NUTRIENT REMOVAL OF TROPICAL BIORETENTION SYSTEM IN TREATING POLLUTED RUNOFF: A PILOT STUDY

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by

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

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ABSTRAK

Kualiti air yang buruk adalah masalah biasa pada masa kini kerana peningkatan pencemaran dari aktiviti manusia. Aliran air pembandaran berasal dari kawasan perumahan, kawasan perindustrian, dan kawasan pertanian yang mengandungi nitrogen (N) dan fosforus (P), yang menyebabkan nitrifikasi dan eutrofikasi. Dalam kajian ini, sistem *bioretention* berskala kecil akan digunakan sebagai *Best Management Practices* (BMP) air hujan untuk menyelesaikan masalah kualiti air di iklim tropika. Kajian ini mempunyai dua tapak *bioretention*, satu tapak ditanam dengan tanaman tropika, iaitu Hibiscus Merah Panas (*Hibiscus rosa-sinensis*), Amaryllis (*Hippeastrum*), Singapore Daisy (*Sphagneticola trilobata*), Lobster claw (*Heliconia rostrata*), Alternanthera (*Alternanthera kultivar*) dan satu tapak tanpa tanaman tropika. Kajian ini akan menyelidik kecekapan penyingkiran pencemar di antara 2 tapak *bioretention* dalam merawat air yang tercemar dan kadar infiltrasi menggunakan dua kaedah, ujian *single ring infiltration* dan ujian *Guelph permeameter*. Kajian tapak *bioretention* akan diperhatikan melalui menguji efluen dengan ujian TSS, TN dan TP selama tiga minggu pada 30 minit, 2 jam, 4 jam dan 8 jam selepas air yang tercemar dilepaskan. Hasil kajian menunjukkan kecekapan penyingkiran bahan pencemar untuk tapak tanaman tropika (TSS (76%), TN (78%), dan TP (71%)) lebih baik berbanding tapak tanpa tanaman tropika (TSS (75%), TN (76%) dan TP (54%)). Kadar penyusupan di tapak tanaman tropika (36-48 cm / jam) menunjukkan hasil yang lebih rendah daripada tapak tanpa tanaman tropika (60-108 cm / jam). Walau bagaimanapun, kedua-dua tapak *bioretention* tidak memenuhi syarat dari MSMA (5-20 cm / jam). Kajian ini menyimpulkan bahawa tapak tanaman tropika mempunyai prestasi yang lebih baik dalam kecekapan penyingkiran nutrien, tetapi kadar penyusupan tidak mencapai syarat minimum MSMA.

ABSTRACT

Poor water quality is a common problem nowadays due to the increase in pollution from human activities. Urban runoff comes from residential areas, industrial areas, and agriculture areas containing nitrogen (N) and phosphorus (P), leading to nitrification and eutrophication. In this study, a pilot-scale bioretention system will be used as stormwater Best Management Practices (BMPs) to solve water quality issues in tropical climates. This study included two bioretention pilot sites, a vegetated site with tropical plants, which is Red Hot Hibiscus *(Hibiscus rosa-sinensis)*, Amaryllis *(Hippeastrum)*, Singapore Daisy *(Sphagneticola trilobata)*, Lobster claw *(Heliconia rostrata)*, Alternanthera *(Alternanthera cultivar)* and a non-vegetated control site. The field study investigated the pollutant removal efficiency between 2 pilot sites in treating polluted runoff and infiltration rate using two methods, single ring infiltration test and Guelph permeameter test. The site uptake from the polluted runoff will be observed by testing the effluent with TSS, TN and TP test for three weeks at 30 mins, 2 hours, 4 hours and 8 hours after the runoff being released. The results showed pollutant removal efficiency for TSS (76%), TN (78%), and TP (71%) for the vegetated site, which is slightly better compared to control site (TSS (75%), TN (76%) and TP (54%)). The infiltration rate at the vegetated site (36-48 cm/hr) shows lower results than the control site (60-108 cm/hr). However, both pilot sites did not meet the requirement by MSMA (5 to 20 cm/hr). This study concluded that the vegetated site has slightly better performance on nutrient removal efficiency, but the infiltration rate did not achieve the MSMA minimum requirement.

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LIST OF ABBREVIATIONS

BMPs	Best Management Practices
DID	Department of Irrigation and Drainage
DO	Dissolve Oxygen
DOE	Department Of Environment Malaysia
EC	Electrical Conductivity
MSMA	Urban Stormwater Management Manual for Malaysia
pH	Potential of Hydrogen
REDAC	River Engineering and Urban Drainage Research Center
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background Study

Water quality is deteriorating in many parts of the earth due to the growing population and increased industrialization. Poor water quality means human beings cannot consume it as it contains high nutrients and leads to eutrophication. Most water sources in urban areas face water quality issues as the runoff from residential and industrial areas flows into the nearest water collection point, such as drainage, river, and pond. The urban area has over 90% impermeable surface area compared to the rural area, which most of the polluted urban runoff will not infiltrate into the soil (Boyd et al., 2009). According to Shrestha et al. (2018), nitrogen (N), phosphorus (P), heavy metals and suspended solids are commonly detected in urban water runoff.

Since the 1970s, stormwater management was established to control excess runoff flow that causes flooding problem (Zakaria et al., 2003). Later on, stormwater management has shifted its focus to water cycle protection in the ecosystem because runoff has become one of the non-point source pollutants, especially in urban area due to human activities and large impermeable surface area. To maintain the quality of water sources, stormwater Best Management Practices (BMPs) have been introduced to many countries.

Stormwater BMPs like wetlands, bioretention, retention ponds and detention ponds have been applied in many developed countries such as United States (US), United Kingdom (UK), China, Japan and German to treat urban runoff. Based on studies conducted by Rodak et al. (2020), results obtained from stormwater BMPs performance show success in removing pollutants from urban runoff.

Bioretention system is one of the popular stormwaters BMPs applied in many countries to treat polluted runoff. It is one of the easiest stormwater BMPs to construct in urban area. It only requires a small space and low cost for construction. It is also commonly referred to as biofiltration systems, rain gardens, or bioswales for their similarities in appearance and construction (Lopez-Ponnada et al., 2020). It is not just aesthetically pleasing, but it is also very functional in nutrient removal.

There are two types of studies can be conducted to test the bioretention system, which is laboratory and field studies. Examples of laboratory studies are column and mesocosm studies. The column study, where only soil elements will be tested on pollutants removal. The mesocosm study, where the experiment includes the vegetations that will contribute in removing pollutants. Field studies consist of pilot study and field study, in which pilot study is on-site testing with small scale and field study is on-site testing with more extensive scale. In past studies, many researchers have conducted pilot studies on bioretention systems (Skorobogatov et al., 2020), but their studies were not conducted in a tropical climate. Therefore, in this study, the effectiveness of the bioretention system in tropical climates will be evaluated using a pilot study.

1.2 Problem Statement

Poor water quality issue is prevalently happening in the urban area due to less permeable space that allows the runoff to infiltrate into the ground. The runoff flowing on the impermeable surface carries many pollutants such as nitrogen, phosphorus, heavy metals, oil and grease (Skorobogatov et al., 2020). Humans cannot withstand the pollutants if the concentration of pollutants is too high in the water source. Other than that, the natural water cycle also cannot adapt to the high contamination of pollutants. Therefore, bioretention is the most effective way to be implemented in treating urban runoff.

Many past studies have been tested the pollutants removal efficiency using bioretention. However, most of the studies were lack of results on pollutants removal efficiency using pilot-scale bioretention systems compared to column and mesocosm studies (Skorobogatov et al., 2020). Furthermore, there is a lack of results testing a bioretention system using tropical vegetations since not many tropical countries have conducted the study with different types of tropical vegetations. Besides that, the pollutants removal efficiency was also related to the infiltration rate and there is a lack of studies on infiltration rate with the presence of tropical vegetations.

The main output of this study was to understand the effectiveness of tropical plants in treating urban runoff full of nitrogen, phosphorus and heavy metal. Moreover, the presence of tropical plants in affecting the infiltration rate of filter media to support treating urban runoff will also be investigated.

1.3 Objective of the Study

The objectives of this study are listed as below:

1. To compare the nutrient removal efficiency of bioretention in treating polluted runoff under tropical climate with and without tropical plants.
2. To evaluate the differences in infiltration rate between filter media with and without tropical plants in the bioretention system.

1.4 Scope of Study

This study mainly focuses on the nutrient removal efficiency of the bioretention system in treating polluted runoff by using tropical plants under tropical climates. During the three weeks of study, the polluted runoff will be obtained from the main drain in Parit Buntar, Perak. The pollutants in the selected runoff come from the commercial area, landscape and residential area. Laboratory testing on the water quality to be conducted are TSS, TN and TP only. Vegetations used in this study are Red Hot Hibiscus *(Hibiscus rosa-sinensis)*, Amaryllis *(Hippeastrum)*, Singapore Daisy *(Sphagneticola trilobata)*, Lobster claw *(Heliconia rostrata)* and Alternanthera *(Alternanthera cultivar)*. Filter media used are a mixture of sand, topsoil and coconut husk according to the ratio suggested in Urban Stormwater Management Manual for Malaysia (MSMA) (DID, 2012). Finally, single ring infiltration test and Guelph permeameter test will be used for infiltration test on pilot site with and without tropical plants to support nutrient removal study.

1.5 Dissertation Outline

Chapter 1 highlight the background study, problem statement, objectives and scope of study. While Chapter 2 compiles the literature review related to the bioretention research, especially nutrient removal and infiltration rate in the bioretention system. In Chapter 3, the research methodology for the experiment preparation and data collection procedure will be explained. Followed by Chapter 4, which presents the analysis of data and discussion on the achievement of research objectives. Lastly, Chapter 5 will conclude the outcome of this research and suggest some recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, there will be some review of research regarding bioretention systems that have been implemented in various countries. Other than that, results from the previous studies will be described in details in this chapter.

2.2 Polluted urban runoff

Urban runoff is the surface water of rainwater flow from the urbanization area, mainly from the rooftop, roadside, parking lot, and landscape in residential and industrial areas. The different amount of runoff flow between permeable area (natural) and impermeable area (urban) is shown in Figure 2.1. The impermeable surface area flows 45% more of urban runoff into the river than permeable surface area, due to the inability of urban runoff to infiltrate into the ground and evaporate into the air as many as permeable area. The pollutants in urban runoff can be divided into six groups: suspended solid, organic matter, inorganic matter, heavy metals, microorganisms, and nutrients (Barbosa et al., 2012). However, pollutants contained in urban runoff were originated from fertilizer, wet and dry deposition, leaves, animals, emission gases from vehicles and grind tire debris (Wei et al., 2013), which mainly consists of nitrogen (N) and phosphorus (P).

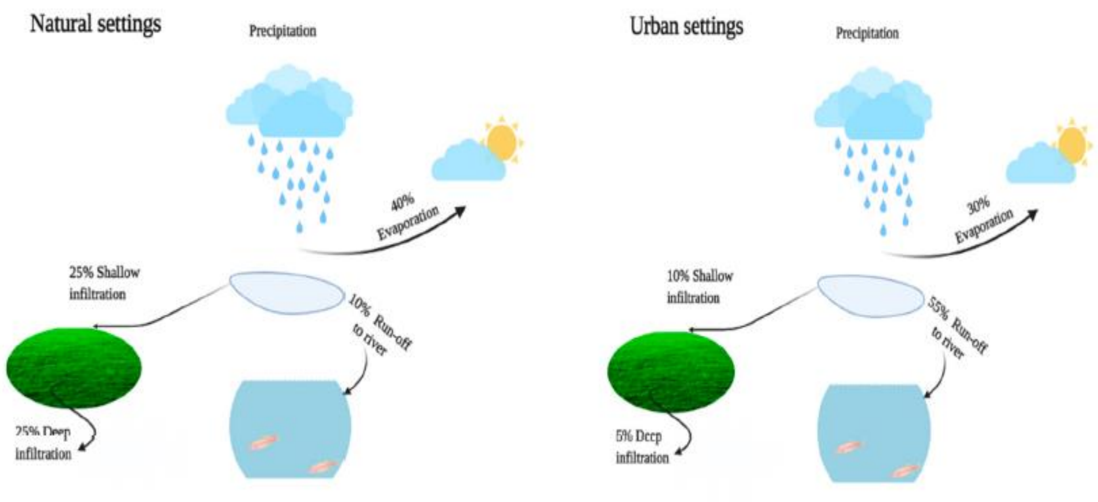

Figure 2.1: Different amount of water runoff between permeable (left) and impermeable (right) area (Ali et al., 2021).

Based on Department of Environment Malaysia (DOE) (2019), a few land categories contribute to polluted urban runoff, such as agriculture, industrial, residential, commercial, road, and highway. As polluted urban runoff containing nitrogen and phosphorus cannot infiltrate into the ground due to impermeable surface area, it will be collected at water receiving points such as rivers.

High nutrient content in water receiving bodies can cause many problems in the ecosystem as it leads to eutrophication. The eutrophication process happens when excessive nutrients leach into water bodies which can cause algae bloom to occur. It will cover all the water surface and blocked the sunlight. The presence of algae blooms consumed oxygens in the water for its rapid growth. Living things in the water, such as aquatic plants and fish, will be suffocated due to lack of oxygen.

Urban runoff in Malaysia faced a similar problem due to lack of knowledge on stormwater management. Furthermore, most of the land used categories in Malaysia is agriculture (DOE, 2019). Hence, high nutrient in water runoff origin from fertilizer is the cause of polluted water runoff. It is crucial to improve stormwater management in Malaysia to overcome the problem.

2.3 Stormwater Best Management Practices (BMPs)

Stormwater Best Management Practices (BMPs) are an efficient way to implement in urban area due to less permeable area (Rodak et al., 2020). Examples of stormwater BMPs are wetland, bioretention, swale, detention pond and retention pond. Each stormwater BMPs has different treatment technology and removal efficiency. Further detail on each stormwater BMPs will be explained in this subtopic.

2.3.1 Stormwater Basin

A stormwater basin is an excavated basin for the temporary detention of stormwater runoff. The stormwater runoff will be collected in the basin and will infiltrate into the existing soil. There are two types of the stormwater basin, which is detention and retention basin. A Detention basin is more commonly constructed because it can maintain the outflow to control flood, predominantly undeveloped areas (Park et al., 2012). The undeveloped area lacks drainage to discharge the stormwater runoff to the river, while the retention basin will retain the stormwater and create a permanent pond.

The function of the stormwater basin is to remove excess nutrient content in the stormwater runoff. Other than removing nutrient, a stormwater basin is also suitable for removing sediment by filtering it. The treated stormwater will infiltrate into the underground to store excess water for aquifer recharge (Wen et al., 2020). Many countries have widely used this method, such as Canada, Europe, US, and France (Zhu et al., 2020).

The advantages of constructing a stormwater basin are to prevent flood and improve stormwater collection. Furthermore, the treatment process was natural without any support from equipment or machine. Next, it can be used for recreational purpose when there is no water retained in the basin. While for disadvantages, the stormwater basin would become a mosquito breeding place if it is not correctly maintained. Moreover, the size of the basin usually takes a large area to be established.

2.3.2 Swale

Swale is a shallow drain that collects and channels stormwater from the road and yard (Monrabal-Martinez et al., 2018). It is also one technique that can be used as preliminary treatment before conveying to a pond. It has two designs that can be chosen, such as parabolic shape and trapezoidal shape. It is easier to design and construct a trapezoidal shape than a parabolic shape. Furthermore, the maintenance of trapezoidal shape is less problematic.

Although the effectiveness of treating stormwater is not as good as bioretention and wetland, it can help to reduce the pollutants and sediments with vegetated grass along the swale (Gavrić et al., 2021). The grass in swale will slow down the flow of stormwater, and the sediments will settle between the grass and soil particle while infiltrating into the soil.

Constructing swale along the roadside is beneficial as it would increase the impervious area, reducing the probability of flooding scenario. A swale is very suitable for rural areas because it can replace the drainage system to convey stormwater runoff (Ekka et al., 2021). Hence, it is safer compare to drainage due to shallow depth. However, swale has one disadvantage: the connection of underground pipes is easily exposed to blockage with soils and sediments.

2.3.3 Wetland

Wetland is one of the stormwater treatment technologies applied in many countries in past decades. The stormwater was filled in the wetland pond, and the vegetation in the wetland will treat it. The vegetations will absorb all the nutrients and pollutants to purify the stormwater. There are a few categories of vegetation that are suitable to be used in the wetland to treat stormwater, such as trees, shrub and grass, according to the Urban Stormwater Management Manual for Malaysia (MSMA) (DID, 2012). Trees can prevent bank failures due to large roots. The shrub is good in stabilizing bank erosion because it can cover all pond’s bank, while grass can trap sediments effectively compare to other types of vegetations.

Two systems can treat stormwater in the wetland, which is surface and subsurface flow systems (Figure 2.2). The difference between these two systems is the treatment flow of stormwater. For surface flow, the stormwater will be treated by vegetations through stormwater flow. While for subsurface flow, the stormwater was treated by vegetations and filter media as the effluent for subsurface flow will be collected underneath the wetland. Based on Lu et al. (2016) research, a subsurface flow system has more efficient result on nutrient removal because the stormwater flows through the filter media and enhanced filtration process.

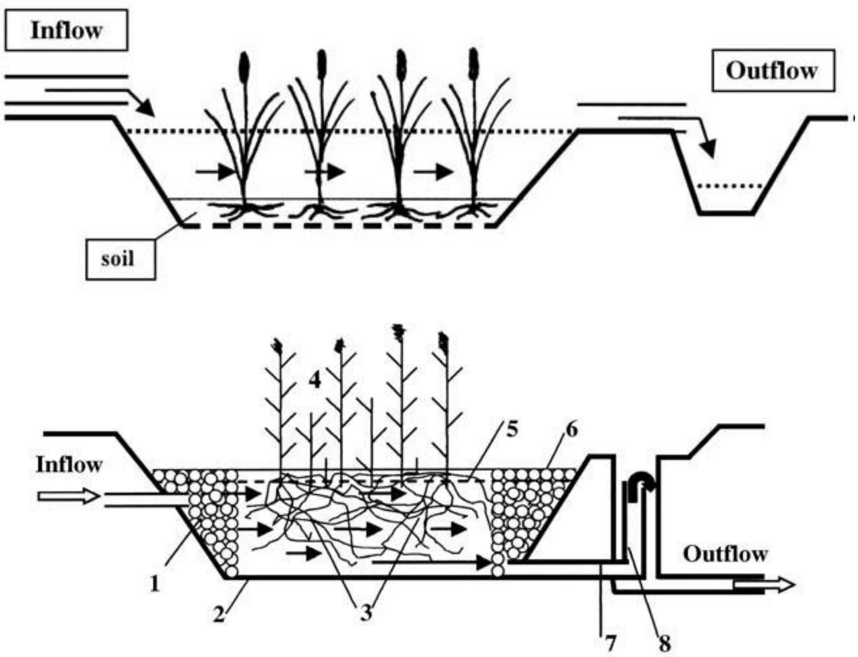

Figure 2.2: Types of system in wetland: surface flow system (top) and subsurface flow system (bottom) (Bilal, 2019).

The most significant advantage of using wetland to treat stormwater is that wetland would mimic natural ecosystem, which the stormwater were treated naturally in physical, chemical, and biological states (Lu et al., 2016). It also can maintain the biodiversity of the ecosystem. Besides that, wetland can be used as flood protection since they can hold a large amount of water. This treatment method is low cost and feasible to be constructed (Khalifa et al., 2020). The disadvantage of the wetland is that it cannot be constructed in an urban area and steep area since it takes a large area to be constructed. Moreover, the wetland is easily exposed to high sediment inflows, which leads to frequent maintenance.

2.3.4 Green Roof

Rapid urbanization can cause global warming, especially in urban areas, with less permeable space to insulate the temperature. The green roof has become one solution to provide green ecosystem to urban areas (H. Liu et al., 2021). The green roof (Figure 2.3) is a layer of vegetation on a flat or sloped surface of a building roof. It was divided into two types, extensive green roof and intensive green roof. Their differences are the depth of soil and type of vegetation. The extensive green roof has thinner soil, lighter weight, and lower maintenance than the intensive green roof, but the choice of vegetation is limited.

According to Cristiano et al. (2021), green roofs have a high retention capacity of stormwater to reduce the flood risk during heavy rain. It can also increase the thermal insulation because the green roof would cover the building roof from direct sunlight. Hence, it can reduce the building’s electricity consumption (Aboelata, 2021; H. Liu et al., 2021). Next, implemented of green roof in the urban area will restore permeable space and increase biodiversity.

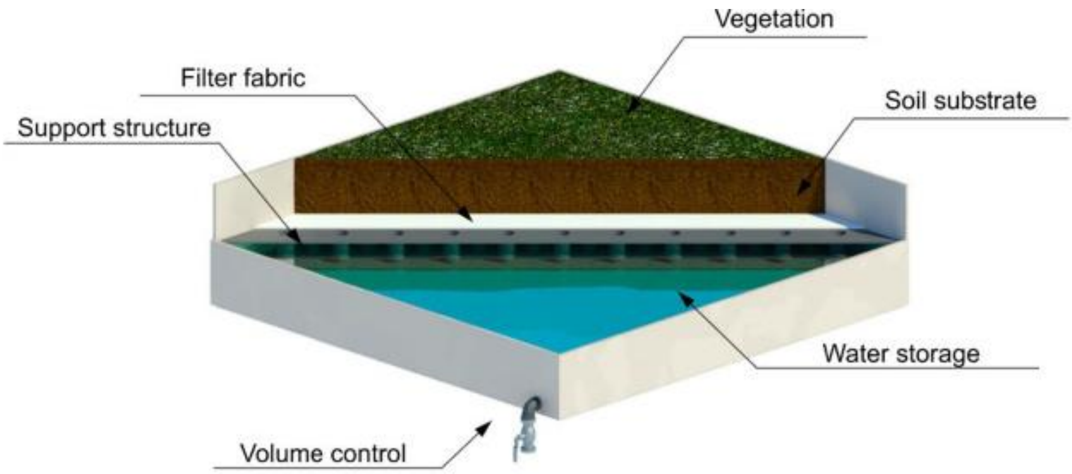

Figure 2.3: Example of a schematic diagram of multilayer green roof (Cristiano et al., 2021).

2.3.5 Bioretention

Bioretention was introduced as a stormwater Best Management Practices (BMPs) to treat stormwater since the 1990s (Zakaria et al., 2003). Bioretention is a treatment method consisting of 2 important elements to remove pollutants from stormwater: vegetation and filter media. Bioretention is different from the stormwater basin as bioretention can hold a lesser inflow volume than the stormwater basin.

Bioretention is mainly used to treat nutrients and sediments in the stormwater, such as total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS). Many countries have proven excellent results by using bioretention can treat stormwater efficiently (Skorobogatov et al., 2020). Usually, bioretention is used to treat urban runoff as only small spaces are needed to construct it. It can even be constructed beside pavement road for landscaping purpose.

There are many advantages of bioretention other than treating urban runoff. For example, bioretention will act as a permeable area and reduce the runoff volume and rate to reduce the runoff peak flow to avoid flooding in urban areas (Shafique, 2017).

Next, bioretention can maintain the natural water cycle to treat the urban runoff before releasing it underground. Last but not least, it is very aesthetically pleasing because the most suitable vegetations used were landscaping vegetations. Moreover, other countries have implemented the bioretention system for landscaping purpose at the roadside, parking lots and road median. An example of constructed bioretention at the roadside was shown in Figure 2.4.

Figure 2.4: Example of bioretention at roadside (Shrestha et al., 2018).

2.4 Bioretention Component

Bioretention have three main components in its design, which is vegetation, filter media and drainage layer. Pollutant removal in urban runoff begins with water runoff that infiltrates into filter media, and the sediment will remain in it. At the same time, the vegetation will absorb other pollutants such as nitrogen, phosphorus and heavy metals. Past studies have proven that different nutrient removal efficiency was shown by using different types of filter media and vegetation (Skorobogatov et al., 2020). Many studies have also proven infiltration process using a good mixture of filter media can contribute to high nutrient removal (Xiong et al., 2020). While drainage layer to channel the treated urban runoff will be constructed depends on the surrounding condition, such as permeable or impermeable surface area.

2.4.1 Vegetations

The selection of vegetations is essential because suitable vegetation can remove pollutants in urban runoff more efficiently. Vegetations have a high potential in removing total nitrogen (TN) and total phosphorus (TP). Vegetations did not affect removing total suspended solids (TSS), but they can influence the pathogen removal in urban runoff (Dagenais et al., 2018). Besides that, vegetations can also maintain the infiltration capacity and reduce soil erosion and stormwater volume through the transpiration process (Muerdter et al., 2018).

There are a few categories of vegetations that can be chosen for the bioretention system: trees, large shrubs, shrubs, subshrubs, perennials, grasses, and grass-like plants (Central California Coast Low Impact Development Initiative, 2017). The selected vegetations must be suitable with the location of the bioretention that will be constructed. Most past studies used shrubs, perennials and grass-like plants to remove nutrients and pollutants in urban runoff (Skorobogatov et al., 2020). Based on MSMA (DID, 2012), the criteria of selecting vegetations as listed below:

a) Selected vegetations are native species that can adapt to local climate and soils.
b) Vegetations are selected based on their hydraulic zone.
c) The vegetation layout has to be random and natural.
d) A canopy should be established with shrubs and herbaceous vegetations.
e) Trees have to be planted along the perimeter of the bioretention design area.

Vegetation used in the bioretention system has been well established in temperate countries such as Australia and USA (Goh et al., 2017). It is crucial to choose vegetation depending on the country's climate because each vegetation has a different tolerant limit towards the climate. For example, vegetation from the submerged category can tolerate the dry season because it can store water. Table 2.1 is a summary of vegetations used in past study.

Table 2.1: Past study of vegetation used in bioretention system.

COUNTRY	***PLANT***	***AUTHOR***
Malaysia	Red hot hibiscus	(Goh et al., 2017)
USA	Ixora Alternantera	(Chowdhury et al., 2018)
USA	Crabgrass	(Liu et al., 2014b)
India	Alternantera	(Abbasi and Tauseef, 2018)
Singapore	Elateriosperrnutn tapos	(Chen et al., 2014)
Korea	Spirea japonica	(Geromino et al., 2013)
Australia	Carex appressa	(Zinger et al., 2013) (Bratieres et al., 2008)

2.4.2 Filter Media

To construct an efficient design of a bioretention system, a good mixture of filter media to be used as soil planting bed must provide water and nutrients to support the growth of vegetations (New Jersey Department of Environmental Protection, 2009). According to Doan and Davis (2017), filter media in the bioretention system can remove heavy metal efficiently, even without additives. Other than heavy metal, total suspended solids (TSS) also can be reduced by filtration through the filter media (Shrestha et al., 2018).

An ideal soil composition to remove pollutants in a bioretention system are a mixture of topsoil, sand and compost (Goh et al., 2017). The function of topsoil in filter media is to preserve and protect the ground surface from erosion. The use of sand maintains the infiltration rate in filter media while compost in filter media provide nutrients for vegetations. By referring to MSMA (DID, 2012), the recommended depth of filter media is between 450 to 1000 mm, consisting of 50-80% of sandy loam, 10-20% of clay, and 10-20% of composite organic matter. Based on Vol et al. (2015), the depth of the filter media would affect the pollutant removal, where the deeper the depth of filter media, the higher the pollutant removal.

2.4.3 Drainage Layer

Bioretention can be designed as permeable or impermeable systems, depending on the system's location to be constructed. For permeable system design (Figure 2.5), the stormwater will infiltrate into surrounding soil after passing through filter media and the sand bed of bioretention. The treated stormwater will restore the groundwater. This type of design is suitable to be implemented along roadside or median parking lots. It is because the concentration of the stormwater from road and highways is not as high as other places such as residential and industrial area.

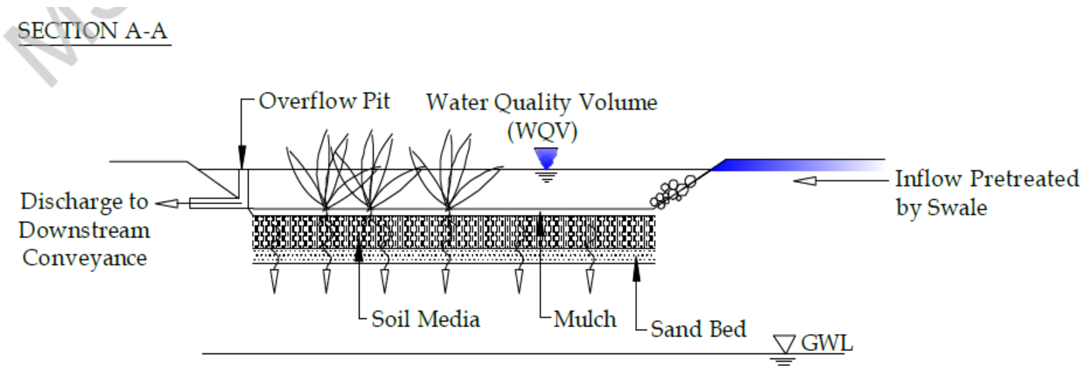

Figure 2.5: Permeable system design (DID, 2012).

For impermeable system design (Figure 2.6), it has a perforated pipeline as a drainage layer under the sand bed (transition layer) to collect all the treated stormwater that has pass through the filter media. The treated stormwater will then flow into the perforated pipe and discharge into the water storage. A liner will be applied under the bioretention system to cover the existing soil from infiltration of stormwater. The impermeable drainage layer is suitable for treating stormwater at the residential, industrial and commercial area to avoid the stormwater and wastewater mixture from that particular area infiltrate into the existing soil.

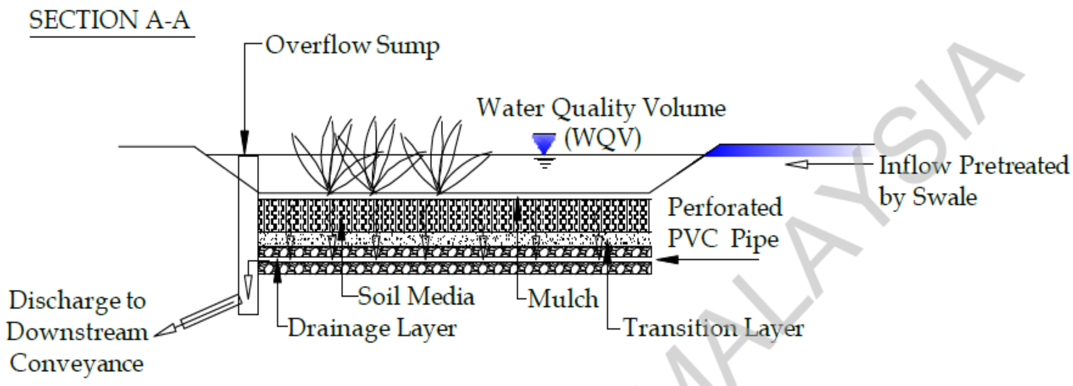

Figure 2.6: Impermeable system design (DID, 2012).

2.5 Efficiency of Bioretention

The efficiency of bioretention can be viewed in two ways, quality removal efficiency and quantity control efficiency. Quality removal efficiency is the effectiveness of the bioretention system on pollutant removal. Targeted pollutant removal in stormwater BMPs manuals from different countries has different requirements. Quantity control efficiency is to manage flooding problems using bioretention in the urban area. The quantity control of urban runoff depends on infiltration rate, inflow and outflow of the bioretention system. Further explanations on quality removal and quantity control of bioretention will be discussed in the next subtopic.

2.5.1 Quality Efficiency of Bioretention

Urban runoff quality depends on the human activity at that particular land use. In the urban runoff, pollutants usually contain nutrients, organic and inorganic matter, heavy metal, oil and grease, and suspended solids. Nitrogen and phosphorus are two nutrients that are commonly present in urban runoff. Moreover, suspended solids can also contribute to the concentration of nutrients carried along in the urban runoff. From past research, He et al. (2020) have concluded that many types of pollutants can be removed effectively by bioretention.

There is different targeted pollutants reduction in each stormwater BMPs manuals from different countries. In this study, the efficiency of the pollutants reduction target by bioretention system will refer to MSMA Malaysia. According to MSMA, DID (2012), the targeted efficiency of pollutants removal is 80% for total suspended solids, 50% for total nitrogen and 60% for total phosphorus.

2.5.1(a) Total Suspended Solid (TSS) Removal

The sediments in the urban runoff came from the road, rooftop and house yard. Besides particle soils and silts, organic materials such as bacteria and algae also contribute to sediment in urban runoff. Total suspended solids (TSS) can be treated by physical treatment, which is filtration by filter media (He et al., 2020). Different types of filter media give different results on TSS removal. Furthermore, the presence of additives or fillers in the filter media can also support TSS removal from the urban runoff.

However, high content of TSS in the urban runoff would affect the bioretention system, which can cause clogging in the filter media. In other word, sediments will block the pores between filter media particles. Clogging would affect the permeability of the filter media to flow the urban runoff. In Shafique's (2017) research, it was stated that using mulch can prevent clogging problem in the bioretention system since it has a large pore size between particles. While in research by He et al. (2020), the use of soil was reduced and replaced with peat soil as filter media to overcome the clogging problem.

According to Shrestha et al.'s (2020) study, runoff from dairy farm production was used, and the TSS concentration of the influent is three to five times higher than parking lots, highways and urban roadways (Shrestha et al., 2020). Therefore, it might trigger the treatment of the bioretention system, especially the TSS concentration at the effluent. Vol et al.'s (2015) research has mentioned that the thickness of filter media would affect the TSS concentration at the effluent. The thicker the filter media, the lower concentration of TSS at the effluent due to more retention time through the thickness of filter media to be treated.

2.5.1(b) Total Nitrogen (TN) Removal

Total nitrogen in urban runoff usually comes from human activities such as farming activities and fuel combustion. The urban runoff flows and collect the excess nutrients and infiltrate into the soil. High-containing nitrogen in water sources can reduce water quality because of the eutrophication process, which will lead to algae bloom on the water surface. The algae bloom will dissolve oxygen as they decomposed, fish and other aquatic life will die from lacking oxygen. From this phenomenon, it can disturb the natural ecosystem in the water source. Therefore, to overcome this problem, vegetation in the bioretention system is important to treat the urban runoff from nitrogen contamination by absorbing it as their nutrients to growth (Shrestha et al., 2020).

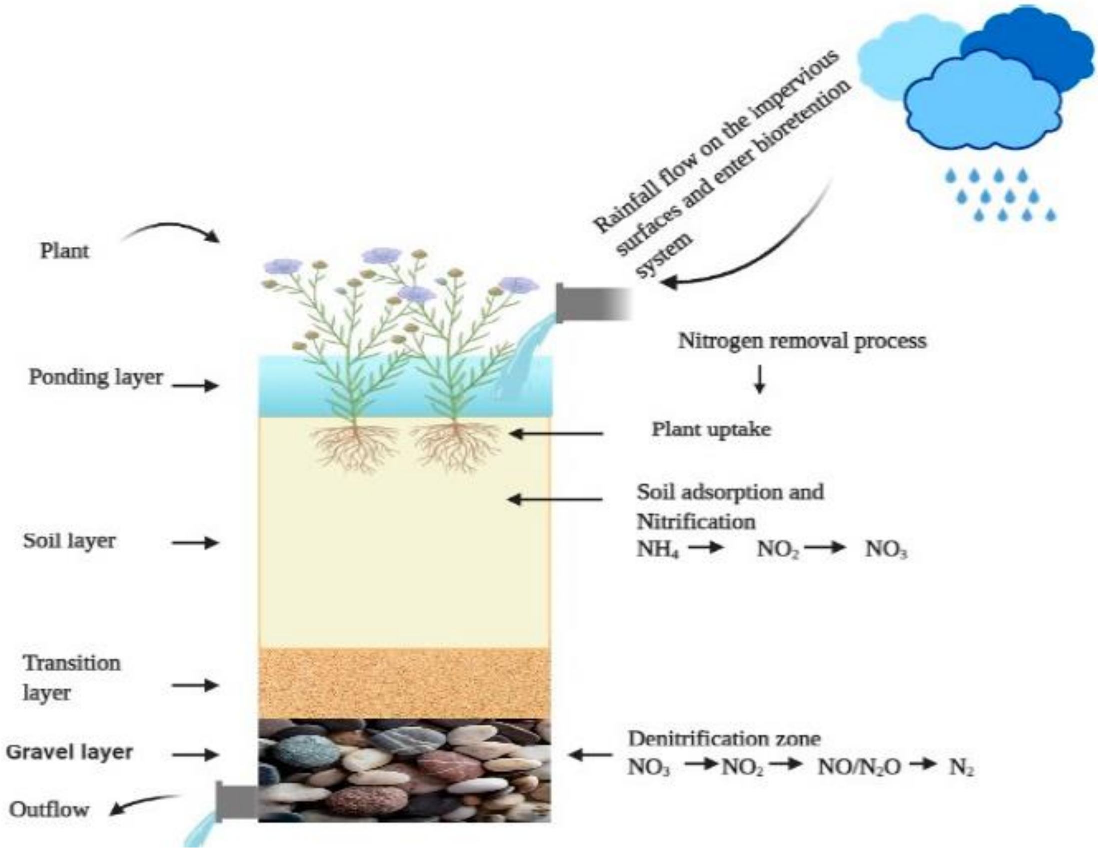

Figure 2.7: The process of nitrogen removal in bioretention system (Ali et al., 2021).

The process of nitrogen removal by plant uptake has shown in Figure 2.7. Nutrients from impervious surface area infiltrate into the bioretention system, and the nitrification process will occur naturally, which is the oxidation of ammonia to nitrite and nitrate. Vegetations will consume it as their nutrients to grow. In contrast, the remaining nitrate and nitrite pass through filter media, where denitrification processes occur at the outflow of the bioretention system.

TN results in Lopez-Ponnada et al.'s (2020) research show that a modified bioretention system has 33% higher TN removal than a conventional bioretention system. The difference between modified and conventional bioretention system is the presence of additives in filter media such as tree leaves and wood chips. Modified bioretention system has a low concentration of TSS because of the benefits from addictive in filter media. Other than that, vegetation presence in temperate climates also has higher TN removal (Lopez-Ponnada et al., 2020). Therefore, this study will adopt tropical vegetation in a tropical climate to determine nitrogen removal efficiency.

2.5.1(c) Total Phosphorus (TP) Removal

Most of the phosphorus in urban runoff comes from the industrial and residential areas since both use fertilizer, detergents and produce human waste. According to (DID, 2012), there are two forms of phosphorus pollutants, which is particulate phosphorus and dissolved phosphorus. Particulate phosphorus can be removed by filtration and sedimentation. Sand can be used as filter media to increase the efficiency of phosphorus removal. While for dissolved phosphorus, the treatment processes that might occur are adsorption, plant uptake and harvesting (DID, 2012).

According to MSMA, an excellent mixture of filter media to remove nutrient are sand, topsoil and compost. There are many choices available for compost in the market to be chosen. Therefore, Shrestha et al. (2020) used low phosphorus compost to reduce the quantity of phosphorus in the bioretention system. However, the results did not show a good phosphorus removal efficiency compared to the pilot site with no low phosphorus compost. The pilot site with no low phosphorus compost has 12% higher phosphorus removal efficiency than the pilot site with low phosphorus compost. To conclude that low phosphorus compost does not contribute to phosphorus removal in bioretention.

2.5.2 Bioretention Quantity Control Efficiency

2.5.2(a) Infiltration Rate

An adequate infiltration rate in a bioretention system will improve pollutant removal effectiveness, as a high infiltration rate will reduce the retention time. In contrast, a low infiltration rate would increase the retention time between nutrients and vegetations (Skorobogatov et al., 2020). However, too high infiltration rate would give poor nutrient removal efficiency, while too low infiltration rate will reduce the amount of urban runoff to be treated. Therefore, bioretention design with optimum rate must be achieved to have a good pollutants removal efficiency and treat enough amount of runoff that flows into the system.

Based on Dagenais et al. (2018), a few factors affect the infiltration rate. For examples, the presence of vegetations in the bioretention system. Past research explained that the system with vegetations would improve the infiltration rate compared to the system without vegetations (Skorobogatov et al., 2020). It is because vegetations influence the progress of permeability over time in the system. Furthermore, the size of the root is also one of the factors leading to a reasonable infiltration rate. In other words, a thicker diameter of roots able to create significant macropores. Hence, vegetation plays a vital role in maintaining media permeability and reducing clogging problem (Le Coustumer et al., 2012).

Infiltration rate is affected by the size of pore between particle in bioretention media. It is contrived by compaction and media texture. If the media were compact and mainly consist of clayed media, the infiltration rate will decrease (LeFevre et al., 2015). Other than that, infiltration capacity also contributes to the effectiveness of the bioretention system in controlling rainfall-runoff, especially in the impervious area (Shafique, 2017). A few factors affect the infiltration capacity (Figure 2.6): the extension and detention depth of the bioretention system, hydraulic conductivity of filter media, filter media surface area, and stormwater event. Consequently, an appropriate infiltration rate and capacity are needed to maximize the treatment of the bioretention system. The best infiltration rate for a bioretention system is not more than 200 mm/hr to ensure the filter media can maintain the moisture for vegetation growth (DID, 2012).

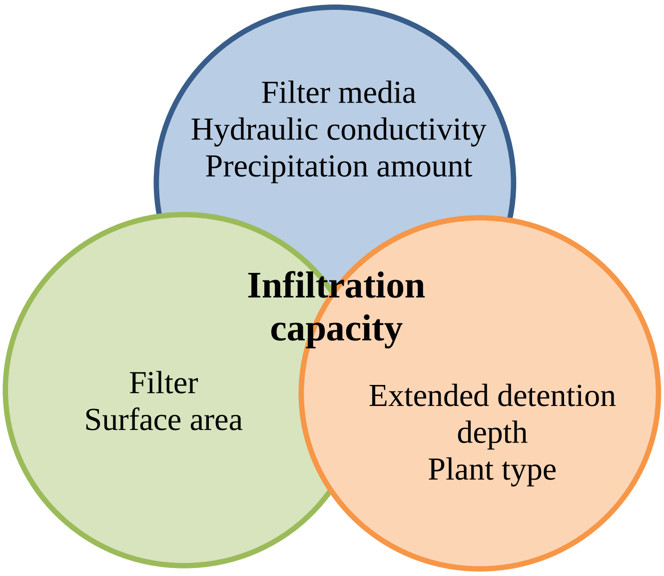

Figure 2.8: Factors that affect the infiltration capacity in bioretention system (Shafique, 2017).

2.5.2(b) Inflow and Outflow

To maintain the efficiency of the bioretention system, the quantity of stormwater at inflow and outflow should be sufficient. The inflow of the stormwater may flow through the subsurface pipe or open channel into the system. The flow from the inlet