Stormwater quality enhancement and biodiversity in tropical stormwater wetlands toward sustainable assessment approach

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ABSTRACT
Constructed wetlands have become one of the effective green technologies to improve water quality, especially from stormwater runoff. One of the important components involved in the treatment is the presence of the macrophyte or wetland plant species in the systems. There are a lot of oversea studies on the effectiveness of wetland plants in water quality improvement, using their respective local plant species. However, even though the stormwater wetland has been proved to be effectively in treating water quality in Malaysia, there is a lack of research being conducted to prove the effectiveness of local plant species in pollutants removal, under tropical climate. Thus, the aim of this study is to investigate the effectiveness of wetlands plants species for pollutant removal and water quality improvement using a few local plant species. The water quality of the whole stormwater wetland system will be evaluated through physiochemical and nutrient test. In additional to that, evaluation of species diversity will be conducted as well to prove that the systems was sustainably designed and rehabilitated. The study on species diversity will be conducted through biological assessment (bioassessment) and the important data will be used to formulate the relationship between the hydrology and water quality with species diversity. At the end, the outcome will provide useful insight on sustainable rehabilitation and design approach for future stormwater wetlands, which not only improve water quality, but also able to sustain the ecosystem and preserve wildlife biodiversity in urban development.

Keywords: Stormwater wetlands; macrophyte; biodiversity; bioassessment; conservation.

1 Introduction

Water pollution is one of the raging environmental issues that affect the human life quality as well as the health of ecosystem. There are many sources of water pollution and one of the examples came from stormwater runoff. Stormwater runoff is unfiltered water that reaches streams, lakes, sounds, and oceans by means of flowing across impervious surfaces. These surfaces include roads, parking lots, driveways, and roofs. The problem occurs when the water that is running directly into the streams is often picking up pollutants along the way. These pollutants can include motor oils and gasoline that leak from vehicles, fertilizers and pesticides from lawns and gardens, and anything else that will float or dissolve in water. The pollutants not only affect the water quality, but it also affects the other life such as benthic macroinvertebrate (Pratt et al. 1981). Thus, the characterization of stormwater runoff pollutant is necessary for a water quality management plan to urban stream (Lee and Bang, 2000) and also habitat degradation (Novotny and Witte, 1997). A lot of conventional methods had been introduced to treat the water and make it safe and benefits for all living things. However, the methods sometimes unable to maintain for a longer period of time due to its highly cost operation and maintenance. Even though the methods show an improvement in water quality, the affect to other wildlife population are less documented. To solve this issue, the world has changed to a better method which is the green technologies. One of the examples of green technologies is the constructed wetlands. Constructed wetlands are classified as human-made wetlands, which is designed and engineered to control hydrology, configuration, substrate and vegetation. Stormwater wetland is one of the constructed wetland, which purposely to solve the stormwater and urban runoff. The main function is to utilize the natural processes involve wetland vegetation, soils and the associated microbial assemblages, which are the active agents in the treatment process (Figure 1). There are a few studied being reported from stormwater wetland related to stormwater runoff issues (Livingston 1989; Strecker et al. 1992) and nonpoint source pollution (Hammer 1992; Mitsch and Cronk, 1992). In Malaysia, a few stormwater wetlands were construct to improve the water quality. Sim et al., (2008) had identified the performance of nutrient removal for nitrogen (82.11%), nitrate-nitrogen (70.73%) and phosphate (84.32%) respectively, along 6 wetlands cell in Putrajaya Wetlands Malaysia. Mohd. Noor (2009) had reported that the percentage pollutant removal occur in the constructed wetlands for BOD was 9.7% to 80%, COD was 5.7% to 62.9%, DO was 6.5% to 17.8%, turbidity was 25.9% to 30%, TSS was 50% to 100% and TP was 24% to 46% in the Universiti Sains Malaysia (USM).

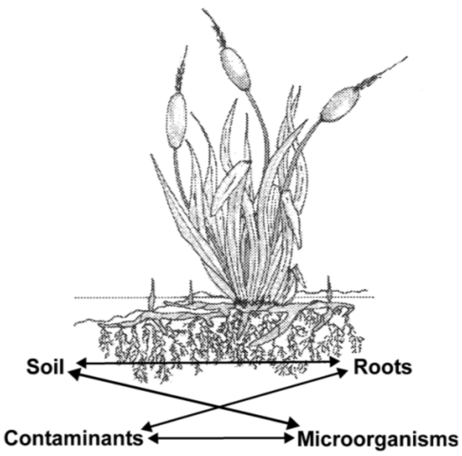


Figure 1 Possible interaction in the root zone of wetlands for wastewater treatment (Stottmeister et al., 2003)

Stormwater wetlands will be less performs if the plants absence in the system. Plant is one of the major factors to determine the successful of the treatment in the wetland. Based on the Greenway (2005), the idea to maximize the removal efficiency from both nutrients and pathogens is by increasing the numbers of diversity of macrophytes (wetland plants) and natural disinfection process. The diversity of macrophytes or wetland plants can be distinguished into emergent plant, submerged plant, floating-leaved plant and floating plant (Sculthrope, 1967). Wetlands plants involved some major effects in terms of the physical (temperature, light penetration, soil characteristics) and chemical environment of wetlands (dissolved oxygen, nutrient availability) and provide the basis of support for nearly all wetland biota (Cronk and Fennessy, 2001). This contribution from plants in the wetlands helps to increase the effectiveness of natural disinfection process (via sunlight and/or natural microbial die-off). There are a lot of reports on percentage removal of nutrient from different plant in the wetlands had been carried out all over the world (Perdemo et al., 1999; Headley et al., 2000; Kurniadie and Kunze, 2000).

In Malaysia the effectiveness of wetland plants species to treat stormwater runoff under tropical climate condition was less studied. Besides, the capability for water quality improvement from local wetland plant species such as *Hanguana malayana* is less documented. Since the characteristic of tropical climate is constant temperature throughout the year and seasonal variations is dominated by precipitation, stormwater wetlands became one of the important green technologies in Malaysia to solve the water quality issues from stormwater runoff.

Wetlands are among the most effective stormwater Best management Practices (BMPs) in terms of pollutant removal, and also offer aesthetic value. The primary goal for this study is to investigate efficiency of wetlands plants species for pollutant removal and water quality improvement and to evaluate species diversity through biological assessment (bioassessment). Both important data will be used to formulate the relationship between the hydrology and water quality with species diversity. At the end, the outcome will be the sustainable rehabilitation approach and design for future stormwater wetlands.

2 Study site

The Universiti Sains Malaysia (USM) Engineering Campus is located in Mukim 9 of the Seberang Perai Selatan District, Pulau Pinang and set as a pilot project of an ecologically sustainable development in terms of urban storm water management. The area of the campus is about 320 acres and made up of mainly oil palm plantation land and is fairly flat. The Bio-Ecological Drainage System (BIOECODS), based on integrating stormwater BMPs namely control-at-source approach, into urban planning and designed to achieve multiple objectives, is the most promising approach in newly developing or urbanizing areas (Ab. Ghani et al., 2004). With respect to the need for water quality improvements, constructed wetlands (Figure 2) are designed as a community treatment facility. Apart from water quality, the wetlands is also designed as a habitat area for biodiversity conservation within a development, supporting species such as small mammals, birds, fish, reptiles and plants.

Table 1 Wetland Plant Species in Constructed Wetland, USM Engineering Campus

Type	Plant name
Type 1 (0.3m depth)	*Eleocharis variegata*
Type 2 (0.3m depth)	*Hanguana malayana*
Type 3 (0.6m depth)	*Lepironia articulata*
Type 4 (0.6m depth)	*Typha augustifolia*
Type 5 (1.0m depth)	*Phragmites karka*

Table 2 Design Criteria for the Stormwater Wetland, USM Engineering Campus

Contributing drainage area	1,011,714.11 m^2
Water quality volume (WQV)	14,164 m^3
Length	250 m
Width	50 m
Length to width ratio	5:1
Wetland surface area	12,500 m^2
Water depth	03 - 1.0 m
Extended detention depth	1.2 m
Wetland volume	16,312 m^3

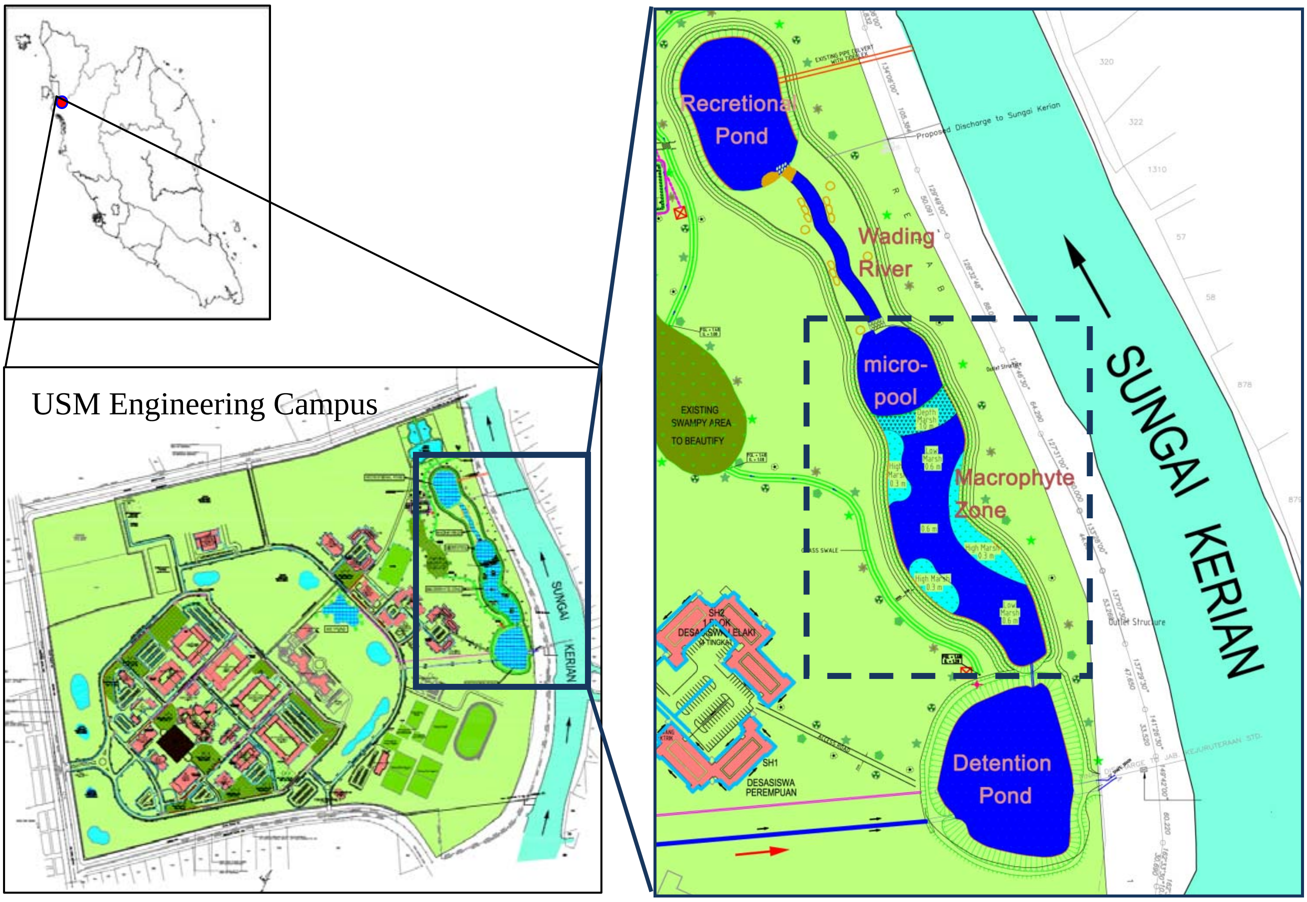


Figure 2 Stormwater Wetlands in USM Engineering Campus

3 Study approach

The study approached will not only focused on a single aspect of water quality improvement via wetlands plant species and stormwater wetland system, but it will also covered the biodiversity status and how it affected from this wetlands. Numerous wildlife species of all taxonomic orders depend on wetland as a habitat. From the lowest trophic level, such as plankton, macroinvertebrate, to the higher trophic level such as bird, experience the changes due to alteration ecosystem made by human. Some of the report had showed that the introduction of non-native species and habitat modification have caused the extinction 16 endemic species, subspecies or other distinctive population since the late 1800s (Sada & Vinyard, 2002).

Many researchers and engineers not really concentrate to the study of this ancillary component in stormwater wetlands. Since most of the stormwater wetland type is free water surface flow (FWS), a large area consumption probably had initiated the problem in balancing ecosystem in the future if the selection of plant only concentrate on the ability to treat water but ignored the ecological benefit. There are less studied and proved on how wildlife species contribute to the water treatment in wetland. As wildlife species diversity was part of the ecosystems, their present and protection need to be added in the studies, and not only assumed its present as to fulfill an aesthetic value. The relationship between the change in biodiversities of wetlands and the water quality has been rarely reported and studied. Thus, from the evaluation of biological condition of water body through biological assessment or bioassessment, the outcome of biodiversity status can be determine to predict the stability and sustainability of stormwater wetland ecosystem. Bioassessment should not be separated with the physical and chemical water quality assessment since three important component; hydrology, soil and biodiversity play it own part in stabilizing stormwater wetlands (Figure 3).

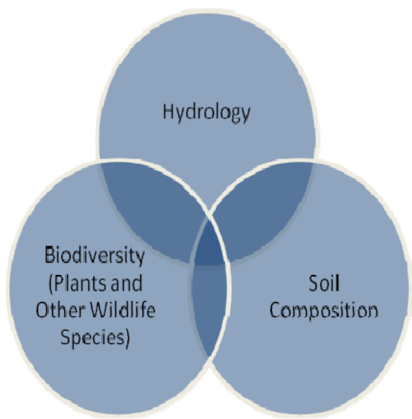


Figure 3 Three Main Components in the Stormwater Wetlands

3.1 Study background

This study background consists of four important stages (Figure 4). The first stage will be the sampling point identification. The identification is needed to consider the environmental factors such as the composition of species present, the types of species present and water depth, which influent the result of the water quality and biodiversity. The second stage will be the data collection from each sampling station. Each sampling station will collect three important components, the plant sample, water sample and biological sample, besides onsite measurement for in-situ data and rainfall data. The sample then will be further analysis to the third stages (laboratory analysis) to determine the plant growth, nutrient plant uptake, water analysis and species composition and identification. At the end of the analysis, the data will be further interpretation to the last stage, which is stage four, to fulfill the main objective listed above. All this stages will be run for a year to consider the climate factors and other environmental changes such as dry, wet season, migratory season of birds and reproduction month for some species of invertebrate. A one year data will be sufficient to give important information and pattern of changes in the stormwater wetlands.

3.2 Data collection and analysis

Data collection and analysis are important stages in this study, as been describes in the study background above. Each of the data collection and analysis provide important information to describe the condition in the stormwater wetland. A specific methodology for each analysis provides information and help to understand the stormwater wetland system. There are four main analysis will be conducted to understand the suitability and the performance of each plant species and how it contribute to the water quality and biodiversity improvement in the stormwater wetland system.

a) Monthly plant growth measurement

The data for plant growth observation can be used to determine the health of the plant throughout the year. It is important as it can determine the suitability of using the plant in the wetland system. Three measurements will be taken for plant growth; (1) Dry weight analysis, (2) Root mass analysis and (3) root shoot ratio analysis. Most the measurement will be take place at root since the root allow a plant to absorb water and nutrient from surrounding soil and healthy root system is a key to a healthy plant. Root mass is recommended as the final measurement as the plant must be removed from its growing medium in order to capture accurate data. The root: shoot ratio is one of measurement that can help to assess the overall health of the plants. It's important to combine the data from the root: shoot ratio with data from observation to get an accurate understanding of what is happening with the plants. For example, an increase in root: shoot ratio could be an indication of a healthier plant, provide the increase came from greater root size and not from a decrease in shoot weight.

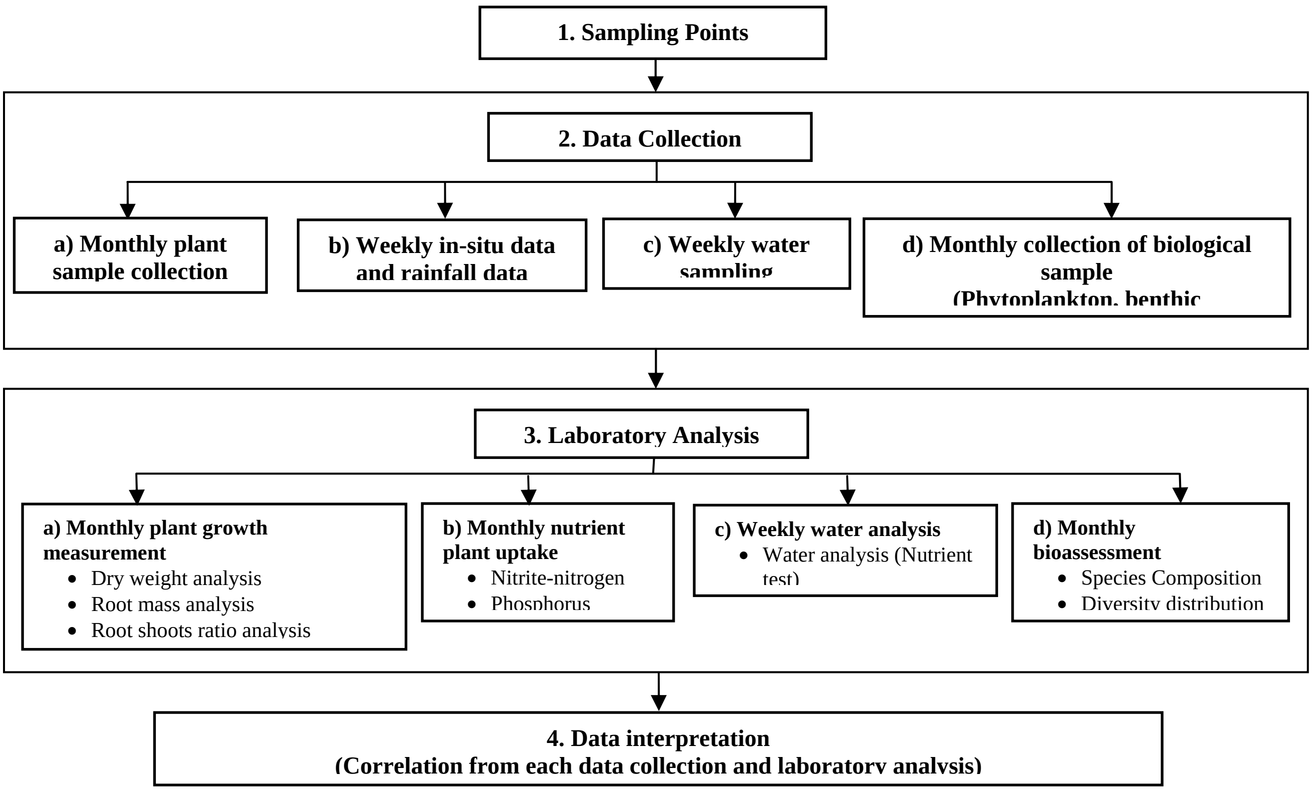


Figure 4 Research methodology flow chart

b) Monthly nutrient plant uptake

Plant analysis is the technique to determine the elemental content in a tissue of a particular plant part. Nutrients concentration in plant tissues can be measured in a plant extract obtained from fresh plant material, (i.e., tissue analysis), as well as in whole dried plant material. Two test of nutrient test uptake will be conducted; (1) Total Nitrogen (N) by Kjeldhal method and (2) Total Phosphorus (P). The test for the nitrogen will be purposely done to relate the role of the plant in the nitrogen cycle while phosphorus element test will be useful in order to determine the effect of the plant to other species communities' growth such as phytoplankton and benthic macroinvertebrate. Both nutrients can affect the water quality if the concentration present was high in the water body. Thus, the analysis can provide a useful information on how percentage nutrient uptake by plant and justify the effectiveness of wetland plant as a tool water treatment in stormwater wetlands.

c) Monthly bioassessment (phytoplankton, benthic macroinvertebrate and birds)

Three different species or indicators will be chosen to study the biodiversity; phytoplankton, benthic macroinvertebrate and birds. The reason to choose these indicators are due to their important role in the food web and its distribution, affect by environment quality in the wetland. The main objective was also to see the pattern of diversity distribution for each trophic level and how it correlates to each other and to the stormwater wetland ecosystem. The interconnection from each of the indicators can be seen at the end the study from the low trophic level (plankton) until the high trophic level (bird). Each of the indicators had different sampling procedure and strategies. For phytoplankton, the samples will be collected at the surface water by filtering forty liters (40L) of water, using plankton net with 35µm mesh size. The collected water samples will be transferred into sample bottles and formalin 5% will be added as preservative. The identification of phytoplankton will be based on taxonomic key reference until lowest taxon possible. For benthic macroinvertebrate, each sampling station will be collected by using D-framed net with a diameter 0.38 meter. The species will be transferred by using a pairs of forceps and a pipette (for small insects or larvae). All the aquatic insects and larvae collected will be preserved in 70% ethanol in the universal bottles. Some of the invertebrate will be identified directly to the naked eyes or by using the magnifying glass. The benthic macroinvertebrate will be sorted into petri dish, and identified by using a taxonomical key to the lowest taxon possible. Finally, for birds, daily visual observation will be carried out and handle by using binocular and with the help of digital camera to capture the picture of each bird species. The identification will be conduct through onsite observation and sound identification and not through mark and recapture method. This is because it is hard to setup a trap to catch the birds in an open area and less numbers of big tree. However, through visual observation, the data obtain can still be used to predict the species present in the stormwater wetlands.

d) Weekly water sampling and analysis and rainfall data collection

The sampling will be purposely done to measure the overall water quality level in the stormwater wetland. At the same time, rainfall data will be taken as a supporting for the weather event occurs during the sampling. For water quality sampling, two 500 ml bottles (representing replicate 1 and replicate 2) will be used to collect the water sample. The bottles will initially rinse with the wetland water and then fill with the wetland water samples. The water sample will be preserved in the cold compartment (usually used ice box). It must be preserve under low temperature to prevent any biological activity of any microorganisms that can affect the composition of nutrient in the water. The in-situ parameter will be taken at the sampling stations during the sampling. The parameters involved are the physico-chemical parameter including temperature, pH, dissolved oxygen, and conductivity. The parameters will be taken by using YSI Sonde meter. The nutrient analysis were total suspended solid (TSS), nitrite, nitrate, ammonia, biological oxygen demand (BOD), chemical oxygen demand (COD), and ortho-phosphate. Laboratory analysis will be carried out to determine the concentration of phosphate (PO_4^-) by referring Phosver3 (ascorbic acid) method technique. The concentrations of nitrite (NO_2^-) and nitrate (NO_3^-) will be determined using Diazotization method (0.002-0.3 mg/l) and Cadmium reduction method (0.3-30.0 mg/l). The concentration of ammonia (NH_4^+) will be determined by referring to Nessler method (0.02-2.50 mg/l). TSS, BOD and COD experiment will be handling by referring to Standard Methods for the Examination of Water and Wastewater.

4 Result and discussion

4.1 Preliminary Result

Preliminary sampling was conducted in September 2011. The preliminary sampling was purposely conducted to provide initial information in terms of water quality condition and numbers of species present. The sampling consist of 7 sampling points, 6 sampling points was influent and covered with certain percentage of vegetation (macrophyte zone) while the micropool (open water zone) was absent of vegetation but still include in the stormwater wetlands system (Figure 5). The sampling points possess different types of plant species. Thus, the effectiveness of plant uptake can be compare onsite and in laboratory through plant analysis.

Figure 5 Sampling Points in Stormwater Wetlands

Table 3 showed the improvement in water quality level from inlet, which is in wetland 1 and wetland 2 until its flow through to wetlands downstream, which was at micropool. The results showed that COD, nitrate, ammonia and temperature had gradually decreased in value. This showed that the improvement of water quality had been made in the wetland system before its discharge to the river nearby.

The dissolved oxygen (DO) also increased in value showed that the high production of oxygen had been produced through the process along the wetlands. The preliminary results obtained probably caused by the ecological function of plant, which is not being measured during the preliminary sampling. However, based on the observation, the present of wetland plant in the stormwater wetlands affect the water quality level. The species present in the wetlands during the bioassessment are still less in numbered but it's didn't meant the system hasn't support the biodiversity.

Table 4 showed the number of species present for phytoplankton and benthic macroinvertebrate. The number present was not quite high but it's still showed that the wetland able to provide habitat for species to live. The number of species high in the inlet but starts to decrease towards downstream may due to the effect of nutrient concentration, which starts to decrease as well. The present of some intolerance and tolerance species (Figure 6) of benthic macroinvertebrate showed that the bioindicator are essential to justify the water quality level.

Ten species of birds from eight different families showed the diverse community can be achieved from the stormwater wetland ecosystem (table 5). Based on the preliminary result on bioassessment, the present of variety of species from phytoplankton, benthic macroinverbrate and birds showed the system actually do provide a habitat for species to live and its attract other wildlife species to come such as migratory bird of *Egretta intermedia*.

4.2 Expected outcomes

At the end of the study, a possible outcome and data interpretation from data collection and analysis will be able to explain the main objective of the experiment. The outcome from growth pattern analysis for each wetland plants species will be useful to determine the suitability of the plant to growth in the stormwater wetland under engineering design throughout a year seasonal pattern. The water quality analysis data will be use to explain and support the reason growth pattern produced for plant in the wetland. After the growth pattern identify, the performance of each wetland plants species can be determine through the percentage nutrient uptake and pollutant removal, based on the nutrient uptake test of the plant. The result will be able to provide a scientific data information on how suitable and benefit the plant in the stormwater wetland system for water quality treatment.

As been mention before, the purposed of this study not only cover the effectiveness of plant in the stormwater wetland to improve water quality, but also be able to improve the biodiversity. The results from species diversity data will be useful to predict the possible consequence of the ecosystem after the plants introduced and the water been treated. The species diversity can be one of the important water quality indicators (bioindicator), instead of using chemical analysis data to predict the water quality level of the whole stormwater wetlands system. At the end of the study, both species diversity and water quality data can be correlated to one another to find its relationship in the system. However, a more significant outcome can be produced at the end of the study is a new sustainable design, which not only improve its performance in water quality, but also able retain the natural biodiversity.

Table 3 Preliminary Result in Wetland for Water Quality (September 2011)

Sampling Station	Temperature (°C)	Dissolved Oxygen	pH	Conductivity	Ammonia	Phosphate	Nitrate	Nitrite	TSS	BOD	COD
Wetlands 1	31.11	7.55	7.39	0.133	0.32	0.38	2.6	0.013	0.002	3.22	24
Wetlands 2	31.30	7.30	7.21	0.137	0.26	0.40	2.4	0.011	0.0019	2.49	22
Wetlands 3	31.37	7.08	7.21	0.133	0.23	0.25	1.7	0.012	0.0012	2.38	20
Wetlands 4	30.83	8.89	7.95	0.136	0.2	0.23	2.2	0.004	0.002	1.97	22
Wetlands 5	30.99	8.53	7.75	0.135	0.18	0.28	1.1	0.004	0.0018	2.67	21
Wetlands 6	30.96	8.99	7.92	0.136	0.12	0.35	1.3	0.009	0.0021	3.11	16
Micropool	30.06	8.62	7.79	0.136	0.13	0.3	1.8	0.008	0.002	3.02	8

Table 4 Preliminary result for number of species (September 2011)

Sampling Station	Numbers of Species	
	Phytoplankton	Benthic Macroinverbrate
Wetlands 1	13	12
Wetlands 2	15	11
Wetlands 3	9	12
Wetlands 4	7	7
Wetlands 5	8	8
Wetlands 6	8	10
Micropool	4	5

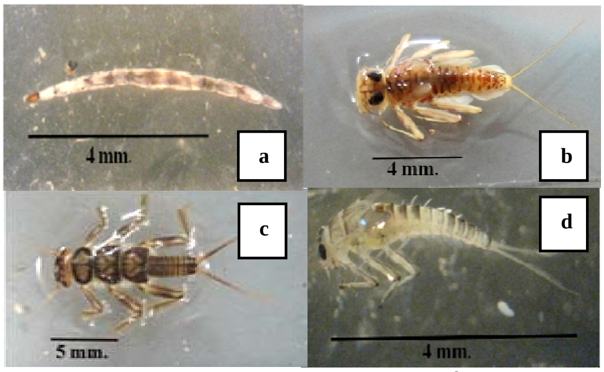
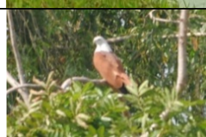


Figure 6 Benthic Macroinvertebrate Species found in the wetland: (a) Family Ceratopogonidae (b) Family Heptagenidae (c) Family Perlidae (d) Family Baetidae

Table 5 Preliminary Result for Bird Species (September 2011)

Family name	Scientific name	Local Name	Picture
Family Ardeidae	*Egretta intermedia*	Plumed Egret, Short-billed Egret, Bangau kendi	
	Ardea purpurea	Purple Heron, Pucung Serandau	
	Ixobrychus cinnamomeus	Cinnamon Bittern, Pucong Bendang	
Family Alcedinidae	*Halcyon smyrnensis*	White-Throated Kingfisher, Pekaka Belukar	
Family Sturnidae	*Acridotheres tristis*	Common Myna, Tiong Gembala Kerbau	
Family Meropidae	*Merops philippinus*	Blue-tailed bee-eater, berek-berek carik dada	
Family Sclopacidae	*Actitis hypoleu*	Common Sandpiper, Kedidi Pasir	
Family Accipitridae	*Haliastur Indus*	Brahminy Kite, Helang Merah	
Family Columbidae	*Streptopelia chinensis*	Spotted Dave, Tekukur	
Family Charadriidae	*Vanellus indicus*	Red Wattled Lapwing, Rapang Minta Duit	

5 Conclusions

A good design practice for stormwater wetlands is to provide a range of habitat areas within the macrophyte zone to support a variety of wetland plant species, ecological niches and perform a range of treatment processes. Wetland plants are one of the important tools in the stormwater wetland design practice. The plants influence the performance of the wetlands for the water quality improvement. Suitable plants only able to improve water quality and nutrient uptake, but also can provide ecological benefit such as comfortable habitat for animal to live. When an engineer able to fulfill the biodiversity criteria for every stormwater wetland design, a significant contribution in order to protect the species population from the major concern of extinction can be made and help to maintain healthy ecosystem for future generation.

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