaining in the hand consists of residues such as roots and fibers that resist decomposition
H9	Practically fully decomposed peat in which there is hardly any recognizable plant structure. When squeezed it is a fairly uniform paste
H10	Completely decomposed peat with no discernible plant structure. When squeezed, all the wet peat escapes between the fingers

Based on a study conducted on the microstructure of decomposed peat soil conducted by Afip & Jusoff (2019), the samples of tropical peat soil collected from Kota Samarahan, Sarawak shows that all samples have an organic content range of above 75%. Equation 1 shows the organic content formula used to determine the organic content percentage where C is the carbon content of the peat soil sample while N is the ignition loss. The results shown in Table 2.2 shows that the three samples that were used for the experiment has an organic content average of 91.27%. This indicates that natural peat soil has very high organic content that exceeds 75%. Therefore, peat soil is deemed to be suitable for usage in the constructed wetland system as the organic content of the soil will provide the soil with integrity and reduce the need for artificial fertilization to promote plant growth.Based on a study conducted on the microstructure of decomposed peat soil conducted by Afip & Jusoff (2019), the samples of tropical peat soil collected from Kota Samarahan, Sarawak shows that all samples have an organic content range of above 75%. Equation 1 shows the organic content formula used to determine the organic content percentage where C is the carbonate content of the peat soil sample while N is the ignition loss. The results shown in Table 2 shows that the three samples that were used for the experiment has an organic content average of 91.27%. This indicates that natural peat soil has very high organic content that exceeds 75%. Therefore, peat soil is deemed to be suitable for usage in the constructed wetland system as the organic content of the soil will provide the soil with integrity and reduce the need for artificial fertilization to promote plant growth.

$$OC\% = 1 - 1.04(C - N) \qquad \text{Eq 1}$$

Table 2.2: Loss on Ignition and Organic Content Percentage of Peat Samples (Afip & Jusoff, 2019)

Sample number	1	2	3	Average
Loss on ignition, %	91.18	93.89	90.27	91.78
Organic content, %	90.27	93.65	89.88	91.27

2.2 Constructed Wetland Treatment Systems

Constructed wetlands that are used for treatment systems work by making use of the natural activities that occur in an ecosystem to assist in the treatment of wastewaters. The controlled environment of the wetland systems allows for readjustments to the environment of the constructed wetlands to better suited the ecosystem needs (Shin et al., 2013). The wastewater treatment system works by filtering and treating the pollutants of the wastewater before releasing it to the environment. Generally, the constructed wetland system uses natural degradation processes and nutrient uptake from the ecosystem to separate the biomass of pollutants from the wastewater.

There are several kinds of situations where the application of constructed wetlands can be necessary to treat wastewater. One of the practical uses of constructed wetlands can be seen in treating domestic or municipal wastewater. These types of wastewaters that come from a point source pollution can be treated using constructed wetland ecosystem. The presence of agricultural and urban runoffs can be naturally treated without the aid of human input (Masi, 2004). There is a low energy demand that comes with the usage of constructed wetlands thus it is very suitable. However, the area that needs to be freed up for the construction of the wetland will need to be considered as it generally uses a lot of space in the environment. These large areas will ensure that high rate of biodegradation will occur without consuming much energy (Masi, 2004). Other than that, industrial runoffs can also be treated by employing constructed wetland systems.

Various types of pollutants such as sulphides and heavy metals can be found in industrial wastewater depending on the factory settings (Saeed et al., 2018). Depending on the medium of the wetland component, it can help support the chemical and biological removal of these wastewater thanks to the aquatic plants that inhabit the wetlands. Saeed et al. (2018) conducted a study that uses constructed wetland using construction materials as the main media for treatment of industrial wastewater from the industrial area of Dhaka, Bangladesh. The results shows that the removals of Phosphorus in wetlands with high amounts of recycled construction materials were very high. Beyond that, the removal of solid waste from the wastewater was also increased thank to the high retention time in the wetlands thanks to the construction waste medium. This shows that the medium in constricted wetlands system allows for efficient removal of wastewater components.

For the structure of the constructed wetland system, there are usually two types of treatment systems that are implemented. The first type is called surface flow wetland. The treatment system of the surface flow wetland such as in Figure 2.3 is very similar to how a natural wetland operates in nature. The type of aquatic plant that usually inhabit this ecosystem are wetland plants, floating plants and submergent plants (Shin et al., 2013). Besides wastewater treatment, this type of wetland also houses an environment that includes fauna such as fish, insects and birds thus creating an environment that is suitable for parks and recreation purposes.

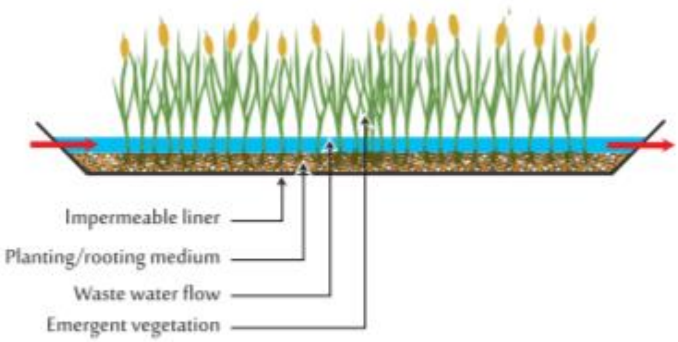

Figure 2.3: Structure of Surface Flow Wetland (Shin et al., 2013)

Other than that, there is also subsurface flow wetland. This type of wetland differs from surface flow wetland in the aspect that water does not flow above the surface of the soil medium. As shown in Figure 2.4, the medium of the gravel also has a lot of pore spaces to allow free flow of water. Beyond that, it also enables for decomposition process of biodegradable material. There are two types of subsurface flow wetland which is horizontal surface flow and vertical surface flow. Horizontal surface flow wetland has been in used since the 1980s where it was first implemented in Denmark (Vyzamal 2010). The procedure of how it works is that the wastewater will flow horizontally along the medium of the soil until it reaches the outlet of the wetland system.

During the flow, pollutions will be removed by a variety of chemical and physical processes in anaerobic, aerobic, and anoxic zones (Vyzamal 2010). Other than that, suspended solids from the wastewater were removed by means of filtration with very high efficiency. These processes have allowed for treatment of domestic wastewater and municipal wastewater to be done using this wetland system. Zhang et al (2014) stated that some developing countries have been using constructed wetland systems to treat their domestic runoff such as Nepal where high strength wastewater from 80 households were treated using constructed wetlands.

Other than that, there is also vertical surface flow wetland systems. As shown in Figure 2.5, the way that this constructed wetland treatment system works is that water is flowed vertically through the soil medium until it reaches the bed of the medium. This differs from horizontal subsurface flow as the water flows through the bed of the medium. Vyzamal (2010) stated that this type of subsurface flow also treats organic matter and suspended solids very well. However, vertical subsurface flow wastewater treatment systems provide more suitable environment for nitrification as it allows for more oxygen to diffuse into the medium bed thus increasing the rate of nitrification for the wastewater (Vyzamal, 2010).

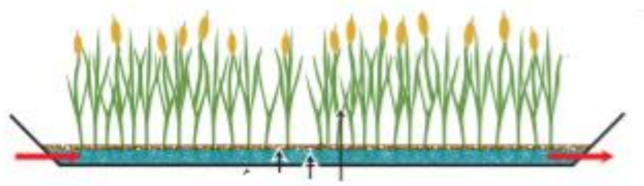

Figure 4: Horizontal Subsurface Flow Wetland (Shin et al., 2013)

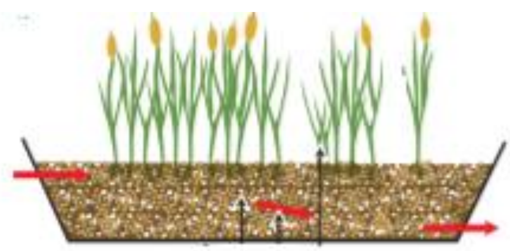

Figure 2.5: Vertical Subsurface Flow Wetland (Shin et al., 2013)

2.3 Performance of Constructed Wetland in Treating different Types of Wastewaters

The viability of constructed wetland systems as a wastewater treatment has pushed for the system to be used to treat different types of wastewaters. However, the efficiency of the system can be affected by several factors regarding the wastewater type. Depending on the hydraulic retention time, type of vegetation and the organic loading rate of the wastewater, it can determine whether the constructed wetland can efficiently treat the wastewater or not (Maitlo et al., 2018).

To analyse the efficiency of the constructed wetland system, a few studies using constructed wetland to treat different types of wastewaters will be observed. Maitlo et al. (2018) conducted a study to treat the domestic wastewater of village Majeed Keerio in Sakand, Pakistan. The process of analysing the treated wastewater was done by measuring COD, total suspended solids (TSS), total nitrogen (TP) and total phosphorus (TP) parameters and comparing them with the National Environmental Quality Standard (NEQS) of Pakistan to determine whether the system is suitable for treatment of domestic wastewater. The constructed wetland system consisted of filter beds, an anaerobic reactor and other parameters that will treat the wastewater before the sample is collected for lab assessment. Figure 2.6 shows that from a sample size that was taken in a monthly period, the average monthly reduction of COD was 3.66% of the wastewater sample. The reduced COD values in wastewater increases the water quality of the treated wastewater and allowing for safe release to the environment without harming the oxygen supply of the body of water.

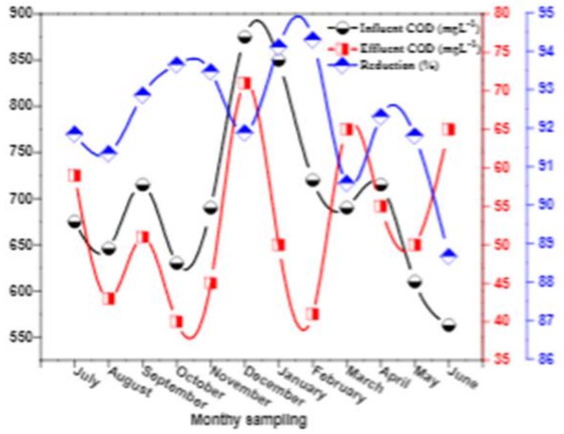

Figure 2.6: COD Removal Efficiency (Maitlo et al., 2018)

Figure 2.7 shows the average monthly reduction of TSS from influent and effluent of from the constructed wetland. It is shown that the average monthly reduction for TSS is 1.111% which is well within the NEQS set for domestic wastewater. Releasing wastewater with low values of TSS will ensure that the environment is not clogged with solids from the effluent thus decreasing the chances of major environmental damage.

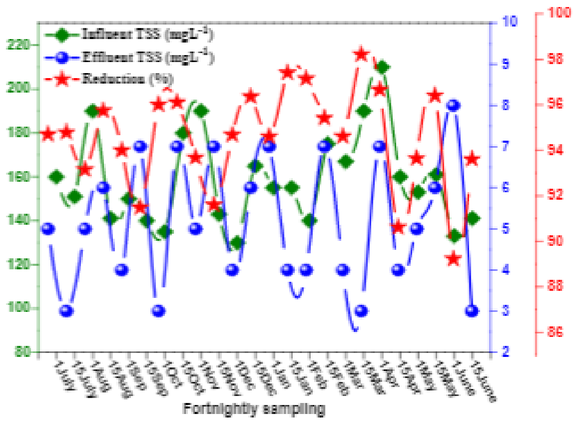

Figure 2.7: Monthly Reduction rate of TSS (Maitlo et al., 2018)

In addition, the TP and TN removal percentage were shown as 2.99% and 72.44% respectively. The rate of removal for both nutrients were affected by the chemical mechanism and biological mechanisms such as the aerobic and anaerobic processes. The study has shown that by using constructed wetland system for the treatment of domestic wastewater, the water quality of the effluent released is sustainable for the environment therefore reducing the negative effects it can have to a habitat.

Other than domestic wastewater, constructed wetland has also been used to treat industrial wastewater. Valero et al. (2020) conducted a study to analyse the treatment of industrial wastewater from the tannery industry using constructed wetland system. The study uses a horizontal subsurface flow constructed wetland system that was implemented in Murcia Region, Spain. The parameters that were measured were the TP and TKN that were absorbed form the wastewater in a 3-day and 7-day retention period. Table 2.3 shows the results for the parameters pH, electrocoagulation (EC), TKN and TP. The results show that for TKN, the removal rate for a 3-day retention period was 9.6% and 1.4% for 7-day retention period. Meanwhile, the TP rate was 77.7% and 66.4% for 3-day and 7-day retention period respectively. These results shows that constructed wetland used in the study may need improvements to increase the removal rate of nitrogen. Adjustments such as different usage of macrophyte plants may need to be implemented if a higher efficiency removal rate is to be achieved. By comparing the two studies above, a constructed wetland system may be more suitable for domestic wastewater treatment system since the type of wastewater typically contains lower concentration of chemical compounds and suspended solids.

Table 2.3: Chemical Composition of Wastewater after 3- and 7-days Retention Period (Valero et al., 2020)

Parameters	I_3	O_3	I_7	O_7	Removal Efficiency$_3$ (%)	Removal Efficiency$_7$ (%)	*p*-Values
pH	7.9 ± 0.1 b	7.4 ± 0.0 a	7.2 ± 0.2 a	7.4 ± 0.1 a	—	—	0.030
EC (dS m^{-1})	13.7 ± 0.9 b	11.6 ± 1.3 ab	11.0 ± 0.4 a	11.6 ± 0.4 ab	15.3	−5.6	0.019
TKN (mg L^{-1})	816 ± 12 b	737 ± 39 b	510 ± 60 a	503 ± 27 a	9.6	1.4	0.821
TP (mg L^{-1})	7.7 ± 6.8 c	1.7 ± 1.6 a	4.5 ± 2.6 b	1.7 ± 0.1 a	77.7	66.4	0.015

2.4 Types of Aquatic Plants in Constructed Wetland

To maximize the full efficiency of constructed wetlands, the bed soil of the wetland must be cultivated with plants. The plants play a big role in allowing for the treatment process to occur. Plants provide a suitable area for attachment and growth of bacteria while also stabilising the waterbed and slow down the water inflow (Shin et al., 2013). Beyond that, it also helps in the removal of nutrients that are contained in the wastewater and improve the ability of soil to absorb the nutrients during treatment process. There are several types of plants that are mainly used in constructed wetlands. The most found species of macrophytes are emergent macrophytes.

2.4.1 Emergent Macrophytes

Emergent macrophytes are a type of life form that has dominated wetlands and are separates the land from uncultivated soil and lagoons. The physical properties of the plant such as the plant tissue helps to filter the suspended solids and prevent resuspension of suspended solids (Vymazal, 2013). They also provide transportation of oxygen to the roots thank to their virtue of large internal air spaces (Nasir 2020). Some examples of emergent macrophytes are Phragmites australis (Common reed) and Typha spp. (Cattails).

2.4.2 Floating level Aquatic Macrophytes

These type of macrophytes are attached to the substratum and possess leaves that float on the water surface. They have a high diversity of species, ranging from Potamogeton natans (Pond weed) and Hydrocotyle vulgaris (Pennyworth). Nasir (2020) also stated that there are other species that freely float on the water surface such Pistia stratiote (water lettuce) and Spirodella spp. (Duckweed).

2.4.3 Submerged Aquatic Macrophytes

These types of plants are usually rooted to the bottom of the soil where their vegetative parts are predominantly submerged. Some common submerged aquatic macrophytes that can be found are E. densa (Brazilian pondweed) and V. spiralis (Eelgrass). Each type of macrophyte has its own potential to perform in different types of constructed wetlands depending on the morphology of the microphyte (Rehman et al., 2016). Table 4 shows the three types of macrophytes that are commonly used in constructed wetland systems. Emergent macrophytes can be used for all the constructed wetland systems such as horizontal flow and vertical flow. Next, floating macrophytes are generally used in free surface horizontal flow constructed wetland.

Other than that, submerged macrophytes are also used in free surface horizontal flow constructed wetland. Beyond that, the type of macrophytes that are used in constructed wetlands can also differ depending on the type of wastewater treatment that is needed to be performed. Plants can play a vital role in eliminating contaminants, supplying oxygen, increasing substrate porosity and infiltration rates, and creating an environment conducive to microbial fixation, even though they are not used in all wetlands systems. In tests comparing the elimination of pollutants from planted and non-planted wetlands, the former consistently outperformed the latter. However, according to certain research, aquatic plants do not play a substantial role in the elimination of polluted compounds (Cardinal et al., 2014).

Furthermore, constructed wetlands that contains more than one constructed wetland system can have a mix of different type of macrophytes, depending on the purpose of the wetland design (Machado et al., 2017). To summarize, emergent macrophytes are useful in filtering soil and nutrients during runoff and absorption of nutrients. Floating macrophytes have roots that will extend throughout the water basin, allowing for good filtration and reduction of residue treatment in wastewater. Submerged macrophytes that are fully grown underwater can treat the water in the basin by utilizing the nutrients for their growth. The submerged plants can intake nutrients using their leaves and roots.

Table 2.4: Type of Macrophytes Used in Constructed Wetlands (Rehman et al., 2016

Types of macrophytes	Morphology	Type of constructed wetlands
Emergent macrophytes	Extensive internal lacunar system, well developed roots buried in the soil, shoot emerged from the water surface	Free surface horizontal flow Subsurface horizontal flow Subsurface vertical flow
Floating macrophytes	Well-developed rhizome system, Buoyant leaf bases floating on water surface	Free surface horizontal flow
Submerged macrophytes	Aerenchyma, small gas pathways, thick leaves and cuticles, entire plant body submerged in water	Free surface horizontal flow

2.4.4 Plant Growth Rate in Constructed Wetlands

The plants inhabiting a constructed wetland system utilize the nutrients from wastewater treatment systems for growth. The wetland plants can absorb nutrients such as Nitrogen and Phosphorous needed for healthy growth. However, plant growth responses differently depending on the concentrations of wastewater influent that is treated in their system. Additionally, different marsh plant species have varying capacities for absorbing nutrients such as nitrogen and phosphorus from wastewater. Those regarded to be efficient at digesting nutrients exhibit quick growth rates in resource-rich situations and the capacity to concentrate luxury nutrients in their above- and below-ground biomass (Zhang et al., 2008).

Changes in biomass build-up and tissue Nitrogen and Phosphorous concentrations are believed to reflect differences in nutrient absorption and plant usage efficiency between species and developmental stages (Zhang et al., 2008). Osei et al. (2019) also stated that a variety of growth trends can be observed by different plants in the same constructed wetland environment. Their use of Cymbopogon nardus (CN) and Bambusa vulgaris (BV) in a vertical flow constructed wetland shows that both plants have different number of leaves, number of plants and plant height. The number of leaves for CN decreased from an average of 87 to 70 leaves at the end of their study period while their BV setup increased from an average of 533 leaves to 700 leaves. It shows that different types of plants respond in different ways to their respective environment. Thus, enough nutrition availability and an optimal nutrient ratio are required to encourage wetland plant development, resulting in preferential resource allocation to above-ground tissues and increasing nutrient removal in artificial wetlands. A combination of the right strength of wastewater and constructed wetland system will need to be implemented to provide a healthy environment for plant growth.

2.5 Nutrient Removal Efficiency in Wetlands

A wetland system operates very similarly when compared to a typical sewage treatment plant as both systems are used for treatment of wastewater to produce a more suitable effluent that is suitable for discharge for the environment. Wetland systems remove the harmful pollutants and nutrients in the wastewater, therefore preserving the water quality in the area. The wetland system removes the harmful nutrients and contaminants from agricultural runoff carried through its system by using its surrounding environment. The wetland system will absorb the nutrients before transferring them to the wetland plants, sediment, or atmosphere. Purdue University Cooperative Extension Service (1989) stated that nitrates can be absorbed by aquatic plants residing in the wetland system before being converted to nitrogen gas through denitrification. Other than that, ammonium can also be absorbed by aquatic plants before undergoing volatilization process. Furthermore, organic nitrogen and metals can be absorbed by the wetland system where the nutrients are deposited to the wetland bottom. The processes that happen in the wetland system prevents possible movement of contaminated water downstream. This allows for safe discharge of effluent from the wetland system without causing harm to the ecosystem surrounding the wetland.

The idea of using of natural wetland systems for biological treatment of wastewater has been explored and proven to be effective in past works. The effectiveness of wetlands in reducing the nutrient loading of Nitrogen and Phosphorous has been shared by Fisher and Acreman (2004). Data from 57 wetlands were studied and it is shown that wetlands occupying the riparian area are most likely to reduce the Nitrogen and Phosphorous loadings running through their system. Figure 2.8 shows the percentage of wetlands that exhibited nutrient reduction and nutrient retention during the study. Riparian wetlands have a higher percentage of reducing nitrogen and phosphorous species compared to swamps and marshes. These results shows that water quality in wetland systems have decreased nutrient content when treated in natural wetlands. Natural wetlands can treat the stormwater that flows throughout their system and release the effluent to the environment without affecting the environment. Mimicking the functions of a natural wetland will enable for more environmentally friendly approach to wastewater treatment compared to other existing methods.

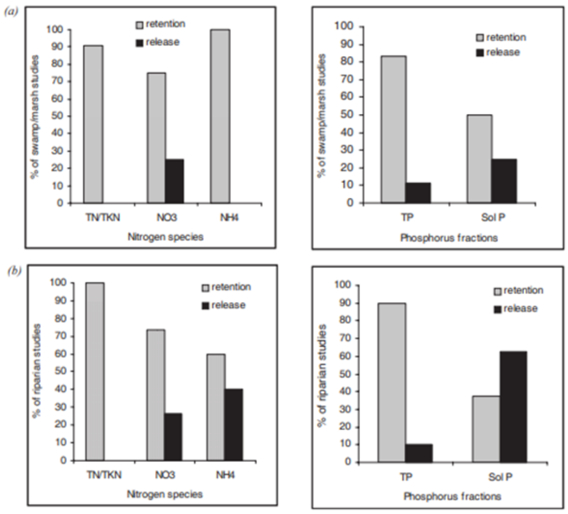

Figure 2.8: Nitrogen and Phosphorus content in Wetlands (Fisher & Acreman, 2004)

Beyond that, Sileshi et al. (2020) also conducted a similar study regarding the water quality in a wetland system. The study consists of sampling three riverine wetlands in Jimma, Ethiopia to analyse the impact of the wetlands water purifying effect. they described that the effluent from the wetlands have reduced concentrations of TN and TP. Beyond that, it also shows decreased organic loads after joining the wetland. Sileshi et al (2020) concluded that "therefore, this study suggested that when the influents are marginally polluted the natural riverine wetlands can serve as natural treatment systems without affecting their ecological quality." (p.11). Therefore, water quality in wetland systems can be concluded to be safe for the environment in terms of their nutrient loadings and other measured parameters.

2.6 Peat Soil Application in Wetland System

Peat soils can be found in various parts of the world in environments known as peatlands. It was estimated that peatlands cover approximately 4.23 million km2 of the earth, or 2.84% of the global total land area (Xu et al., 2018). Furthermore, the existence of peatlands provides many benefits to the environment surrounding it. Peatlands, as a component of an ecosystem, serve a variety of functions, including economic, hydrological, environmental, and biodiversity. One of the uses for peatlands from an environmental standpoint is that it serves as a carbon sink. Natural peatlands obtain peat from decomposing plant material, eliminating CO_2 from the atmosphere while also degrading dead plant material under anaerobic circumstances, resulting in methane (CH_4) emissions with a greenhouse gas (GHG) effect around 30 times that of CO_2 (Humpenöder et al., 2020). This indicates that peat soil can serve as a suitable environment for maintaining healthy plant growth and reducing the carbon levels of their surrounding area, thus keeping the environment healthy.

2.7 Summary

Thorough reviews have been done on peat soil for better understanding of the study. Topics concerning the characteristics of peat soil such as organic matter content, nutrient content and have been explored. Besides that, the different types of constructed wetland systems and their wastewater treatment efficiency were analysed alongside the type of plants that were suitable for each system. Therefore, vertical flow constructed wetland was chosen as the system that would be implemented in this study. The type of plant that would be used for the study would be floating macrophyte plant (Eichhornia crassipes). Removal efficiencies of nutrients and parameters such as chemical oxygen demand (COD), nitrogen, phosphorous, turbidity, and nitrate were investigated in this study.

CHAPTER 3
METHODOLOGY

3.1 Introduction

To determine the suitability of constructed wetland system for peat soil restoration and the suitability of integrating peat soil within the constructed wetland, the approach that was taken for this project was to construct small scale models of the constructed wetland system. Figure 3.1 shows the flowchart of the project regarding on the procedure that will be followed during the duration of the study. The steps were listed out after further understanding of the problem statement and objectives of the study. The steps that were involved in the methodology of the project was the collection and characterization of the peat soil, macrophyte, stormwater sample, cultivation of aquatic macrophyte, construction of VCFW wetland system, sampling and analysis of water qualities and plant characteristics, data interpretation and report writing.

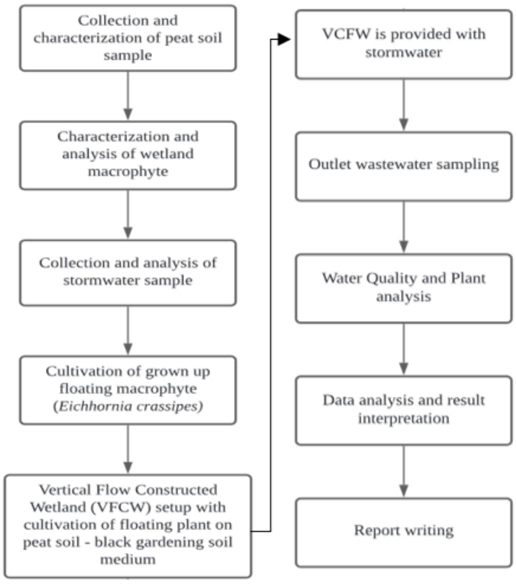

Figure 3.1: Project Flowchart

3.2 Collection and Characterization of Peat Soil sample, Plant species and Stormwater Sample

3.2.1 Collection and characterization of Peat Soil

The peat soil samples that were used for this experiment was bought at a wholesale plant nursery in Ipoh, Perak. The peat soil samples were very soft and spongy, showing early indications that it is fibrous peat. To obtain further information on the condition of the soil, Von Post test was conducted to evaluate the texture of the peat soil. The test involved the squeezing of peat soil sample and conducting assessment on the soil that was protruding between the fingers. Based on the initial assessment, the soil is classified as belonging to one of the (H1-H10) humification or decomposition categories. The peat soil was also mixed with black gardening soil as shown in Figure 3.2 with a 1:1 ratio to provide more strength to the peat soil. Testing for condition of peat soil was also done after project duration to analyse the differences.

Figure 3.2: Peat Soil – Black Gardening Soil Mixture

3.2.2 Characterization of Wetland Plant Species

The macrophytes used for this study is Eichhornia crassipes, more commonly known as a water hyacinth. It is a free floating macrophyte and typical length is 9 cm. Figure 3.1 shows the water hyacinth that was used for the experiment. The length of the stem of the plants ranges from 20cm to 45cm. The plants used for the study were collected from the bank of the lake located in Oval Park, Universiti Teknologi Petronas (UTP).

Figure 3.3: *Eichhornia crassipes*

3.2.3 Collection of Stormwater Sample

Due to the limitations in sourcing treated wastewater effluent, stormwater sample was used for the project. The stormwater sample was collected from the lake that is in Oval Park, Universiti Teknologi Petronas (UTP). Samples were collected using 20L jerry cans from the lake. The samples were then tested for their TP, TN, and nitrate, BOD, and COD content before using it for the project.

3.2.4 Cultivation of Aquatic Plants

The emergent macrophyte used for the experiment, Eichhornia crassipes were initially cultivated in a basin where it is placed in a water medium that is filled with gardening soil. The macrophytes were cultivated for a week prior to the construction of the constructed wetland for the project.

3.3 Constructed Wetland setup

The construction of wetland system will be dependent on the type of flow that will be used for this study. Therefore, it was identified that vertical flow constructed wetland (VFCW) system will be used for the project. The use of the VFCW system ensures that water sample can be treated effectively by the emergent plant and its ecosystem and maximize the treatment capability of the constructed wetland. The emergent plant, Pontederia crassipes is cultivated on peat soil in a small-scale vertical flow constructed wetland system. There are four different pilot VFCW models that were setup for the project, each with different levels of peat soil used in their system where 10cm, 20cm, and 25cm of peat soil are used. The peat soil also has a mixture of black gardening soil to improve the quality of peat soil. One VFCW system was setup by only using 25cm of peat soil without any mixture of gardening soil to evaluate the performance of natural peat soil without plant ecosystem.

The wetland system is made in a cylinder tank as shown in Figure 3.5 where the outlet is located on the bottom of the tank, allowing the stormwater sample to flow through the wetland system. The dimension of the tank is 21cm x 32cm. The base of the wetland system consists of coarse aggregates with a nominal size of 20mm which allows the peat soil to settle in without being washed away. The depth of aggregates used for all the models are 15cm. On top of that, a wire mesh netting was also placed on top of the coarse aggregates. After placement of peat soil above the gravel, distilled water is poured into the wetland system to allow the soil to settle in before it is drained out and replaced with stormwater sample. Wastewater is charged directly into the VFCW with a hydraulic retention time of 3 days. The outlet of the tank is connected to a stopcock valve by using 0.5-inch polyvinyl chloride (PVC) pipes where the outlet flow can be controlled when stormwater sample is needed to be collected. Figure 3.4 shows the schematic diagram of the experimental set-up.

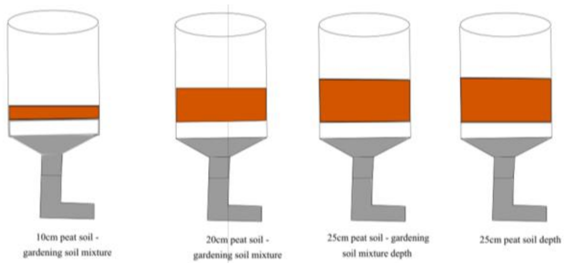

Figure 3.4: Schematic diagram of constructed wetland setup

Figure 3.5: VFCW Setup

3.4 Water Quality Analysis

Sampling was performed weekly during the afternoon after the commencement of the project. Samples are taken from week 1 until week 3. The effluent from the VFCW was collected by opening the valve that is connected to the VFCW. The valve is opened for 10 minutes to let water flow before collection. Then, the samples are collected using 1-L plastic bottles for each VFCW. The water quality parameters that were measured for the water sample are TN, TP, nitrate, BOD, and COD. All measurements were measured in unfiltered samples from the VCFW systems.

3.4.1 Total Nitrogen Analysis

The TN content of the water sample were analysed using Persulfate digestion method. After collection of water sample, the sample were inserted into two HR Total Nitrogen Hydroxide Digestion Reagent vials. One of the vials contained 2mL of water sample while the other one contains 2mL of deionized water. Both vials were mixed with Total Nitrogen Persulfate Reagent Powder Pillow. Both vials were shaken vigorously for 30 seconds before being placed into DRB200 reactor and heated for 30 minutes with a temperature of 105˚C. After being cooled to room temperature, TN Reagent A Powder Pillow was added into both vials and shaken for 15 seconds until three minutes observation time begins. Then, TN Reagent B powder Pillow was added into both vials and a two-minute observation time was observed after both vials are shaken for 15 seconds. 2mL sample for both vials were then added to two Tn Reagent C vials before 5 minutes observation time is observed until the colour of the solution in the vials change as shown in Figure 3.6. The vials were then measured using spectrophotometer for TN content.

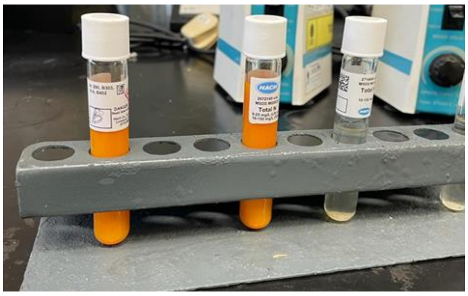

Figure 3.6: TN Vials

3.4.2 Total Phosphorus Analysis

The TP method used was adapted from Hach Company method. 5mL of sample is added to a Total and Acid Hydrolyzable Test Vial alongside one Potassium Persulfate Powder Pillow for Phosphonate. The vial is then shaken until it is dissolved before being placed into a DRB200 reactor and heated for 30 minutes at a temperature of 150˚C. After being cooled to room temperature, 2mL of 1.54N Sodium Hydroxide Standard Solution is added to the vial. The vial is then placed into the spectrophotometer and zero measurement was taken. PhosVer 3 Powder Pillow is added to the vial and mixed for 30 seconds before a two-minute reaction time is observed. The vial is then measured for TP content in the spectrophotometer. Figure X shows the simplified procedure for the analysis of TP.

3.4.3 Nitrate Measurement Analysis

The nitrate method used was adapted from Hach Company (2019). Ten millilitres of sample should be placed in a square sample. Combine the contents of one Nitra Ver 5 Nitrate Reagent Powder Pillow Stopper with the contents of one Nitra Ver 5 Nitrate Reagent Powder Pillow Stopper. For 1 minute, forcefully shake cell. Observe the five-minute reaction time. Fill the second square sample compartment with 10mL of sample to create a blank. After wiping the blank, slide it into the cell holder with the fill line pointing right. Then, with the fill line pointing right, place the prepared sample cell into the cell holder and run the programme in the spectrophotometer to retrieve the results.

3.4.4 BOD measurement Analysis

Five sample volumes will be determined prior to gently stirring the material in a beaker. Five 300-mL BOD bottles are filled with the sample volumes. Each bottle will be filled with prepared dilution water. Each bottle is sealed with a stopper and then flipped numerous times to mix it. A 300mL BOD container will be filled with prepared dilution water to prepare the blank. Before inserting the probe into the blank, it is rinsed with deionized water. When the value is stable, the progress bar will be used to determine the value. Rinse the probe with deionized water. Each prepared sample bottle will have a stopper inserted before being sealed with dilution water and sealed with a bottle cap. For each prepared sample, the preceding processes are repeated. Before placing prepared sample bottles in a 20°C incubator, the probe is cleaned with deionized water. After five days, the remaining dissolved oxygen is measured and used to calculate the BOD value (Hach Company, 2021).

3.4.5 COD Analysis

Reactor digestion method will be used for the analysis of COD in water sample. A sample volume of 100mL is added to a 250mL beaker and agitated. The DRB200 reactor has been pre-heated. Two millilitres of sample and two millilitres of ionised water are poured into the vial. The vial is shaken and then inserted into the DRB200 Reactor. The vial is heated for two hours and then cooled for twenty minutes before being placed in the tube rack. The cell holder is inserted with a blank sample cell. The prepared sample cell is then inserted into the cell holder. The COD reading will be taken (Hach Company, 2021).

3.5 Plant Growth and Nutrient Analysis

The plant growth rate of the macrophytes was also measured during the period of the study. The method of obtaining the growth rate is by measuring the number of offshoots that grew during the duration of the study. The final values will be compared with the initial values to compare the growth rate of the plants in different soil depth. The physical appearance of the macrophyte was also observed during the duration of the project. Beyond that, nitrogen and phosphorous for plant tissue is also needed to be done before commencement of project. Equation 2 shows the calculation method used to determine plant growth.

Plant growth = Final offshoot value – Initial offshoot value Eq 2

3.5.1 Total Phosphorous

The method used to find the Phosphorous content in plant tissue is by using colorimetry. The procedure follows the methods described by Plank (1992). In 150-mL beakers or 50-mL porcelain crucibles, weigh 1 g + 500μg of dried and powdered plant tissue. Samples are digested using either the wet oxidation or the dry ashing procedures. Transfer samples quantitatively into 100-mL volumetric flasks and dilution with distilled water. Dilute the samples and the 20, 40, 60, and 80 mg P L standards 1:100 with the working solution using a dilutor-dispenser. Allow at least 30 minutes for colour to develop before reading. A visible spectrophotometer is used to determine the concentration at 660 nm.

3.5.2 Total Nitrogen

In a Kjeldahl digestion tube, place the sample (weight depends on the nitrogen content) or standard and add 1.1 g of salt/catalyst combination. With each batch of samples, digest blanks containing only reagents. Add 3 mL concentrated H2SO4 to the mixture. Slowly bring to a temperature of 200oC. After the frothing subsides, increase the temperature to 350–375°C and continue heating until the digest clears. Continue digesting at 350 to 375 degrees Celsius for a further 35 minutes to 1 hour after clearing. Allow the digest to cool slightly before adding 20 mL deionized water. If the digest has solidified, it is critical to agitate the contents of the tube using a vortex mixer to dissolve the solid. In a 50-mL flask, add 5 mL of H3BO3 indicator solution and set the flask beneath the condenser, with the condenser tube below the indicator solution's surface. To the digested sample, add 20 mL of 10 M NaOH. Transfer the tube immediately to the Kjeldahl distillation device and begin distilling. Collect distillate until it reaches roughly 35 mL in the H3BO3 flask, which normally takes 12 minutes (Plank, 1992). Figure 3.7 shows the overall flowchart of water quality analysis and plant analysis parameters that were tested.

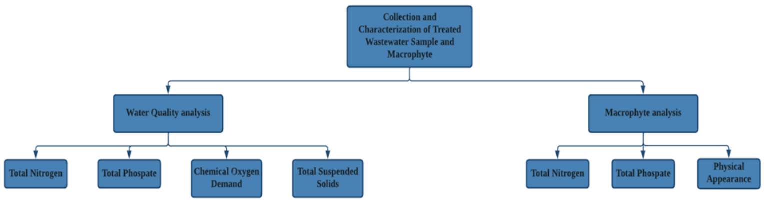

Figure 3.7: Overall flowchart of water quality and plant analysis

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Characteristics of the Stormwater

As mentioned before, the stormwater that was used for this project is collected directly from the lake. The water that discharges into the lake may have come from all different sources such as stormwater from the surrounding buildings and surrounding commercial buildings outside of UTP. Therefore, the parameters of the influent needs to be analysed before conducting to determine the level of contamination of the stormwater sample. Table 4.1 shows the water quality parameters of the influent. The data that is provided was measured prior to the project commencement and unfiltered and as raw as possible. The results showed that there is a high content of nitrogen in the stormwater sample. This may be attributed to the decomposition of proteins and organic matter in stormwater. It could also be caused by the presence of nitrogen from yard waste and urea, which is commonly found in fertilizers (United States Environmental Protection Agency, 2021). When compared to other similar studies, TN values on an urban lake analysed during a study conducted by Natarajan et al. (2018) were as high as 6.167 mg/L while Xu et al. (2017) stated having values ranging from 13 mg/L to 14 mg/L in urban stormwater. The difference in values may be influenced by big catchment area which the stormwater sample was collected from, causing for high nitrogen content.

Table 4.1: Characteristics of Stormwater Influent

Parameters	Values	Units
TP	7.8~~3~~	mg/L
TN	115.0	mg/L
Nitrate	10~~.0~~	mg/L
COD	432.0	mg/L
Turbidity~~BOD~~	~~12~~.065	~~mg/L~~NTU

4.2 Characterization of Peat soil

4.2.1 Moisture Content

Table 4.2 shows the three samples of peat soil placed in crucibles were used to determine the moisture content of peat soil with water content values of 351%, 289%, and 497% and has a mean average of 379%.. The difference in moisture content from each crucible indicates that the peat soil used for the study is a mixture of peat soil from different depths. The moisture content of peat soil depends on the depth of the ground water table, therefore the peat soil have different depending on the depth of soil it was collected from. The mean average of peat soil could also indicate that the peat soil was taken from a specific depth according to the water table of the area it was collected form. Shien et al., (2011) also found similar values in peat soil moisture content, showing values ranging from 300% to 600% for peat soil sample collected from Matang, Sarawak.

Table 4.2: Moisture content of peat soil

No	Weight of crucible (g)	Weight of crucible with moist soil (g)	Weight of crucible with dry soil (g)	Mass of soil solids (g)	Mass of pore water (g)	Water content, w (%)
1	68.79	130.13	82.4	13.61	47.73	351
2	65.96	122.27	80.45	14.49	41.82	289
3	54.16	101.89	62.15	7.99	39.74	497

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4.2.2 Organic Matter Content

The organic matter content of the soil was calculated using Loss on Ignition (LOI) method. The first sample from the moisture content calculation was used to determine the organic matter content of the peat soil. Results from Table 4.3 indicate that the organic matter content of the peat soil is 69%. The high percentage of organic matter in peat soil is expected as peat soils contain high amounts of decomposed organic matter originating from plants and animals. However, organic matter content of peat soil can be affected by the humification level, therefore the soil organic matter depends on the different factors that affect humification such as the temperature and weather (Teong et al., 2016). This also increases the accumulation of carbon in peat soil, making it a very good carbon sink.

Table 4.3: Organic matter content of Peat Soil

Weight of dry soil (g)	Weight of burned soil (g)	Inorganic content (%)	Organic content (%)
13.61	4.2	31	69

4.2.3 Phosphorous Content

The phosphorous content of peat soil obtained from TP measurement is 7.9 mg/L. The results show that the phosphorous content is high in peat soils, which is typical for drained peat samples. The high phosphorous content may also be attributed to the use of fertilizers and organic compost materials such as manure that can increase its content percentage. It could also be state that the peat soils have been used for agriculture purposes which increase the phosphorous content. The peat soil sample used in this study could also originate from phosphorous sink in peatlands where phosphorous is not recycled in its soil system.

4.3 Nutrient Removal Efficiency for Stormwater

The nutrient removal efficiency of the VFCW was measured based on the initial concentration of stormwater influent that was collected and analysed before treatment process. Due to the time constraints, only sample collected from the first week until the third week were analysed. Results obtained from the characterization of the VFCW effluent showed that some of the nutrient and total suspended solids concentration from the stormwater influent were reduced.

4.3.1 Total Nitrogen (TN)

The concentrations of nitrogen in stormwater after treatment through VFCW are shown in Figure 4.1. The total nitrogen concentration of VFCW with soil depths of 10cm, 20cm, 25cm, and the control showed an increase in nitrogen concentration from the influent which is 115mg/L as shown in Table 4.4. The high increase in nitrogen concentration can be attributed to a lot of factors such as little amounts of dissolved oxygen. The amount of dissolved oxygen present in the constructed wetland affects the nitrification rate needed to consume the nitrogen compounds, as the bacteria growth rate can decrease with less amounts of dissolved oxygen (Trygar, 2009). The oxygen not evenly spread around the VFCW would cause for little nitrification reaction. The presence of acidic peat soil could also be the factor that affects lack of nitrification. Nitrification rates slows down in acidic soils, therefore it could result in high amounts of unoxidized nitrogen (International Plant Nutrition Institute, 2013). Without nitrification, denitrification process will not occur as not enough nitrate concentration levels are available for the process to happen. Therefore, the VFCW system was not able to oxidize the inorganic nitrogen and the nitrogen levels increase with added effluent into the VFCW.

Table 4.4: Nitrogen concentration of effluent

Soil depth	Week 1	Week 2	Week 3	increase (%)
10cm	221	410	582	506
20cm	250	472	591	514
25cm	166	311	479	417
Control (25cm)	332	525	786	683

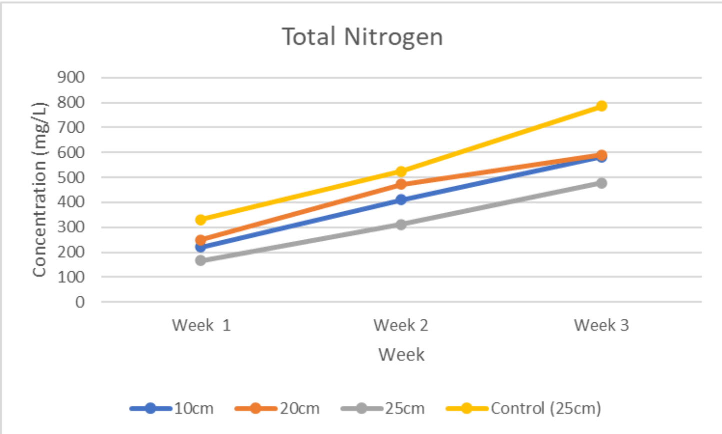

Figure 4.1: Nitrogen increase rate

4.3.2 Total Phosphorous (TP)

The effluent samples for TP removal efficiency show mixed results. The removal efficiency for VFCW with 10cm and 20cm shown in Table 4.5 were 54% and 33% respectively. However, the concentration of TP in VFCW with 25cm soil depth and the control had an increase in phosphorous content. The reasoning for this occurrence can be caused by the initial high concentration of stormwater and phosphorous from plant demineralization and peat soil content. Leaching of soil from the constructed wetland system may have caused the nutrients to leak through the effluent, thus increasing phosphorous concentration in effluent and reducing the phosphorous needed for plant growth. Both factors may have affected the effluent and increased the phosphorous concentration. The reduced amount of soil in 10cm and 20cm VFCW may have reduced the chance for increased contamination of phosphorous. Figure 4.2 shows the water quality analysis for Total Phosphorous.

Table 4.5: Phosphorous concentration of effluent

Depth of soil (cm)	Initial Concentration	Week 1	Week 2	Week 3	Removal Efficiency (%)
10	7.8	6.591	5.52	3.6	54
20	7.8	7.18	6.1	5.23	33
25	7.8	8.04	13.03	10.8	-38
Control	7.8	10.5	19	31	-297

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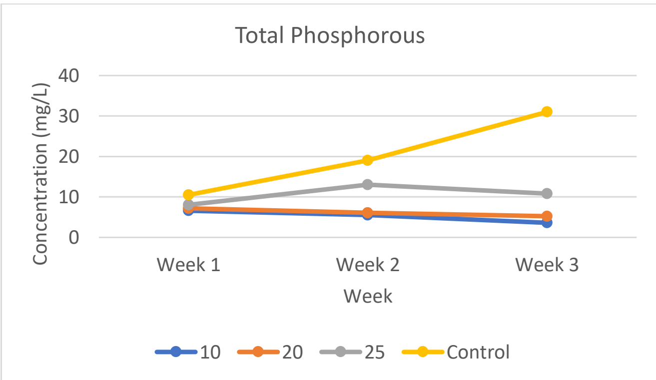

Figure 4.2: Water Quality Analysis for TP

4.3.3 Nitrate

The nitrate concentration of effluent from all constructed wetland systems shows a removal efficiency that can be observed in Table 4.6. Figure 4.3 shows that the nitrate content reduction of effluent from week 1 to week 3 was close to values from Table 4.6. The nitrate that was present in the stormwater influent may have been absorbed by the water hyacinth, as plants need nitrate for proper growth and development. The large surface area of the water hyacinth roots may have influence the absorption capabilities of nitrate. Similar results can be observed from a study by

Sharm aet al., (2014) where nitrate removal efficiency was 52.99% and Kalankesh et al., (2019) which has a nitrate reduction of 73.3% using horizontal flow constructed wetland systems planted with Lavandula latifolia (spike lavender).

Table 4.6: Nitrate concentration of effluent

Depth	Initial concentration	Nitrate (mg/L)			Removal efficiency (%)
		Week 1	Week 2	Week 3	
10	10	8	3	4	60
20	10	10	1	6	40
25	10	10	8	8	20
Control	10	5	8	5	50

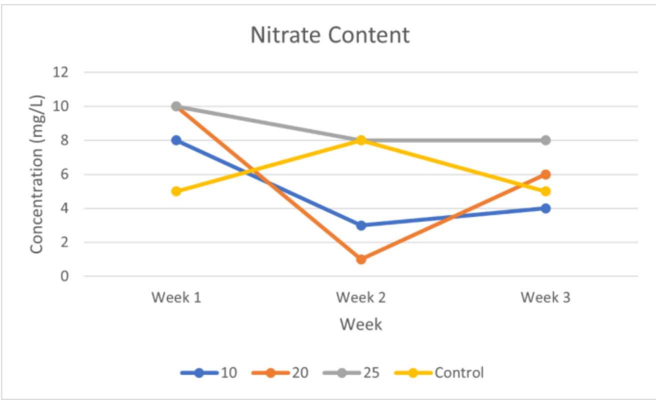

Figure 4.3: Water quality analysis for nitrate

4.3.4 Chemical Oxygen Demand (COD)

The effluent concentration for the constructed wetland shows a 51% and 54% decrease for 10cm and 20cm constructed wetland soil depth when compared to the initial concentration as shown in Table 4.7. However, Figure 4.4 shows that VFCW with 25cm soil depth and the control both showed increase in COD concentration. The number of organic materials in the system may have interfered with the concentrations of COD, causing a sharp increase. Furthermore, the combination of stormwater with high amounts of decaying plant matter from the peat soil may have increased the COD levels. The VFCW may have not be suitable for treatment of stormwater with high COD, and further treatment methods were needed to be implemented to further decrease COD levels.

Table 4.7: COD concentration of effluent

Depth	Initial COD	Week 1	Week 2	Week 3	Removal Efficiency (%)
10cm	432	395.00	296.00	210.00	51
20cm	432	335.00	249.00	200.00	54
25cm	432	737.00	1263.00	1710.00	-296
Control (25cm)	432	1548.00	2574.00	3480.00	-706

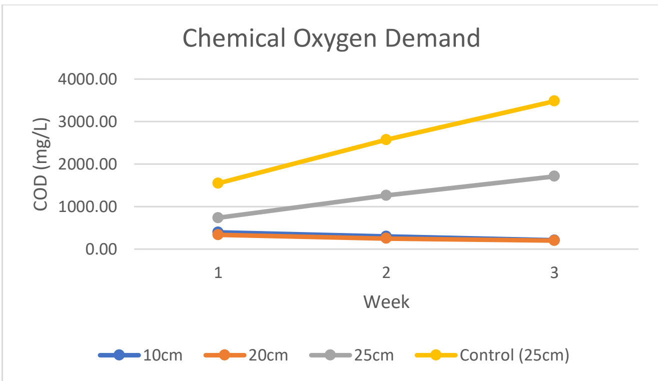

Figure 4.4: COD removal efficiency

4.3.5 Turbidity

The turbidity concentration for VFCW with 10cm and 20cm soil depth showed reductions from week 1 to week 3. However, the turbidity concentration for both 25cm soil depth and control VFCW showed increase in turbidity concentration. This can be caused by soil leaching. The soil may have leaked alongside the effluent, causing increase in turbidity concentration. The turbidity reduction efficiency of VFCW with 10cm and 20cm of soil depth in Table 4.8 showed removal efficiency of 38% and 77% respectively. The values are similar with a previous study by Sanchez et al., (2018) which had a removal efficiency ranging from 43% to 77%. Figure 4.5 shows the water quality analysis of turbidity using VFCW.

Table 4.8: Turbidity of effluent

Depth	Initial Concentration	Week			Removal Efficiency (%)
		Week 1	Week 2	Week 3	
10	65	52	45.24	40.24	38
20	65	41.6	26	15	77
25	65	1.87	18.6	101	-55
Control	65	160	305	475	-631

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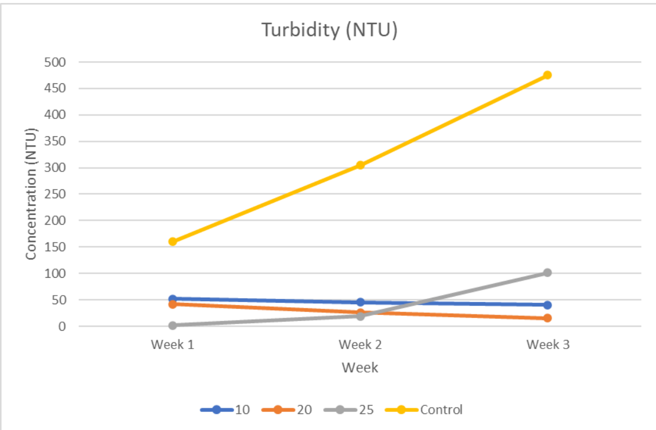

Figure 4.5: Turbidity reduction

4.4 Plant Analysis

4.4.1 Plant offshoot growth rate

The water hyacinth plant is known to be an aggressive grower that can easily multiply in numbers depending on the nutrient content of the water body it inhabits. The offshoots may propagate to inhabit other areas of the water body, thus multiplying in numbers. The number of the offshoot of the plants is measured to determine the growth rate of the plant. The initial number of offshoots for the water hyacinth were ranging from 5 to 8 for all plants while the number of offshoots that grew during the duration of the study for constructed wetland with soil depth 10cm, 20cm, 25cm and control were 29, 36, 22 and 18 respectively. It was observed that the number of offshoots were higher in constructed wetland with less soil depth compared to the others. This may suggest that less soil matter allowed for better growth of roots and more efficient absorption of nutrients. Furthermore, the plant also doubled itself for all VFCW systems in three weeks, indicating that the stormwater sample has nutrient contents that are adequate for the propagation of new plant.

4.5 Summary

The parameters that have been tested for the stormwater influent and effluent showed reduction in nutrient content and turbidity. However, COD, phosphorous, and nitrogen all showed increase in concentration in the control VFCW. The suitability of using peat soil as the only medium for water treatment process is deemed to be not suitable. The initial concentrations of peat soil nutrient content and high strength of stormwater sample has caused increase in effluent concentrations. However, all VFCW showed capabilities in cultivating plants and sustaining a healthy environment for plant growth as the number of shoots has doubled since the beginning of the study.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This study was done to determine the feasibility of integrating peat soil into a constructed wetland system and improve its overall performance while also increasing water quality and maintain an ecosystem in a constructed wetland. Based on the analysis on the parameters from the effluent and the macrophyte used, peat soil was capable of maintaining a healthy ecosystem while also performing water treatment. The use of aquatic macrophytes has also proven to be helpful in water treatment systems, as the plants aid the peat soil in filtering and absorbing the nutrients out of the stormwater. However, certain parameters such as the nutrient and chemical oxygen demand did not met the standards for removal efficiency. Further research on peat soil characteristics and properties must be done to identify the best possible method of implementing peat soil in constructed wetland systems. The suitability of each constructed wetland system with peat soil medium should also be analysed to maximize the water treatment capabilities of peat soil. Even though peat soil does not treat all nutrients effectively, it provides a new understanding on the capabilities of peat soil as a suitable environment for plant growth and the treatment efficiency of peat soil for standard wastewater parameters.

5.2 Recommendation

The usage of different medias together with peat soil could aid the treatment process for wastewater for future studies. Further research should also be done on the land usage and design of constructed wetland to maximize its treatment capabilities. Evaluation of the strength of wastewater and stormwater used for treatment of constructed wetland would also need to be done for further understanding of constructed wetland. Different types of plants could also be cultivated in constructed wetland systems in future studies depending on their characteristics and nutrient absorbing capabilities.

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