EFFECT OF FLOATING PLANT GROWTH RATE ON WATER QUALITY PERFORMANCE OF WETLAND IN TREATING DOMESTIC SEWAGE

NUR DHANIAH ATHIRAH BINTI SHAMSUDIN

SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
2022

EFFECT OF FLOATING PLANT GROWTH RATE ON WATER QUALITY PERFORMANCE OF FLOATING CONSTRUCTED WETLAND IN TREATING DOMESTIC SEWAGE

By

NUR DHANIAH ATHIRAH BINTI SHAMSUDIN

This dissertation is submitted to

UNIVERSITI SAINS MALAYSIA

As partial fulfilment of requirement for the degree of

BACHELOR OF ENGINEERING (HONS.)

(CIVIL ENGINEERING)

School of Civil Engineering
Universiti Sains Malaysia

August 2022

Appendix A8

UNIVERSITI SAINS MALAYSIA

SCHOOL OF CIVIL ENGINEERING
ACADEMIC SESSION 2021/2022

FINAL YEAR PROJECT EAA492/6
DISSERTATION ENDORSEMENT FORM

Title: EFFECT OF FLOATING PLANT GROWTH RATE ON WATER QUALITY PERFORMANCE OF FLOATING CONSTRUCTED WETLAND IN TREATING DOMESTIC SEWAGE

Name of Student: NUR DHANIAH ATHIRAH BINTI SHAMSUDIN

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature:

Date : 9.8.2022

Approved by:

(Signature of Supervisor)

Name of Supervisor : DR. GOH HUI WENG

Date : 9.8.2022

Approved by:

(Signature of Examiner)

Name of Examiner : DR. NURIDAH SABTU

Date : 9.8.2022

ACKNOWLEDGEMENT

Alhamdulillah, I am grateful to Allah SWT for providing me with the chance to accomplish my Final Year Project. First and foremost, I would like to thank Dr. Goh Hui Weng from River Engineering and Urban Drainage Research Centre (REDAC) USM for her advice and supervision during the duration of this study. I sincerely appreciate the time, effort and also financial support she invested to help me complete my dissertation.

I also would like to express gratitude to REDAC for sponsoring laboratory suppliers for this research project. Not to forget, I am grateful to all of the officers, master students, and technicians which is Poova and his colleagues, En. Syafiq and En. Faizol, for their assistance, guidance, and cooperation during all of my laboratory setup and experimental work at Environmental Laboratory 3. Finally, my heartfelt gratitude goes out to all of my colleagues, especially those who accompanied and lend me some help on this journey throughout semesters 7 and 8. I am also grateful to all of my family members who have provided moral support from afar. They have always been there for me with love, support, and patience. Thank you very much.

ABSTRAK

Sistem buatan manusia yang meniru fungsi dan struktur tanah lembap semulajadi dipanggil tanah lembap binaan. Sistem ini mempunyai keupayaan untuk merawat air kumbahan dengan teknologi dan keperluan tenaga yang rendah, berpatutan dan mudah diselenggara. Walau bagaimanapun, cara ia berfungsi di iklim tropika masih belum diketahui dan terdapat keperluan untuk mengetahui kelestarian tumbuhan terapung dalam merawat kumbahan domestik. Kajian ini bertujuan untuk mencapai tiga objektif utama, iaitu untuk membandingkan kecekapan tumbuhan merawat pencemaran kumbahan domestik, untuk menyiasat kadar pertumbuhan tumbuhan terapung yang dipilih dalam rawatan kumbahan domestik dan untuk mengesyorkan tumbuhan terapung terbaik untuk tanah lembap binaan. Data dikumpulkan melalui tanah lembap binaan di USM, Kampus Kejuruteraan yang diintegrasikan dengan Keladi Bunting dan Pokok Kiambang. Parameter yang dikaji ialah permintaan oksigen kimia (COD), jumlah pepejal terampai (TSS), dan ammonia nitrogen (AN). Penemuan menunjukkan bahawa kecekapan penyingkiran Keladi Bunting lebih tinggi untuk COD (40.96%), TSS (43.94%), dan NH_3-N (24.35%) berbanding dengan Pokok Kiambang dengan COD (26.86%) TSS (17.79%) dan NH_3-N (15.55%). Walaupun Keladi Bunting mempunyai kadar pertumbuhan yang lebih rendah daripada Pokok Kiambang tetapi ia mempunyai biojisim yang lebih tinggi untuk menyerap nutrien dengan hanya melibatkan penambahan kecil liputan kawasan. Oleh itu, Keladi Bunting adalah lebih munasabah untuk dipilih sebagai tumbuhan terapung di tanah lembap binaan kerana ia memerlukan kurang penyelenggaraan untuk mencapai Prestasi A bagi TSS dan COD dan Prestasi B bagi NH_3-N berdasarkan Piawaian Pelepasan Air Sisa Malaysia.

Kata Kunci: Prestasi tanah lembap binaan bersama tumbuhan terapung, kumbahan domestik kadar pertumbuhan tumbuhan terapung,

ABSTRACT

A man-made system that mimics the function and structures of natural wetland are called constructed wetlands. It has the ability to treat sewage water with low technology, low energy requirements, affordable and easy to maintain. However, how it works in tropical climates is still unknown and there is a need to figure out the sustainability of floating plants in treating domestic sewage. This study sought to achieve three main objectives that are first, to compare the pollutant removal efficiency of floating plants in treating domestic sewage, to investigate the growth rate of selected floating plants in domestic sewage treatment and to recommend the best plant for use in floating plant constructed wetland. The data was collected through a pilot constructed wetland in USM, Engineering Campus that is integrated with two species of floating plants which is Water Hyacinth and Water Lettuce. The parameters studied were chemical oxygen demand (COD), total suspended solids (TSS), and ammoniacal nitrogen (AN). The findings reveal that the removal efficiency of Water Hyacinth is higher for all COD (40.96%), TSS (43.94%), and NH_3-N (24.35%) compare to Water Lettuce with COD (26.86%) TSS (17.79%), and NH_3-N (15.55%). Even Water Hyacinth has a lower growth rate than Water Lettuce but they have higher biomass to uptake nutrients with just a small increment of area coverage. Therefore, Water Hyacinth is more reasonable to implement in floating plant constructed wetland as it needed less maintenance than Water Lettuce to achieve standard A for TSS and COD and standard B for NH_3-N based on Malaysia Wastewater Effluent Discharge Standards.

Keywords: Floating Plant Constructed Wetland performance, Floating plants growth rate, Domestic sewage

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSION

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CWS	Constructed Wetland System
FCW	Floating Constructed Wetland
COD	Chemical Oxygen Demand
TSS	Total Suspended Solid
AN/NH_3-N	Ammonia Nitrogen
PVC	Polyvinyl chloride
DO	Dissolved Oxygen
PWD	Public Works Department Malaysia
ES	Ecosystem Services
GHG	Greenhouse gases
FWS	Free Water Surface
SSF	Subsurface Flow
HSSF	Horizontal Subsurface Flow
VSSF	Vertical Subsurface Flow
TP	Total Phosphorus
TN	Total Nitrogen
mm	millimeter
HR	High Range
LR	Low Range

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Water contamination has occurred as a result of urban development, either directly or indirectly. Rise of population in the area definitely increases domestic sewage. Most country have their own sewage treatment facilities for water treatment. However, conventional wastewater treatment methods are rather expensive and are not accessible in developing regions such as rural areas. Therefore, if there is another system which back to nature, economical, conserves low energy and technology, easy to maintain and can perform the same function to treat domestic sewage, it would be favorable for wastewater management plans, particularly in dense areas where land is limited.

Wetlands are areas where water covers the soil or is present at or near the soil's surface all year or for varying periods of time throughout the year, including the growing season (US EPA, 2015). The case study focusing on the design, development, and performance of artificial wetland functioning to treat water is widely recognized. However, greater attention should be paid to the long-term effective treatment and sustainable operation of created wetlands employing floating plants in the treatment of domestic sewage in Malaysia.

The plants used in a Constructed Wetland System (CWS) might be floating aquatic plants, submerged plants, or emergent plants. Typically, emergent plants are utilised to treat run-off. We need to explore deeper into the efficacy of floating plants in treating domestic sewage in this study since they are thought to be the major biological component of CWS. Eventually, the floating plants have the same trait, they grow quickly and are invasive.

Therefore, it is crucial to investigate the growth rate of the floating plants in order to determine the fixed harvesting time for maintenance.

The study's highlight is about floating constructed wetland that includes Water Hyacinth, *Eichhornia crassipes*, and Water Lettuce, *Pistia stratiote* only. They are chosen because of their rapid growth rate, and long, fibrous roots to assimilate nutrients. Aside from that, they are easy to stock and harvest for maintenance works. During the study period, the effect of two plants' growth rates will be related to the water quality performance of water samples at selected points through COD, TSS, and NH_3-N tests in treating pollution of domestic sewage via floating plant constructed wetland.

1.2 Problem Statements

In Malaysia, many constructed wetlands are built to treat surface runoff. One of them was in Putrajaya Lake. Despite several case studies for floating constructed wetlands in treating domestic sewage in another country, how it works in tropical climates still unknown based on the suitability of floating plants due to many factors such as temperature, pH, etc. Therefore, studies need to be conducted to compare pollutant removal efficiency of selected floating plants in treating domestic sewage under tropical climate.

Plants nutrient uptake depends on nutrient supply or pollution in the domestic sewage. Selected floating plants are generally known for rapid growth or invasive. Larger biomass mats will cover area of the pond where absorption of nutrient occur. However, at some time it will be too dense where space of growth is limited. Thus, the growth rate of selected floating plants needs to be investigated for nutrient uptake of domestic sewage.

Researchers discovered that water hyacinths flourish on sewage because they absorb and digest nutrients and minerals from it. On the negative side, it is classified as an invasive species due to its fast-growing ability to blanket large portions of lakes and cut off the supply of sunlight and dissolved oxygen to aquatic life beneath them. In this case, the rapid growth rate may deteriorate the water quality if maintenance works are not scheduled appropriately and a foul smell can be produced from the lake if it can’t be controlled. Therefore, removal efficiency co-relationship with the growth rate is crucial to find better recommendation between selected floating plants.

1.3 Aim and Objectives

The fundamental aim of this research is to develop an effective plan for the operation and maintenance of Floating Plant Constructed Wetland as one of the solutions to treat domestic sewage in the future. This can be achieved by addressing all the following objectives:

1. To compare the pollutant removal efficiency of selected floating plants in treating domestic sewage.
2. To investigate the growth rate of selected floating plants in domestic sewage treatment.
3. To recommend the best plant for use in floating plant constructed wetland.

1.4 Scope of Work

This research is only limited to a pilot-scale floating constructed wetland located at USM Engineering Campus near Environmental Lab 3.

The selection of the type of floating plants is based on the availability and their characteristics to help purify the domestic water on the campus. Growth of Water Hyacinth, *Eichhornia crassipes*, and Water Lettuce, *Pistia stratiote* before and after 7 days domestic sewage released will be observed. A 1m x 1m frame made of PVC pipe is used to determine the area coverage of plants. Plus, 3 drone view will be taken by phases at different time.

For inlet, the domestic sewage taken from the manhole in student hostel in USM engineering campus. The scope of work for this research is to get data collection of water sampling in the nutrient pond at the inlet and 4 points in the pond's cells. Each cell is separated by a barrier and has integrated arrangement of selected floating plants. The water samples then will be tested in-situ for DO, pH, and temperature and at the lab for COD, TSS, and NH_3-N for a whole week.

1.5 Significance of Study

The findings of this study will provide a better solution for the long-term considering that it has a similar function to improving water quality at a lower cost. This study would be beneficial to the government, the client of the new proposed development project, Public Works Department Malaysia (PWD), and also society.

Rapid development, as the general public is aware, has resulted in long-term environmental issues that have a negative impact on our ecosystems. Therefore, wetlands propose nature-based solutions for sustainability. Recently, urban development has acknowledged the benefits of preserving wetlands and has recommended the construction of constructed floating wetlands as a pollution mitigation strategy with low operational and maintenance expenses. This study has revealed a lower risk to the environment, which can be used as baseline information when drafting a wetland management plan or revising an existing one.

This study looked into all of the significant issues in order to raise awareness of the Floating Plant Constructed Wetland as a way to address future water demands. Aside from that, the performance of constructed wetland practices will be assessed. If present management practices are ineffective, the operation and maintenance plan will be developed with thorough guidelines whenever essential reactions can be undertaken by relevant engaged parties.

1.6 Structure of Dissertation

This research is comprised of five (5) chapters in total.

Chapter 1 presents a brief overview of the research topic. The problem statements were established and followed by the aim and objectives. The scope of work explains where all the limitation of this study was highlighted. The significance of the study where how the findings of the study can be beneficial to selected individuals is explained.

Chapter 2 addresses the literature review focused on constructed floating treatment wetland, domestic water quality performance, and invasive floating plants. The relevant literature review includes the definition, mechanisms, and operation and maintenance issues.

Chapter 3 describes the methodologies employed in this research involving data collection and data analysis. The selected method for data collection that combined both qualitative and quantitative approaches is explained. Then, the selected data analysis methods are discussed. This chapter provides the sites and sampling routines; technics and methods of sample preparations, characterizations, and preservations; details of each process setting; programming used, and all the equipment utilized.

Chapter 4 appointed for results and discussions which presents the purging duration result for parameters such as COD, TSS, and NH_3-N, floating plants growth rate, the correlation between them, and removal efficiency for domestic wastewater for floating constructed wetland.

Chapter 5 states the conclusion and recommendation based on the results and discussions transcribed in chapter four. This chapter includes the potentials and possibilities for future assessments as well.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature is divided into 8 subsections where it summarises all the literature about the natural and constructed wetland, the importance of constructed wetland, constructed wetland types, vegetation used and its role and lastly, floating treatment wetland advantages.

2.2 Wetland

Wetlands are areas where water covers the soil or is present at or near the soil's surface all year or for varying periods of time throughout the year, including the growing season (Balwan et al., 2021). Wetlands, known as "the kidneys of the landscape," play an important role in providing humans with ecosystem services (ES) such as flood control, biodiversity conservation, groundwater replenishment, climate change mitigation and adaptation, and cultural values (Pattison-Williams et al., 2018). It is surrounded by emergent, floating, and submerged plants with a high level of biodiversity and is used to clean lake and river water (Nelson, 2016). Wetlands can be categorized as natural wetlands and constructed wetlands.

2.2.1 Natural Wetland

A natural wetland is an area having a natural surface water source, a natural groundwater source, or a mix of natural surface water and natural groundwater that is not controlled by diversion, impoundment, withdrawal, excavation, or any other artificial methods. Except for Antarctica, it can be viewed on every continent. Wetlands are divided into two types: coastal or tidal wetlands and inland or non-tidal wetlands (Balwan et al., 2021).

Coastal/tidal wetlands are areas where seawater and freshwater mingle to create a habitat with changing salinities. As a result, many shallow coastal regions are unvegetated mud and sand flats. However, some plants have successfully adapted to this climate. In tropical regions such as Malaysia, mangrove swamps with salt-loving vegetation or trees are abundant. Meanwhile, inland/non-tidal wetlands are most abundant in floodplains along rivers and streams, isolated depressions surrounded by dry land, lake and pond margins, and other low-lying regions where groundwater intercepts the soil surface or precipitation sufficiently saturate the soil (Balwan et al., 2021).

Figure 2.2.1: Mangrove in Langkawi, Malaysia

2.2.2 Constructed Wetland

A constructed wetland is an artificial wetland that replicates and enhances the performance of naturally existing wetlands' purification processes (Pilli et al., 2020). In addition to other man-made facilities such as treatment plants, constructed wetlands are a viable alternative for providing continuous clean water supplies in order to fulfil ecological, economic, and societal needs (Stefanakis, 2019).

Ohio ranks second only to California in terms of the biggest percentage loss of wetlands from the 1780s to the 1980s, with a loss of 90% (Mitsch, 1992). Rivers and streams can no longer purify themselves due to the loss of wetlands and their conversion to other land uses. As a result, water quality has deteriorated, and fertilizers continue to enter the lake. Wetland loss can affect biodiversity and water availability while also increasing GHG emissions and soil erosion (Sun et al.,2017). Wetland destruction also has an impact on water bird hatching and survival, resulting in biodiversity loss (Maseko et al., 2017). As a result, wetland formation, where conversion of a non-wetland region into a wetland is critical. Wetlands are constructed to remediate both nonpoint and point sources of water pollution (Vymazal et al., 2010).

Constructed wetlands are a very efficient solution for wastewater remediation from a variety of sources, including domestics, highways, industry, and mining, particularly tannery enterprises (Wang et al., 2017). For several decades, wastewater treatment systems that use little fossil fuel, energy, or technology have represented a sustainable option in many nations throughout the world (Chen et al., 2016).

2.3 Importance of Constructed Wetland

Constructed wetlands are claimed to be an addition to traditional systems because of their low cost and low energy consumption, ease of operation and maintenance, and potential application in poor nations with severe water pollution concerns (Hassan et al., 2021). Constructed wetland System (CWS) clean wastewater through the combined activity of microbes and plants in the wetland's physical and chemical environment. The intake wastewater provides the substrates needed for microbial growth (Kulshreshtha et al., 2022).

These ecologically engineered systems were developed and built to use natural processes including wetland plants, soils, and the related microbial communities to aid in wastewater treatment (Kouki, S. et al., 2009). Wastewater enters the constructed wetland system and travels perpendicular to the water flow via unvegetated and highly vegetated zones through a network of shallow ponds, channels, basins, and other sites where aquatic vegetation has been established to eliminate contaminants by a complicated connection between plants and microbes (Barco et al., 2021).

Since 2009, Frangipani Resort & Spa in Langkawi Geopark has been one of Malaysia's hotels to use this eco-technology. This has significant advantages, especially in terms of the hotel's financial resources being spent in lowering the cost of sewage management and water use. Furthermore, because treated wastewater is reused, the technology contributes indirectly to more sustainable wastewater and water resource management (Akhir et al., 2016).

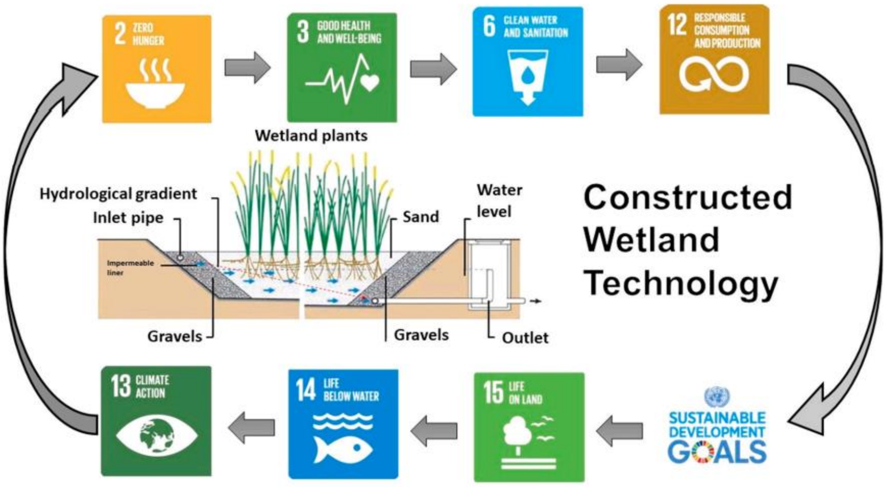


Figure 2.3: Schematic diagram showing the relationship and importance of constructed wetland System (CWS) with United Nations Sustainable Development Goals 2030.

2.4 Type of Constructed Wetland

In general, constructed wetlands are classified into water level in the system, which determines whether it is free water surface flow or subsurface flow, the macrophytes used and the direction of water movement in the system (Vymazal, 2014).

According to Wu et al. (2014), the major two flow types of built wetlands are surface flow and subsurface flow. The distinction between these two varieties is that the first contains significant macrophytes and an exposed water surface, whereas the second has no clear water surface (Almuktar, S.A. et al., 2018). To obtain a high pollutant removal efficiency, subsurface flow is separated into vertical flow and horizontal flow, which can be merged into a single system (hybrid) (Vymazal, 2014).

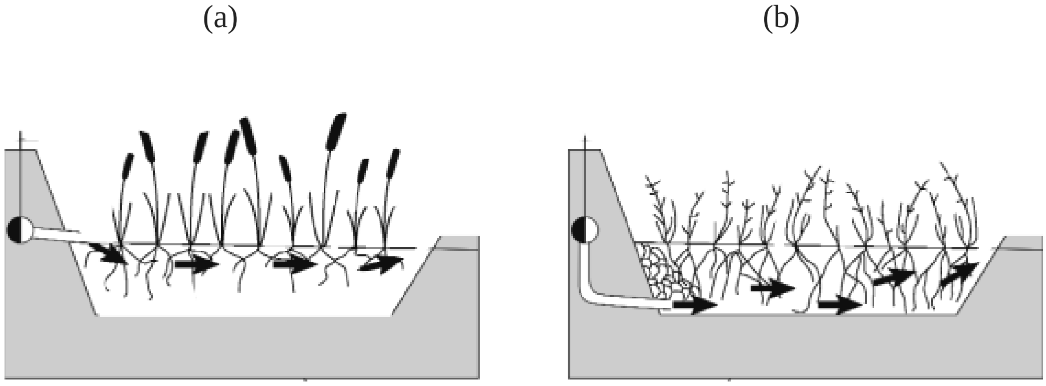


Figure 2.4: Design of constructed wetlands (a) free water surface (FWS) wetlands, and (b) subsurface flow (SSF) wetlands (from Taylor & Associates 1992).

2.4.1 Free Water Surface (FWS-CWS)

FWS-CWS occur when the surface of the wastewater flow is higher than the substrate (Adewuyi et al., 2012). Typically consists of a basin or soil to support the roots of plants (submerged, free floating, or emergent) and water running through the system at a relatively shallow depth (Davis, 1995). The oxygen content in the FWS-CWS changes with depth (Agarry et al.,2018). Depending on the water level, the upper layers near the water's surface have a high oxygen concentration, whilst the lower layers have extremely low or no oxygen concentration (Omondi et al., 2020). As a result, the upper layers support aerobic (nitrification) activities whereas the lower layers promote anaerobic (denitrification) processes. When compared to subsurface flow wetlands, FWS-CWS require a larger area but more efficient in removing organics and suspended particles (Kadlec et al., 2009).

2.4.2 Subsurface Flow (SSF-CWS)

Subsurface Flow is made of basin or canal with a barrier to prevent seepage with bed that has a sufficient depth of porous medium such as rock or gravel (Brovelli et al., 2011). The water level in the bed will remain below the rock or gravel media's surface (Davis, 1995). SSF wetlands have several advantages over FWS wetlands, including cold weather endurance, less odour concerns, more sorption and exchange sites, and more efficient land use (Davis, L., 1995). The disadvantages of SSF wetlands are their greater cost as compared to FWS, their usage for tiny flows, and pore clogging (Gunter et al., 2020).

Wetlands with subsurface flow are classified based on their flow pattern (Tousignant et al., 1999). The horizontal subsurface flow (HSSF) and the vertical subsurface flow (VSSF) are the two types of flows seen in SSF CWS (Nivala et al., 2013). A hybrid wetland system consisting both of them. The usage of these integrated wetland systems is now popular around the world due to their efficacy in removing nitrogen compounds from a variety of wastewater types (Ayaz et al., 2012).

2.4.2.1 Horizontal Subsurface Flow (HSSF)

The horizontal subsurface flow (HSSF) is made up of a channel under the ground surface (Dan et al., 2011). The wastewater is supplied into the system at the intake and runs slowly through the porous medium beneath the bed's surface in a more or less horizontal course until it reaches the outlet zone, where it is collected before exiting via a level control device at the outlet. The wastewater will come into touch with a network of aerobic, anoxic, and anaerobic zones throughout its journey. The aerobic zones will form around the marsh vegetation's roots and rhizomes, which will leak oxygen into the substrate (UN-HABITAT, 2008). During the transit of wastewater through the rhizosphere, microbial degradation, as well as physical and chemical reactions, clean the wastewater (Cooper et al., 1996). The organic contaminants (TSS, BOD_5, and COD) in wastewater may be effectively removed by HSSF wetland. The removal of nutrients (particularly nitrogen) is limited because to the limited oxygen movement inside the wetland; nonetheless, HSSF wetlands reduce nitrates in the wastewater (UN-HABITAT, 2008). Horizontal subsurface flow created wetlands are known to be good for denitrification but bad for nitrification (Vymazal, 2014), in contrast to vertical subsurface flow constructed wetlands (VSSF).

2.4.2.2 Vertical Subsurface Flow (VSSF)

Wetlands built using VSSF consist of a flat bed of graded gravel covered with sand and seeded with macrophytes (UN-HABITAT, 2008). With the intermittent supply of water to the system, vertical-flow created wetlands are ponded and drained (Stefanakis et al., 2014). Vertical flow wetlands are run in batch mode rather than continuous flow mode. The effluents flow vertically down through the substrate from the planted layer. Pumps are used to aerate the system. Wastewater progressively percolates down through the bed and is collected at the base by a drainage network. The bed drains fully and enables air to replace the mattress (UN-HABITAT, 2008). Plant roots transport some oxygen to the subsoil, while dry times facilitate oxygen diffusion. As a result, the oxygen level in VSSF is high, promoting the development of aerobic bacteria for nitrification (Almuktar et al., 2018). After learning about the difficulties of horizontal systems in terms of wastewater nitrification inability owing to a lack of oxygen availability in such systems, this form of wetland became popular for implementation (Stefanakis et al., 2014). It was also discovered that the VSSF is effective in removing organic materials and suspended particles (Hassan et al., 2021).

2.5 Role of Vegetation

Some nutrients can be absorbed by stems and leaves but root systems are predominantly responsible for nutrient intake (Jones et al., 2017). Plant roots frequently form a mesh-like structure that functions as a natural filter for suspended contaminants in wastewater (Oon et al., 2017). Plant root systems with charges boost their capacity to trap and attract particles (Umar et al., 2015). Elements such as dissolved metals in contaminated water are absorbed directly by roots and transferred to the root surface by mass-flow, cation-exchange, osmosis, capillary action, or ion diffusion (Sharma et al., 2021). The convective process by which nutrients travel with water into roots, reach leaves via xylem tissue under transpiration pressure, and are eventually removed as the plant transpires is known as mass-flow. Cation exchange involves the exchange of metal cations as well as the pumping of H^+ from root hairs into water via proton pumps. Root exudates include carbon sources required for microbial metabolism and hence contribute to pollutant retention by promoting bacterial growth and the expansion of microbial biofilm (Singh et al., 2016). Biofilms capture metals and nutrients in water, create complexes with negatively charged functional groups on them, and so help in their removal (Sharma et al., 2021). Vegetation also has been shown to improve water quality indirectly by reducing water velocity for erosion and sedimentation, modifying light intensity for algal photosynthesis and lowering wastewater temperature (Jones et al., 2017).

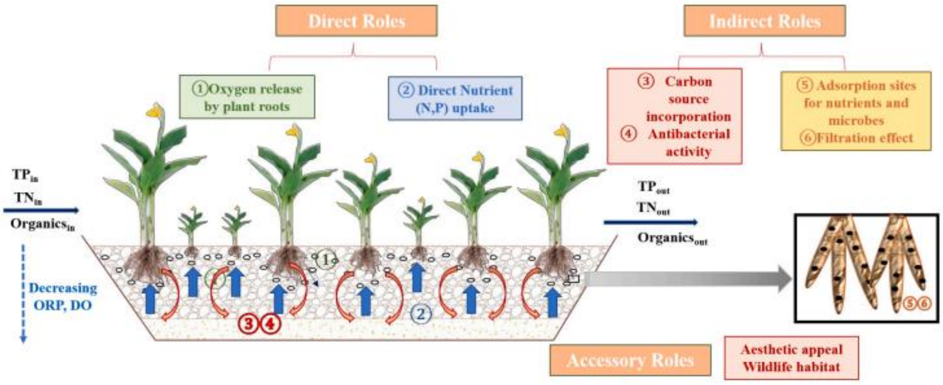


Figure 2.5: Various roles of plants in constructed wetlands
(Kulshreshtha et al., 2022)

2.6 Plants used in Free-Surface Constructed Wetland

The present study on the sustainable design of CWS should prioritize plant selection (Vymazal, 2011). The plant species determines the method of wastewater treatment (D.L. Jones et.al, 2017). Emergent plants, submerged plants, and floating plants are examples of macrophytes that are widely employed in FWS-CWS (Tousignant et al., 1999). Although more than 150 macrophyte species have been employed in CWS across the world, only a small number of these plant species are often planted in CWS in practise (Vymazal, 2013).

2.6.1 Emergent Plants

Emergent wetlands can be used to remove surface and subsurface pollution (Tousignant et al., 1999). Emergent macrophytes, which are normally found above the water's surface, are known to stabilize the substrate. Emergent aquatic plants have sediment-rooted stems, leaves, and flowers that reach partially or completely out of the water (Almuktar et al., 2018). Furthermore, these plants are cultivated in water that is around 50 cm above the earth (Saeed and Sun, 2012). Macrophytes such as Acorus calamus L., Carex rostrate Stokes, Phragmites australis (Cav.) Trin. ex Steud., Scirpus lacusris (L.) Palla, and Typha latifolia L. (Saeed and

Sun, 2012) as well as genera such as Iris spp., Juncus spp., and Eleocharis spp. (Wu et al., 2015) are typical examples. The potential of emergent plants is quite low especially in constructed wetlands for the treatment of municipal or domestic sewage (Vymazal et al., 2007).

2.6.2 Submerged Plants

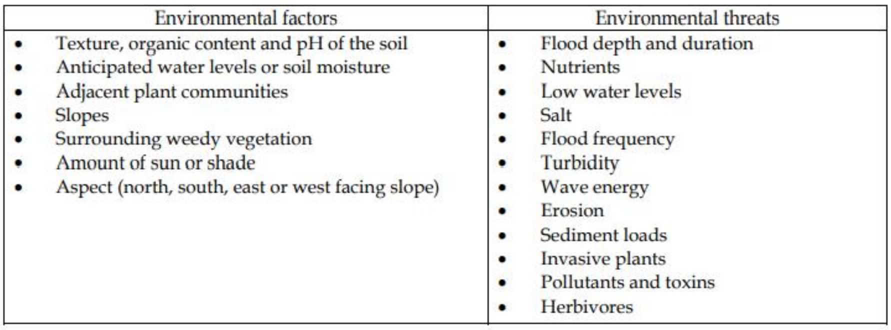
The majority of submerged plants are rooted in sediments, with the majority of the plant body at or below the water's surface (Mudge, 2018). Aerated water is required for the development of submerged macrophytes. Furthermore, water covers the plant tissues responsible for photosynthetic activities (Almuktar et al., 2018). However, these plants are mostly used to polish secondary treatment facilities and tertiary wastewater treatment systems (Saeed and Sun, 2012). Examples include Myriophyllum spicatum L., Ceratophyllum demersum L., Hydrilla verticillata (L.f.) Royle, Vallisneria natans (Lour.) H. Hara, and Potamogeton crispus L. (Wu et al., 2015).

2.6.3 Floating Plants

Plants in a floating treatment wetland might be either floating-leaved or free-floating. Floating plants can have roots or not, have most of their leaves and plant tissue floating on top of the water and have the potential to take nitrogen and phosphorus from wastewater through denitrification processes, which they then integrate in their biomass (Almuktar et al., 2018). Lemna minor L., Spirodela polyrhiza (L.) Schleid., Eichhornia crassipes (Mart.) Solms, Salvinia natans (L.) All., and Hydrocharis dubia (Blume) Backer are the examples commonly seen in lakes and ponds (Wu et al., 2015).

According to the 2nd edition of the Malaysian Urban Stormwater Management Manual (Manual Saliran Mesra Alam Malaysia, 2012), constructed wetland specific planting criteria should include vegetation that is adapted to the local climate and soil, can tolerate pollutants in water or wastewater, has higher biomass production and rapid growth, but should avoid the use of noxious species. Because of the nutrition intake process through its roots, floating plants will expand over time, particularly invasive species with fast growth. In the meanwhile, the plants will cover the majority of the marsh, posing environmental hazards, as indicated in MSMA 2nd edition Appendix AX1.1.2.

Table 2.6.3.1: General Site Condition to Investigate (Shaw and Schmidt,2003)



Environmental factors	Environmental threats
• Texture, organic content and pH of the soil • Anticipated water levels or soil moisture • Adjacent plant communities • Slopes • Surrounding weedy vegetation • Amount of sun or shade • Aspect (north, south, east or west facing slope)	• Flood depth and duration • Nutrients • Low water levels • Salt • Flood frequency • Turbidity • Wave energy • Erosion • Sediment loads • Invasive plants • Pollutants and toxins • Herbivores

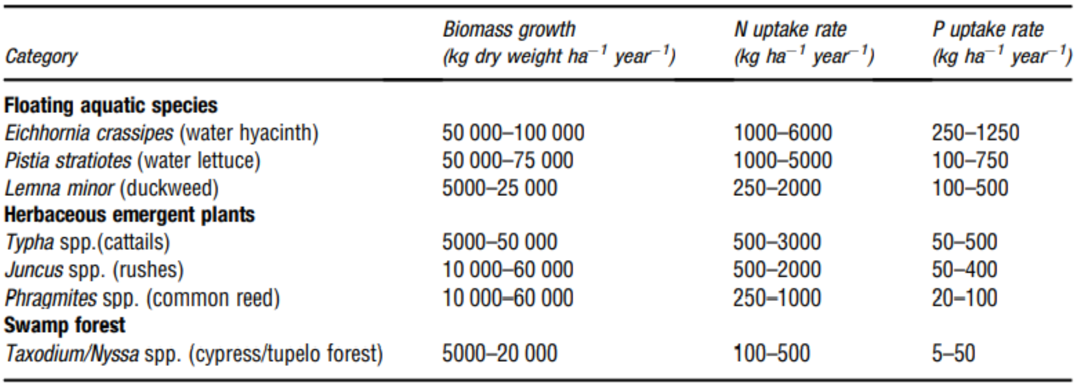
Numerous studies have found that free-floating aquatic plants such as water hyacinth (Eichhornia crassipes), water lettuce (Pistia stratiotes), and duckweed (Lemnaceae) can lower nutrient concentrations in wastewater (Hubbard, 2010). During their lives in domestic wastewater, the development of E. crassipes and P. stratiotes varies. The anatomy and physiology were altered by the physical and chemical properties of domestic wastewater (Sudjarwo et al., 2014).

In many situations, invasive plants such as water hyacinth (Eichhornia crassipes) and water lettuce (P. stratiotes L.) are employed in these phytoremediation water systems, particularly in tropical or subtropical climates (El-Gendy et al., 2005). This is due to the fact that, as compared to native plants, invasive plants have a substantially better nutrient removal efficiency due to their high nutrient intake capacity, rapid growth rate, and large biomass output (Reddy and Sutton, 1984).

Water lettuce and water hyacinth, both floating macrophytes, have a high capacity for nutrient accumulation and a strong root structure that promotes prolific development (Gupta P et al., 2012). Microorganisms attached to their root surface can oxidise the biodegradable matters present in wastewater (Nayanathara et al., 2017). During the early stages of development, nutrient absorption efficiency is generally at its peak (Reddy et al., 1990). They also have a comparable growth rate (Sood et al., 2012). Both plants may reproduce both sexually and asexually (Gaikwad et al., 2017; Nassouhi, Danial et al., 2018). Both reproduction technologies provide a high number of manufacturing possibilities in a short amount of time. Water Lettuce biomass doubles in less than 5 days, triples in 10 days, quadruples in 20 days, and has its initial biomass increased by a factor of 9 in less than one month, whereas Water Hyacinth grows double in 5 to 15 days (Nayanathara et al., 2017). The quick reproduction and rapid development of these two macrophytes are directly related to nutrient absorption in an aqueous media. However, if their development is unchecked, they can become invasive (Julien et al., 1996). 25 days is the maximum period to allow P. stratiotes in the system (Gupta P et al., 2012).

Nitrogen has a general impact on biomass production, growth, enzyme activity, and pigment content (Arruda et al., 2009). Domestic wastewater solution is used to absorb nitrogen by the root systems of E. crassipes and P. stratiotes. Nitrogen enters the cell metabolism of E. crassipes and P. stratiotes and is then employed as an energy and protein source (Taiz et al., 2010). The floating aquatic species, Eichhornia crassipes, has one of the highest potentials for nutrient uptake, while P. stratiotes follow close behind (Jones et al., 2017).

Table 2.6.3 2: Biomass production and nutrient uptake potential of typical plants used in constructed and natural wetlands (Jones et al., 2017).



Category	*Biomass growth (kg dry weight ha^{-1} year^{-1})*	*N uptake rate (kg ha^{-1} year^{-1})*	*P uptake rate (kg ha^{-1} year^{-1})*
Floating aquatic species			
Eichhornia crassipes (water hyacinth)	50 000–100 000	1000–6000	250–1250
Pistia stratiotes (water lettuce)	50 000–75 000	1000–5000	100–750
Lemna minor (duckweed)	5000–25 000	250–2000	100–500
Herbaceous emergent plants			
Typha spp.(cattails)	5000–50 000	500–3000	50–500
Juncus spp. (rushes)	10 000–60 000	500–2000	50–400
Phragmites spp. (common reed)	10 000–60 000	250–1000	20–100
Swamp forest			
Taxodium/Nyssa spp. (cypress/tupelo forest)	5000–20 000	100–500	5–50

Figure 2.6.3.1: Water Hyacinth (*Eichhornia crassipes)*

Figure 2.6.3.2: Water Cabbage (*Pistia stratiotes)*

Water Lettuce may be found on all continents except Antarctica (Dray et.al., 2002) while Water Hyacinth can be found in tropical and semi-tropical nations (USGS, 2010). Environmental elements like as temperature and pH can all have an impact on the development and optimal functioning of E. crassipes and P. stratiotes. Sharma HD et.al, (2004) state that they are not suitable for cold regions since it will destroy the plants outer leaves. The temperature range for optimal water hyacinth growth, according to Gaikwad and Gavande (2017), is between 28°C and 30°C. Meanwhile, the optimum growth temperature for Water Lettuce was 21–30◦ C (Ali et al., 2020). The temperature taken is in range of a relevant temperature for plant-microbe growth in between 20-30^{o}C in temperate region (Othman et al., 2020). Water Lettuce and Water Hyacinth were cultivated in water culture at various pH values. Water Hyacinth produced the most at pH 7.0 but it can tolerate pH values from 4 to 10 (Nayanathara et al., 2017), whereas Water Lettuce produced the most at pH 4.0 (Chadwick et al., 1966).

Because Water Lettuce plants are smaller than water hyacinth plants, they are ideal for low-cost harvesting (Mustafa et al., 2021). Meanwhile, Water Hyacinth height can reach up to 1m above the water's surface, however it is most commonly 20-30 cm (Dersseh et al., 2019).

2.7 Floating Constructed Wetland Advantages

FCW work similarly to CWS where water, bacteria, plant parts, algae, and pollutants interacts to remove toxins from water (R.Sharma et al., 2021). However, it had a slow water flow and shallow water depth, resulting in a long retention period that enhances sediment settlement and increases interaction time between the wastewater and the wetland components (Hassan et al., 2021). The roots of the plants in the FCW prevent suspended particulates entering the system vertically, lowering its speed and allowing these materials to settle (Oliveira et al., 2021). Furthermore, variations in the water level below the plants have little effect on their growth (Ladislas et al., 2012) as plants get nutrients straight from the water from both sediment beds and the aquatic phase without forming roots in the sediment (Oladoja, 2016) due to freely accessible roots (Kadlec and Wallace, 2009).

Plant-bacteria interactions primarily remove organic matter, nitrogen, and phosphorus through decomposition, plant absorption, microbial assimilation, denitrification, sorption, entrapment in roots, and lastly sedimentation and precipitation (Abed et al., 2019). Plant shape, biomass development, growth rate, heavy metal tolerance, and environmental depends on their ability to absorb nutrients (Ladislas et al., 2013). Plants having higher total biomass, bigger fibrous root systems, and higher biomass may store and eliminate more metals than plants with lower total biomass and coarser roots due to higher surface area (Li et al., 2015). Furthermore, the increased surface area of fibrous roots allows for more contact area to influence pH change in surrounding water, oxygen release, and exudate release, thus enhancing plant removal efficiency (Schuck and Greger, 2019).

FCW can function in both aerobic and anaerobic conditions, with greater elimination of organic matter through aerobic conditions. Particulate matter is captured in the dense root network where microorganisms such as rhizospheric bacteria is attached and aerobically digested, which reduces plant stress and degrades contaminants (Sharma et al., 2021). As a result, the system's phytoremediation potential is enhanced even further (Afzal et al., 2014).

FCW may purify water in a sustainable manner with little maintenance and operational costs without any complicated technical tool for installation (Magwaza et al., 2020). The entire cost is mostly determined by floating plants, and manpower for harvesting and planting (Wang and Sample, 2014). Because the approach does not 'claim' any land space, they do not require extra regions or infrastructure for wastewater treatment. Thus, FCW may provide a solution to the problem of restricted land area (Keizer-Vlek et al., 2014), as their aesthetic value of blossoming plants and the sensation of green matches any landscape in the city.

2.8 Performance of Floating Constructed Wetland

2.8.1 Chemical Oxygen Demand (COD)

Chemical oxygen demand (COD) is one such bulk characteristic used as an indication for organic pollutants in water (Sinha et al., 2019). COD analysis is quick and straightforward, measuring the quantity of oxygen corresponding to the organic matter in water that is vulnerable to oxidation. As a result, COD is regarded as a realistic indication of organic contamination in water (Luo, 2013).

COD_{Cr} is a method of determining COD using $K_2Cr_2O_7$ that is primarily used for monitoring water quality in highly contaminated water bodies such as sewage or wastewater. COD analysis with $KMnO_4$ on the other hand is known as COD_{Mn} or permanganate index and is often favoured in clean water bodies such as surface or river water (Ma et al., 2016).

When compared to open reflux titration, the closed reflux-spectrophotometric detection method has a quicker response time, reduced chemical consumption, lower cost, and lower secondary pollutant creation. However, frequent issues found during COD measurement include bubble formation, turbidity, colour interference, and a limited range of spectrophotometric equipment (Sinha et al., 2019). The COD ratings are also influenced by experimental circumstances such as pH, chemicals, temperature. (Sinha et al., 2019).

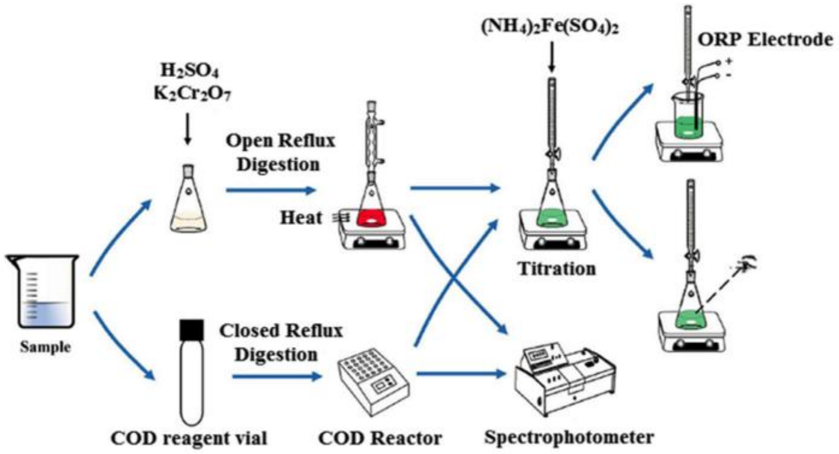


Figure 2.8.1: Standard dichromate manifold for COD detection. (from Ma, 2017)

2.8.2 Total Suspended Solid (TSS)

TSS in water is constituted of inorganic material such as silt, fine sand, and aquatic minerals, organic substances such as detrital particles composed of carbohydrates, proteins, and lipids, and microorganisms larger than two microns in a body of water. TSS content is an important criterion for characterising water quality (Pozdnyakov et al., 2005). The more suspended particles there are in the water, the cloudier it becomes.

TSS content might have a direct and considerable impact on the optical characteristics of water via sunlight absorption and scattering (Hou et al., 2017). This can impair phytoplankton photosynthesis and hence phytoplankton productivity (Guildford et al., 2007) and can disrupt the benthic community by changing aquatic creature habitats (Havens et al., 2005). TSS concentration may have an impact on other water components such as TP (total phosphorus), TN (total nitrogen), and other micro contaminants that induce eutrophication or water pollution (Xie et al., 2003). Traditional TSS monitoring depends on in-situ data gathered at discrete stations and laboratory measurements, which is costly and time-consuming

(Puigserver et al., 2010). Thus, TSS was analyzed by filtering the stormwater through a 45 mm glass fibre filter (Noor et al., 2004) with the help of vacuum pump (Kamarudin et al., 2018).

2.8.3 Ammoniacal-Nitrogen (NH_3-N)

Ammoniacal nitrogen in the form of free ammonia (NH_3) and ammonium ions (NH^{4+}) can be seen found in domestic wastewater (Cruz et al., 2018). Organic nitrogen (40%) and ammonium nitrogen (60%) make up the majority of the nitrogen in domestic wastewater (R.P. Schwarzenbach et al., 2010). At pH less than 8.75, $NH^{4\,+}$ is the predominate form, but at pH more than 9.75, ammonia nitrogen is mostly present as NH_3 (C. Molins-Legua et al., 2006). Ammoniacal-nitrogen (NH_3-N) is hazardous to aquatic life (V. K. Gupta et al., 2015), resulting in decreased reproduction and development or death (Gutierrez et al., 2016).

Eutrophication can also increase ammoniacal nitrogen (AN) levels in domestic wastewater (Ting et al., 2018). Eutrophication causes algal blooms, the development of exotic aquatic macrophytes, oxygen deprivation, and species extinction (Khajah et al., 2016). Excess nutrient deposition, particularly nitrogen (N) and phosphorus (P), triggers water eutrophication (Belal et al., 2016).

Nitrogen removal can be accomplished by biological processes such as nitrification-denitrification (Grady et al., 2011). Bacteria may break down ammonia into nitrite (NO_2) and nitrate (NO_3), which plants can use to develop. Various detection technologies, including the use of Nessler, have been developed to manage and monitor ammonia nitrogen concentrations (Molins-Legua et al., 2006).