Biochemical Oxygen Demand Removal Enhancement of Agricultural Runoff Using Treatment Train System

by

Amir Al Hafiz bin Abd Razak

24566

Dissertation submitted in partial fulfilment

of the requirements for the

Bachelor of Engineering (Hons)

(Civil and Environmental)

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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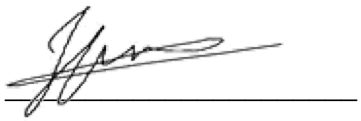

(Dr. Husna Binti Takaijudin)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

Jan 2021

CERTIFICATION OF ORIGINALITY

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

(AMIR AL HAFIZ BIN ABD RAZAK)

ABSTRACT

Agricultural runoff is a non-point source pollution that is unpredictable and difficult to control. The pollutants in agricultural runoff come from fertilizers, sediments, pesticides, and waste coming from croplands and live-stock operations. To measure the quality of water, guidelines prepared by the Department of Irrigation and Drainage, Malaysia called the Urban Stormwater Management Manual (MSMA) suggests the use of indicators, namely biochemical oxygen demand (BOD) measurement. Best Management Practices (BMPs) and Low Impact Development (LID) have been utilized as a method to manage agricultural runoff. Treatment train systems are LID-BMPs arranged in a series that aims to treat and manage agricultural runoff. This study focuses on the use of treatment train systems to reduce the concentration of BOD in agricultural runoff. Characterization of agricultural runoff from a nearby palm oil plantation was done which acted as a benchmark to the synthetic runoff that was prepared and used as influent to the treatment train system. From the characterization study, it was found that agricultural runoff from the palm oil water channel had an average BOD_5 reading of 12.08mg/L and the main river had a lower average reading at 5.48mg/L. The BOD measurements of the main river had a decreasing BOD reading the more downstream the samples were taken due to dilution. A treatment train system was setup with three varying configurations to evaluate the efficiency of BOD removal. The three configurations consists of no vegetation set which acts as the control, vegetated set, and vegetated set with saturated zone. All three configurations showed high final removal rates of BOD at 96% for the control, and 98% for both vegetated sets without and with saturated zone. The control set showed an average final BOD_5 reading of 1.99mg/L, classifying it as Class II according to Water Quality Standards, while both vegetated set without and with saturated zone had an average final BOD_5 reading of 0.91mg/L and 0.87mg/L respectively, classifying both sets as Class I. The performance of the treatment train system was compared to the use of single bioretention system. When only the first bioretention cell was taken into consideration, the control set had an average BOD_5 reading of 7.53mg/L, the vegetated set had a higher average BOD_5 reading of 8.78mg/L compared to the control set, while the vegetated set had the lowest average BOD_5 reading of 5.99mg/L. This would classify all three sets as Class IV which is similar to untreated water, so it can be said that treatment train systems exhibit better performances in BOD removal compared to single bioretention systems.

ACKNOWLEDGEMENT

First and foremost, I owe my thanks to my supervisor, Dr Husna bt Takaijudin, for her never-ending support and deep insight in the course of my final year project here in Universiti Teknologi Petronas. The assistance Dr Husna has provided me in completing this project is one of the main factors of success in this study, and it has also helped me gain invaluable skills and knowledge that would have otherwise gone undiscovered. It is through her help that this project was able to be completed in time with minimal issues.

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TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

ARI	Average recurrence interval
BMP	Best Management Practices
BOD	Biochemical oxygen demand
DID	Department of Irrigation and Drainage
DOE	Department of Environment
LID	Low Impact Development
MSMA	Urban Stormwater Management Manual
PVC	Polyvinyl chloride
R&D	Research and Development
TN	Total nitrogen
TOC	Total organic carbon
TP	Total phosphorus
TSS	Total suspended solids
USCS	Unified Soil Classification System
UTP	Universiti Teknologi Petronas

CHAPTER 1
INTRODUCTION

1.1 Background Study

Humanity has evolved into an era where agricultural productivity and efficiency are at its peak, and it only continues to grow as humans are able to access better technology as the years pass. Over time, humans have discovered methods and ways to increase crop yield, improve productivity, and enhance efficiency. Now, agriculture is one of the biggest sectors that boosts economies. Agriculture acts as a tool to combat poverty through providing a living by producing jobs as well as improving food security. However, with the introduction of advanced technologies in the agricultural sector comes consequences. Over the years, agricultural runoff has become more of an issue. Agricultural runoff is a non-point source of water pollution where water flows from agricultural land use and ultimately reaches bodies of water such as streams and lakes or be absorbed into the Earth. Agricultural runoff is a non-point source of pollution and major contributor to water pollution. The source of contamination stems from fertilizers, sediments, pesticides, and waste coming from croplands and live-stock operations (Wiens, 1980).

The use of inputs such as fertilizers and phosphorus not only help crops flourish, but once it is washed off by the rain, the agricultural runoff carries the input as well and when it reaches water bodies such as rivers and lakes, it acts as a catalyst to the growth of algae which leads to a phenomenon called algal bloom. Unfortunately, the funding required in order to treat the occurrence of algal bloom is very costly (Biello, 2014). The occurrence of algal bloom creates areas in the water body where there is no oxygen present due to all the oxygen content in the water being consumed by algae and releasing carbon dioxide. The lack of oxygen leads to organisms such as bacteria and fish to suffocate and die. The algae also block sunlight from reaching the bottom of the water body which leads to vegetation not being able to perform photosynthesis.

According to Wiens (1980), non-point sources of water pollution is becoming more of a concern as point sources are easier to control. Being a non-point source, control over where and when it occurs becomes more difficult because of its random and unpredictable nature. However, the consequences it brings is not something to dismiss as the impact it brings towards

the ecosystem may be devastating if not controlled. Wiens (1980) mentions that agricultural land use and water systems are linked due to the hydrologic cycle that occurs, where both land use and water systems are affected by each other. This leads to water bodies such as rivers containing relatively high levels of bacterial contamination from agricultural watershed. For example, Bryan's 1976 study (as cited in Wiens, 1980) stated that runoff coming from dairy farms containing manure had shown an increase in fecal coliform levels, which in turn would lead to high concentrations of BOD.

BOD is a biological measurement that acts as an indicator of organic pollution in water. According to Urban Stormwater Management Manual for Malaysia (MSMA) prepared by the Department of Irrigation and Drainage, BOD is the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature (Department of Irrigation and Drainage, 2012). The test involves collecting and incubating a sample for a standard 5-day period and identifying the change in dissolved oxygen. A high BOD concentration would imply that more oxygen is required by organisms and signifies a low quality of water. Water bodies can be classified into five classes indication the level of pollution it experiences as shown in Table 1.1. From a river water quality monitoring program conducted by the Department of Environment (DOE) in 2015, none of the rivers that were monitored could be categorized as clean in terms of BOD as can be seen in Figure 1.1 (DOE, 2015).

TABLE 1.1: Water Quality Standards in Malaysia

Parameter	Unit	Classes				
		I	*II*	*III*	*IV*	*V*
Ammonia Nitrogen	mg/L	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
TP	mg/L	<0.1	<0.1	<0.1	0.1-0.3	<0.5
BOD	mg/L	<1	1-3	3-6	6-12	>12
COD	mg/L	<10	10-25	25-50	50-100	>100
TSS	mg/L	<25	25-50	50-150	150-300	>300

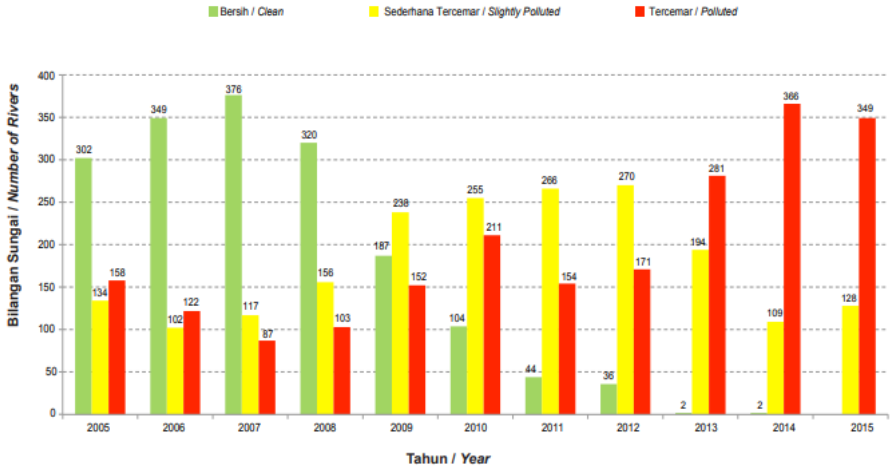

FIGURE 1.1: River Water Quality Trend Based on BOD Sub-Index (2005-2015)

To facilitate the removal of pollutants, Best Management Practices (BMP) and Low Impact Development (LID) approaches have been utilized as a treatment process. As stand-alone treatment systems, the efficiency of removing pollutants is limited and it is believed that the utilization of treatment trains would help improve the overall performance (Revitt et al., 2017). The use of treatment trains can be considered cost effective and these systems take advantage of natural processes, namely infiltration to remove pollutants (Simpson & Roesner, 2018). Bioretention systems function by intercepting runoff infiltrating vertically through a soil media, and treatment occurs through various processes such as evaporation, transpiration, sedimentation, filtration, sorption, enhanced denitrification, and biological processes (Laurenson et al., 2013). According to Goh et al. (2017) *Red Hot Chinese Hibiscus* may act as a suitable plant for the vegetation due to the plant requiring low to moderate maintenance. A typical bioretention system can be referred to in Figure 1.2.

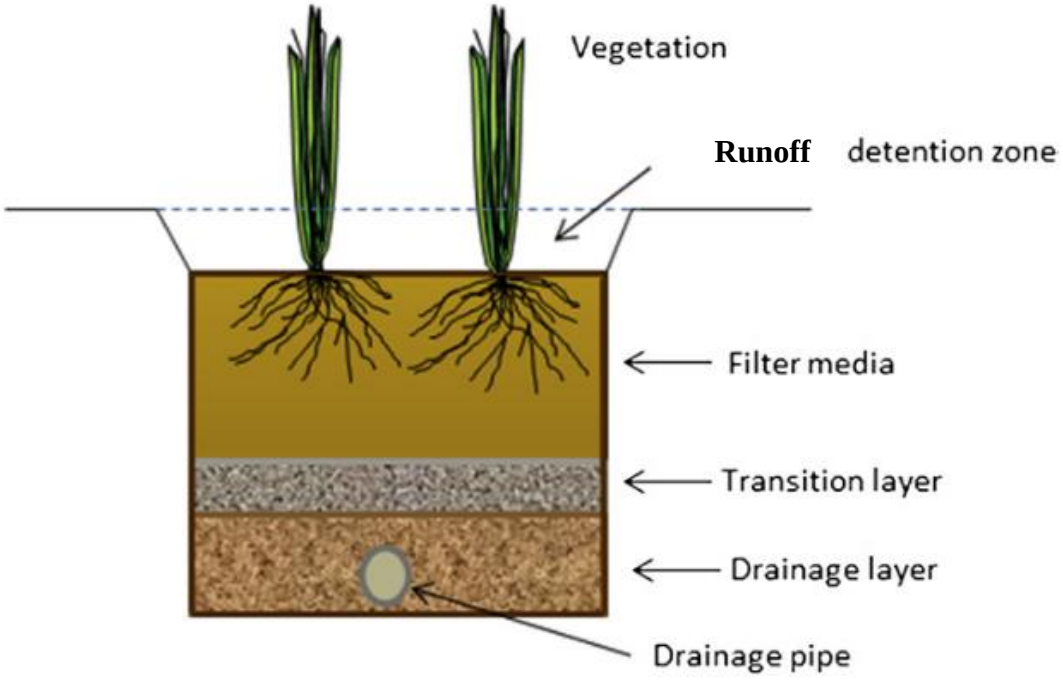

FIGURE 1.2: Cross-section of a bioretention system

1.2 Problem Statement

Water is a vital resource in the agricultural sector. Water sources for agricultural and irrigation use usually includes rivers, reservoirs, lakes, rain, and even groundwater. Water is used by the crops and plants for photosynthesis as well as help transport nutrients found in the soil into the plant. Modern day agricultural practices use a high number of additives such as fertilizers and pesticides to increase the quality and quantity of yield. These substances end up in the agricultural runoff which causes water pollution. The Department of Irrigation and Drainage of Malaysia (DID) has prepared an Urban Stormwater Management Manual that includes standards and practices that should be followed for all matters related to water management. One of the indicators that can be used to characterize pollutants for runoff is biochemical oxygen demand (BOD). A high BOD value would indicate a high amount of organic pollution in a body of water which has the potential to disrupt the local ecosystem. Agricultural runoff from plantations contain all sorts of pollutants such as pesticides and fertilizer that has seeped into the soil. Treatment train systems are introduced to act as a filter to remove BOD in runoff.

1.3 Objectives

1. To characterize agricultural runoff from a nearby site as a pollutant source benchmark
2. To measure the concentration of biochemical oxygen demand (BOD) in agricultural runoff passing through a treatment train system
3. To compare the effectiveness of BOD removal in a treatment train system and a single bioretention system

1.4 Scope of Study

The scope of this study focuses on BOD in agricultural runoff and the performance of treatment train systems in the removal of BOD concentrations. Characterization of agricultural runoff obtained from a nearby plantation was conducted to determine the average readings of BOD concentration in agricultural runoff and used to develop a synthetic runoff with similar characteristics of the collected agricultural runoff samples to perform this study. Treatment train systems were set up and the ability and efficiency of the treatment train systems to remove BOD was conducted. Different soil configurations in the treatment train were used in order to identify any factors that may improve BOD removal. The outcome of the BOD removal monitoring were used to illustrate the performance of the treatment train systems in removing BOD. Not only that, a comparative study was also conducted between the performance in treatment train systems and a single bioretention system. The treatment train system consists of a series of bioretention cells. Different configurations of the soil media were prepared and their performance in BOD removal were evaluated.

CHAPTER 2

LITERATURE REVIEW

2.1 Urban Stormwater Management Manual (MSMA)

The Urban Stormwater Management Manual (MSMA) prepared and provided by the Department of Irrigation and Drainage, Malaysia acts as a guideline in preparing all matters related to stormwater management. It is mentioned that there are several indicators that can be used to characterize pollutants, with BOD being one of them listed indicators. Various BMP types are recommended for present use, including bioretention facilities. The guidelines mention that "these devices use a filtering action to remove pollutants, mainly particulate material" (DID, 2012). The guidelines include information on treatment selections of various BMP types. Treatment selections are provided with various information as shown in Table 2.1. MSMA also defines low, medium, and high treatment targets for the BMPs in removal of total suspended solids (TSS), and nutrients in total nitrogen (TN) and total phosphorus (TP) which indicates the performance of the BMPs as can be seen in Table 2.2. The guidelines also classify water quality standards according to pollutant loadings, with BOD being one of the parameters. The water quality standards classification can be seen in Table 2.3.

TABLE 2.1: Bioretention selection according to MSMA

BMPs Type	Pollutant Removal Efficiency			Cost
	Gross Pollutants	TSS	Nutrient (TN & TP)	
Bioretention	Low	High	High	Medium

TABLE 2.2: Classification of Treatment Targets for Individual BMPs

Pollutant	Target of Treatment		
	Low	Medium	High
TSS	Less than 40% of particulates greater than 0.125mm retained.	40-70% of particulates greater than 0.125mm retained.	More than 70% of particulates greater than 0.125 mm retained.
Nutrients (TN & TP)	Less than 10% reduction	10-40% reduction	More than 40% reduction

TABLE 2.3: Water Quality Standards in Malaysia

Parameter	Unit	Classes				
		I	*II*	*III*	*IV*	*V*
Ammonia Nitrogen	mg/L	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
TP	mg/L	<0.1	<0.1	<0.1	0.1-0.3	<0.5
BOD	mg/L	<1	1-3	3-6	6-12	>12
COD	mg/L	<10	10-25	25-50	50-100	>100
TSS	mg/L	<25	25-50	50-150	150-300	>300

2.2 Agricultural Runoff

Agricultural runoff is a non-point source of pollution which is neither uniform nor predictable, which makes the management of agricultural runoff difficult and more complex (Wang et al., 2018). Agricultural runoff is a result of water flowing through agricultural land use and washing away with it the components and inputs in agriculture, such as pesticides, manure, and fertilizers such as phosphorus. A study by Dunne et al. (2005) mentioned that agricultural runoff usually contains higher concentrations of nutrients such as nitrogen and phosphorus and organic matter, which leads to an increase in BOD concentrations when compared to municipal effluent. The effects of agricultural runoff are detrimental to the environment, especially the ecosystem of the water bodies that are affected. According to Wiens (1980) agricultural land use is directly related to water systems, where chemicals applied to the land from pesticides and fertilizers may be carried away by the surface waters of overland flow, interflow, or groundwater flow, and will reach water bodies such as rivers and lakes. Pollutants of concern in agricultural runoff have the capability of affecting fish spawn gravels, limiting light penetration and biological productivity, and accelerated eutrophication effects (Wiens, 1980). A study performed by Ghane et al. (2016) compared the transport of contaminants between agricultural drainage water and urban stormwater runoff and found that croplands transported higher nitrate and TP loads while carrying lower TSS loads compared to urban areas. In the study, a comparison between fertilized field and unfertilized field was made and while the unfertilized field had not receive fertilizer or manure in 11 years, the area showed a cumulative nitrate load per area of 58% of that of the fertilized field.

2.3 Biochemical Oxygen Demand

Based on the Urban Stormwater Management Manual for Malaysia (MSMA) prepared by the Department of Irrigation and Drainage, biochemical oxygen demand (BOD) is the amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature (Department of Irrigation and Drainage, 2012). BOD is one of the indicators of water pollution listed in (MSMA). A higher concentration of BOD means that a high amount of oxygen is required by organisms, signifying that the water quality is low. Albeit chemical oxygen demand (COD) and concentrations of total organic carbon (TOC) are faster and more accurate at determining water quality, the data "provides little information on the biological nature of organic compound decomposition" (Schreiber & Neumaier, 1987). Oxygen required by bacteria to decompose organic matter should be evaluated so that the effects of agricultural runoff on the oxygen resources in the water body may be determined. Previous studies have noted that sample collection should be tested for BOD measurements within 3 to 4 hours, and if the situation does not allow it, the samples may be kept at low temperatures for storage and tested within 24 hours (Schreiber & Neumaier, 1987). Based on a characterization study performed by Udeigwe et al. (2010) the BOD_5 measurements for agricultural runoff coming from plant agriculture generally have a BOD_5 range of 11.6mg/L to 40.1mg/L as can be seen in Table 2.4.

TABLE 2.4: Characteristics of water samples generated from different sources (Udeigwe et al., 2010)

Source material	Sample size	pH	BOD_5
CM	7	6.7 (1.0)	34.4 (15.3)
CR	2	5.5 (0.2)	30.2 (6.6)
GR	5	6.2 (0.3)	40.1 (11.3)
PM	8	6.6 (0.5)	66.1 (8.5)
RR	4	6.0 (0.4)	20.8 (6.5)
SB	4	6.2 (0.1)	48.4 (4.4)
SR	4	6.1 (0.2)	14.4 (3.7)
SS	3	5.5 (1.6)	50.2 (13.2)
WR	9	5.9	11.6 (3.2)

Data represent the mean values with the standard deviation of each given in parenthesis

CM cattle manure, *CR* corn residue, *GR* grass residue, *PM* poultry manure, *RR* rice plant residue, *SB* soy bean residue, *SR* sugarcane residue, *SS* sewage sludge, *WR* wetland plant residue

2.4 Best Management Practices (BMPs) and Low Impact Development (LID)

In order to minimize environmental impacts of water pollution, an economical solution would be to utilize best management practices (BMPs) and low impact development (LID). BMPs and LIDs are water management approaches that have been used to manage runoff as close to

its source as possible (Fletcher et al., 2015). Bioretention systems have been identified by (MSMA) as a component of BMPs that can improve the quality of effluents. Bioretention systems function by intercepting runoff infiltrating vertically through a soil media, and treatment occurs through various processes such as evaporation, transpiration, sedimentation, filtration, sorption, enhanced denitrification, and biological processes (Laurenson et al., 2013).

A treatment train system is an integration of best management practices (BMPs) and low impact development (LID) in a series. The use of single system BMPs and LIDs are not too effective according to a study by Revitt et al. (2017). The study also mentions that soil layers may become saturated with pollutants over time, limiting the removal efficiency of pollutants of the system (Revitt et al., 2017). Following that, a study by Goh et al. (2017) found that a well-designed engineered soil is an important factor in setting up a bioretention system, as it ensures the requirements for pollutant removal are met. The study also mentions that the use of Red Hot Chinese Hibiscus (*Hibiscus rosa-sinensis*) which is a common landscape shrub found in tropical countries is a suitable plant that can be used as vegetation due to the plant requiring low to moderate maintenance as well as being a hardy plant species that is able to withstand dry weather (Goh et al., 2017). Should the plant face any difficulties getting suited with the column configurations, a Ti plant (Cordyline fruticose) shall serve as a backup option as the plant has shown promising performances in a study by Hermawan et al (2020) and it crosses most of the criteria that have been provided by MSMA (2012) such as low maintenance, good root penetration, tolerance to pollutants, and the adaptation to the local climate and soils while also being locally available.

2.5 Summary of Past Literature

Through past literature and even the proper guidelines prepared in MSMA, not much information is available in the performance of treatment train systems in removal of BOD. As can be seen in the guidelines in MSMA, most of the content in preparation of single bioretention systems focuses on the removal of TSS as well as nutrients and pollutants, with little focus on BOD removal. The guidelines merely mention BOD as a pollutant indicator and nothing more. Even then, the guidelines focus on single treatment systems and have limited information on treatment systems arranged in series. Other than that, most of the guidelines focuses on treating stormwater runoff with much more detail compared to agricultural runoff.

CHAPTER 3

METHODOLOGY

The research methodology flowchart in Figure 3.2 represents the process flow of this study as well as the activities conducted.

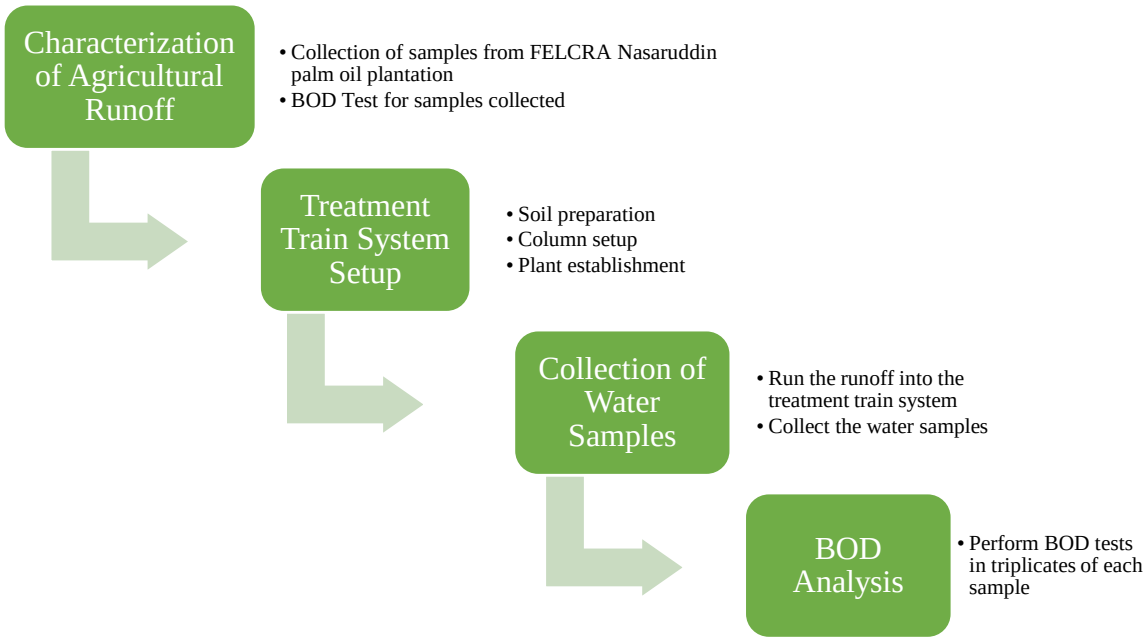

FIGURE 3.1: Research methodology flowchart

3.1 Characterization of Agricultural Runoff

Samples are taken from a palm oil plantation nearby located at Jalan Felcra Nasaruddin for characterization purposes to be used as a benchmark. The samples were collected and analyzed for its BOD concentrations. Two types of samples were collected, which were from the palm oil water channel and the river where the water channels flow into. Samples were taken from three different locations along the water channel and three more locations along the river which can be seen in Figure 3.2. From the characterization study done, the pollutant source can be used as a benchmark for the performance of the treatment train system in removing BOD of the synthetic runoff used.

FIGURE 3.2: Location of agricultural runoff sample collection at Felcra Nasaruddin

3.2 Treatment Train System Setup

A series of three bioretention columns will be set up as shown in Figure 4. Three different column configurations will be used containing different configurations, which are;

I. No vegetation with 300mm soil depth (control)
II. Vegetation with 300mm soil depth
III. Vegetation with 300mm soil depth and saturated zone

The bioretention column consists of a ponding zone, soil media, sand layer, and gravel layer. A Ti plant (Cordyline fruticosa) is planted in the ponding zone for columns with vegetation as a replacement to the Red Hot Chinese Hibiscus plants that were planted prior because it was found that the plants were wilting. The soil media is made up of 60% sand, 30% topsoil, and 10% compost that is mixed together. The soil media depth is 300mm, the sand layer depth is 95mm, and the gravel layer depth is 100mm. The water tank holds 150L of synthetic runoff acting as the influent. The system is controlled by valves which allows for the influent to flow through column 1, which will flow to column 2 and column 3 with time. The outlets of each column simulate a free falling of the runoff which helps aerate the runoff to allow for more supply of oxygen to the runoff.

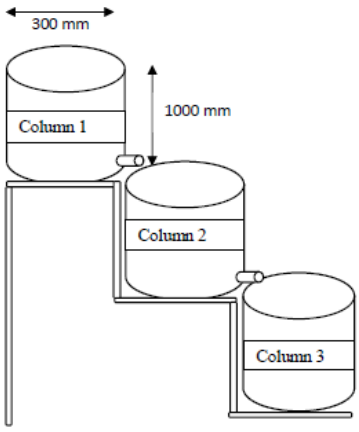

FIGURE 3.3: Treatment train cross-section

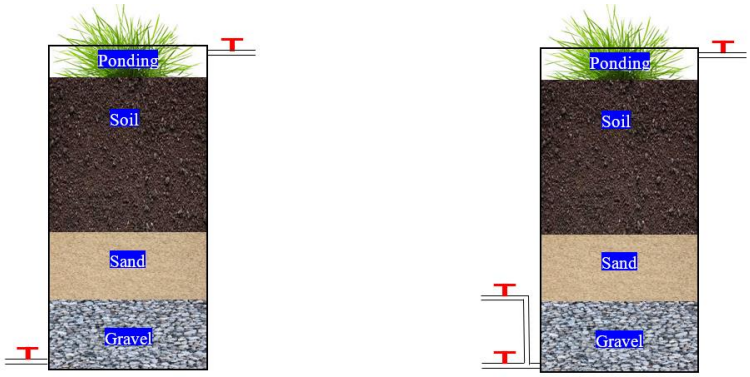

FIGURE 3.4: Column without saturated zone (left) and column with saturated zone (right)

The saturated zone is controlled by having and L-shaped tube connected to the outlet. In this way, the columns will retain water up to 10mm according to the length of the L-shaped tube and will discharge naturally due to the pressure head that is built up. The introduction of the saturated zone is to increase the retention time of the runoff inside the column configuration. Previous studies also performed tests involving a saturated zone.

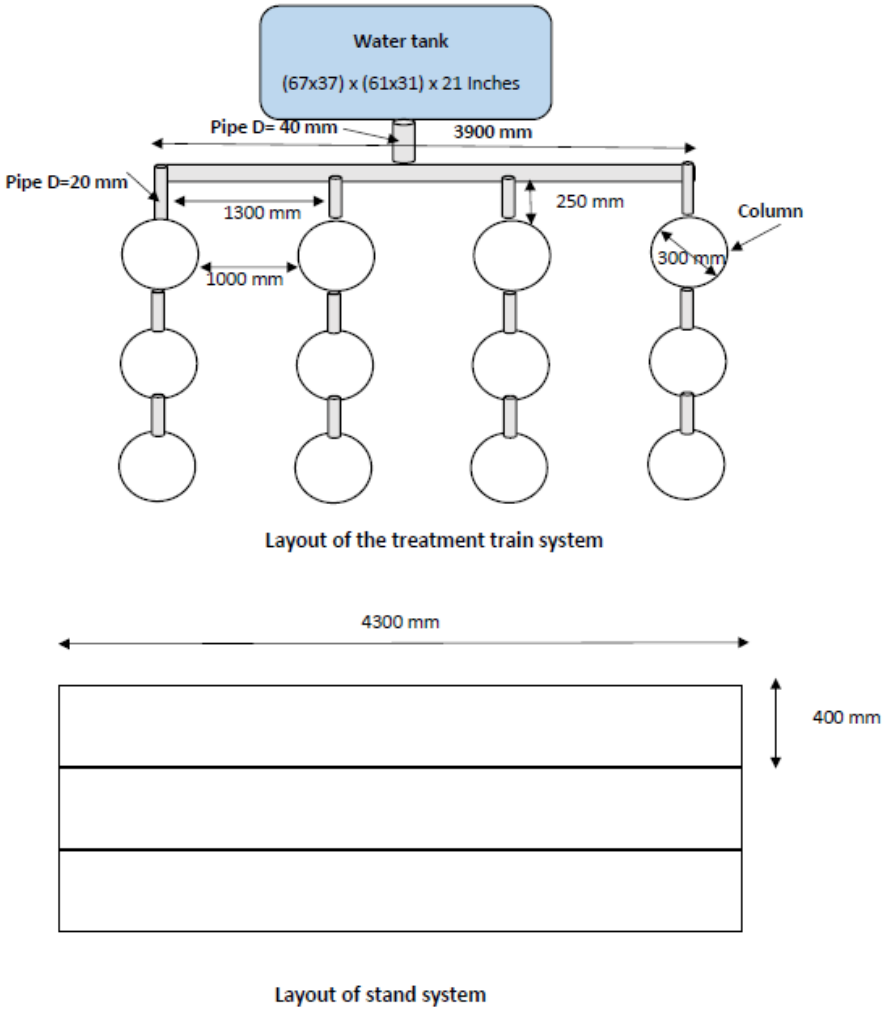

FIGURE 3.5: Layouts of the treatment train system (top) and stand system (bottom)

FIGURE 3.6: The setup of the treatment train system

The soil was collected in a location nearby UTP's Research and Development (R&D) building. Soil classification was conducted to identify the type of soil collected. The soil was oven dried for 24 hours before performing specific gravity test, particle size distribution test, and hydrometer test. Once done, the soil is mixed to consist of 60% soil, 30% sand, and 10% compost using an industrial mixer. Then, the columns were placed with a gravel layer, sand layer, and the soil mixture layer with filter media in between the layers. Openings were made at the bottom of each column and inserted with PVC tubing for the outflow. Another opening was also made at the top of each column to control the overflow.

FIGURE 3.7: Location of soil collected

3.3 Preparation of Synthetic Agricultural Runoff

The use of synthetic agricultural runoff in this study was to overcome the limitation of using actual agricultural runoff that would require multiple trips to obtain large volumes of the agricultural runoff that would act as an influent to the system. The synthetic runoff is prepared with measurements according to Table 3.1 which includes the measurements scaled according to the 60-gallon water tank (227 liters) that was used. The calculations were made according to a characterization study and was compared to past literature.

TABLE 3.1: Composition of synthetic agricultural runoff

Synthetic Agricultural Runoff Constituents	Chemical	Amount (g)
Nitrate	Potassium nitrate (KNO_3)	11.824
Ammonium	Ammonium chloride (NH_4Cl)	2.753
Total Phosphorus	Potassium di-hydrogen phosphate (KH_2PO_3)	1.87
Organic Nitrogen	Urea (CH_4N_2O)	0.466
Glucose	Glucose ($C_6H_{12}O_6$)	22.720

The synthetic runoff was prepared by measuring each chemical constituent using a weighing scale with a tolerance of 0.01g. The chemical constituents are then put into a beaker and mixed with tap water. The synthetic runoff is then poured slowly into the water tank while stirring continuously. The synthetic runoff is prepared prior to every run, as it begins to be contaminated with algae after 3 to 4 days.

3.4 Collection of Synthetic Runoff Samples

Samples are collected from the influent and discharge from column 1, column 2, and column 3 for all configurations for BOD testing. First, the valves at each column configuration were adjusted to a flowrate of around 0.008L/s which is scaled down by a factor of 500 of 3-month average recurrence interval (ARI) of rainfall. The synthetic runoff is not allowed to enter the column configurations until the flowrate has been adjusted to avoid discrepancies in the volume of water in the system. As the flowrate has been set appropriately, the synthetic runoff is allowed to flow for 15 minutes and the final discharge at the end of each column configuration to measure the amount of volume left inside of the column setup. Once collected, the samples were stored in a dark condition and immediately tested to not allow for external factors to take action and disturb the samples. Samples were taken in three replicates for influent as well as each discharge from the columns for all configurations to obtain an average reading as well as to eliminate any false readings.

3.5 Method of Testing

3.5.1 Specific Gravity of Soil by Pycnometer Method

The specific gravity of the soil collected was used for soil classification and was tested using a pycnometer top and jar. The specific gravity of the soil was computed as the ratio of mass of soil particles to the mass of water at the same volume. Firstly, an empty pycnometer jar was weighed to the nearest 0.05kg and the values are recorded as W1. Oven dried soil samples were filled into the jar and weighed and recorded as W2. Water was added into the jar until two-thirds full. The jar was left for some time to allow the soil particles to settle before filling the jar with water until the tip of the pycnometer top. The jar was weighed again and recorded as W3. Finally, the jar was emptied and washed, filled with water to the tip of the pycnometer top and weighed and recorded as W4. This process was repeated with another jar to confirm the results of the first test.

FIGURE 3.8: Pycnometer jar filled with soil and water

The specific gravity of soil is calculated as follows;

$$G_s = \frac{W2 - W1}{(W4 - W1) - (W3 - W2)}$$

3.5.2 Particle Size Distribution of Soil (ASTM D6913)

The distribution of the particle size of the soil particles was tested for soil classification. The soil was oven dried for 24 hours and was passed through a series of sieves of progressively smaller mesh size and the amount of material that is retained in each sieve was weighed and measured as a fraction of the whole mass. The sieves were arranged in the following order;

FIGURE 3.9: Arrangement of sieves for sieve analysis

Following that, hydrometer analysis was also conducted for the fines of the soil which were finer than 63µm. A 152H hydrometer was used for the hydrometer test. Soil was collected from an oven dried sample that has been sieved passing the 63µm sieve into the pan. The soil is put into a dispersing solution inside a conical flask and placed on a mixing rack and is mixed for 24 hours. Then, the soil is transferred slowly into a 1000mL measuring cylinder. Another 1000mL measuring cylinder is filled with distilled water for washing the hydrometer bulb in between readings. Both measuring cylinders are placed inside a water bath to control the temperature. The timer is started and the readings of the hydrometer are taken at 30 seconds, 60 seconds, 2 minutes, 4 minutes, 8 minutes, 15 minutes, 30 minutes, 1 hour, 2 hours, and 24 hours. The hydrometer readings are corrected according to temperature of the water bath. The effective length was determined using the Table 3.1;

TABLE 3.2: Values of L (effective depth) for use in Stokes' formula for diameters of particles for ASTM soil hydrometer 152H

Original hydrometer reading (corrected for meniscus only)	Effective depth, *L*, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth, *L*, cm	Original hydrometer reading (corrected for meniscus only)	Effective depth, *L*, cm
0	16.3	21	12.9	42	9.4
1	16.1	22	12.7	43	9.2
2	16.0	23	12.5	44	9.1
3	15.8	24	12.4	45	8.9
4	15.6	25	12.2	46	8.8
5	15.5	26	12.0	47	8.6
6	15.3	27	11.9	48	8.4
7	15.2	28	11.7	49	8.3
8	15.0	29	11.5	50	8.1
9	14.8	30	11.4	51	7.9
10	14.7	31	11.2	52	7.8
11	14.5	32	11.1	53	7.6
12	14.3	33	10.9	54	7.4
13	14.2	34	10.7	55	7.3
14	14.0	35	10.5	56	7.1
15	13.8	36	10.4	57	7.0
16	13.7	37	10.2	58	6.8
17	13.5	38	10.1	59	6.6
18	13.3	39	9.9	60	6.5
19	13.2	40	9.7		
20	13.0	41	9.6		

The diameter of the soil particles were measured with the following equation;

$$D = K\sqrt{\frac{L}{t}}$$

Where the value K is a function of temperature and particle density obtained from Table 3.2, L is the effective depth, and t is the elapsed time in minutes.

TABLE 3.3: Values of K* for several unit weights of soil solids and temperature

Temp, °C	ε_s of Soil Solids							
	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
16	0.0151	0.0148	0.0146	0.0144	0.0141	0.0139	0.0137	0.0136
17	0.0149	0.0146	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134
18	0.0148	0.0144	0.0142	0.0140	0.0138	0.0136	0.0134	0.0132
19	0.0145	0.0143	0.0140	0.0138	0.0136	0.0134	0.0132	0.0131
20	0.0143	0.0141	0.0139	0.0137	0.0134	0.0133	0.0131	0.0129
21	0.0141	0.0139	0.0137	0.0135	0.0133	0.0131	0.0129	0.0127
22	0.0140	0.0137	0.0135	0.0133	0.0131	0.0129	0.0128	0.0126
23	0.0138	0.0136	0.0134	0.0132	0.0130	0.0128	0.0126	0.0124
24	0.0137	0.0134	0.0132	0.0130	0.0128	0.0126	0.0125	0.0123
25	0.0135	0.0133	0.0131	0.0129	0.0127	0.0125	0.0123	0.0122
26	0.0133	0.0131	0.0129	0.0127	0.0125	0.0124	0.0122	0.0120
27	0.0132	0.0130	0.0128	0.0126	0.0124	0.0122	0.0120	0.0119
28	0.0130	0.0128	0.0126	0.0124	0.0123	0.0121	0.0119	0.0117
29	0.0129	0.0127	0.0125	0.0123	0.0121	0.0120	0.0118	0.0116
30	0.0128	0.0126	0.0124	0.0122	0.0120	0.0118	0.0117	0.0115

* Units for K: mm $(\text{min/cm})^{1/2}$

The percent finer is calculated as;

$$\%Finer = \frac{aR_c}{W_s} \times 100$$

Where a is the correction factor for particle density according to Table 3.3, R_c is the corrected hydrometer reading, and W_s is the original dry mass.

TABLE 3.4: Correction factors a for unit weight of solids

ε_s of soil solids	Correction factor α
2.85	0.96
2.80	0.97
2.75	0.98
2.70	0.99
2.65	1.00
2.60	1.01
2.55	1.02
2.50	1.04

3.5.3 Biochemical Oxygen Demand Analysis (Electrochemical Probe Method)

The samples will be poured into BOD bottles, and labeled as such;

I. I (1, 2, 3) – representing the influent
II. A (1, 2, 3) – representing the control column configuration
III. B (1, 2, 3) – representing the vegetated column configuration
IV. C (1, 2, 3) – representing the vegetated column with saturated zone configuration

Each sample was filled into BOD bottles with differing volumes and filled up to the neck of the bottle with aerated distilled water that has been prepared 24 hours prior to testing with nutrients added. The dissolved oxygen of each bottle was measured with a DO meter probe that has been calibrated. Once measured, distilled water is added up to half of the bottle's neck and a stopper was inserted in each of the prepared sample bottles to prevent trapped air bubbles. To avoid evaporation from occurring, the bottle is capped off, wrapped with aluminium foil and labeled. Then, the bottles were stored in an incubator at 20°C (68°F) for five days. After 5 days, the remaining dissolved oxygen was measured.

Since no bacterial seed was added for the entire duration of this project, the BOD is calculated as follows:

$$BOD_5 \text{ mg/L} = ((D1 - D2) - (B1 - B2) \times f) \div P$$

Where:

BOD_5 = BOD value from the 5-day test (mg/L)

D1 = DO of the prepared sample immediately after preparation (mg/L)

D2 = DO of the prepared sample after incubation in mg/L

P = Decimal volumetric fraction of sample used

B1 = DO of the bacterial seed control immediately after preparation (mg/L)

B2 = DO of bacterial seed control after 5-days at 20 °C (68 °F) in mg/L

f = ratio of the bacterial seed in the diluted sample to the bacterial seed in the bacterial seed control.

f = (% seed in diluted sample) ÷ (% seed in seed control)

Averaged results are considered satisfactory if all the criteria that follows is true for more than one of the sample dilutions:

• The remaining DO is at least 1 mg/L.

• The final DO value is at least 2 mg/L less than the initial DO value.

• Toxicity at higher sample concentrations is not seen.

• There are no obvious anomalies.

The removal rate of BOD can be calculated as such;

$$\text{Removal rate (\%)} = \frac{BOD_{influent} - BOD_{sample}}{BOD_{influent}} \times 100\%$$

3.6 Gantt Chart

3.6.1 Gantt Chart for FYP I

TABLE 3.5: Gantt Chart for FYP I

Project Activities	WEEK											
	1	2	3	4	5	6	7	8	9	10	11	12
Research Topic Confirmation												
Literature Review												
Treatment Train System Setup												
Research Proposal Defense												
Submission of Interim Draft Report												
Submission of Interim Report												

3.6.2 Gantt Chart for FYP II

TABLE 3.6: Gantt Chart for FYP II

Project Activities	WEEK													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Characterization of Agricultural Runoff														
Collection of Samples and Data														
Data Analysis														
Preparation of Dissertation and Viva														
Viva														
Dissertation Submission														

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Soil Classification

A total of 2278 grams of soil was used for the particle size distribution. The 50g of soil collected in the pan from the sieve distribution was further used for the hydrometer test. The particle distribution can be seen more clearly through Figure 4.1;

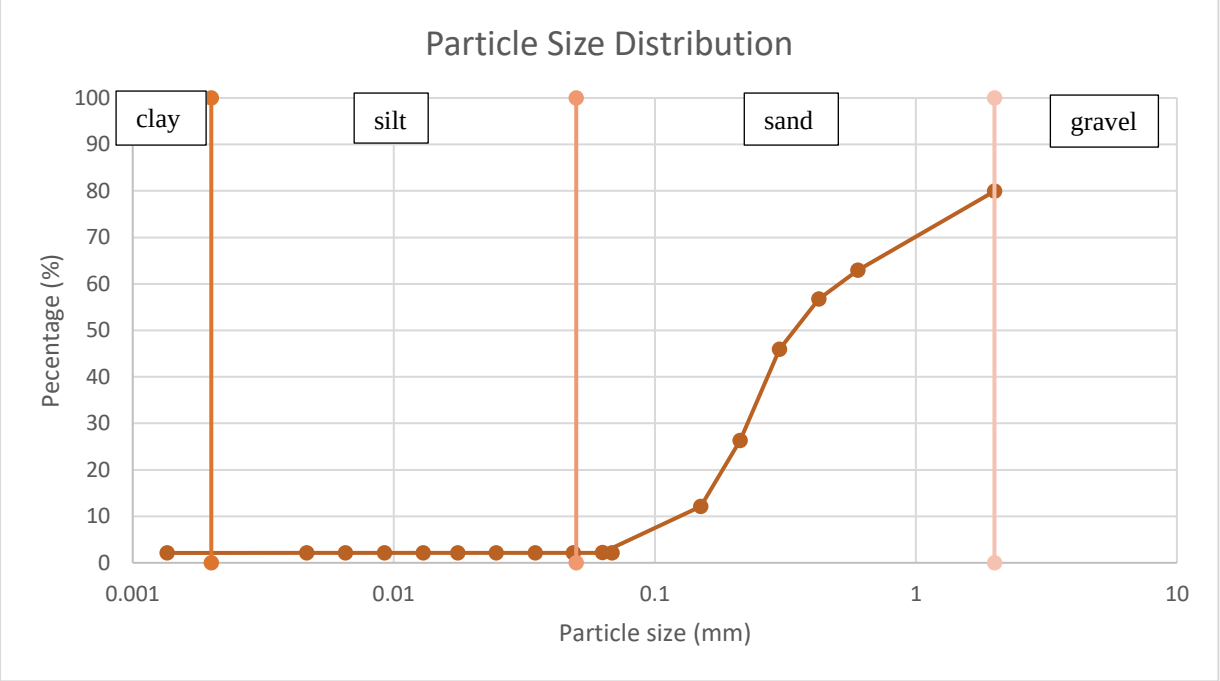

FIGURE 4.1: Graph representation of particle size distribution of soil

From the graph, the values of effective size of particles D_{60}, D_{30}, and D_{10} were determined to be 0.5166mm, 0.2286mm, and 0.1325mm respectively. From that, the coefficient of uniformity, C_u, has been calculated to be;

$$C_u = \frac{D_{60}}{D_{10}} = 2.2597$$

and the coefficient of curvature, C_c, is;

$$C_u = \frac{D^2{}_{30}}{D_{60} \times D_{10}} = 0.76386$$

From those two values, the soil is considered to be poorly graded as the coefficient of curvate, C_c, which is 0.76386 is outside of the range of well graded soil which is between 1 to 3.

The primary soil component consisting of 79.9% of the total soil sample was sand, followed by silt at 17.9% and clay at 2.1%. The primary soil component is coarse grained, followed by a fine-grained secondary component of silt which consisted of more than 12% fines, and a tertiary component of clay. Therefore, according to the Unified Soil Classification System (USCS), the soil is classified as silty poorly graded sand with clay. The recommended soil composition in MSMA is sandy loam soil which has a soil composition of 60% sand, 30% silt, and 10% clay. Thus, it would be recommended to add more silt and clay into the soil to achieve the recommended composition according to MSMA.

4.2 Agricultural Runoff Characterization

Figure 4.2 displays the BOD_5 measurements of water samples taken from Felcra Nasaruddin palm oil plantation.

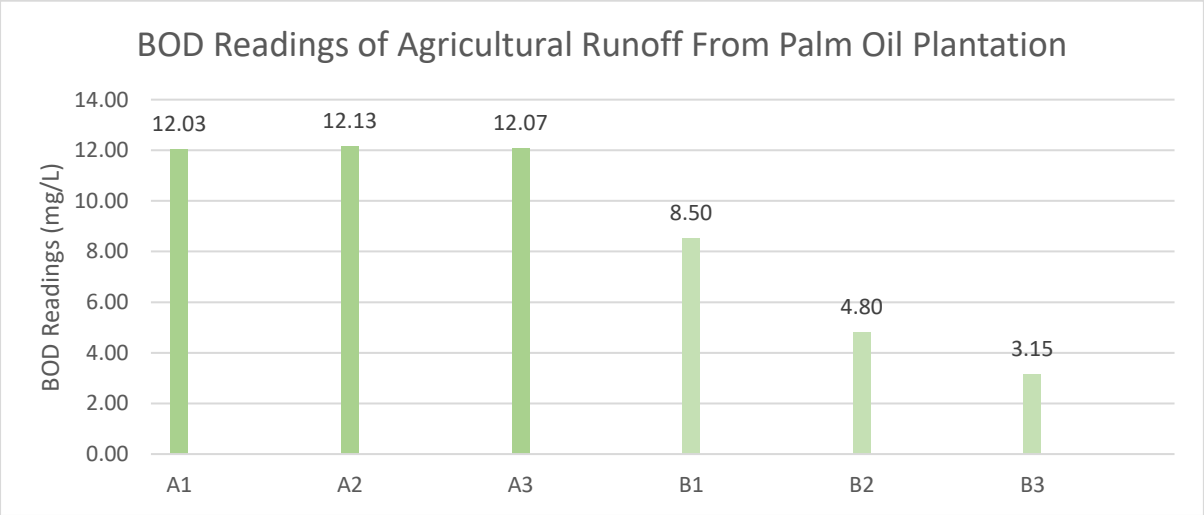

FIGURE 4.2: BOD readings of agricultural runoff from palm oil plantation

Samples A1, A2, and A3 were taken from the palm oil water channel, while samples B1, B2, and B3 were taken from the river where the water channels flow into. According to the literature review conducted, the samples taken from the water channel show that the BOD readings are within range of most plant agricultural BOD readings. The readings taken from the river are shown to be lower the more it goes downstream due to the constituents being diluted, resulting in lower BOD readings.

4.3 Biochemical Oxygen Demand Analysis

Overall, five runs were conducted from the start of this study, with three trial runs to get used to the process and improving the system. Each run takes five days from the start of the run to the measurement of BOD of the samples. Each run would require a new synthetic runoff to be prepared as algae accumulates in the water tank after two days which would affect the results. The first three runs helped determine the appropriate volume of sample to be used, and the fourth run helped identify any problems in collecting samples from the vegetated set with saturated zone. From the fourth run, it was found that running the synthetic runoff through the vegetated set with saturated zone required a minimum of two hours and constant monitoring, as leaving the saturated zone inside the column configurations lead to the vegetation wilting. Though five runs were conducted, only the fifth run showed promising and acceptable results that could be used for further analysis. The average BOD readings of the five runs can be seen in Table 4.1 and the trend over each run can be seen in Figure 4.3. Certain BOD readings cannot be accepted due to the samples having bubbles present in the bottle, a remaining DO reading of less than 1mg/L, a small difference between final DO and initial DO (excluding the final effluents), and unable to collect the sample due to time constraints.

TABLE 4.1: Average BOD reading of each configuration from the first run to the fifth run

	Average BOD Reading (mg/L)				
Sample	Run 1	Run 2	Run 3	Run 4	Run 5
Influent	39.88	40.44	-	-	51.23
A1	-	12.58	-	8.85	7.53
A2	-	-	-	2.65	3.51
A3	-	-	-	0.73	1.99
B1	-	36.52	-	-	8.78
B2	-	-	-	8.61	2.17
B3	-	28.5	-	1.16	0.91
C1	-	-	-	-	5.99
C2	-	-	-	-	-
C3	-	-	-	-	0.87

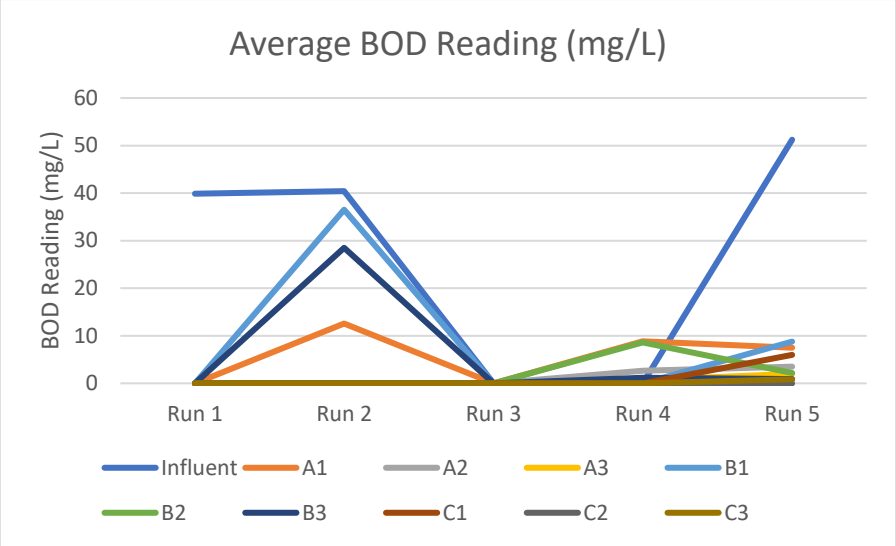

FIGURE 4.3: Average BOD reading over each run conducted

Through the five runs conducted, the fifth run is considered as the readings are more acceptable and reliable. The sample for column C2 was unable to be collected due to time constraints as the columns with vegetation and saturated zone took a long time to discharge the runoff. The reduction of BOD passing through the treatment train can be seen in the Figure 4.3 and the removal rates can be seen in Figure 4.4.

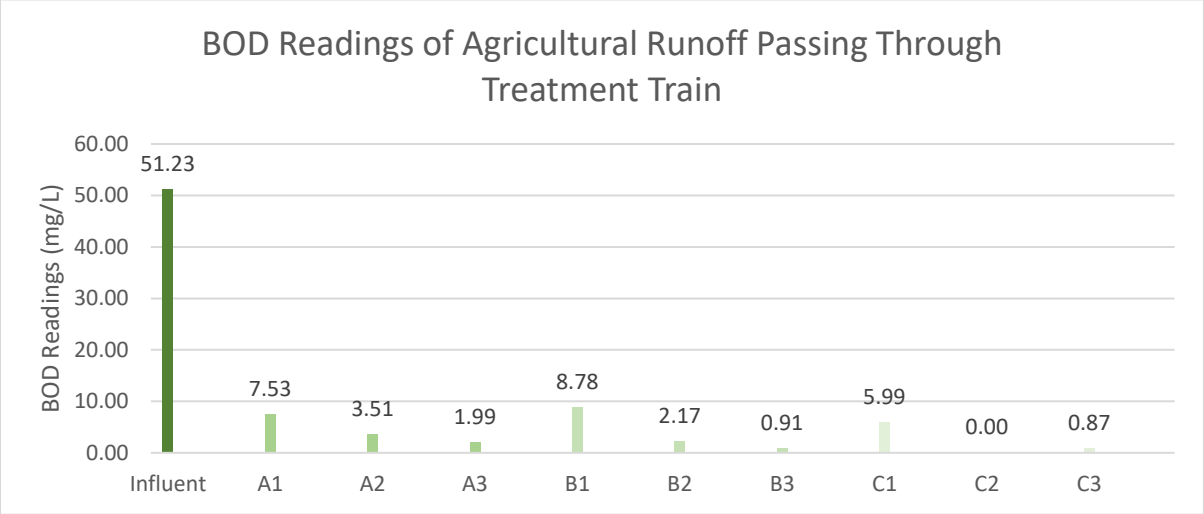

FIGURE 4.4: BOD readings of agricultural runoff passing through treatment train system

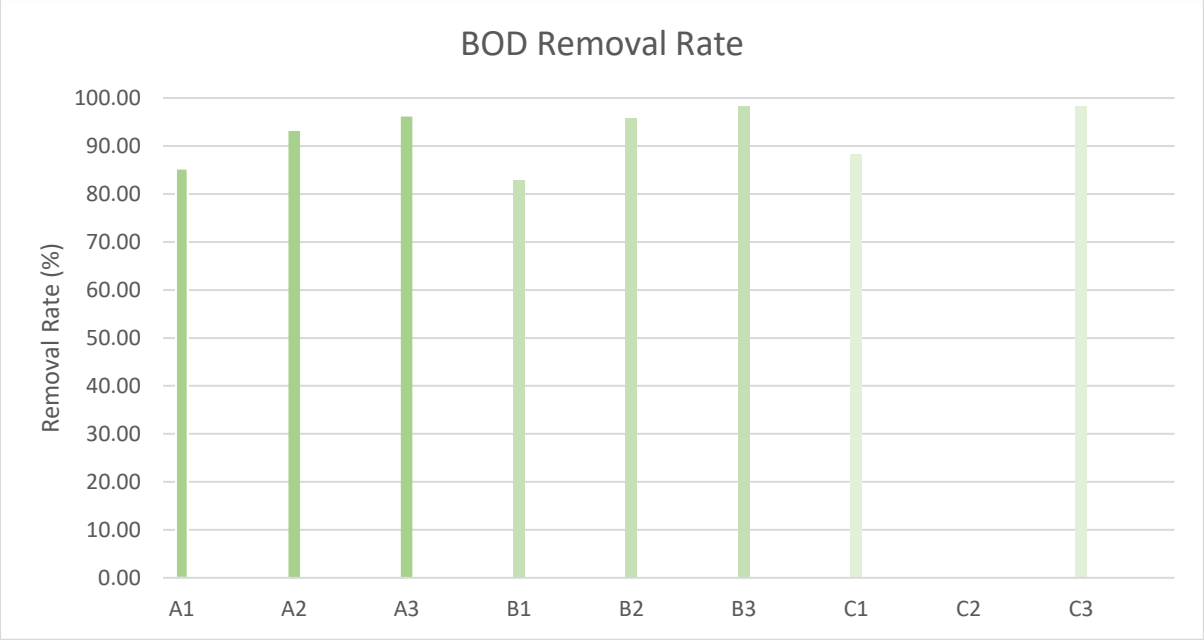

FIGURE 4.5: BOD removal rate of column configurations

The reduction of the BOD measurements can clearly be seen as the agricultural runoff passes through each bioretention configuration. Each column configuration shows an initial reduction of more than 82%. When comparing the performance of the vegetated set to the control set, the control set shows a higher initial removal rate of 85% to 82%, while the vegetated set shows better final removal rates of 98% to the control set's 96%. Out of the three configurations, the vegetated set with saturated zone shows the best performance with an 88% initial removal rate and 98% final removal rate. Though the vegetated set with saturated zone requires higher maintenance and monitoring, as leaving the saturated zone in the setup causes the vegetation to wilt. From the results, the control set can be classified as Class II according to Water Quality Standards, while both vegetated set without and with saturated zone can be classified as Class I. If each set was to consider the first column as a single bioretention system, all three configurations would be classified as Class IV, which shows that the arrangement of bioretention systems in a series contributes greatly in removing BOD of agricultural runoff. The reduction of the BOD measurements can be attributed to the soil media as it filters the pollutants present in the runoff. In addition to that, the cascading discharge of each column configuration assisted in aerating the runoff as it cascades into the next column.

From the Analysis of Variance (ANOVA) it can be seen that the p-value is 0.001136 which is less than 0.05, which means the null hypothesis stating that the means of the different configurations are the same can be rejected and the alternative hypothesis stating that the means of the different configurations are different can be accepted, thus it is evident that the difference in performance of the three configurations is significant. The ANOVA can be seen in Figure 4.6.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
A3	3	5.98	1.993333333	0.131733333
B3	3	2.72	0.906666667	0.006933333
C3	3	2.6	0.866666667	0.004133333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.451822222	2	1.225911111	25.75443511	0.001136	5.143253
Within Groups	0.2856	6	0.0476			
Total	2.737422222	8				

FIGURE 4.6: ANOVA of the three column configurations

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, the objectives of this project were achieved. Agricultural runoff from a nearby palm oil plantation was characterized and used as a benchmark for the synthetic runoff and it was found that the samples collected from the palm oil water channel had an average BOD_5 reading of 12.08mg/L and the main river had a lower average reading at 5.48mg/L. The BOD measurements of the main river had a decreasing BOD reading the more downstream the samples were taken due to dilution. Next, the concentration of BOD in agricultural runoff passing through the treatment train system configurations were measured. The three configurations showed high final BOD removal rates at 96% for the control, and 98% for both vegetated sets without and with saturated zone and the control set was classified as Class II according to Water Quality Standards, while the two vegetated sets without and with saturated zone were classified as Class I. The control set showed an average final BOD_5 reading of 1.99mg/L while both vegetated set without and with saturated zone had an average final BOD_5 reading of 0.91mg/L and 0.87mg/L respectively. This can be attributed to the cascading flow of discharge as well as soil media in filtering the pollutants. Lastly, the effectiveness of BOD removal in treatment train system was compared to a single bioretention system. When only the first bioretention cell was taken into consideration, the control set had an average BOD_5 reading of 7.53mg/L, the vegetated set had a higher average BOD_5 reading of 8.78mg/L compared to the control set, while the vegetated set had the lowest average BOD_5 reading of 5.99mg/L. This would classify all three sets as Class IV, so it can be said that treatment train systems exhibit better performances in BOD removal compared to single bioretention systems.

It would be recommended that further studies include monitoring the performance of the treatment train system for a longer period of time to observe if the quality of effluent degrades as the system is used for extended periods of time. Other than that, implementing the system on an actual palm oil plantation or agricultural farm would portray more convincing results as this would eliminate the use of synthetic runoff and would show the performance of the system on agricultural runoff. This is because the synthetic runoff needs to be prepared every time a run is to be conducted, as the synthetic runoff only lasts for two to three days before algae starts to accumulate inside the water tank, disrupting the BOD readings. Lastly, the study can include monitoring other benefits of treatment train system in more detail such as the retention ability of the system.

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APPENDICES

1. Sieve Distribution of Soil Sample

Sieve size	Weight of sieve (g)	Weight of sieve + soil (g)	Weight of soil (g)	Percentage of mass retained (%)	Cumulative percentage retained (%)	Percent passing (%)
2mm	380	837	457	20.1	20.1	79.9
600µm	405	792	387	17.0	37.1	62.9
425µm	369	510	141	6.2	43.2	56.8
300µm	358	605	247	10.8	54.1	45.9
212µm	340	787	447	19.6	73.7	26.3
150µm	313	635	322	14.1	87.8	12.2
63µm	364	591	227	10.0	97.8	2.2
pan	526	576	50	2.2	100.0	0.0
	Total		2278		100.0	

2. Hydrometer Readings of Soil Sample

Elapsed Time, t (in minutes)	Hydrometer Reading, R_h	Corrected Reading, Rc	Effective Length (cm)	Diameter (mm)	Percent finer (%)
0.5	1.0295	1.0290	11.50	0.06858	2.140
1.0	1.0290	1.0285	11.60	0.048704	2.139
2.0	1.0275	1.0270	11.90	0.034881	2.136
4.0	1.0270	1.0265	11.95	0.024717	2.135
8.0	1.0260	1.0255	12.10	0.017587	2.133
15.0	1.0250	1.0245	12.30	0.012949	2.131
30.0	1.0240	1.0235	12.45	0.009212	2.129
60.0	1.0235	1.0230	12.50	0.006527	2.128
120.0	1.0230	1.0225	12.60	0.004634	2.127
1440.0	1.0210	1.0205	12.95	0.001356	2.123

3. First Run BOD Readings

Sample	Volume of sample (mL)	Initial DO, DO_i	Final DO, DO_f	$DO_i - DO_f$	BOD (mg/L)	Avg, BOD (mg/L)	Comments
Influent	50	7.96	1.37	6.59	39.54	39.88	
		7.91	1.28	6.63	39.78		
		7.91	1.19	6.72	40.32		
Column A1	50	7.80	6.70	1.1	6.6	5.76	Final DO must be atleast 2mg/L less than initial DO
		7.78	6.87	0.91	5.46		
		7.78	6.91	0.87	5.22		
Column A2	50	7.69	6.96	0.73	4.38	3.84	Final DO must be atleast 2mg/L less than initial DO
		7.66	7.00	0.66	3.96		
		7.64	7.11	0.53	3.18		
Column A3	50	7.69	6.82	0.87	5.22	5.28	Final DO must be atleast 2mg/L less than initial DO
		7.66	6.75	0.91	5.46		
		7.68	6.82	0.86	5.16		

4. Second Run BOD Readings

Sample	Volume of sample for BOD (mL)	Initial DO, DO_i	Final DO, DO_f	$DO_i - DO_f$	BOD (mg/L)	Avg, BOD (mg/L)	Comments
Influent	50	7.64	0.98	6.66	39.96	40.44	Remaining DO must be atleast 1mg/L
		7.66	0.89	6.77	40.62		
		7.61	0.82	6.79	40.74		
Column A1	50	7.77	5.64	2.13	12.78	12.58	
		7.77	5.68	2.09	12.54		
		7.74	5.67	2.07	12.42		
Column A2	50	7.78	7.96	-0.18	-1.08	-1.08	Bubbles present (1st and 2nd bottle)
		7.81	7.95	-0.14	-0.84		
		7.84	8.06	-0.22	-1.32		
Column A3	50	7.50	7.77	-0.27	-1.62	-1.86	Bubbles present (1st bottle)
		7.51	7.84	-0.33	-1.98		
		7.48	7.81	-0.33	-1.98		
Column B1	50	7.69	2.03	5.66	33.96	36.52	
		7.75	1.50	6.25	37.5		
		7.77	1.42	6.35	38.1		
Column B2	50	7.71	0.85	6.86	41.16	40.44	Remaining DO must be atleast 1mg/L
		7.76	0.88	6.88	41.28		
		7.76	1.28	6.48	38.88		
Column B3	50	7.44	2.90	4.54	27.24	28.5	
		7.48	2.55	4.93	29.58		
		7.48	2.70	4.78	28.68		

5. Third Run BOD Readings

Sample	Volume of sample for BOD (mL)	Initial DO, DO_i	Final DO, DO_f	DO_i - DO_f	BOD (mg/L)	Avg, BOD (mg/L)	Comments
Influent	50	8.16	0.55	7.61	45.66	45.9	Remaining DO should be more than 1mg/L
		8.23	0.56	7.67	46.02		
		8.25	0.58	7.67	46.02		
Column A1	50	8.11	7.43	0.68	4.08	3.7	Difference should be more than 2mg/L
		8.14	7.56	0.58	3.48		
		8.14	7.55	0.59	3.54		
Column A2	50	8.07	7.93	0.14	0.84	0.62	Difference should be more than 2mg/L
		8.09	7.96	0.13	0.78		
		8.07	8.03	0.04	0.24		
Column A3	50	7.89	7.94	-0.05	-0.3	-0.2	Difference should be more than 2mg/L
		7.90	7.95	-0.05	-0.3		
		7.91	7.91	0	0		
Column B1	50	7.89	6.78	1.11	6.66	6.7	Difference should be more than 2mg/L
		7.92	6.78	1.14	6.84		
		7.89	6.79	1.1	6.6		
Column B2	50	7.85	6.77	1.08	6.48	6.64	Difference should be more than 2mg/L
		7.86	6.68	1.18	7.08		
		7.86	6.80	1.06	6.36		
Column B3	50	7.70	6.88	0.82	4.92	5.12	Difference should be more than 2mg/L
		7.72	6.83	0.89	5.34		
		7.70	6.85	0.85	5.1		

6. Fourth Run BOD Readings

Sample	Volume of sample collected (mL)	Volume of sample for BOD (mL)	Initial DO, DO_i	Final DO, DO_f	DO_i - DO_f	BOD (mg/L)	Avg, BOD (mg/L)	Comments
Influent	650	150	8.12	0.69	7.43	44.58	43.5	Remaining DO should be more than 1mg/L
			8.14	1.33	6.81	40.86		
			8.12	0.61	7.51	45.06		
Column A1	650	150	7.73	3.20	4.53	27.18	26.54	
			7.69	3.44	4.25	25.5		
			7.72	3.23	4.49	26.94		
Column A2	800	150	8.00	6.60	1.4	8.4	7.94	
			7.99	6.67	1.32	7.92		
			7.95	6.70	1.25	7.5		
Column A3	1300	150	8.14	7.76	0.38	2.28	2.18	
			8.08	7.77	0.31	1.86		
			8.07	7.67	0.4	2.4		
Column B1	550	150	7.88	0.71	7.17	43.02	42.92	Remaining DO should be more than 1mg/L
			7.89	0.76	7.13	42.78		
			7.82	0.66	7.16	42.96		
Column B2	740	150	7.76	3.46	4.3	25.8	25.84	
			7.72	3.32	4.4	26.4		
			7.76	3.54	4.22	25.32		
Column B3	1500	150	7.86	7.25	0.61	3.66	3.48	
			7.76	7.22	0.54	3.24		
			7.83	7.24	0.59	3.54		
Column C1	670	150	6.97	0.68	6.29	37.74	37.88	Remaining DO should be more than 1mg/L
			6.96	0.60	6.36	38.16		
			6.89	0.60	6.29	37.74		
Column C2	800	150	7.54	0.57	6.97	41.82	41.92	Remaining DO should be more than 1mg/L
			7.60	0.57	7.03	42.18		
			7.52	0.56	6.96	41.76		
Column C3	1500	150	7.93	1.34	6.59	39.54	38.4	Difference should be more than 2mg/L
			7.78	1.53	6.25	37.5		
			7.87	1.51	6.36	38.16		

7. Fifth Run BOD Readings

Sample	Volume of sample for BOD (mL)	Initial DO, DO_i	Final DO, DO_f	$DO_i - DO_f$	BOD (mg/L)	Avg, BOD (mg/L)	Removal Rate (%)	Comments
Influent	30	9.06	4.10	4.96	49.6	51.23	-	
		9.10	4.06	5.04	50.4			
		9.16	3.79	5.37	53.7			
A1	150	9.17	5.13	4.04	8.08	7.53	85.30	
		9.07	5.44	3.63	7.26			
		9.05	5.42	3.63	7.26			
A2	150	9.02	7.42	1.6	3.2	3.51	93.14	
		8.96	7.56	1.4	2.8			
		8.94	6.67	2.27	4.54			
A3	150	8.72	7.89	0.83	1.66	1.99	96.11	
		8.71	7.74	0.97	1.94			
		8.70	7.51	1.19	2.38			
B1	150	8.97	5.30	3.67	7.34	8.78	82.86	
		8.95	4.15	4.8	9.6			
		8.90	4.20	4.7	9.4			
B2	150	8.76	7.91	0.85	1.7	2.17	95.76	
		8.70	7.86	0.84	1.68			
		8.74	7.17	1.57	3.14			
B3	150	8.59	8.15	0.44	0.88	0.91	98.23	
		8.59	8.09	0.5	1			
		8.57	8.15	0.42	0.84			
C1	150	8.59	5.71	2.88	5.76	5.99	88.30	
		8.54	5.57	2.97	5.94			
		8.56	5.42	3.14	6.28			
C2	-	-	-	-	-	-	-	Unable to collect due to time constraints
		-	-	-	-			
		-	-	-	-			
C3	150	8.57	8.10	0.47	0.94	0.87	98.31	
		8.57	8.15	0.42	0.84			
		8.55	8.14	0.41	0.82			