WATER QUALITY LEVEL IN STORMWATER RUNOFF THROUGH CONSTRUCTED WETLAND UNDER TROPICAL CLIMATE

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ABSTRACT

The acceleration of urbanization with variable land use and increasing population, the natural environment has consistently deteriorated especially river water. The climatic change will change the rainfall pattern as well as evaporation and evapotranspiration. Urban stormwater runoff is becoming important to be treated before discharge into the river water as pollutant was carried off and gave significant impact to aquatic ecosystem. The incoming pollutant concentration by stormwater runoff would be increasing the actual pollutant level in river water body. Constructed wetland as one of the best management practice has been potentially to overcome this problem. However, an assessment of how much the urban stormwater pollutant level reduction and water quality can be achieved is needed. Therefore, this study was conducted to evaluate the performance of water quality level in stormwater runoff through a constructed wetland under tropical climate. This study was conducted in actual constructed wetland according to the design criteria and requirement as specified in MSMA 2nd Edition located in Universiti Sains Malaysia (USM) Engineering Campus, Nibong Tebal, Penang, Malaysia. The parameters that investigated in this study were pH, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN) and total suspended solid (TSS). This study was conducted for eight months and grab sampling method were applied for 14 sampling stations. The mean of water quality index (WQI) of the inlet constructed wetland was 79.26 ± 3.94 indicated as slightly polluted at Class III with WQI ranged from 70.22 to 85.00. After passing through the treatment at constructed wetland, the mean of WQI of the outlet constructed wetland was 84.49 ± 3.68 indicated as clean at Class II with WQI ranged from 74.74 to 89.31. High and low intensity of rainfall event will affect the level of pollutant as the land used of catchment area was same. The results showed a reduction of pollutant level for TSS and AN with 72.99% and 74.06% of percentage reduction, respectively throughout the constructed wetland. These results may be explained further by the treatment media in constructed wetland. Therefore, an appropriate design of constructed wetland with the consideration of pollutant level in catchment area land used is necessary to be identified as the constructed wetland shown the high contribution of the stormwater runoff quality enhancement.

Keywords: Constructed wetland, pollutant level, stormwater runoff, treatment media, water quality index

1. INTRODUCTION

The acceleration of urbanization with variable land use and increasing population, the natural environment has consistently deteriorated, especially river water (Chow and Yusop, 2014; Du et al., 2010). The climatic change will change the rainfall pattern as well as evaporation and evapotranspiration. Urban stormwater runoff also known as nonpoint source will enter the river water body together with pollutant such as sediment, organic matter, oil and grease and also nutrient (Wu and Chen, 2013). The incoming pollutant concentration by stormwater runoff would be increasing the actual pollutant level in river water body. Water quality index (WQI) and national standard for Water Quality in Malaysia (NWQS) would be the way for measurement that will be used to identify levels and class of polluted river water (DOE, 2013). WQI will consist six sub-indexes, namely, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN), suspended solid (SS) and pH. These sub-index parameters are involved with physical, chemical and biological reaction in the water body and the changes may affect the surrounding living thing. Therefore, the urban stormwater runoff is becoming important to be treated before discharge into the river water as pollutant was carried off and gave significant impact to aquatic ecosystem.

Constructed wetland as one of the best management practice has been potentially to overcome this problem. Constructed wetland consists two types, namely, horizontal flow and vertical flow. Horizontal surface flow constructed wetland is normally will be used due to economical way as pollutant treatment, especially stormwater and wastewater. The horizontal surface flow constructed wetland will have an open water area and seem like natural marshes (Kadlec and Wallace, 2008). According to the Urban Stormwater Management Manual for Malaysia or “Manual Saliran Mesra Alam” (MSMA 2nd Edition), constructed wetlands comprising of three main zones, namely, inlet zone, macrophtye zone and open water zone (DID, 2012).

In Malaysia, Mohd. Noor (2009) found that total phosphorus removal was ranged in between 24% to 46% after throughout the constructed wetland. Sim et al. (2008) indicate that constructed wetland can remove approximately 82.11% and

84.32% of total nitrogen and phosphate, respectively. Lim et al. (2001) had reported that the percentage removal of nitrogen in constructed wetland was 22%. Another study reported that suspended solid will accumulate with the contaminants as high concentration of organic found in wetland sediment (Tu et al., 2014). However, an assessment of how much the urban stormwater pollutant level reduction and water quality can be achieved is needed. Therefore, this study was conducted to evaluate the performance of water quality level in stormwater runoff through a constructed wetland under tropical climate.

2. METHODOLOGY

This study was conducted in actual constructed wetland according to the design criteria and requirement as specified in MSMA 2nd Edition located in Universiti Sains Malaysia (USM) Engineering Campus, Nibong Tebal, Penang, Malaysia as shown in Figure 1. USM Engineering Campus is approximately 320 acres consisting of mainly oil palm plantation land and is fairly flat. The source of pollutant in USM Engineering Campus can be from plant landscaping, plant watering, herbicide, pesticide, fertilizer, car park area, recreational area, roof top and also from the surface runoff.

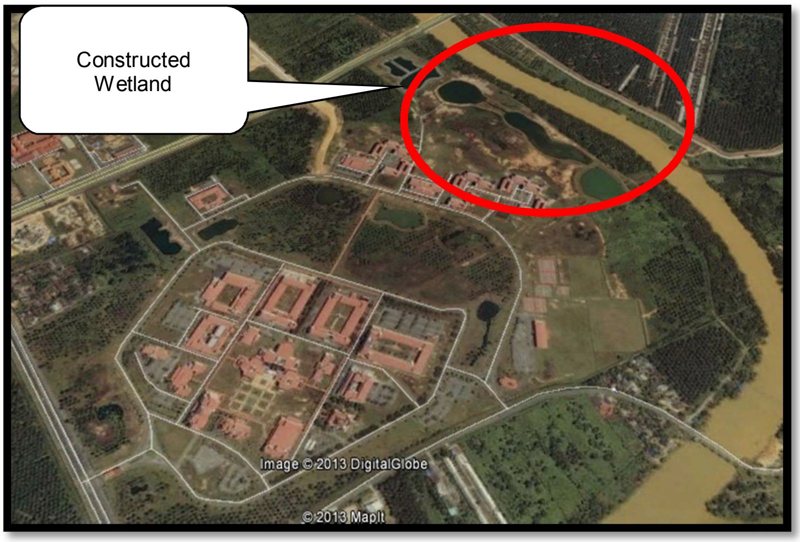

Figure 1: Map of Universiti Sains Malaysia Engineering Campus (Google Maps, 2013).

Six species of macrophyte had been selected, namely, *Elocharis variegate, Scirpus grossus, Phragmite karka, Typha angustifolia, Lepironia articulate* and *Hanguana malayana* had been cultivated at constructed wetland. The water sampling were conducted from May 2013 until December 2013 based on rainfall event. Grab sampling method was being applied for 14 sampling stations and preservation of the sample was made. The parameters that investigated in this study were pH, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN) and total suspended solid (TSS). In-situ measurements were conducted using YSI Pro 10102030 for DO and pH and using Marsh Mcbirney Flo-mate TM Model 2000 for velocity measurement. The laboratory analysis of water quality was carried out at the River Engineering and Urban Drainage Research Centre, REDAC Laboratory, USM to determine the concentration as shown in Table 1. The testing was conducted in three replicate at laboratory by following the standard method which complies with the standard of the American Public Health Association (APHA), 2012.

Table 1: Standard Method (APHA, 2012, and HACH, 2013).

Parameter	Standard Method
pH	APHA-4500-H-B
Dissolve Oxygen (DO)	APHA-4500O-C
Total Suspended Solid (TSS)	APHA-2540D
Biochemical Oxygen Demand (BOD_5 at 20°C)	APHA-5210B
Chemical Oxygen Demand (COD)	HACH-8000
Ammoniacal Nitrogen (AN)	HACH-8038

The percentage of removal and Water Quality Index (WQI) were used to determine the performance of urban stormwater pollutant removal through the constructed wetland. WQI was determined by six sub-index parameters, namely, DO, BOD, COD, AN, SS and pH. The equivalent river classes can be determined by the WQI formula as in Eq. [1].

$$WQI= 0.22(SIDO) + 0.19(SIBOD) + 0.16(SICOD) + 0.15(SIAN) + 0.16(SISS) + 0.12(SIpH) \quad [1]$$

Then, the WQI result will be compared to the values shown in Table 2 and Table 3.

Table 2: Water Quality Index (Department of Environment [DOE], 2013).

Parameter	Class I	Class II	Class III	Class IV	Class V
WQI	> 92.7	76.5 – 92.7	51.9 – 76.5	31.0 – 51.9	< 31.0

Table 3: Water Quality Index Range (Department of Environment [DOE], 2013).

Parameter	Index range		
	Clean	**Slightly Polluted**	**Polluted**
WQI	81-100	60-80	0-59

The percentage of removal on each sampling by rainfall event was determined using the Eq. [2] as follow:

$$\text{Percentage of removal, \%} = \frac{C_{in} - C_{out}}{C_{out}} x100 \qquad [2]$$

where C_{in} and C_{out} are the concentration of influent and effluent of the cell. Data analysis was conducted using Microsoft Excel.

3. RESULT AND DISCUSSION

The assessment of water quality in stormwater runoff shown an improvement through the constructed wetland. Based on the results obtained, the mean of WQI at Inlet zone of constructed wetland was 77.41 ± 4.72 indicated as slightly polluted at Class II while WQI at Outlet zone of constructed wetland was 84.90 ± 4.95 indicated as clean at Class II. The range of WQI at Inlet zone and Outlet zone were from 70.22 to 85.00 and from 74.74 to 89.31 for each, respectively. The six parameters that contribute to the WQI value were DO, BOD, COD, AN, SS and pH. The influence of DO, BOD, COD, AN, SS and pH, concentration was ranging from 4.22 mg/L to 6.86 mg/L, from 0.27 mg/L to 3.39 mg/L, from 20.00 mg/L to 30.00 mg/L, from 0.24 mg/L to 0.46 mg/L, from12. 00 mg/L to 44.00 mg/L and range from 7.18 mg/L to 9.66 mg/L for each, respectively at the inlet zone of constructing wetland. The effluent concentration at Outlet zone constructed wetland was range from 3.04 mg/L to 6.19 mg/L, from 1.23 mg/L to 3.63 mg/L, from 8.67 mg/L to 20.00 mg/L, from 0.00 mg/L to 0.16 mg/L, from 3.00 mg/L to 10.00 mg/L and range from 7.15 mg/L to 8.31 mg/L for DO, BOD, COD, AN, SS and pH, respectively. Overall, 9.68% of water quality enhancement was achieved through constructed wetland.

The pollutant level in stormwater runoff through constructed wetland in term of TSS and AN showed that water quality level had improved throughout the constructed wetlands as shown in Table 4.

Table 4. Mean ± Standard deviation for TSS and AN throughout constructed wetland.

	Macrophyte	Marsh	Velocity (m/s)	TSS (mg/L)	AN (mg/L)
Inlet zone			0.18 ± 0.13	24.86 ± 10.21	0.38 ± 0.07
Cell 1	*Eleocharis variegata*	High	0.04 ± 0.02	18.76 ± 9.25	0.26 ± 0.05
Cell 2	*Scirpus grossus*	High	0.04 ± 0.02	13.33 ± 5.88	0.20 ± 0.06
	Phragmites karka	Low			
Cell 3	*Typha angustifolia*	Low	0.03 ± 0.01	11.81 ± 6.31	0.18 ± 0.05
	Scirpus grossus	High			
	Lepironia articulata	High			
Cell 4	*Lepironia articulata*	Low	0.04 ± 0.01	7.52 ± 3.90	0.10 ± 0.17
	Eleocharis variegata	Low			
	Eleocharis variegata	High			
	Hanguana malayana	Low			
Outlet zone	*Typha angustifolia*	High	0.28 ± 0.20	6.71 ± 2.36	0.10 ± 0.05

Based on the obtained result, the TSS concentration from the Inlet zone was in the range of 12.00 mg/L to 44.00 mg/L and the treated water at the Outlet zone was in the range of 3.00 mg/L until 10.00 mg/L. The inflow concentration of TSS was characterized by a general trend of decreasing during the period evaluated as in Figure 3. Overall performance of constructed wetlands showed the decreasing of TSS concentration which is 72.99% as shown in Figure 2.

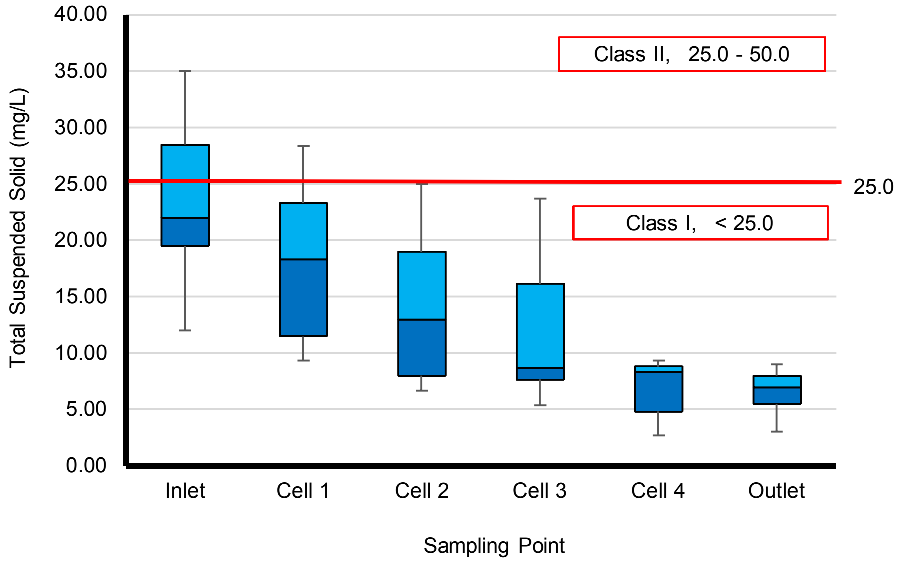

Figure 2: Trend of TSS concentration throughout the constructed wetland.

The AN concentration from the Inlet zone was in the range of 0.24 mg/L to 0.46 mg/L and the treated water at the Outlet zone was in the range of 0.00 mg/L until 0.16 mg/L was obtained in this study. The inflow concentrations of AN were characterized by a general trend of decreasing during the period evaluated. Overall performance of constructed wetlands showed the decreasing of AN concentration which is 74.06% as shown in Figure 3.

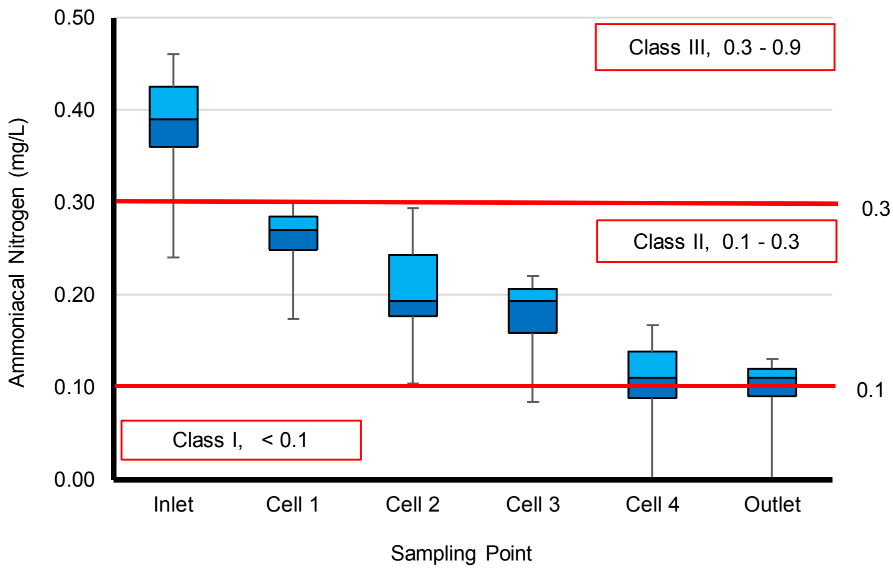

Figure 3: Trend of AN concentration throughout the constructed wetland.

The highest removal of TSS and AN were shown from Cell 4 which is 36.29% and 41.13%, respectively. Cell 4 contained *Lepironia articulate* with a low marsh of benthymetry zone, *Eleocharis variegata* with high and low marsh of bathymetry zone and *Hanguana malayana* with low marsh of benthymetry zone and the flow velocity was 0.04 ± 0.01 m/s. Despite of this, there were many factors that influence the increasing of water quality level in constructed wetland. In this study, the trend of water quality level in term of TSS and AN concentration was due to selected of macrophtyte species as treatment media in constructed wetlands, hydrologic characteristic, a benthymetry zone of macrophyte and the mechanism involved namely, sedimentation, filtration and resuspension.

Macrophyte play important role for pollutant removal, especially for suspended solid and ammonia-nitrogen. Macrophyte will provide a large surface area, will reduce water velocity and reinforced of settling and filtration by the roots of macrophyte (Brix, 1997). Macrophyte also will uptake ammonia-nitrogen and converts inorganic nitrogen into organic compound as a wall for cells and tissues (Vymazal, 1995). However, further study is needed, in order to know which the characteristic of macrophyte species that most influencing the removal of suspended solid and ammonia-nitrogen in constructed wetland.

Next, the hydrologic characteristic may also influence the increasing of water quality level in constructed wetland such as hydraulic residence time and velocity. The study reported by Mangangka et al., (2013) show that hydraulic residence time was strongly effected the pollutant removal when higher removal was shown in the small event of rainfall compared to large event of rainfall. Every species of macrophyte may have different characteristic which will influence the hydraulic residence time in order the suspended solid being settle and trap in constructed wetland and also the uptake of ammonia-nitrogen (Vymazal, 1995).

Besides, the macrophyte bathymetry zone also can influence the TSS concentration in term high and low marsh zone where were defined by the depth of water. The decreasing of AN concentration also correlated with decreasing concentration of TSS due to the ammonia-nitrogen will coagulate with suspended solid. This study showed that the highest decreasing of TSS and AN concentration was in Cell 4 which is a high marsh zone. According to MSMA 2nd Edition, high marsh zone is from 0.30m below the pool to the normal pool elevation while the low marsh zone is from 0.30m to 0.60 m below the normal permanent pool elevation or water surface elevation (DID, 2012). So, further study is needed in order to know how the bathymetry of macrophyte zone will influence the settlement of suspended solid and contribute to reduction of ammonia-nitrogen in constructed wetland.

In constructed wetland, when the water has low velocity and with the present of macrophyte and gravel, sedimentation will occur significantly. Suspended solid will coagulate with each other and form large particle of suspended solid. This principal also applied as organic and inorganic ammonia-nitrogen coagulate with suspended solid and will also form larger particles of suspended solid. The slow water moving will give physical settling to suspend solid particle and the large particle will be trapped and settle down to the soil with the present of macrophyte and gravel. This trapping process seems like a filtration process where suspended solid particle will filter first in Cell 1, then the rest of non-filter suspended solid particle will flow to the next cell. Resuspension will occur in three mechanisms, namely, bioturbation, wind-driven turbulence and gas lift (Kadlec and Wallace, 2008).

4. CONCLUSIONS

In conclusion, the constructed wetland had the potential to increase the water quality level in stormwater runoff under tropical climate. The WQI value was increasing after passing through the constructed wetland from slightly polluted to clean. The pollutant level in term of TSS and AN concentration shown an approximately 72.99% and 74.06% of removal can be achieved after throughout the constructed wetland where the highest removal of TSS and AN were shown from Cell 4 which is 36.29% and 41.13%, respectively. However, further study on how the influencing factor of the water quality level is vital maximizing the stormwater quality in constructed wetland.

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