EFFECTIVENESS OF BOD REMOVAL FROM DOMESTIC SEWAGE IN CONSTRUCTED WETLAND USING PILOT SCALE STUDY

IQMAL AIZA BIN ZAKARIA

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By

IQMAL AIZA BIN ZAKARIA

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Title: EFFECTIVENESS OF BOD REMOVAL FROM DOMESTIC SEWAGE IN CONSTRUCTED WETLAND USING PILOT SCALE STUDY

Name of Student: IQMAL AIZA BIN ZAKARIA

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

Signature:

Approved by:

Dr. GOH HUI WENG
Senior Lecturer (CEng, IET, Reg. No.: 662492)
River Engineering & Urban Drainage Research Centre (REDAC),
Engineering Campus, Universiti Sains Malaysia,
14300 Nibong Tebal, P. Pinang
Tel: 604-599 5490 Fax: 604-599 6926

(Signature of Supervisor)

Date : 8/8/2022

Name of Supervisor : DR. GOH HUI WENG

Date : 9/8/2022

Approved by:

ASSOC. PROF. DR. MOHD REMY ROZAINY MOHD ARIF ZAINOL
DEPUTY DIRECTOR
RIVER ENGINEERING & URBAN DRAINAGE RESEARCH CENTRE (REDAC)
ENGINEERING CAMPUS, UNIVERSITI SAINS MALAYSIA
14300 NIBONG TEBAL
PENANG

(Signature of Examiner)

Name of Examiner : ASSOC. PROF. TS. DR. MOHD REMY ROZAINY MOHD ARIF ZAINOL

Date : 10/8/2022

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ABSTRAK

Kumbahan domestik ialah air buangan yang dihasilkan oleh aktiviti manusia dari tempat kediaman, komersil, institusi dan industri di mana air buangan domestik diasingkan daripada air buangan industri. Kepekatan kumbahan domestik untuk bahan pencemar mungkin berbeza mengikut sumber kumbahan yang dihasilkan daripada parameter garis panduan SPAN. Pencirian air buangan telah dilakukan untuk menentukan maklumat mengenai kepekatan bahan pencemar yang ada. Sintetik kimia telah ditambah ke dalam kumbahan justeru menghasilkan kepekatan pencemar yang hampir serupa dengan influen ideal pada masa yang sama boleh mencerminkan prestasi sebenar penyingkiran bahan pencemar. Prestasi *constructed wetland* yang dibina dikawal oleh jenis, tumbuh-tumbuhan, dan medium penapis yang digunakan. Dengan menggunakan skala rintis sebagai medium, penyiasatan sistem *Constructed Wetland* yang dibina telah diperiksa untuk keberkesanan penyingkiran BOD dalam kajian ini. Kajian telah dijalankan dalam tempoh tiga minggu, dengan sampel diambil di setiap kolam: kolam nutrien, kolam rawatan dan kolam terbuka atau kolam ikan. *Grab Sample* air buangan yang dikumpul daripada peringkat rawatan yang berbeza telah diuji untuk BOD_5. *Constructed Wetland* didapati mempunyai kecekapan penyingkiran BOD yang sangat tinggi dan juga perbezaan yang agak sedikit antara 3 minggu yang diuji. Kecekapan penyingkiran BOD untuk purata bagi tiga minggu adalah 91.8%. Dari segi perbandingan sistem, aliran bawah permukaan yang dibina mengatasi prestasi aliran sistem di atas permukaan untuk penyingkiran BOD. Keberkesanan penyinkiran BOD adalah tinggi sepanjang tempoh kajian untuk aliran bawah permukaan dengan purata kecekapan penyingkiran 95.17% berbanding aliran permukaan sebanyak 91.8%. Dalam sistem hibrid seperti dalam kajian skala rintis ini, kelebihan sistem SSF dan SF boleh digabungkan untuk melengkapi proses penghasilan BOD efluen yang lebih rendah.

ABSTRACT

Domestic sewage is wastewater generated by human activity in residential, commercial, institutional, and industrial settings in which the domestic wastewater is segregated from the industrial wastewater. Domestic sewage concentrations for pollutants may vary according to the different sources of generated sewage from the SPAN Guidelines standard design parameters. Characterization of the wastewater were carried out to determine the information regarding the concentration of the pollutant present. Chemical synthetics were added to the sewage which results in similar pollutant concentration to the ideal influent which can reflect an actual performance of pollutant removal. The performance of constructed wetlands is governed by the types of constructed wetland, vegetation, and filter medium utilised in the bed. By using a pilot scale constructed wetland as a medium, the investigations of the constructed wetland system were examined for the effectiveness of BOD removal in this study. The study was carried out over a period of three weeks, with sampling done in each pond: nutrient pond, treatment pond and open pond. Grab samples of wastewater collected from different stages of treatment were tested for BOD_5. The wetland was found to have a very high efficiency of removal of BOD with relatively little variability between the weeks. The three-week average BOD removal efficiency was approximately 91.8%. In terms of system comparison, subsurface flow constructed wetlands outperformed surface flow constructed wetlands in the removal of BOD. The effectiveness of elimination of BOD was high throughout the study period for subsurface wetland with the average removal efficiency of 95.17% compared to surface wetlands with 91.8%. In hybrid systems such as in this pilot scale study, the advantages of the SSF and SF systems can be combined to complement processes in each system to produce an effluent low in BOD.

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LISTS OF ABBREVIATIONS

BOD	Biological Oxygen Demand
CB	Contact Bed
COD	Chemical Oxygen Demand
CW	Constructed Wetland
CWS	Constructed Wetland System
DO	Dissolved Oxygen
EQR	Environmental Quality Report
OM	Organic Matter
SF	Surface Flow
SSF	Subsurface Flow
STP	Sewage Treatment Plant
TDS	Total Dissolved Solid
TP	Total Phosphorus
TSM	Total Solid Material
USM	Universiti Sains Malaysia
WWTP	Wastewater Treatment Plant

CHAPTER 1

INTRODUCTION

1.1 Background Study

Nowadays, the wastewater released domestically must be treated before being discharged into the environment, and this treatment is mandated by law. It is particularly apparent in small-scale communities with a low population, when implementing a multipart treatment system is not economically justifiable. The selection of wastewater treatment methods, on the other hand, is challenging and requires a pertinent decision maker. The selection of the best combination of technologies to treat wastewater is a difficult process that requires certain knowledge, such as prior experience, expertise, and human-kind thinking. (Castillo *et al.*, 2017)

Treating wastewater generated from domestic activities is essential for water resource conservation and avoidance of environmental effect. The use of wetlands is one of the alternative treatment approaches to this environmental issue. Wetlands is an improved wastewater treatment method with low-cost budget with simple construction, operation and maintenance. The performance of a constructed wetland as an alternative for wastewater treatment is the subject of this study. Several treatment processes were designed to treat wastewater generated from a domestic area. The treatment of domestic wastewater was monitored to determine the efficiency of constructed wetland as wastewater treatment alternative approach. (Khotimah *et al.*, 2021)

The use of wetlands may be less expensive to construct than other types of treatment. Therefore, it is cost efficient as it is low in construction and operation expenses. Wetlands are natural process utilisation; therefore, it is easy to construct as it may be built using local resources. In addition to this, it is easier to handle compared to the conventional treatment facility as it only needs simple operation and maintenance.(Un-Habitat, 2008)

In general, there are two main types of constructed wetlands namely surface flow and subsurface flow. In surface flow constructed wetlands, water flows above ground while subsurface flow constructed wetlands are designed to keep the water level below the top of the rock or gravel media to minimize human and ecological exposure. (Halverson, 2004)

Based on the Environment Quality Report, the three important parameters to determine the water quality is Total Suspended Solid (TSS), Biological Oxygen Demand (BOD) and Ammonia. However, there are already many studies based on TSS, and Ammonia parameter that has been done. The study based on BOD parameter is uncommon thus it has been chosen as the parameter in this project to acts as an indicator for pollutant removal.

BOD is a measure of the amount of oxygen required to remove waste organic matter from water in the process of decomposition by aerobic bacteria (those bacteria that live only in an environment containing oxygen). BOD is used, often in wastewater-treatment plants, as an index of the degree of organic pollution in water

In this study, the pilot scale study site selected is in the USM Engineering Campus of Nibong Tebal, Penang. This study is significant, given the rising volume of wastewater, there are a need of an alternative method that are more environmentally friendly and sustainable. From observations being made, it was found that there is no common alternative method to support the ongoing conventional wastewater treatment or even as a replacement for it which requires further study. Therefore, this study is conducted to find out the performance level of constructed wetland as an alternative method to conventional wastewater treatment with parameter BOD as the main indicator of nutrient removal.

1.2 Problem Statement

Conventional method for wastewater treatment is to use Sewage Treatment Plant (STP), but when it is located far away from the source of the wastewater, it will be an issue in terms of cost effectiveness and access. The conventional centralized energy- and cost-intensive technique (physical, chemical, and biological treatment) has shown to be fairly limiting and not totally sustainable. It is practically imperative to seek new, low-cost, and ecologically friendly alternatives to address these significant challenges. (Dongqing Zhang et al, 2009). Therefore, the alternative method is to use wetlands as treatment.

Most of the wetlands in Malaysia are used to treat runoff water. Putrajaya for instance holds the largest wetland in a tropical country. Putrajaya wetland is the first wetland in Malaysia, and it is used to treat surface runoff from an upstream catchment produced by development and agricultural operations It was intended for stormwater treatment, flood control, and recreational usage. (Sim *et al.*, 2008). Thus, there are not many localized studies using Constructed Wetland System (CWS) are applied to treat domestic sewage.

In this study, the source of the sewage supplied which flows into the constructed wetland system may not meets the standard design parameter for sewage concentration for pollutants according to SPAN Guidelines. To produce a study which are similar to the actual application of wastewater treatment in domestic area, the pollutants concentration in this study must at least have similar concentration and characteristics to the SPAN Guidelines.

When all requirements are met for the study to be conducted which can reflects the actual application of wastewater treatment, then the effectiveness of constructed wetland can be determined. It needs to be known whether CW can act as an alternative for conventional method and effective in removing BOD throughout the system.

There are two types of constructed wetlands: free water surface flow (SF) wetlands and subsurface flow (SSF) wetlands. From the two types of wetlands, it can be assumed that the treated effluent from subsurface flow and surface flow may result in different effectiveness of pollutants removal. Hence, the study to compare the BOD removal between the outcome of the two types of wetlands is proposed in this project.

There are not enough established systems to show CW's treatment capabilities. The absence of engineering guidelines on the design and construction of the CW further discourages the government and commercial sector from adopting such a system. Furthermore, CW deployment is hampered by a lack of technical understanding and a huge land area need. Therefore, recommendation for future studies is needed to be made and proposed so that a more detailed study can be produced and reviewed.

Although the beneficial usage of constructed wetlands for wastewater treatment is widely established, our understanding of the dynamics and long-term functioning of these systems is still in its infancy. As the ambiguities around the usage of constructed wetlands are addressed, this approach will take its appropriate position alongside more conventional wastewater treatment options.

The research findings in the experimental wetlands cannot directly reflect the actual performance of a large-scale field project due to their limited scale and short running period. Nonetheless, they can provide solid evidence that constructed wetlands can improve BOD removal capability in wastewater treatment.

Although, there are many research studies, it is possible to critically evaluate and summarize the available knowledge of the indicated areas, only a few studies reviewed and summarized the existing knowledge on some of the above-mentioned topics with specific focus on BOD removal.

1.3 Objectives

The objectives of this research are listed below:

1. To characterize the BOD concentration in the raw sewage to achieve the standard design parameter.
2. To study BOD removal efficiency of the constructed wetlands system in treating the domestic sewage from source to outlet.
3. To compare the effectiveness between sub-surface flow and surface flow constructed wetland in BOD removal.

The main purpose of this study was thus to evaluate the performance of a pilot-scale Constructed Wetland with BOD as a parameter to measure the pollutant removal. Another one was to investigate the pollutant removal of Surface and Sub-Surface Constructed Wetland.

1.4 Scope of Study

A pilot scale study of constructed wetland in USM Engineering Campus was created to occupy the research work. Water sampling includes inlet from water tank and

7 points at ponds and outlets are collected. The water samples are measured both in-situ and at laboratory.

To optimize the operating factor required for the pollutant removal in constructed wetland, the operating parameter used to measure the pollutant removal are BOD concentration. The boundary of the study is to take the BOD readings from the water sampling. The focus of the study is to measure the concentration of the BOD to determine the removal efficiency of pollutants in the constructed wetlands.

The removal efficiency of BOD in the wastewater sample are proven by the observation of the colour of the water sample at the outlet. The comparison of BOD removal performance between the sub-surface flow and surface flow will be made in this study.

1.5 Expected Outcome

1. Verification of sewage condition based on SPAN Guidelines for Design Parameter of Sewage Water.
2. Efficiency of the wetland in removing water pollutants based on domestic sewage water.
3. Determination of BOD removal rate for surface and subsurface flow.

1.6 Significance of Study

Wastewater treatment plant is often can be in higher demand due to rapid development. Thus, constructed wetland can be an alternative method to provide helps in supplying good water quality to human and aquatic lives while fulfilling domestic demand. Specifically, it removes BOD from effluent that will destroy the aquatic lives in the area by utilizing natural process. Lastly it can provide an alternative and improved wastewater treatment method with low-cost budget by simple construction (low construction and operation costs), as well as simple operation and maintenance (can be constructed with local materials).

1.7 Dissertation Outline

This thesis is organised into five chapters and appendices that attempt to present the work conducted on the research subject in a way that is consistent with the development of the subject matter at hand. Each contribution to the thesis is presented in a separate, self-contained chapter.

Chapter 1: Introduction. The first chapter serves as an introduction. This chapter briefly introduces the study's background and explains the thesis's broad structure in terms of problem statement, objectives, and scope of work.

Chapter 2: Literature Review. The second chapter is the literature review which focuses on some of the previous studies related to this research work, which can be categorised by paper, topic, methodology, or outcome. This chapter also reviews several research works that have been done on wastewater treatment using wetlands.

Chapter 3: Methodology. The third chapter describes in detail the method used to conduct the research using the pilot scale constructed wetland. This chapter covers the wastewater characterization, data collection and constructed wetland design. The method for Water Quality Testing is also included that used is to measure the BOD concentration of the wastewater flowing through the constructed wetland.

Chapter 4: Results and Discussions. The fourth chapter comprises of results of the water quality testing and discussion on the findings. This chapter contains a summary of the results BOD concentration as well as the performance of the CWS in achieving the objectives.

Chapter 5: Conclusion and Recommendation. The fifth chapter summarises the work as well as providing recommendations based on the study's objectives. Furthermore, this chapter addresses some unresolved issues and discusses the potential and opportunities for future research directions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the rapid expansion of the economy and the rise in residents' living standards, there is an increasing amount of sewage discharge that must be treated. This type of sewage has a high concentration of organics (such as protein, carbohydrates, fat, and urea), pathogenic microbes, and suspended particles. This chapter contains sections which cover the topic of wetland and its design as well as the water quality parameter and wastewater treatment in Malaysia as it is now.

2.2 Domestic Sewage

Humans have increased the intake of nutrients, particularly nitrogen and phosphorus, into natural ecosystems via domestic sewage.(Aslan and Kapdan, 2006)

Domestic sewage is wastewater that is taken from houses, hotels, restaurants, schools, and shopping centres on a regular basis. It has a vast range of sources and a large amount. Domestic sewage water comprised of black and grey water component. Grey water is often regarded as wastewater that has not been contaminated by toilets and thereby includes sources such as baths, showers, hand basins, washing machines, baths, dishwashers, and kitchen sinks (De Gisi *et al.*, 2016). It has lower contamination levels, making it much easier to treat and process. Black water on the other hand is the effluent from toilets and bathrooms that contains faeces and urine.

In general, domestic wastewater constitutes greywater and blackwater, in which greywater is the wastewater generated from households through showering and washing activities, and blackwater is the mixture of faeces, urine and flush water discharged from toilets. It should be noted that blackwater only constitutes a small portion of the total domestic water, but it contains the majority of the organic matter, nutrient, and total pathogen. (Tan et al., 2019)

2.2.1 Properties of Domestic Sewage

Wastewater is classified according to its physical, chemical, and biological components. Physical analysis determines the physical properties of wastewater, such as temperature, colour, odour, turbidity, and total solids. In general, wastewater temperatures are slightly higher than water temperatures, and dissolved oxygen solubility is similarly temperature dependent. Temperature influences solid settling as well. The greater the temperature, the lower the viscosity of the sludge, and hence the better the settling. (Gaurab, 2019)

Chemical properties of wastewater include factors that cannot be seen, tasted, smelled, or touched. Chemical properties include nitrogen, pH, phosphorus, chloride, sulphate, metals, and organic compounds, as well as biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Prior to treatment, wastewater is generally somewhat alkaline. However, as the wastewater passes through the anaerobic process, the pH becomes somewhat acidic (Gaurab, 2019)

Domestic wastewater comprises a variety of microorganisms that may be classed as protista, plants, and animals in terms of biological properties. (Gaurab, 2019)

The BOD of wastewater is an indirect indicator of organic pollutant levels. Only organics that are biochemically degradable are oxidised in BOD analysis (School of PE, 2018). Therefore, the biological properties of domestic sewage will be studied using BOD as its primary focus.

2.2.2 Domestic Sewage Treatment

The recent economic crisis has forced many factories to cut production, resulting in lower wastewater flow and, in some cases, serious violations of effluent standards at conventional wastewater treatment plants (WWTP). Some medium and small-scale factories have been discovered illegally dumping untreated wastewater effluent straight into water bodies to save the operational and maintenance costs of traditional wastewater treatment facilities, generating more significant environmental concerns. As a result, a less expensive wetland system has been suggested to replace the current WWTP. (Chen *et al.*, 2006)

The primary goal of wastewater treatment is to eliminate organic materials and nutrients rather than to recycle them. The optimal treatment technique is determined mostly by the concentration of pollutants and the nature of the wastewater. (Jiao, 2021)

Conventional method for wastewater treatment in Malaysia is to use Sewage Treatment Plant (STP). Conventional water treatment employs a variety of physical, chemical, and biological procedures. Preliminary, main, secondary, tertiary, and/or advanced water treatment are all terms used to indicate different levels of treatment in increasing sequence of treatment level. (Pakharuddin *et al.*, 2021)

As an alternative to conventional treatment technologies, a series of natural systems have been developed that improve on the water treatment processes that occur naturally in nature; in them, purification is acquired through natural physical, chemical, and biological processes, which are developed in a plant-soil-water system. (Pérez Villar *et al.*, 2012a)

An alternative method such as using the constructed wetland system for treatment is still not as common as it should be. The existing and newly developed constructed wetland systems in Malaysia are all designed for stormwater or surface water treatment. Nutrient levels in these waters are generally low depending on land use activities in the catchment. (Sim *et al.*, 2008)

According to the study conducted in Langkawi Resort. Results shows that treated effluent values obtained at the end of the treatment aligned with the current Department of Environment standards for domestic wastewater discharge. (Akhir et al., 2017)

Sewerage service is an important part of public sanitation, which protects public health by reducing the risk of disease outbreaks due to pollution by domestic wastewater. In Malaysia, the major challenges of the development of a sewerage system are population density, piped water and energy supply, and funding for operation and maintenance. (Tan et al., 2019)

2.3 Introduction to Wetlands

Wetlands is an integrated systems in which water, plants, animals, microorganisms, and the environment interact together to improve water quality. Wetlands are classified as one of the best management practises (BMPs) for treating stormwater in Malaysia.

Wetlands are frequently seen as nature-based solutions capable of providing a plethora of services of immense social, economic, and environmental value to humanity (Thorslund *et al.*, 2017). Wetlands are well-known for providing ecosystem services and therefore have a significant potential to be utilized as nature-based solutions to a wide range of environmental, social, and economic concerns. Land-use, water-use, and climate change can all have an influence on wetland operations and services. These changes occur at scales that extend well beyond the local scale of a single wetland. However, engineering and management decisions are often based on wetland projects and local built environments.

Wetland is often defined to include three major components (Mitsch and Gossilink, 2000):

- Distinguished by the presence of water, either at surface or within the root zone.
- Have unique soil conditions (hydric soils) that differ from adjacent uplands.
- Supports vegetation adapted to the wet conditions (hydrophytes) and conversely, are characterized by an absence of flooding-intolerant vegetation.

2.3.1 Constructed Wetland System (CWS)

There are thousands of constructed wetlands across the world that receive and treat a range of municipal, industrial, and urban runoff wastewaters. Because of its operational simplicity and cost effectiveness, constructed wetlands can gain rapid popularity as an alternate technique of wastewater treatment.

Constructed wetlands (CW) has a long-term performance and remains steady for many years. It has lower total lifetime costs and, in many cases, lower capital costs than conventional treatment systems. Therefore, constructed wetland could be an attractive alternative to the conventional wastewater treatment to solve the problem of managing wastewater particularly for rural areas with low population density, as it is simple to operate and maintain and it is cost- and energy effective. (Tan et al., 2019)

Based on the same principles as natural wetlands for wastewater purification, a man-made constructed wetland with effective management can improve effluent water quality. The nitrogen in the water is eliminated by the wetland system through a variety of mechanisms, including biological, physical, and chemical reactions. Under appropriate conditions, its biological capabilities like as ammonification, nitrification-denitrification, and plant uptake are regarded as critical for nitrogen removal. Microbial uptake and accumulation have a role as well. (Chang *et al.*, 2011)

In a constructed wetland, wastewater is treated through an integrated combination of biological, physical, and chemical interactions between plants, substrate, and microorganisms. Constructed wetlands are advocated as a low-cost wastewater treatment method due to the minimal requirements for their operation and upkeep. (Pérez Villar *et al.*, 2012b).

In the experiment to evaluate the free water surface wetlands as tertiary sewage water treatment, the experiment indicates that wetlands are equally efficient as traditional sewage treatment plants (STPs) in the removal of micro-pollutants. (Breitholtz *et al.*, 2012)

Constructed wetland system are engineered systems that have been designed and constructed to use the natural functions of wetlands for wastewater treatment. CWS currently are evolving into an acceptable, low maintenance, and cost-effective alternative for small-scale wastewater treatment. (Yoon, Kwun and Ham, 2001). Furthermore, CWS have significantly lower total lifetime costs and often lower capital costs than conventional treatment systems. When a constructed wetland is deployed to treat wastewater, the microbiological processes may vary. It may offer aerobic, anaerobic, and anoxic conditions conducive to the removal of organic materials and nutrients, particularly nitrogen, by microorganisms.

The effectiveness of a constructed wetland system is determined on the vegetation and filter media utilized. The Department of Irrigation and Drainage has published an urban stormwater management manual (MSMA) as a guideline for eliminating dissolved pollutants from stormwater. However, there are no suitable standards for selecting the medium and plant utilised in constructed wetland for treating domestic wastewater. (Parde *et al.*, 2021)

Constructed wetland are of two types i.e., surface flow constructed wetland (SFCW) and sub-surface flow constructed wetland (SSFCW). Surface flow constructed wetland can be defined when water flows above earth in surface flow constructed wetlands. Subsurface flow constructed wetlands, on the other hand, are intended to maintain the water level below the top of the rock or gravel medium, so limiting human and biological exposure. (Halverson, 2004).

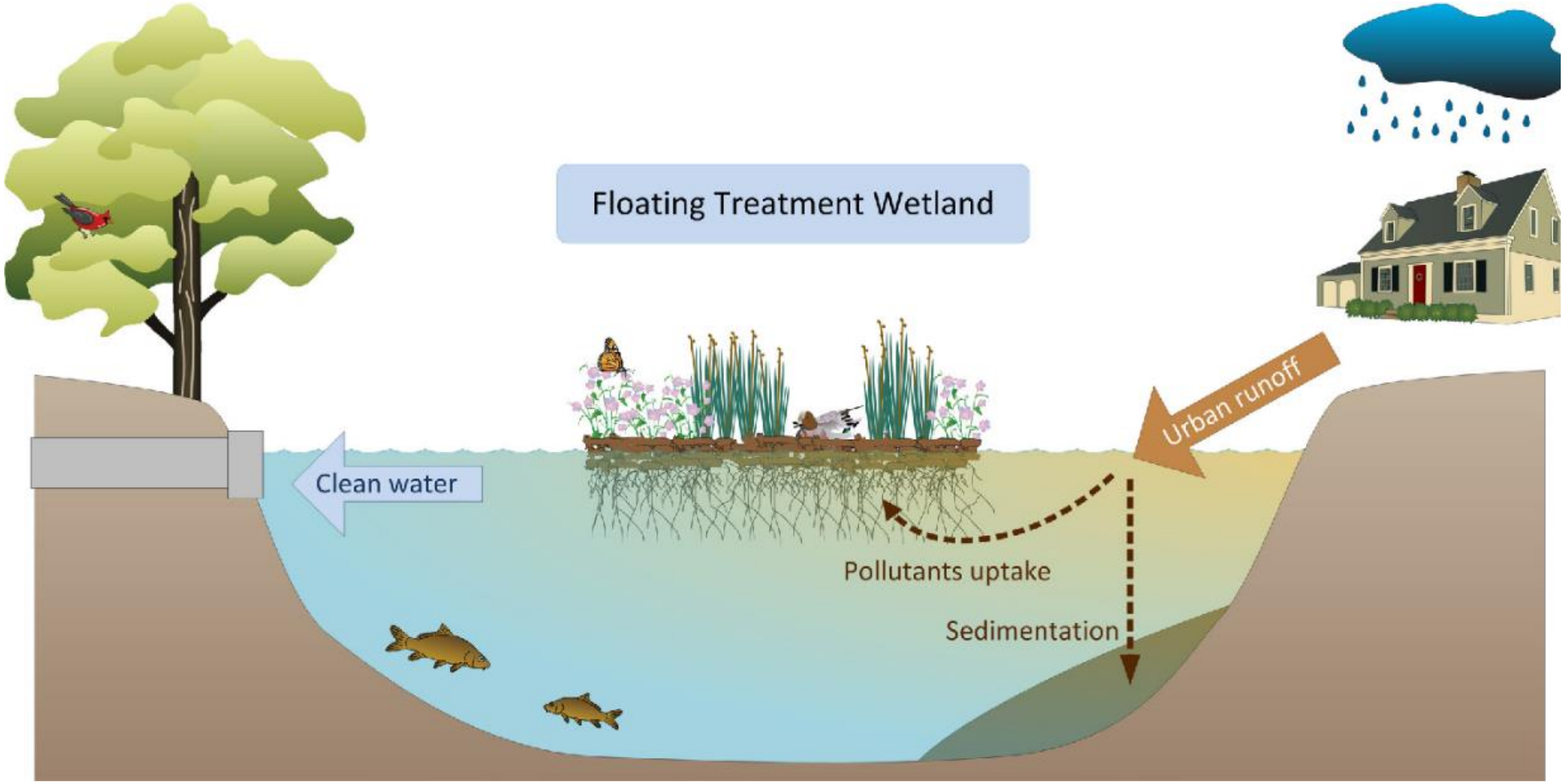

Figure 2.1 Application of Wetland (Sample *et al.*, 2013)

2.3.1.(a) Surface Flow (SF) System

Surface Flow Constructed Wetland (SFCW) is one of the most frequent water ecological restoration approaches. SFS feature a shallow flow of wastewater over a saturated substrate, SF systems are similar to natural wetlands. Surface flow constructed wetland (SFCW), has been shown to be successful in cleaning low-pollution water. Low-pollution water has a low carbon to nitrogen (C/N) ratio, and nitrogen contaminants are often dominated by nitrate. (Zhang *et al.*, 2021)

The constructed wetland, known as SFS can mimic natural systems as the water flows over the bed surface and is filtered through a dense stand of aquatic plants.

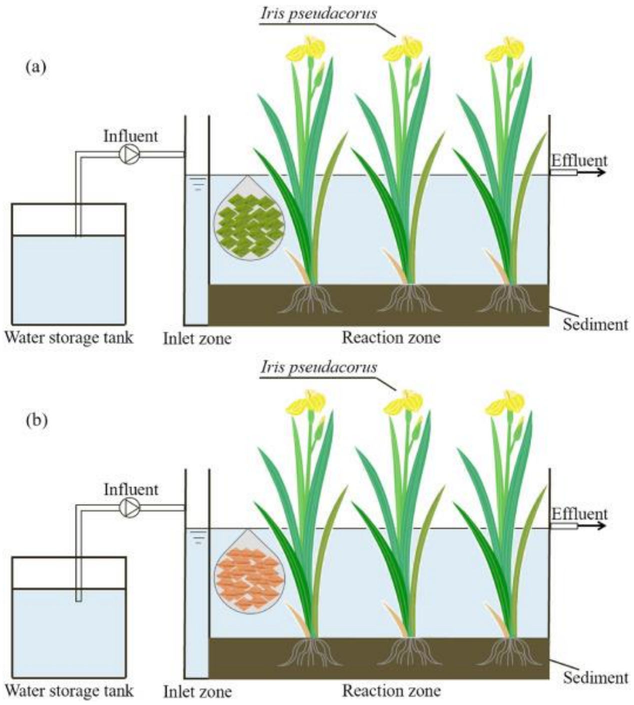

Figure 2.2 Schematic of the SFCW system (a) adding fresh biomass and (b) adding withered biomass. (Wu *et al.*, 2022)

When compared to SSFS, SFS have the disadvantage of lower construction, operation, and maintenance expenses. The drawbacks are in aspects of low pollutant removal efficiency, huge land area occupancy, and increased sensitivity to the issues.

SFCW are commonly used in places with abundant land resources or as part of integrated constructed wetland systems. (Yu *et al.*, 2022)

2.3.1.(b) Subsurface Flow (SSF) System

For more than 30 years, constructed wetlands with subsurface flow have been employed for wastewater treatment. Water runs horizontally or vertically through the substrate in an SSFS system, promoting plant growth. SSFS are typically excavated into the earth, lined, filled with granular media, and planted with emergent macrophytes. Water will circulate through the granular media, interacting with biofilms, plant roots, and rhizomes. To remove pollutants, a variety of approaches are applied.(García *et al.*, 2010)

The majority of CWs are intended to treat municipal or household wastewater. Municipal CWs now focus not only on common pollutants, but also on distinctive parameters such as pharmaceuticals, endocrine disrupting compounds, and linear alkylbenzene sulfonates. (Vymazal, 2007)

The treated effluent from subsurface flow and surface flow may have differing pollutant removal efficacy. Sub-surface flow wetlands demonstrate higher rates of contaminant removal per unit land than surface flow wetlands, therefore sub-surface flow wetlands can be smaller while achieving the same level of contaminant removal. (Halverson, 2004)

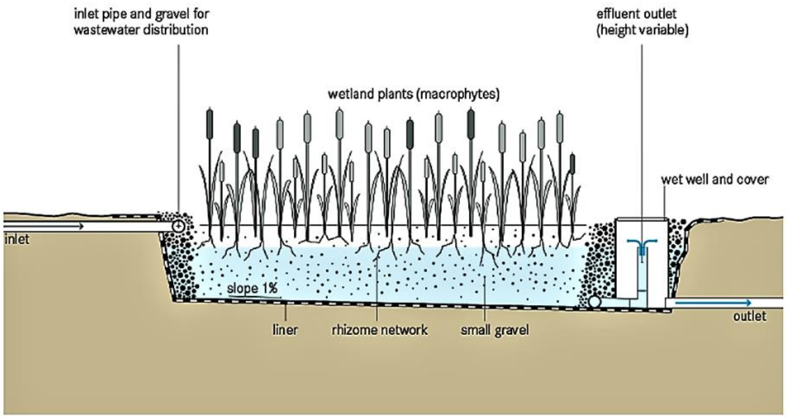

Figure 2.3 Schematic of SSF Constructed Wetland (Tilley *et al.*, 2014)

SSF wetlands are often smaller than SF wetlands for a given wastewater flow, but they cost more per acre. As a result, the possible cost range for constructing an SSF system may overlap with the cost range expected for an SF system. However, both SSF and SF wetland treatment systems have lower capital and operating and maintenance costs than conventional wastewater treatment systems. (Halverson, 2004)

2.3.2 CWS Components

A constructed wetland is composed of water, substrate, plants, invertebrates, and an array of microorganisms. Wetlands that have been constructed include a few main components.

2.3.2.(a) Filter Media

The application of filter media in constructed wetlands is significant for distinguishing them from natural wetlands. 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, and other filter media can be utilised for a constructed wetland (Parde *et al.*, 2021).

Gravel is the most utilised media in constructed wetland. (Abdelhakeem, Aboulroos and Kamel, 2016). It was also reported that a soil and sand mixture in a constructed wetland helps to improved pollution removal efficiency. Gravel-based constructed wetland has greater macro porosity and is less vulnerable to clogging.

2.3.2.(b) Vegetation

Vegetation is an important component of a constructed wetland design. The CW design is very adaptable to many types of wastewaters. Plants have a role in both FWS and SSF systems by absorbing nutrients from wastewater and releasing oxygen into the wetland bed (Tan et al., 2019). The most important job of chosen plants in constructed wetland design is to recreate a natural ecosystem capable of controlling peak flow and treating pollutants. Vegetation may be chosen based on aesthetic value, site layout, and maintenance, and the arrangement can be at irregular points to replicate natural plant growth conditions.(EPA, 2001)

Plants in constructed wetlands absorb and filter pollutants through their roots into above and below ground biomass, minimizing clogging of filter media (Khalifa *et al.*, 2020). Therefore, plants improve the system by providing a suitable condition for microbial population growth. Wetland plants primarily absorb nitrogen (N), phosphorus (P), and other pollutants through the epidermis and vascular bundles of the roots, and then transport them upward to the stem and leaves. Microorganisms reside in plant roots because they provide a source of microbial attachment and exudates, a carbon excretion that contributes to the denitrification process, which increases pollutant removal in anoxic circumstances. (Sandoval *et al.*, 2019)

The macrophytes in typical constructed wetlands are classified into four groups: emergent plants, floating leaf macrophytes, submerged plants, and freely floating macrophytes (Almuktar, Abed and Scholz, 2018). Emergent macrophytes are distinguished by their ability to sustain soil and are typically found above the water's surface. Floating leaf macrophytes are fixed in saturated soils with water depths ranging from 0.5 to 3.0m. Some of the floating leaf macrophytes that have been employed in wetlands are Kuntze, Trapa bispinosa Roxb., and Marsilea quadrifolia L. plants. (Almuktar, Abed and Scholz, 2018)

2.3.3 Removal Efficiency of CWS

Many case studies worldwide have been conducted which shows the removal efficiency of CWS. CWS could be a promising treatment technology for wastewater.

2.3.3.(a) Yörükçal Village, Turkey

Based on previous studies in a rural area located in Black Sea Region (Aydın Temel *et al.*, 2018), a treatment system consisting of a septic tank followed by two horizontal subsurface flow constructed wetland (HSSF-CW) in parallel with diverse vegetation each was developed to treat the sewage of 437 people. This system bed was divided into two equal portions using a curtain wall, and the system consists of four major components: a septic tank, a main manhole (a), two intake manholes (b), two parallel horizontal subsurface flow treatment beds (c), and two outlet manholes (d). Each treatment bed was filled with three gravel layers 20 cm in diameter (5-15 cm), 50 cm in diameter 3-5 cm, and 10 cm in diameter 1.5-3 m above the floor cover material. As vegetation, Juncus acutus L. and Cortaderia Selloana were utilized.

Parameters that were analysed in monthly water samples includes organic matter (OM), ammonium-nitrogen (NH4-N), biochemical oxygen demand (BOD), total nitrogen (TN), total phosphorus (TP), orthophosphate (PO43-), total solid materials (TSM), and total suspended solids (TSS). Analytic test kits were used to analyse them. According to the results of the analysis, the average removal efficiency of Juncus acutus L. and Cortaderia Selloana was 60.3% to 57.7% for (COD), 24.2% to 38.9% for (TN), 31.4% to 49.8% for (OM), 35.4% to 43.3% for TP, 18.9% to 27.1% for (PO43-), 24.4% to 28.7% for NH4-H), 29.5%.

2.3.3.(b) Kaohsiung City, Taiwan

Due to lack of proper planning of disposal of agricultural wastewater, industrial effluents, and domestic wastewater, the Ju-Liao Stream in Kaohsiung City, Taiwan, had excessive biochemical oxygen demand (BOD), ammonia (NH3-N), and suspended solids (SS). According to studies (Lin *et al.*, 2015), the hybrid system, which is a combination of an aerated gravel-packed contact bed (CB) system and a constructed wetland (CW), may effectively remove organic and nutrient contaminants. Thus, in 2010, the Taiwan Environmental Protection Administration (TEPA) and the Kaohsiung City Government launched a hybrid constructed wetland project, which was completed in 2011, to improve the water quality of Ju-Liao Stream and protect the environment there.

Figure 2.4 shows the schematic of the hybrid CW system built in the Ju-Liao Stream's downgradient area. To reduce pollution loading, a first-staged CB system located upstream of the wetland effectively removes pollutants. The CB system's influent and effluent points are S1 and CB. The first-staged system's treated water is then discharged into the stream to dilute the pollutant concentration before being polished by the second-stage CW system. The CW system's influent was at points S2 and S3, and the treated water effluent was at point S4.

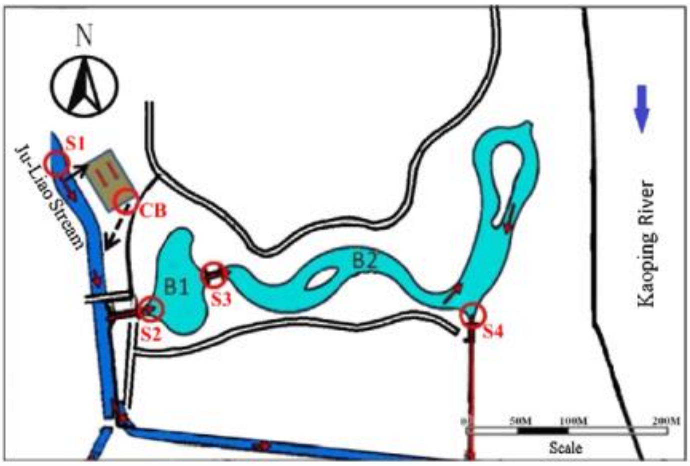

Figure 2.4 Schematic of hybrid CW at Ju-Liao Stream (Lin *et al.*, 2015)

The study's findings indicated that significant removal efficiency for BOD and nutrients pollutants were observed in both the CB and CW systems. According to the study, the CB system could remove up to 69% of SS, 86% of BOD, 82% of TP, and 58% of TN, while the CW system could remove 82% of BOD, 60% of TP, and 27% of TN.

The paper also stated that the removal of SS was hindered by the increase of chlorophyll in the CW system as a result of algae growth. Increasing the spread of floating-leaf wetland plants in the wetland basin would be a promising green technology for controlling algal growth. According to the case study, the CB system could remove the pollutant by the aerobic biodegradation mechanism generated by the associated bacteria on the packed gravel. In short, the hybrid constructed wetland system (a combination of CB and CW systems) may efficiently remove the pollutant.

2.3.3.(c) Andalusia, Spain

An integrated pilot-scale treatment system consisting of a vertical subsurface flow (317m^2), a horizontal subsurface flow (229m2), and a free water surface (240m^2) constructed wetlands operating in series for the treatment of a combined sewer effluent was installed and monitored for approximately 1.5 years. Figure 2.5 shows the design of the CWS in the study.

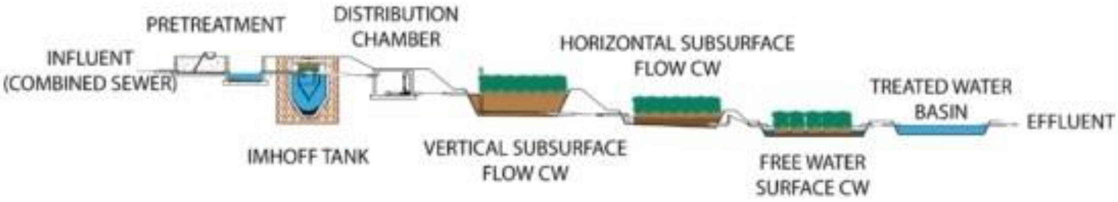

Figure 2.5 Design of Constructed Wetland

The treatment system's objective was to produce effluent acceptable for various water reuse applications. Under dry weather settings, the results demonstrated that the removal of BOD$_5$, COD, and TSS was already taking place in the vertical flow wetland (94%, 85% and 90% respectively). In this regard, horizontal flow and free water surface wetlands proved to be critical treatment units for achieving water quality appropriate for reuse.

Table 2.1 Dry and wet periods' average concentrations of water quality at the effluent of different units of CW system in Andalusia, Spain (ávila *et al.*, 2013)

	Influent	**Imhoff tank**	**HSSF**	**FWS**
Dry period				
BOD$_5$ (mg/L)	393 ± 127	294 ± 80	5 ± 5	7 ± 3