POLLUTANT REMOVAL PERFORMANCES OF TROPICAL WETLAND PLANTS IN TREATING DOMESTIC WASTEWATER USING MESOCOSM STUDIES

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ABSTRAK

Air buangan domestik, juga dikenali sebagai kumbahan, ialah sampah yang dihasilkan dari tempat kediaman, institusi, komersial dan bangunan disebabkan oleh aktiviti manusia. *Constructed wetlands* telah disarankan sebagai penyelesaian alternatif kepada sistem rawatan kumbahan konvensional yang lain untuk merawat air sisa dengan kandungan nutrien yang tinggi kerana ciri-ciri kos efektif, mesra alam dan lestari. Prestasi *constructed wetlands* bergantung pada reka bentuk alirannya, tumbuh-tumbuhan, dan media penapis yang digunakan. Dalam kajian ini, kajian *mesocosm* untuk aliran permukaan dan bawah permukaan telah diuji kecekapan penyingkiran dari pepejal terampai (TSS), jumlah nitrogen (TN) dan jumlah fosforus (TP). Sebanyak 12 *mesocosms* ditanam dengan *Bacopa Caroliniana* (bacopa), *Eichhornia crassipes* (keladi bunting), dan *Salvinia auriculata* (pakis lumut air) dan kawalan tanpa tumbuhan digunakan dalam kajian ini. Tanaman tersebut dipilih kerana mempunyai ciri tumbesaran yang cepat, kemampuan menyesuaikan diri dengan pelbagai keadaan persekitaran dan kemampuan pengambilan nutrien yang tinggi. Setelah diperhatikan, *Salvinia auriculata* (pakis lumut air) lebih efektif untuk menyingkirkan TSS dan TN, sementara *Eichhornia crassipes* (keladi bunting) berpotensi besar dalam menyingkirkan TP. Bagi perbandingan sistem, aliran bawah permukaan *constructed wetlands* lebih baik berbanding aliran permukaan *constructed wetlands*. Kesimpulannya, aliran bawah permukaan constructed wetlands yang ditanam dengan *Salvinia auriculata* dan *Eichhornia crassipes* adalah gabungan yang baik dalam merawat air sisa domestik.

ABSTRACT

Domestic wastewater, also known as sewage, is the waste produced from residential, institutional, commercial and establishments due to human activities. Constructed wetlands have been recommended as an alternative solution to other conventional sewage treatment systems to treat wastewater with high nutrients content due to its cost-effective, environmentally friendly and sustainable characteristics. The performances of constructed wetlands depend on its flow design, vegetation, and filter media used. In this study, mesocosm studies of surface and subsurface flow constructed wetland have been tested on its removal efficiency of total suspended solids (TSS), total nitrogen (TN) and total phosphorus (TP). A total of 12 mesocosms were planted with replicates of bacopa (*Bacopa Caroliniana*), water hyacinth (*Eichhornia crassipes*), watermoss fern (*Salvinia auriculata*) and a control column without vegetation were used in this study. The plants were chosen as they have a fast growth characteristic, adaptability to a wide range of environmental conditions and high nutrient uptake capacity. It was observed that watermoss fern was more effective in removing TSS and TN, while water hyacinth has significant potential in removing TP. As for system comparison, subsurface flow constructed wetlands were better compared to surface flow constructed wetlands. In conclusion, subsurface flow constructed wetlands planted with watermoss fern and water hyacinth is a good combination in treating domestic wastewater.

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NH_4	Ammonium
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
CAS	Conventional Activated Sludge
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CW	Constructed Wetland
CWS	Constructed Wetlands System
DEAMOX	Denitrifying Ammonium Oxidation (DEAMOX)
DO	Dissolved Oxygen
EA	Extended Aeration
EC	Electrical Conductivity
EU	European Union
HF	Horizontal Flow
HSSFCWS	Horizontal Subsurface Flow Constructed Wetland System
H_2S	Hydrogen Sulfide
MSMA	Urban Stormwater Management Manual
N	Nitrogen
NBS	Nature Based Solution
NEQS	National Environmental Quality Standard
NORSBR	Normal Operation Sequencing Batch Reactor
NO_3^-	Nitrate
NO_2^-	Nitrite
OM	Organic Matter
PO_4^{3-}	Orthophosphate
P	Phosphorus
PVC	Polyvinyl Chloride
RBC	Rotating Biological Contractors
SBR	Sequencing Batch Reactor

SFCWS	Surface Flow Constructed Wetland System
SSFCWS	Subsurface Flow Constructed Wetland System
STS	Septic Tank System
TDS	Total Dissolved Solids
TKN	Total Kjedahl Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSM	Total Solid Materials
TSS	Total Suspended Solids
TSSSBR	Two-stage Sequencing Batch Reactor
USM	Universiti Sains Malaysia
VF	Vertical Flow
WWTP	Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

1.1 Research Background

Domestic wastewater, also known as sewage, is the waste produced from residential, institutional, commercial and establishments due to human activities. The households waste comes typically from toilets, bathrooms, kitchen and laundry later disposed of through sewage system. Fresh sewage is a turbid grey liquid that has an earthy, however inoffensive odour. It contains various floating and suspended solids and pollutants in proper solution (Mara, 2013).

Sewage treatment is defined as a method to extract the contaminants from sewage to get a product that can be reutilized or released to the environment (Abdel-Raouf et al., 2012). Conventional activated sludge (CAS) is a common sewage treatment technology widely used. It succeeds in meeting a legal effluent quality standard where aerobic microorganism metabolizes organic fraction present in the wastewater under constant oxygen supply. However, it still unsustainable because of its low resource recovery potential and price effectiveness due to its high energy demand and enormous environmental footprint on the other (Kehrein et al., 2020). In the current situation, a transition from pollutant removal towards recourse recovery is proposed with sewage recognized as a resource rather than a waste stream.

Nature-Based Solution (NBS) was introduced as an alternative and non-traditional approach to environmental issues. In the current European Union (EU) policy context, the use of natural ecosystems as sensible solutions is promoted by several strategies (Potschin et al., 2015). Constructed wetland system (CWS) is an engineered structure designed and constructed to utilize the natural process involving wetland vegetation, soils, and related microbial assemblages to help treat wastewater (ElZein et al., 2016). Vegetation plays an essential role in CWS to treat wastewater (Sandoval et al., 2019). CWS planted with vegetation may have higher removal efficiency of nutrients than the system without vegetation (Zhu et al., 2018). Through adsorption, filtration, absorption and secretion of organic acids, complexation, oxygen transport and providing a suitable environment for microbial growth, tropical aquatic vegetation has a significant impact on the performance efficiency of CWs (Upadhyay et al., 2016).

Besides vegetation, the design of constructed wetland should also be taken into consideration. In current studies, hybrid wetland systems consist of two stages of constructed wetland such as vertical flow (VF) and horizontal flow (HF) is a more advanced operating system for the treatment of various types of wastewater, mostly in removing ammonia, nitrogen and phosphorus (Upadhyay et al., 2016). Therefore, this project focused on studying the pollutant removal efficiency of tropical wetland vegetation and the performances of constructed wetland systems under different designs.

1.2 Problem Statement

A conventional wastewater system is a typical wastewater treatment system consisting of collecting, transporting, treating, and discharging wastewater. However, construction, maintenance and repair costs, and the cost of hiring experienced personnel for precise operation, make these such an expensive technology (Mburu et al., 2013). Therefore, in a small community, three alternative methods can be implemented for wastewater treatment: alternative wastewater collection systems, engineered treatment systems, and natural treatment systems (Aydın Temel et al., 2018).

Septic tank system (STS) is one of the alternative collection systems for onsite treatment mainly found in rural areas. The pipe connection to the main sewerage network is not available or impractical (Richards et al., 2016). However, the discharge of septic tanks may increase the risk of contaminants entering groundwater and lead to the potential risk to human health and the aquatic ecosystem (Richards et al., 2017).

Constructed Wetland System (CWS) is an engineered and ecological-based wastewater treatment system low in capital, operation, maintenance and repair cost (Aydın Temel et al., 2018). However, the performance of CWS depends on the design and vegetation planted in the bed. A CWS planted with vegetation have a higher possibility of removing the efficiency of nutrients than those without vegetation (Zhu et al., 2018). In most of the past studies, the use of aquatic macrophytes in CWS has been evaluated in a temperate climate, but some species of aquatic macrophytes have not been tested in tropical regions (Caselles-Osorio et al., 2017).

The design of CWS plays an essential role in treating wastewater. There are two types of CWS: surface flow and subsurface flow (Parde et al., 2021). As such, the combination of appropriate media along with the structural design of CWS could further accelerate the removal of contaminants. Therefore, a comparison study between surface and subsurface flow should be done to determine the structure's efficiency.

1.3 Objectives

The objectives of this study are listed as follows:

a. To compare the pollutant removal efficiency between tropical wetland plants in treating domestic wastewater.

b. To evaluate pollutant removal performance of surface and subsurface flow in a constructed wetland.

1.4 Scope of Work

This study compares the pollutant removal efficiency between specific tropical wetland plants to treat domestic wastewater using mesocosm. Three types of vegetation are selected, which are Bacopa (Bacopa Caroliniana), water hyacinth (*Eichhornia Crassipes*) and watermoss fern (*Salvina Auriculata*) Bacopa (*Bacopa Caroliniana*). For each type of vegetation, there will be three replicates. The source of domestic wastewater is from the sewage manhole in Universiti Sains Malaysia Engineering Campus, Nibong Tebal, Pulau Pinang. The sewage is collected from all hostels. The period of this study is three weeks with a retention time of 48 hours in each mesocosm. The mesocosm is designed with two different outlets which are surface flow and subsurface flow. The samples are collected to test the performances between these two flows to treat the domestic wastewater. Lab testing such as total suspended solids (TSS),total nitrogen (TN) and total phosphorus (TP) are conducted to evaluate the efficiency of every vegetation.

1.5 Dissertation Outline

This study is divided into five chapters. Chapter 1 briefly introduces the study, including research background, problem statement, research objective and scope of work. Chapter 2 reviews the literature that is related to wastewater treatment which is conventional wastewater treatment and nature-based solution (constructed wetland). Flow design and past studies on vegetation used in the constructed wetland are also explained in this chapter. Chapter 3 explains the methodology used in this study, covering the wastewater characterizations, vegetation selection, and mesocosm design. The experiment procedure and water quality lab testing are also included. Chapter 4 presents the result of water quality, the performances of the mesocosm study and a discussion of the findings from the study. Chapter 5 summarizes the outcome of this study and provides practical recommendations for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Characteristics of Domestic Wastewater

Wastewater is characterized in terms of its physical, chemical and biological compositions. The composition and strength of wastewater change every hour depend on domestic water usage. Wastewater treatment is conducted to treat the products that have been produced.

2.1.1 Physical Characteristics of Domestic Wastewater

Physical characteristics of wastewater are determined by physical analysis, such as temperature, colour, odour, turbidity and total solids. Generally, the wastewater temperature is slightly higher than the water temperature and the solubility of dissolved oxygen also depends on temperature. Solid settlement is also influenced by temperature. The higher the temperature, the lower the viscosity of the sludge, in result the settlement will be better (Gaurab, 2019).

Colour is an important indicator of wastewater. Fresh wastewater is a light brownish-grey colour and it changes over the time due to increase of wastewater in collection system and more anaerobic conditions has developed. Sometimes, because of biochemical changes caused by bacteria, the colour changes from grey to black (School of PE, 2018). Therefore, an unpleasant odour develops. Hydrogen sulphide (H_2S) is the main source of odour in wastewater produced by anaerobic microorganisms that reduce sulphate to sulphide (Gaurab, 2019).

Turbidity is the cloudiness of a fluid causes by large numbers of individual particles that generally invisible to the naked eyes. If the sewage is fresher, the turbidity will be higher.

2.1.2 Chemical Characteristics of Domestic Wastewater

Chemical characteristics of wastewater consists of parameters that could not be observed, tasted, smelled or felt. Nitrogen, pH, phosphorus, chloride, sulphate, metals and organic materials such as biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are parameters that categorized as chemical characteristics.

Domestic wastewater before treatment is usually slightly alkaline (Gaurab, 2019). However, when the wastewater undergoes anaerobic process, the pH will turn slightly acidic. It is because in anaerobic process, methane (CH_4), carbon dioxide (CO_2) and H_2S are produced and cause the pH of wastewater to drop. Many wastewater treatment plants require pH to be maintained at neutral at the final effluent.

Most nitrogen excreted by humans is in the form of organic nitrogen. After going through biochemical process, organic nitrogen will slowly be converted into ammonia. Then, it will be oxidized by nitrifying bacteria. An excessive ammoniacal nitrogen can cause taste and odour problem. Total Kjedahl Nitrogen (TKN) is a combination of organic nitrogen and ammonia which is the most common form of nitrogen in wastewater. In the end of nitrification process, if content of nitrate is high, the wastewater will be oxidized (Von Sperling, 2015).

Total phosphorus (TP) could be present in organic and inorganic forms (Von Sperling, 2015). Usually, the phosphorus found in aqueous solution include orthophosphate, polyphosphate and organic phosphate. After biological decomposition, phosphorus is converted into orthophosphates. While for polyphosphate, it is used in synthetic detergent and contributed to the wastewater. Polyphosphate also can be hydrolysed to orthophosphate.

Biochemical Oxygen Demand (BOD) is an indirect measure of organic contaminant in wastewater. In BOD analysis, only organic matters that are biochemically degradable will be oxidized. Chemical Oxygen Demand (COD) is used to measure content organic matter of wastewater. COD values include oxygen demand created by both biodegradable and non-biodegradable substances (School of PE, 2018).

2.1.3 Biological Characteristics of Domestic Wastewater

In terms of biological characteristic, domestic wastewater contains various microorganisms that can be classified as protista, plants and animals. Wastewater also contains pathogenic organism which is generally originated from human infected with disease or carries a disease (Gaurab, 2019). It is usually presence in several hundred thousand to ten of million per 100ml of sample. However, some bacteria found in sewerage is non-pathogenic and helpful in oxidation and decomposing of sewerage.

2.2 Standard Treatment Process of Wastewater

As wastewater is often contaminated with physical, chemical and biological compositions, it has a major negative impact on the environment with potential to damage animal habitats and harm many ecosystems irreparably (Tee et al., 2016). Wastewater treatment procedures are aimed at improving the quality of wastewater. The main reasons for collecting and treating wastewater are to avoid disease transmission through water and to protect aquatic ecosystem (Tee et al., 2016). Physical treatment, chemical treatment and biological treatment are three primary methods that have been implemented for conventional treatment system for treating wastewater (Patel, 2018).

2.2.1 Physical Treatment

The physical composition of wastewater, such as suspended solids may contribute to the formation of sludge deposition and anaerobic conditions in the water if the untreated wastewater is discharged into the aquatic environment (Tee et al., 2016). Therefore, physical processes are used to pre-treat the wastewater. To remove solids, processes such as screening, sedimentation and skimming are used. There are no chemicals used in this process.

Aeration is also an effective physical treatment technique, where it involves pumping air through the water to provide oxygen to it. Other than that, filtration of contaminants helps in removed suspended solids using special filters. Sand filter is one of the most common filters used in filtration method (Patel, 2018).

2.2.2 Chemical Treatment

Chemical treatment involved the use of chemical in the wastewater treatment. chlorine, hydrogen peroxide, sodium chlorite and sodium hypochlorite (bleach) are often specialised chemicals that are used to disinfect, sterilise and aid in the purification of wastewater at treatment plants.

Chemical coagulation, chemical precipitation, chemical oxidation and advanced oxidation, ion exchange and chemical neutralization and stabilization are all distinct chemical unit processes that can be applied to wastewater during cleaning.

2.2.3 Biological Treatment

In general, biological treatment methods depend on the activity of microorganisms to oxidize organic and inorganic matter (Marsidi et al., 2018). Biological treatment is divided into three categories: aerobic processes, anaerobic processes and composting. In aerobic process, bacteria decompose organic matter and convert it to carbon dioxide that can be used by plants and this procedure uses oxygen. Secondly, anaerobic process is a process of fermenting waste at given temperature and do not use oxygen. Next, composting is an aerobic process that treats wastewater by combining it with sawdust or other carbon sources (Patel, 2018).

2.3 Type of Wastewater Treatment

Wastewater treatment is a process where it removes contaminants until the effluent can be discharged at a level that natural system can safely tolerate. In treatment process, many facilities use activated sludge process where it requires microorganism cultivation in the wastewater under conditions that can optimize consumption of influent biodegradable organic matter (Hamilton et al., 2006). In a nationwide scale, wastewater treatment represents 0.1 to 0.3% of total energy consumption of the local city and community government (Stillwell et al., 2010).

In Malaysia, Extended Aeration (EA), Oxidation Ditch (DO), Rotating Biological Contractors (RBC), Sequencing Batch Reactors (SBR) and Tricking filters are mechanical plants that are usually applied, where Septic tanks and Imhoff tanks and other low-cost secondary system are widely used in small community (DOE Malaysia, 2009).

2.3.1 Septic Tank

Septic tank system is mostly used as a pre-treatment of domestic wastewater in a rural area (Richards et al., 2016). It has a function to separate sludge, effluent and scum layer of domestic wastewater. Septic tank is an anaerobic system that is widely used due to its simplicity, low operational cost and independency on electricity (Nasr and Mikhaeil, 2015). However, septic tank only remove 60-80% of non-soluble material in wastewater and do not accomplish a high degree of bacterial removal with only 30-50% reduction (Adhikari and Lohani, 2019).

Nasr and Mikhaeil (2015), used four types of septic tanks, which are conventional, single-baffle, two-baffle and packed type in their studies. The four types of septic tank were operated in a period of seven month and fed continuously with domestic wastewater. After time expired, it was found that the packed type of septic tank is a good choice to treat wastewater. However, further processing by a post-treatment is needed to meet environmental standards.

In other studies, two systems of modified septic tanks were designed with four chambers that were connected in series with the first three chambers were operated under anaerobic conditions and the final chamber was an aeration chamber with settling tank. One septic tank system had a suspended growth system, whereas the other one had an attached growth system. The result stated that E.coli does not comply with the Jordanian regulations, hence tertiary treatment is recommended (Abbassi et al., 2018).

Haydar et al. (2018), designed a modified septic tank without pre-settling to treat domestic wastewater in the first run. For second run, perforated plates were installed between the baffles (Figure 2.1). It was found that second run is more efficient where the temperature effect its efficiency and at 48 hours of detention, the treated effluent meets the National Environmental Quality Standard (NEQS). However, the case of a 48-hour detention period, the footprint is larger, thus the cost was higher and further study is needed.

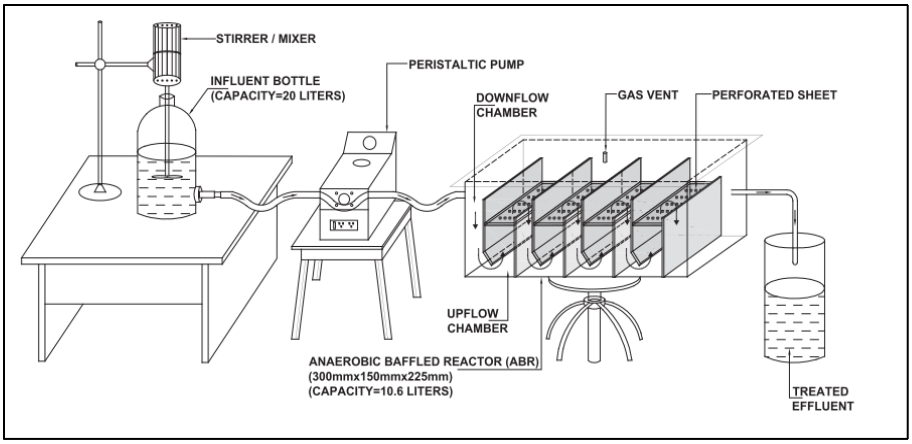

Figure 2.1: The Bench Scale Setup for Second Run

Singh et al. (2019), conducted a more detail study of conventional three-chamber septic tanks by design and upgrade into four-chamber septic tanks. From the result, the efficiency of modified septic tanks was proved by the higher removal rates of chemical and biological oxygen demand. It was concluded that traditional septic tanks are insufficient for efficiently store and treat sewage. Therefore, septic tank performance and life cycle could be improved with more research on pre-treatment of sewage.

2.3.2 Sequence Batch Reactor

Sequence batch reactor (SBR) is a popular technology during 1914-1920. However, during its starting period, it was used by small communities for their sewerage treatment and for high strength industrial waste treatment (Dutta and Sarkar, 2015). In the present, SBR has been utilized not only for sewerage treatment but also used in biological treatment for industrial wastewater that contain difficult-to-treat organic materials due to its upgraded process. SBR is a type of activated sludge processes that compromise a sequence of stages that operate in one tank following the time sequence (Alattabi et al., 2017).

Alattabi et al. (2017), studied on a two-stage settling sequencing batch reactor to improve sludge settleability. In this study, four Plexiglas reactors were used and air was supplied inside each reactor to produce fine air bubbles and overhead stirred was used to achieve anoxic stages. The first reactor was used to evaluate a normal operation sequencing batch reactor (NORSBR) and the second reactor for two-stage settle sequencing batch reactor (TSSSBR). The result showed that two-stage settle sequencing batch reactor improved the sludge settleability and enhanced nitrogen compound removal efficiency.

Simultaneous nitrification, denitrification and phosphorus removal in a sequencing batch reactor was studied by (Li et al., 2019). This simultaneous nitrification, denitrification and phosphorus removal showed an excellent performance and high in removal in TN and TP. However, based on the high efficiency of phosphorus removal in this study, *Propionibibrio* genus in phosphorus removal at low temperature need a further study to reveal its roles.

Du et al. (2017), evaluated a system that simultaneously treat domestic wastewater and nitrate sewage in sequencing batch reactor that called denitrifying ammonium oxidation (DEAMOX) (Figure 2.2). It consists of four stages where the first 5 minutes is feeding the reactor with wastewater and for the next 6 hours is anaerobic reaction process with a magnetic mixing. After that, the treated wastewater will be settling and discharge. This paper highlighted that a regular maintenance for superficial sludge was necessary to maintain the stable performances of this system.

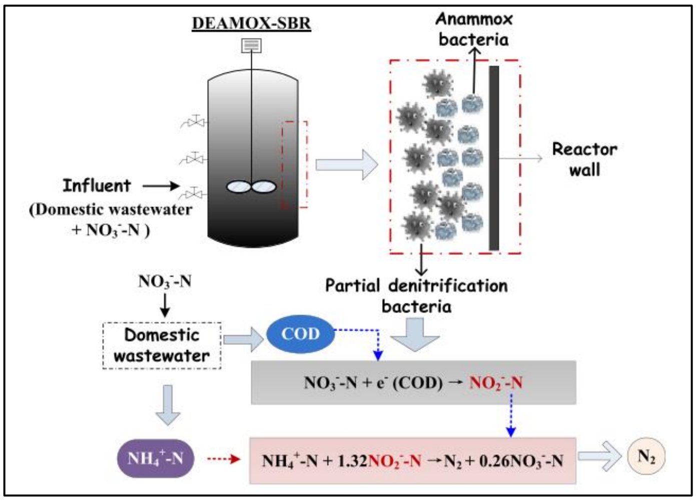

Figure 2.2: The Schematic Diagram DEAMOX-SBR System

Sequence batch reactor system could be expensive in providing aeration during the treatment and the cleaning schedules also may requires the use of more than treatment unit. Monitoring and operating expertise are required to manage the reactor in a way that achieves the intended treatment results (Julien, 2005). As a result, choosing low-cost and efficient alternative wastewater treatment technologies is necessary, particularly in developing regions. CWS are getting a lot of attention as a viable option for treating wastewater for its low cost, ease of operation and low maintenance requirements (Wu et al., 2015)

2.3.3 Nature-Based Solution (NBS)

Nature-based solutions (NBS) involved in operating with nature to handle social challenges, providing advantages for each human-being and biodiversity. It has been widely introduced in European cities in the past few years as a solution for urban challenges such as climate change, urban degradation and aging infrastructure (Frantzeskaki, 2019).

Different types of NBS have been applied in the world such as constructed wetland system (CWS), green roofs, green walls and urban green spaces. By implementing NBS, it helps in reducing flood risk, save energy and hence contributes in sustainable economic growth (Boano et al., 2020). However, CWS are one of the most popular NBS that had been implemented especially in treating domestic wastewater for more than four decades (Haddis et al., 2020).

2.4 Constructed Wetland System (CWS)

Constructed Wetland system (CWS) are an engineered systems that are designed and constructed as a natural processes that treat wastewater where it involves vegetation, soils and associated microbial assemblages (ElZein et al., 2016). In this system, pollutant removal occurred through complex physical, chemical and biological processes (Kadlec and Wallace, 2008), where different types of microorganisms intervene. CWS is an affordable, reliable, cost-effective of operation, simple in design and environmentally friendly (Jehawi et al., 2020).

The efficiency of CWS is depending on their selection of vegetation and filter media. For Malaysia, wetlands are listed as one of the best management practices (BMPs) to treat stormwater. There is a manual from department of irrigation and drainage which is urban stormwater management manual (MSMA) as a guideline for removing dissolved pollutant from stormwater. However, there are no proper guidelines for selection of media and vegetation used in constructed wetland for treating domestic wastewater (Parde et al., 2021).

2.4.1 Filter Media

Filter media in CWS is beneficial for the accumulation of organic matter, phosphorus, sulphate, arsenate and removal of pathogens (Parde et al., 2021). Filter media also offers the existence of both aerobic and anaerobic pores inside the matrix to boost de-nitrification, nitrification and providing an internal carbon source to reduce the reliance of de-nitrification metabolism on the carbon available in wastewater (Khalifa et al., 2020).

The used of filter media in CWS is essential to differentiate between constructed and natural wetland. There are various types of filter media can be used in CWS such as sugar bagasse, marble chips, iron powder, Sylhet sand, soil, biochar of rice husk, coco-peat, cupola slag, recycled bricks, stones, lightweight expanded clay aggregate, gravels, sand, sawdust, coal, zero-valent iron, etc. (Parde et al., 2021).

Usually, gravel substrate that used as a filter media in treatment process of wetland provide neither carbon nor necessary aerobic conditions, therefore their capabilities in reduction of pollutants is very limited. On the other hand, other substrates that are used in wetland's media such as minerals, marine sediments, soils, rock, synthetic materials and industrial by-product more focus on improving nutrients removal rather than reducing clogging potentials (Khalifa et al., 2020). A long term purification of phosphorus is by utilizing sand as a filter media and sand amended with mud and wastewater residuals were found in improving phosphorus removal from secondary effluent of sewage (de Rozari et al., 2016).

From a study of three different quartz sand filter media packing strategies, which are increasing-sized (I-packing), decreasing-sized (D-packing) and uniform-sized (U-packing) packing. It was shown that I-packing reactors presented an aerobic-to-anoxic transition area for efficient total nitrogen removal, while D-packing and U-packing reactors do not appear to be efficient for both nitrification and denitrification. I-packing also suitable for long term wastewater treatment (Song et al., 2015). A study on up-flow constructed wetland with three different filter media consists of sand, zeolite and volcanic cinder found that performance of zeolite as filter media contributes into a higher treatment efficiency compared to sand and volcanic cinder, because of its greater basic surface area, different framework structure and porous composition (Yakar et al., 2018).

In other study, a CWS filled with combination of gravel-sand-gravel as media to treat wastewater for small communities. The media were arranged with 10-15 mm diameter of gravel, 3-5 mm diameter of river sand and 30-35 mm diameter of gravel from top to the bottom layer for depth of 40 cm. It was found the combination of filter media and helps of planted vegetation in CWS achieved pollutant removal efficiency more that 70.0% (Jehawi et al., 2020).

According to Abdelhakeem et al.(2016), gravel is the most widely used as media in CWS. It was also stated that soil and sand mixture in constructed wetland contributes to higher removal efficiency of the pollutants. Gravel based in constructed wetland present higher macro porosity and less exposed to clogging. (Qasaimeh et al., 2015), stated that soil with low permeability is most common component of wetland bottom sediment. Its particle are colloids with high specific surface area that affect soil adsorption properties.

It can be concluded that, combination of common filter media such as gravel and soils can contributed to a higher pollutant removal efficiency with the help of vegetation planted in CWS.

2.4.2 Vegetation

Vegetation in CWS has played an important role in treating domestic wastewater. The plants in CWS uptake and filter pollutants through their roots into their above and below ground biomass, and prevent filter media from being clogged (Khalifa et al., 2020). According to Abdelhakeem et al. (2016), plants increase the system performance by providing a suitable environment for microbial population growth and oxygenating the system. Nitrogen (N), Phosphorus (P) and other pollutants are mainly taken up by wetland plants through epidermis and vascular bundles of the roots and further transported upward to stem and leave. Microorganisms live in plant roots because they provide a source of microbial attachment and release exudates, a carbon excretion that contributes to denitrification process, which improves the removal of contaminants in anoxic conditions (Sandoval et al., 2019).

In typical constructed wetlands, the macrophytes can be divided into few groups, namely emergent plants, floating leave macrophytes, submerged plants and freely floating macrophytes (Almuktar et al., 2018) (Figure 2.3). Emergent macrophytes are recognized for their ability to support substrate and usually found above water surface. *Iris spp., Juncus spp.,* and *Eleocharis spp.* are typical examples of emergent macrophytes (Wu et al., 2015). For floating leave macrophytes, they are fixed in the saturated substrate with water depth of 0.5 to 3.0m. *Kuntze*, *Trapa bispinosa Roxb*., and *Marsilea quadrifolia* L. plants are some of floating leave macrophytes that had been used in wetlands (Almuktar et al., 2018). Submerged plants needed an aerated water for their growth. Wu et al. (2015) stated that *Myriophyllum spicatum L., Ceratophyllum demersum L., Hydrilla verticillate* (L.f) Royle, *Vallisneria natans* (Lour.) H. Hara and *Potamogeton crispus* L. are typical species that categorized as submerged plants. Free floating plants have an ability to remove nitrogen and phosphorus through denitrification process. *Eichhornia crassipes* one of the free-floating plant that commonly used (Almuktar et al., 2018).

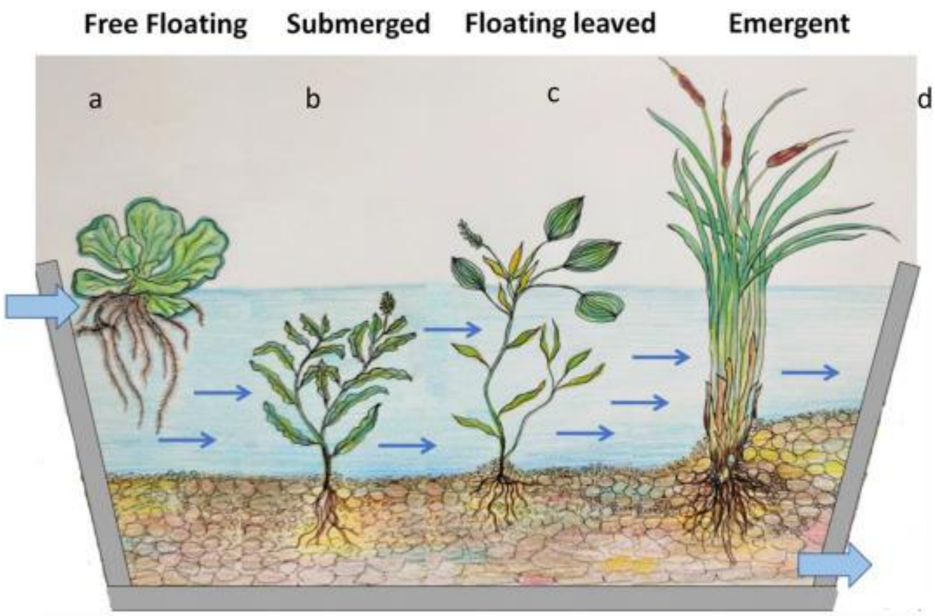

Figure 2.3: Group Type of Macrophytes for Constructed Wetlands (Kataki et al., 2021)

A study conducted by Valipour et al. (2015) revealed that the effectiveness of bio-hedge water hyacinth wetland system in treatment of domestic wastewater. Because of its rapid growth rate and extensive root system, the water hyacinth (*Eichhornia crassipes*) appears to be a promising candidate for pollutant removal among free-floating species. A high nitrogen and phosphorus accumulation in the plant, combined with high productivity and no anatomical changes, water hyacinth may be a viable macrophyte in phytoremediation phase. Water hyacinth acts as a horizontal trickling filter, with submerged roots providing physical support for the growth of bio-film bacteria. Bio-hedge provide a large surface area for the microbial community to adhere and expand on.

In another study, Sandoval et al. (2019) found that Canna, Iris, Heliconia and Zantedeschia were the four most widely used flowering ornamental vegetation genera. Canna spp. is commonly used in Asia, Zantedeschia spp. is popular in Mexico, Iris most used in Asia, Europe and North America and Heliconia spp. commonly used in Asia and parts of the Americas. However, a further studies of ornamental flower plants should be conducted in tropical and subtropical regions since it has a good contaminants removal efficiency in past studies. Table 2.1 showed the summary of vegetation used in previous study.

Table 2.1: Summary of Vegetation Used for Constructed Wetland in Previous Study

Type of Wastewater	Vegetation Category	Species	Removal Efficiency (%)			Reference
			TSS	TN	TP	
Domestic	Emergent	*Typha latifolia*	-	65	82	(Yang et al., 2007)
		Phragmites australis		76	90	
		Canna indica	-	76	85	
		Phragmites karka	-	65	85	
Domestic	Freely floating plants	*Eichhornia crassipes*	65	70	31	(Valipour et al., 2015)
Domestic	Emergent	*Canna* spp.	84	88	90	(Sandoval et al., 2019)
Sewage		*Zantedeschia* spp.	-	53	60	
Domestic		*Iris psuedacorus*	-	30	28	

2.5 Design of Constructed Wetland System

According to Parde et al. (2021), CWS can be used as primary and secondary treatment to treat wastewater. Constructed wetland for wastewater treatment is usually divided into two types, surface flow constructed wetland system (SFCWS) and subsurface flow constructed wetland system (SSFCWS) (Almuktar et al., 2018). SFCWS are like natural wetlands that have a shallow flow of wastewater over a saturated substrate, while in SSF system, wastewater flows horizontally or vertically through the substrate and promotes plant development. Usually, this system can be divided into vertical flow (VF) and horizontal flow (HF) depending on the flow direction. Hybrid CWS is a mixture of different wetland structures which was also implemented for wastewater treatment and in the most design, it generally consisted with two stages of multiple parallel constructed wetland (Wu et al., 2015).

2.5.1 Surface Flow (SF)

SFCWS is also known as free water surface wetland. SFCWS often has horizontal wastewater flow over the plant roots rather than vertical flow. Usually, it needs more land area but less expensive (ElZein et al., 2016). It is also useful for flood prevention and shoreline erosion management, as well as enhancing wastewater quality (Parde et al., 2021). Figure 2.4 shows the schematic diagram of SFCWS.

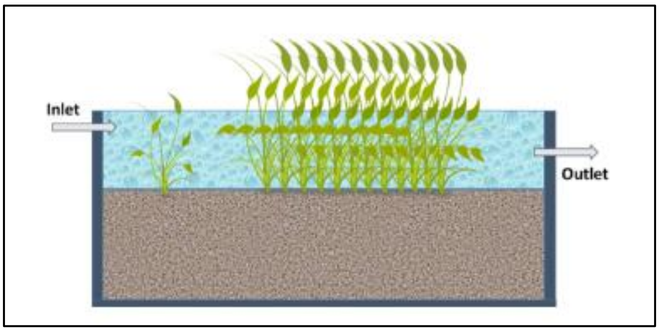

Figure 2.4: SF constructed wetland system (Parde et al., 2021)

SFCWS have been used for decades and have proven to be effective in the treatment of agricultural drainage water (Lavrnić et al., 2018). It can be divided into systems of free-floating, floating-leaved, emergent, submerged macrophytes depends on life form of the dominant macrophytes.

2.5.2 Subsurface Flow (SSF)

SSFCWS have consistently demonstrated the ability to extract organic compounds and particulate matter from wastewater, but has been less effective in removing N and P (Coleman et al., 2001). Since SSFCWS is a modern technology, wetlands performance is still undefined. SSFCWS can be planted or unplanted. Several studies have shown that plants improve treatment efficiency by providing a suitable habitat for microbial community growth and by oxygenating the system (Abdelhakeem et al., 2016).

SSFCWS consists of beds that usually dug into the ground, lined, filled with granular medium and planted with emergent macrophytes. Wastewater will flow through the granular medium, communicating with biofilms, plant roots and rhizomes. A range of techniques were used to eliminate contaminants such as nitrogen and phosphorus (García et al., 2010). SSFCWS can be further categorized as horizontal flow or vertical flow systems (Vymazal, 2005; ElZein et al., 2016).

2.5.2(a) Horizontal Subsurface Flow (HSSF)

In horizontal subsurface flow constructed wetland system (HSSFCWS), the wastewater flows horizontally from the inlet to the outlet zone, passing through a bed of rooted macrophytes (Schierano et al., 2020). The wastewater will go through aerobic conditions. Aerobic conditions happen at the root zones of HSSFCWS, while anaerobic