PERFORMANCE EVALUATION OF CONSTRUCTED WETLAND UNDER TROPICAL CLIMATE: AN EXPERIENCE AT HUMID TROPIC CENTRE AND UNIVERSITI SAINS MALAYSIA ENGINEERING CAMPUS

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Constructed wetland is widely used in developed countries and temperate climate for the stormwater quality improvement. However, constructed wetland in Malaysia can be considered as a new innovation and not widely implemented in all over Malaysia. The aim of this paper is to evaluate the efficiency of constructed wetland in Malaysia through the two experiences of constructed wetland at Universiti Sains Malaysia Engineering Campus, Malaysia and Humid Tropic Centre Kuala Lumpur, Malaysia. The data collected from these wetland systems used to treat stormwater runoff or runoff-impacted surface waters were examined and compared in order to identify any obvious trends that may aid future stormwater treatment wetland design efforts. The parameters measured and discussed in this paper were Turbidity, Total Phosphorus, Biological Oxygen Demand and Chemical Oxygen Demand. The result for USM Engineering Campus constructed wetland showed that the average removal efficiency of pollutant removal for BOD was range from 9.7% to 80%, COD was 5.7% to 62.9%, turbidity was 25.9% to 30.0% and TSS was 50% to 100%. While for HTC constructed wetland, the result showed that the average removal efficiency for BOD was range from 4.55% to 36.67% and COD was 9.1% to 88%, turbidity was 9.76% to 66% and TSS was 12.5% to 45%. Generally, the results obtained show that the constructed wetland under tropical climate is capable to improve stormwater quality before discharging to the nearest water ways. The efficacy of these constructed wetlands to treat stormwater from different sources varied, and modified wetland designs or active management may be necessary to improve water quality even further. The findings can be used significantly to enhance the knowledge in constructed wetland under tropical climate where it can serve effectively for managing urban runoff using control at source approach.

Keywords
Constructed wetland, water quality, removal efficiency, performance, BOD, Turbidity, TSS, COD, tropical climate
Introduction

Stormwater management has evolved dramatically throughout Malaysia since it was first adopted and applied in Malaysia as early as 2000. This original manual was intended to provide guidance in planning and designing effective stormwater best management practices (BMPs) to developer/owner developing properties subject to Drainage and Irrigation Department of Malaysia and Local Government compliance (DID, 2000). The manual effectively manage the impacts of stormwater and prevent adverse impacts to stormwater quality, habitat and flood storage capacity as well as meet the requirements, DID has updated the 1st Manual to reflect the current engineering practice based on local data and experience concerning stormwater management and to incorporate MSMA methods. This revised manual provides appropriate guidance for stormwater management on new development and redevelopment projects and most importantly incorporates MSMA as the “industry standard” for all sites, representing a fundamental shift in how development projects are planned and designed (DID, 2011). The concept in MSMA 2nd edition is to control the stormwater at source quantitatively and qualitatively and provide amenity to the new developed area.

Constructed wetland is one of element in MSMA Manual by incorporating the natural function of wetland to aid pollutant removal from stormwater with the advantage of control over location, design and management to optimize the water quality function (DID, 2011). Constructed wetland can be defined as an engineered system that is designed to imitate natural wetland to exploit the water purification functional value for humans (Kivaisi, 2001). It also can be defined as an area of land where soil is saturated with water either permanently or seasonally and the areas also need to be covered, at least partially, by shallow pools of water (William and James, 2000). Constructed wetland systems can be clearly designed to aid in pollutant removal from stormwater through sedimentation, filtration of fines and biological uptake (Donald, 2001; William & James, 2000). It also provide for quantity control of stormwater by providing a significant volume of temporary water storage above the permanent pool elevation (Wong et al., 2000). Water quality issues have become increasingly important and this forms the main goal in constructed wetland (Kadlec, 2003). The information on water quality for constructed wetland is very important to ensure that the constructed wetland has an ability to remove the contaminants from stormwater runoff.

Constructed wetland offer an alternative way to improve the stormwater quality. They are used to reduce TSS, BOD, nutrient, nitrogen, phosphorus and fecal coliform. Research on thirteen constructed wetland site in the Ireland found that the average pollutant removal rates to be 76.8% to 99.8% for Biochemical Oxygen Demand, 76.3% to 99.7% for Chemical Oxygen Demand and 67%-99.9% for Ammonium Nitrate (NH$_4$-N) (Babatunde et.al, 2008). Stewart and Hackney (2002) did an assessment of stormwater wetlands at Riverside Park, for Liverpool City Council and the concentrations of TSS, TP and TN were found to reduce by an average of 96, 82 and 74% respectively, whilst turbidity and faecal coliforms dropped by 97% and total grease was reduced by 17%. While studied done by Greenway and Woolley (1999) on a few constructed wetlands in Queensland such as constructed wetland at Cairns, Ingham, Townsville, Mackay, Emu Park, Black all, and Goondiwind showed about 16.7%- 80.4% percentage of pollutant removal for BOD, 8.3%-77% for SS, 0-15.7% for TP, 18.02%-82.6% for TN and 8.42%-80.9% for Ammonia Nitrate. While in Malaysia, study done at Putrajaya Constructed Wetland indicated
that the removal rate for the TSS were range from 10.25mg/l to 137.5mg/l, the BOD were range between 0.38mg/l to 1.65mg/l, the TP was 84.32% and the DO were range between 0.78mg/l to 13.25mg/l. This treatment mechanism is based on natural process for the removal of different pollutants with aid of macrophytes and different floating and submerged water plants. Plant plays very important role in removing pollutant in stormwater. The choice of plants are based on water depth, size, physical structure, physiology of the plants and their related adaptive capacity for survival in different water depths or soil types (Harrington and McInnes, 2009). The common plants that applied for temperate season based on literature are common reed (Phragmites australis), cattails (Typha spp.), bulrushes (Scirpus spp.) and reed canary grass (Maine et al., 2009). However, in Malaysia there are a few species that were suggested in MSMA such as Phragmites karka, Typha augustifolia, Hanguana Malayana and Lepironia Articulata (DID, 2011).

Instead of plants selection, the constructed wetland performances also influenced by design criteria where the better design criteria will produce a good performance of constructed wetland. Previous studies suggested that wetland performances in treating stormwater is generally a function of inflow or hydraulic loading rate and detention time, which are in turn functions of storm intensity, runoff volume, and wetland size (area and volume) (Carleton et al., 2001; Barten, 1987; Hickok et al., 1977; Meiorin, 1989; Scherger and Davis, 1982). While Department of Planning and Local Government for Adelaide Region (2009) stated that the design considerations that need to be considered during the designing stage of constructed wetland are hydrology, water quality, maintenance, landscape and vegetation. These design guidelines will help the urban water engineer to design and construct the constructed wetland with optimum removal efficiency.

The main objective of this paper is to evaluate the efficiency of constructed wetland in Malaysia and this will contribute towards model validation and increase the local knowledge and optimization of constructed wetland effectiveness. This paper will discuss about two experiences of performance of stormwater constructed wetland which were situated at Universiti Sains Malaysia (USM) Engineering Campus, Pulau Pinang and Humid Tropic Centre (HTC) Kuala Lumpur. The findings from this study will help to optimize the performance under tropical climate.

STUDY AREA

Case Study 1: Universiti Sains Malaysia (USM) Engineering Campus

USM Engineering Campus project is located in Mukim 9 of the Seberang Perai Selatan District Pulau Pinang. It lies between latitude 100 29.5’ south and 100 30.3’ north and between longitudes 5 9.4’ East and 5 8.5’ west. The locality is known as Sri Ampangan, Nibong Tebal Pulau Pinang which about 2 km South East of the town of Nibong Tebal, about 1.5km North East of the town of Parit Buntar Perak and about 1.5km North West of the town of Bandar Baharu (across Sungai Kerian in Kedah). The area of the campus is about 320 acres and made up of mainly oil palm plantation land and it’s fairly flat. The location of USM Engineering Campus and component of constructed wetland can be seen through the Figure 1, 2 and 3 respectively. The project includes a series of components such as ecological swales, online sub surface detentions and dry ponds
that contribute to the treatment of the stormwater before it leaves the campus. This system was called as Bioecological Drainage System (BIOECODS) was designed to combine infiltration, delayed flow, storage and purification as pre treatment of stormwater before discharging to a constructed wetland. The concept of BIOECODS is to integrate the drainage components with the ecological pond components for further treatment of the stormwater runoff. The design features and types of planted macrophytes for USM Engineering Campus project can be seen through the Table 1 and Figure 4 respectively.

Figure 1: Location of Nibong Tebal, Pulau Pinang

Figure 2: Location of USM Engineering Campus

Figure 3: Component of Constructed Wetland
Table 1: Design of constructed wetland (Zakaria et al, 2003)

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Design criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>1.214 km²</td>
</tr>
<tr>
<td>Length</td>
<td>155m</td>
</tr>
<tr>
<td>Width</td>
<td>60m</td>
</tr>
<tr>
<td>% catchment area</td>
<td>0.7</td>
</tr>
<tr>
<td>Mean residence time</td>
<td>3 days</td>
</tr>
<tr>
<td>Depth</td>
<td>0.6m</td>
</tr>
</tbody>
</table>

Figure 4: Type of Macrophytes for USM Engineering Campus.

Case Study 2: Humid Tropic Centre (HTC), Kuala Lumpur

The site of constructed wetland is located at Humid Tropic Centre (HTC) Jalan Redang, Kuala Lumpur and near to the Drainage Irrigation Department Headquarters, Kuala Lumpur. Kuala Lumpur is capital city for Malaysia. The constructed wetland is part of Manual Saliran Mesra Alam Stormwater Management Ecohydrology (MSMA SME) components at Humid Tropic Centre. The components comprises of constructed wetland, bio-retention, grass swale, rain water harvesting, green roof, porous pavement and greywater reuse system. The location of Humid Tropic Centre and component of constructed wetland can be seen through the Figure 5, 6 and 7 respectively. Stormwater will convey to constructed wetland through the grass swale and bio retention before discharging to the water course.
The design criteria and type of macrophytes that were planted in HTC constructed wetland can be seen through the Table 2 and Figure 8 respectively.
Table 2: Design Criteria of Constructed Wetland

<table>
<thead>
<tr>
<th>Design Parameter</th>
<th>Design criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>5,800 m²</td>
</tr>
<tr>
<td>Length</td>
<td>41 m</td>
</tr>
<tr>
<td>Width</td>
<td>14 m</td>
</tr>
<tr>
<td>% Catchment area</td>
<td>9.9 %</td>
</tr>
<tr>
<td>Mean residence time (d)</td>
<td>1.2</td>
</tr>
<tr>
<td>Depth</td>
<td></td>
</tr>
<tr>
<td>• Forebay / Pool: 1.2 m</td>
<td></td>
</tr>
<tr>
<td>• Low Marsh: 0 m – 0.3 m</td>
<td></td>
</tr>
<tr>
<td>• High Marsh: 0.6 m – 1.0 m</td>
<td></td>
</tr>
<tr>
<td>• Micro Pool: 1.8 m</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: Type of Macrophytes for HTC Kuala Lumpur

Methodology

Water quality data from both locations had been collected at the inlet and the outlet point of constructed wetland during rainfall event. The parameters measured and discussed in this paper were Turbidity, Total Phosphorus, Biological Oxygen Demand and Chemical Oxygen Demand. However, other parameters such as temperature, heavy metals, dissolved oxygen, Total Nitrogen, Total Phosphorus and Total Coliform were also measured and analysis. The sampling and testing procedures conducted were in accordance with the Standard Method for Examination of Water and Wastewater 20th Edition. Then the statistical analysis was carried out to determine the correlation between water quality parameter at the inlet and water quality parameter at the outlet of constructed wetland.

Result and Discussion

The results are evaluated the performance of Constructed Wetland for USM Engineering Campus and Humid Tropic Centre Kuala Lumpur based on water quality parameters such as Turbidity, Biochemical Oxygen Demand, Chemical Oxygen Demand and Total Phosphorus.

Turbidity

Turbidity can be defined as the amount of particles that found at the inlet and outlet of constructed wetland. If the result showed the lower concentration of turbidity its mean that the
water in a good quality. Figure 9 showed the turbidity removal efficiency for USM Engineering Campus while Figure 10 showed the turbidity removal efficiency for HTC Kuala Lumpur. Mohd Noor et al. (2011) stated that the removal efficiency for USM Engineering was 25.9% to 30.0% while in the case of HTC Kuala Lumpur the removal efficiency of turbidity was indicated from range 9.76% to 66%. However, Figure 10 also indicated that most of the dates showed that HTC constructed wetland did not remove turbidity concentrations from the inlet to outlet because some of small particles from the bank of micropool enter together with stormwater and directly flow into the outlet (micropool) zone of the constructed wetland during the rainfall event. Figure 11 showed the correlation of turbidity concentration at inlet and with turbidity concentration at the outlet for USM Engineering Campus and Figure 12 showed the correlation of turbidity concentration at the inlet with turbidity concentration at the outlet for HTC Kuala Lumpur. The R² for USM Engineering Campus was 0.606 and R² for HTC Kuala Lumpur was 0.082. It was showed that the USM Engineering Campus gave the higher R² value compared to HTC Kuala Lumpur.
Biochemical Oxygen Demand

Biochemical Oxygen Demand is a water treatment test to determine the presence of organic pollutant. The BOD indicates the extent of organic pollution in the aquatic system which adversely affect the water quality (Jonnalagadda and Mhere, 2000). Figure 13 showed the BOD Removal Efficiency for USM Engineering Campus and Figure 14 showed the BOD Removal Efficiency for HTC Kuala Lumpur. Based on those figures, the BOD removal efficiency was indicated around 9.7% to 80% for USM Engineering Campus (Mohd Noor et al., 2011) while for HTC was indicated 4.6% to 85%. However Figure 13 indicated that some dates for BOD concentration at USM Engineering Campus, showed there were no reduction at the inlet and outlet due to the higher number of algae, thus contributed to the increasing of DO concentration at the outlet of constructed wetland (Li et al., 2009; Greenway and Woolley, 1999). Besides the numbers of algae, hydraulic retention time is one of factor that contributed towards BOD removal efficiency. A longer HRT will contribute to the higher removal efficiency of BOD. Based on study by Akratos and Tsihrintzis (2007) on the different hydraulic retention time of BOD for 8, 14 and 20 days, the result showed that for 8-day HRT 91.9%, for 14-day 90.6% and for 20-day 91.9%. However this condition was not applicable for USM Engineering Campus with 3 days hydraulic detention time and HTC with 1.2 days hydraulic detention time where the BOD removal efficiency 9.7% to 80% for USM Engineering Campus and 4.6% to 85% for HTC. This condition may be due to the higher number of algae at USM Engineering Campus that contribute a little bit lower of removal efficiency of BOD compared to HTC.

The statistical analysis were carried out for both sites to determine the correlation values between inlet concentration and outlet concentration. Figure 15 showed the correlation of BOD concentration at inlet with BOD concentration at the outlet for USM Engineering Campus and Figure 16 showed the correlation of BOD concentration at the the inlet the inlet with BOD concentration at the outlet for HTC Kuala Lumpur. The $R^2$ value for USM Engineering Campus was 0.523 and $R^2$ value for HTC was 0.177.

![Figure 13: BOD Removal Efficiency for USM Engineering Campus](Mohd Noor et al.,2011)  ![Figure 14: BOD Removal Efficiency for HTC Kuala Lumpur](HTC)
Chemical Oxygen Demand

Figure 17 showed the COD removal efficiency for USM Engineering and Figure 18 showed the COD removal efficiency for HTC Kuala Lumpur. The percentage removal efficiency for USM Engineering Campus was recorded around 5.7% to 80% while for HTC the removal efficiency was recorded up to 55.7%. Figure 19 and 20 showed the correlation of COD concentration at the inlet with COD concentration at the outlet for USM Engineering Campus and HTC respectively. The $R^2$ value for USM Engineering Campus was 0.446 and $R^2$ value for HTC was 0.395. From the obtained result, it was showed that the $R^2$ values for USM Engineering Campus give the higher value compared to the HTC value. The differences in removal efficiency maybe due to size and shape of the unit where the constructed wetland size of USM Engineering Campus is larger compared to HTC which resulting the higher removal efficiency of COD. Study done by Scholz et al. (2009) showed that COD gave the higher removal efficiency passed through the large size of wetland cells and high retention time.
Figure 19: Correlation of COD concentration at the inlet with COD concentration at the outlet for USM Engineering Campus

Figure 20: Correlation of COD concentration at the inlet with COD concentration at the outlet for HTC Kuala Lumpur

**Total Phosphorus**
Vegetation plays an important role in removing phosphorus where phosphorus removal is accomplished via deposition of its insoluble forms within the sediment and plant uptake. The negative values in the removal performance can be explained due to litter decomposition and phosphorus release back to the system. Figure 21 showed the percentage removal efficiency of TP for USM Engineering Campus while Figure 22 showed the percentage removal efficiency of TP for HTC. The percentage removal efficiency for USM was recorded up to 100% (Mohd Noor et al., 2011) and for HTC the recorded removal efficiency was 13% to 86%. The major factor that might be reduced the TP concentration in constructed wetland at USM Engineering Campus is the catchment area that relatively flat which led to the lower TP concentration into the wetlands. The location of USM Engineering Campus’s constructed wetlands is situated at a height of 0.7 m above sea level and this was contributed to the removal of TP (Mohd Noor, 2011; HLA, 1999). Figure 23 and 24 showed the correlation of TP concentration at the inlet with TP concentration at the outlet of USM Engineering Campus and HTC respectively. The $R^2$ for USM Engineering Campus was 0.64 and for HTC was 0.046. From the result obtained, it was clearly showed that USM constructed wetland gave the higher $R^2$ compared to HTC constructed wetland. The contrast result that maybe due to different in watershed topography and sediment derived through the erosion (Kovacic et al., 2006). At the USM Engineering Campus, the wetland watershed relatively flat therefore the sediments export to the wetland was low, while at the HTC, the location was steeper thus resulting the sediment export to the wetland was greater.
Figure 21: TP Removal Efficiency for USM Engineering Campus (Mohd Noor et al., 2011)

Figure 22: TP Removal Efficiency for HTC Kuala Lumpur

Figure 23: Correlation of TP concentration at inlet with TP concentration at the outlet for USM Engineering Campus (Mohd Noor et al., 2011)

Figure 24: Correlation of TP concentration at the inlet with TP concentration at the outlet for HTC Kuala Lumpur

Generally, the removal efficiency of water quality parameters were influenced through the hydraulic retention time, size of constructed wetland, condition of macrophytes and location of watershed either flat or steeper area. A lot of researches had done on hydraulic retention time and showed that longer detention time will retain will give higher removal efficiency (Wong et al., 2000; Guiseppe et al., 2000) While Guiseppe et al. (2000) showed that size of constructed wetland give an influence on removal efficiency and they explained that a good hydraulic performance obtained through a good design of the shape and of the hydraulic structures increases pollutant removal efficiency. Moreover, condition of macrophytes also influences the pollutant removal in constructed wetland. The constructed wetland with dense stand of emergent aquatic vegetation has intentionally to reduce pollutant, where macrophytes also provide place for algae to growth and decrease flow resistance during the rainfall events (Jadhav and Buchberger, 1995)
Conclusion
The removal efficiency from both locations was relatively good as compared to the international literature with the values of biochemical oxygen demand (97.6%), chemical oxygen demand (94.9%), suspended solids (93.7%), and phosphorus (91.8%). The findings also indicated various factors that influenced the removal efficiency of constructed wetland in tropical climate such as hydraulic retention time, size of constructed wetland, condition of macrophytes and location of watershed either flat or steeper area. However, there is a need to study and further investigation to verify this finding. Hence this can be suggested and count in consideration when the designing stage for the constructed wetland under tropical climate is made in order to produce an optimum pollutant removal efficiency. The efficacy of these constructed wetlands to treat stormwater from different sources varied, and modified wetland designs or active management may be necessary to improve water quality even further. The findings can be used significantly to enhance the knowledge in constructed wetland under tropical climate where it can serve effectively for managing urban runoff using control at source approach.

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