PERFORMANCE OF A CONSTRUCTED WETLAND IN REMOVING CONTAMINANTS FROM STORMWATER UNDER TROPICAL CLIMATE

Nur Asmaliza Mohd Noor[1] Lariyah, M.S.[2], Rozi, A.[3] and Aminuddin, A.G.[3]

1 Universiti Teknologi MARA Pahang, Malaysia
2 Universiti Tenaga Nasional, Selangor, Malaysia
3 Universiti Sains Malaysia Engineering Campus, Pulau Pinang Malaysia

ABSTRACT: Rapid growth has resulted increased stormwater flow into receiving waters, with increases in flooding through drainage of stormwater runoff from urban areas to receiving water bodies. The design philosophy of the conventional stormwater drainage system was based on solving localized floods, either by transferring excessive flow in drainage systems downstream by upgrading the drainage system, or relieving localized problems by constructing storm overflows. In response to these issues, there are needs for a paradigm shift in the way stormwater is managed. There are various Best Management Practices (BMPs) techniques which can be used to control stormwater runoff to achieve zero development impact contribution. Constructed wetland system is part of sustainable urban drainage system and this system has a main function as water quality improvement. The objective of this study was to determine the removal efficiency of contaminants in urban stormwater by a wetland constructed in the USM Penang catchment. The result showed that the average removal efficiency of BOD was 9.7% to 80%, DO was 6.5% to 17.8%, turbidity was 25.9% to 30.0% and TP was 24% to 46%. The correlation between rainfall and water quality data for BOD and DO showed the negative correlation while for turbidity and TP showed the positive correlation. In addition, the correlation between inflow and water quality concentration at inlet point are also considered and the result indicated the positive correlation for BOD, DO, turbidity and TP. The finding also suggested that there are no significant differences ($P > 0.05$) for BOD, DO, TP and turbidity by using paired sample test. The analysis proved that the water quality at inlet point has no significant effect to the outlet point

Key Words: constructed wetland, water quality, removal efficiency, stormwater, urban drainage

1. INTRODUCTION

Urbanization has increased the construction of impervious area and significantly altered the hydrology and hydraulic characteristics of catchments. In the long term, the urbanization has increased the occurred of the flash flood and deteriorated the water quality in the urban area. There are various Best Management Practices (BMPs) techniques which can be used as “control at source” methods to control stormwater runoff quantitative and qualitative. Mitch & Gosselink (2000) stated that the constructed wetland is widely used in developed countries for the stormwater quality improvement. In practice in Malaysia, the constructed wetland has been suggested in Stormwater Management Manual (SWMM) and the topic of constructed wetland can be referred in Chapter 35, Volume 13 (DID, 2001). The treatment of stormwater in constructed wetland is the result of a complex interaction between the physical, chemical and biological processes that occur within the system. Li (2009) had the defined constructed wetland as an engineered system comprised of wetland vegetation, soil (or other rooting media) and associate microbial and physiological ecosystem that colonize over time. While Zhang et al. (2009) defined that the constructed wetland as a special designed system of production process in which the principle of the species symbiosis and the cycling and regeneration of substances in an ecological system are applied with adopting the system engineering technologies and introducing new technologies and excellent traditional production measures.

Babatunde et al. (2008) proved that the constructed wetland in developed countries has the capability to improve stormwater quality based on the research on thirteen constructed wetland sites in the Ireland where 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% to 99.9% for Ammonium Nitrate (NH_4-N). While the removal efficiency for constructed wetland in China, TSS around 83%, 66% for BOD, 38% for COD and 53% for TP (Zhang et al, 2009). Besides, a few Australian studies were found such as Shatwell &

Cordery (1998) that studied a pond in Centennial Park in Sydney, achieved typical phosphorus removal of 60-95% and the performance of sediment removal around 80-99%. However, they have pointed out that it would be likely that trapped loads would be re-suspended during very high flows due to lack of hydrologic control. Stewart and Hackney (2002) undertook 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 Geary et al. (2003) found fairly consistent TSS load removal with export during the selected storm event. Constructed wetland in Malaysia can be considered as a new innovation and not widely implemented in all over Malaysia. Therefore there is not much study focus on constructed wetland as a function of stormwater quality improvement under Malaysia condition. Therefore, the objective of this study was to determine the removal efficiency of contaminants in urban stormwater by a wetland that constructed in the USM Penang catchment.

1.1 Site Description

USM Engineering Campus project (Figure 1) has taken a series of measures to reduce runoff rates, runoff volumes and pollutant loads by implementing a source control approach for stormwater management as suggested in the Stormwater Management Manual for Malaysia. This includes a series of components namely ecological swales, online sub surface detentions and dry ponds as part of the BIOECODS that contribute to the treatment of the stormwater before it leaves the campus. This system was designed to combine infiltration, delayed flow, storage and purification as pre treatment of stormwater before discharging to a constructed wetland. In additional to source control, these measures include integrating large scale landscapes into the development as a major element of the stormwater management system. The concept of BIOECODS is to integrate the drainage components with the ecological pond components for further treatment of the stormwater runoff. In combination, this increase runoff lags time, increase opportunities for pollutant removal through settling and bio filtration and reduce the rate and volume of runoff through enhanced infiltration opportunities. The design features and types of planted macrophytes for USM Engineering Campus project can be seen through the Table 1 and Figure 2 respectively.

Table 1: Design criteria of the constructed wetland from Zakaria *et al* (2003)

Catchment area	1.214km^2
Design storm (3 month ARI)	22.5 mm/h
Length	155m
Width	60m
Wetland surface area	9100m^2
Volume	9100m^2
% catchment	0.7
Design inflow rate	0.25m^3/s
Mean residence time	3 days
Slope of wetland bed	1%
Bed depth	0.6m
Media	Peat gravel and soil mixture
Hydraulic conductivity of gravel	10^{-3} m/s to 10^{-2}m/s

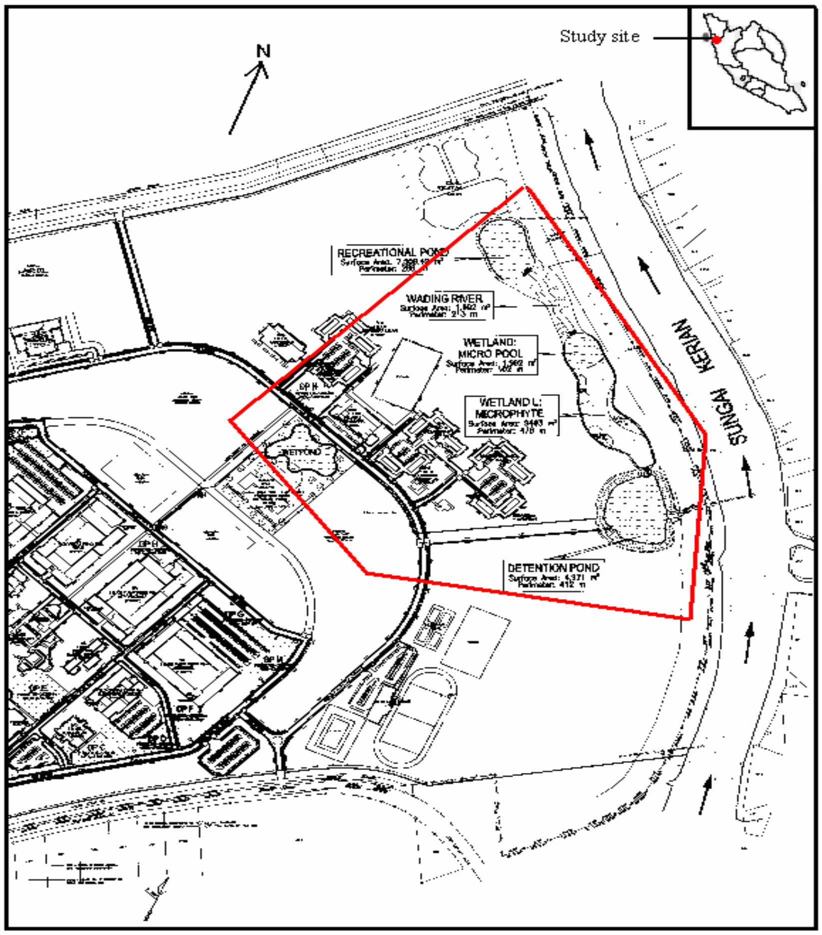

Figure 1: USM Engineering Campus Constructed Wetland
(Zakaria *et al.,* 2003)

1.2 Methodology

Samples of stormwater inflow and outflow were obtained during rainfall events between 2003 -2004 and 2005 - 2006. Samples were collected at the inlet and outlet to the wetland during each event and analyzed for BOD and TP. The sampling and testing procedures were done in accordance with the *Standard Method for Examination of Water and Wastewater 18th Edition* (APHA, 1995). While the water quality parameters (temperature, dissolved oxygen, pH, turbidity, conductivity) were measured concurrently. Then the statistical analysis was carried out to determine the correlation between rainfall and water quality data for BOD, DO, turbidity and TP. In addition the correlation between inflow and water quality data were also measured. A paired sample test was chosen to determine if there are any significant values for water quality at inlet and outlet point. The confidence level of 95% was used in this analysis.

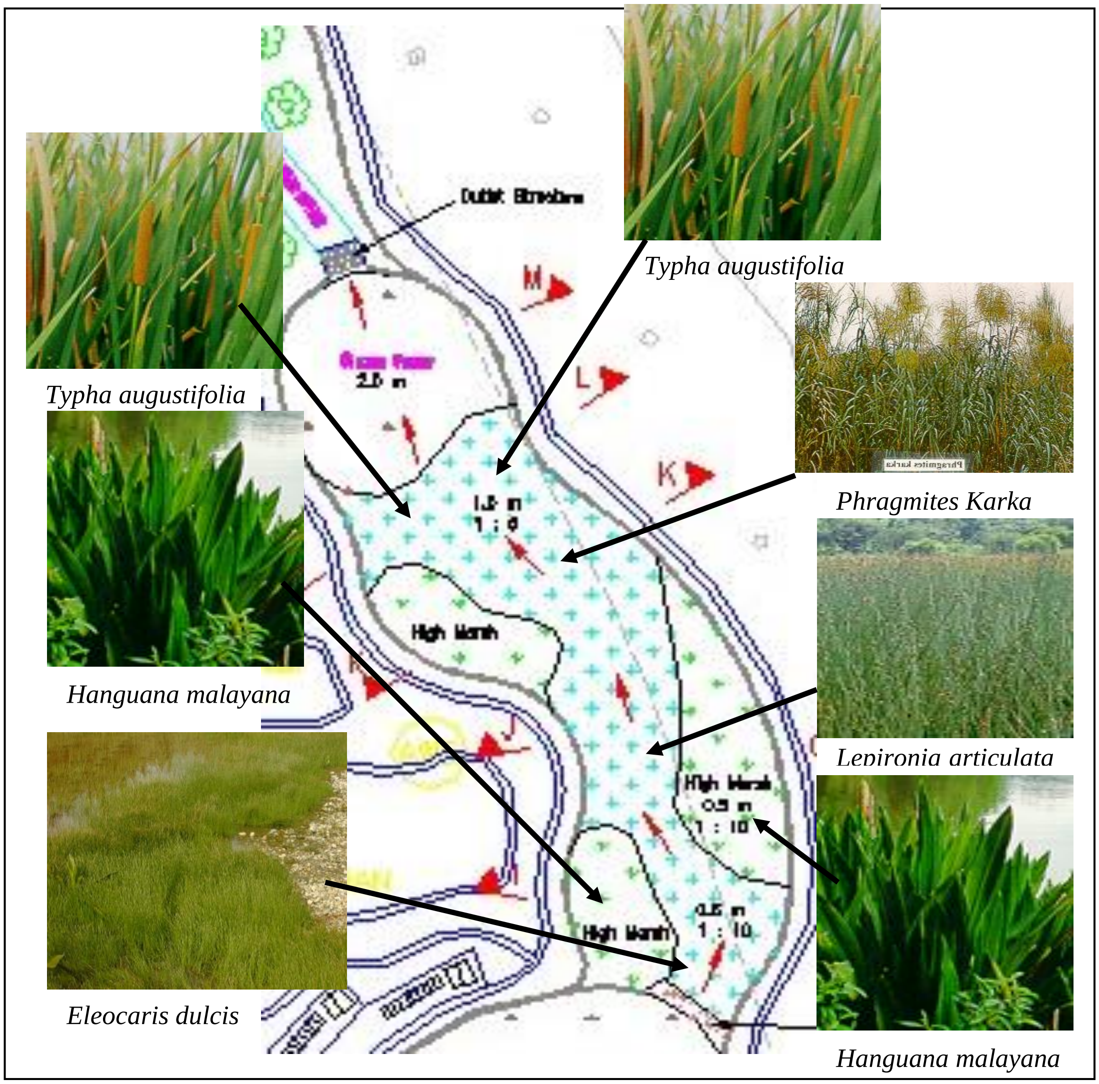

Figure 2 : Types of Macrophytes in USM Engineering Campus constructed wetland (Zakaria *et al*., 2003).

2.0 RESULT

The results are evaluated the performance of constructed wetland based on BOD, DO, TP and Turbidity removal efficiency.

2.1 Biochemical Oxygen Demand

Figure 3 showed the average removal efficiency of BOD for selected storm event and results it showed that the average removal efficiency of BOD around 9.7% to 80%. The BOD concentration had been reduced through the microbiological activities in macrophytes such as microbial decomposition. The microbial decomposition is fixed dissolved carbon into new biomass during photosynthesis (USEPA, 1999) where the macrophytes had provided a place and food for microbial to growth (Lim et al., 2001; Greenway dan Woolley, 1999). However, some of BOD removals were not happen during the date of 19 Julai 2003, 9 September 2003, 25 November 2003, 24 Mac 2006 and 19 Jun 2006 due to the increasing number of algae , thus resulting the increasing concentration of DO at the outlet of constructed wetland (

Li, 2009; Greenway and Woolley, 1999). Figure 4 and 5 showed the correlation of BOD at the inlet point with various rainfall intensity and inflow respectively. The correlation between rainfall and water quality data for BOD showed the negative correlation with R^2 = 0.1081 however the correlation between inflow and water quality data for BOD showed the positive correlation with R^2= 0.0142. In addition, the statistical test using paired sample test was conducted to determine the significant value between concentration of BOD at the inlet and oulet of constructed wetland. The result of P value equal to 0.1189 which was more than 0.05.

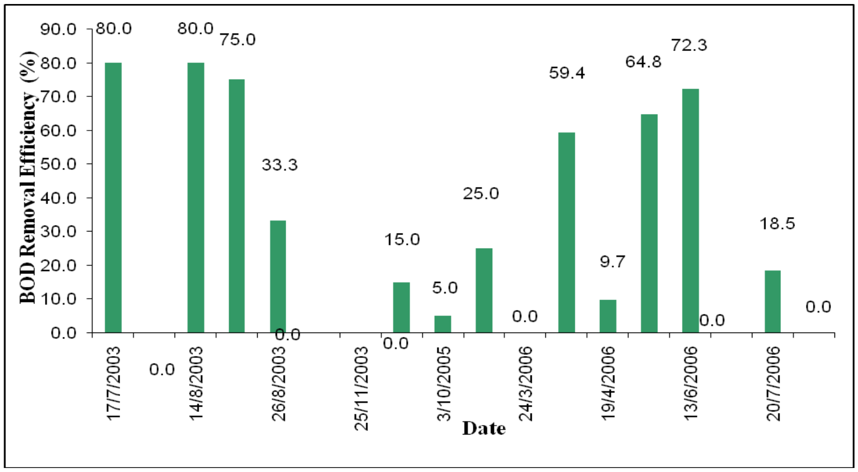

Figure 3: BOD Removal efficiency

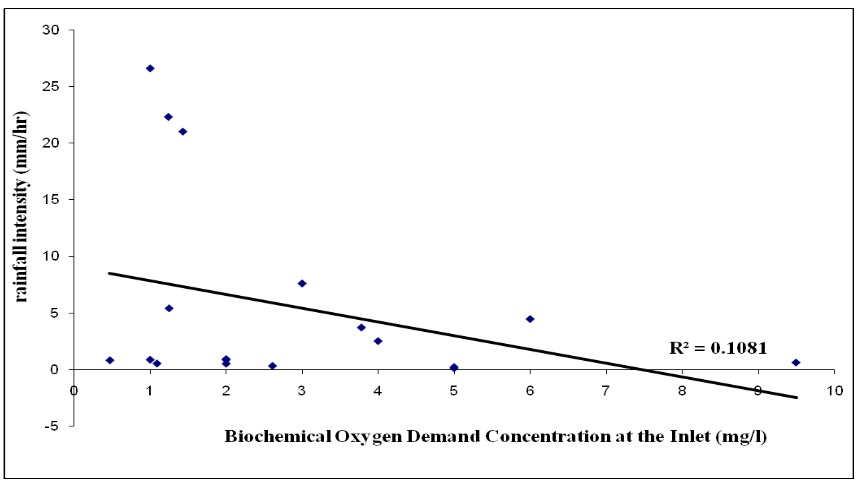

Figure 4: Correlation of BOD concentration at the inlet with various rainfall intensity

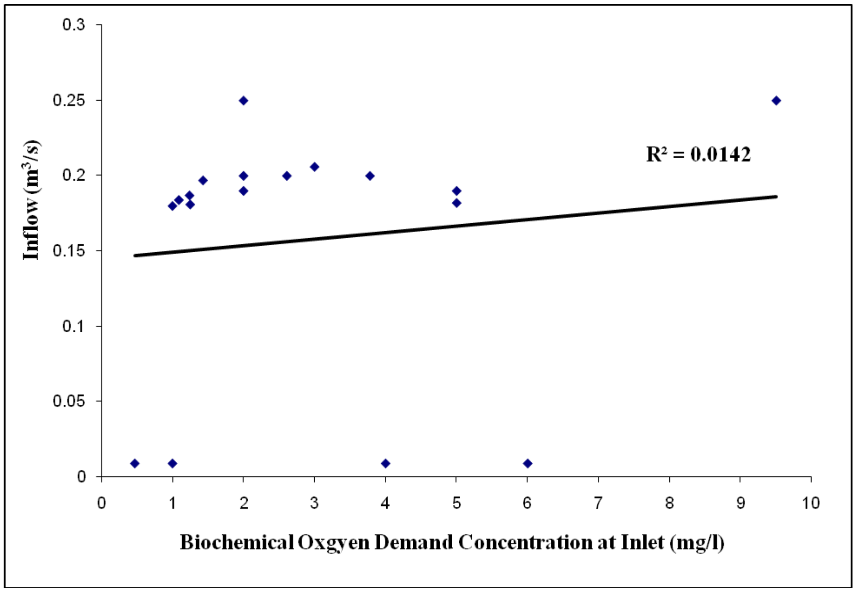

Figure 5: Correlation of BOD concentration at the inlet with various inflow

2.2 Dissolved Oxygen

DO removal efficiency for selected date and average removal efficiency of DO was 6.5% to 17.8% and shown in Figure 6. The removal efficiency of DO was referred to the microorganisms' activities in the bottom of constructed wetland. The macrophytes such as *Phragmites karka* played a role as organic removal through the nitrification process and increasing the DO concentration (Fleet, 2002). The correlation of DO concentration at the inlet towards rainfall intensity was shown in Figure 7, while the correlation of DO concentration at the inlet towards inflow shown in Figure 8. It was shown in Figure 7, the DO concentration had a negative correction to rainfall intensity with R^2= 0.1323, meaning that the rainfall intensity did not affected the DO concentration. While Figure 8 showed the positive correlation to R^2=0.0018 , meaning that the inflow were affected the DO concentration at the inlet point of constructed wetland. The statistical analysis was carried out to determine if there any significant value between DO concentration at the inlet point with DO concentration at the outlet point. The choosen test was Paired Sample Test and P value from that test was 0.9616 which more than 0.05. This P value meant that DO concentration at inlet point had no significant effect towards DO concentration at outlet point.

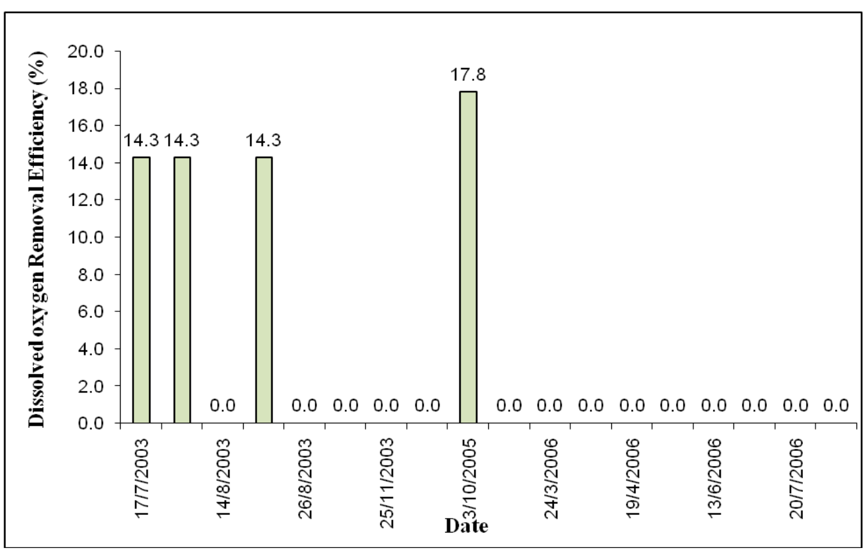

Figure 6: DO Removal Efficiency

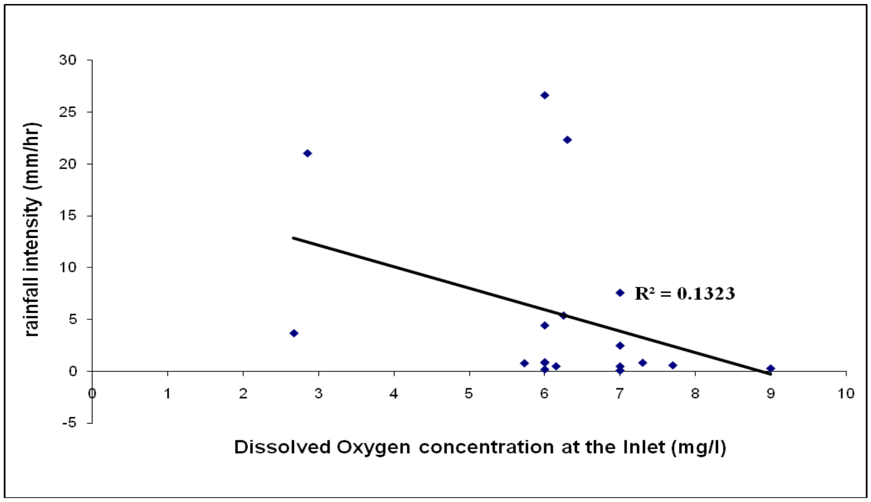

Figure 7: Correlation of DO concentration at the inlet with various rainfall intensity

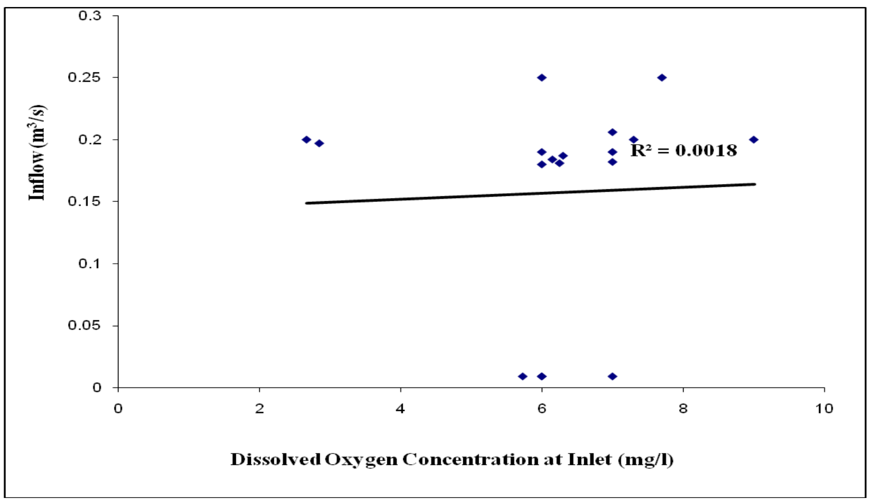

Figure 8: Correlation of DO concentration at the inlet with various inflow

2.3 Turbidity

Figure 9 showed the turbidity removal efficiency for selected storm event and the average removal efficiency was 25.9% to 30.0%. The turbidity value was highly affected by rainfall where if there are rain, the concentration of turbidity become higher. This might be happen during the rainfall, the small particle from road and hostel flow together with stormwater and directly flow into the constructed wetland. This can be seen through Figure 10 which showed the positive correlation of turbidity concentration at the inlet with various rainfall intensity with R^2= 0.017. Furthermore, positive correlation also can be seen as in Figure 11 where the correlation of turbidity concentration at the inlet with various inflow was R^2=0.1011. Moreover lower turbidity concentration at the outlet indicated that there were the sedimentation at the bottom of constructed wetland due to slow velocity of water between 0.1m/s to 0.7m/s. While, P value obtained based on Paired sample test was 0.1051 more than 0.05 and showed that there was no significant value between turbidity concentration at the inlet and outlet of constructed wetland.

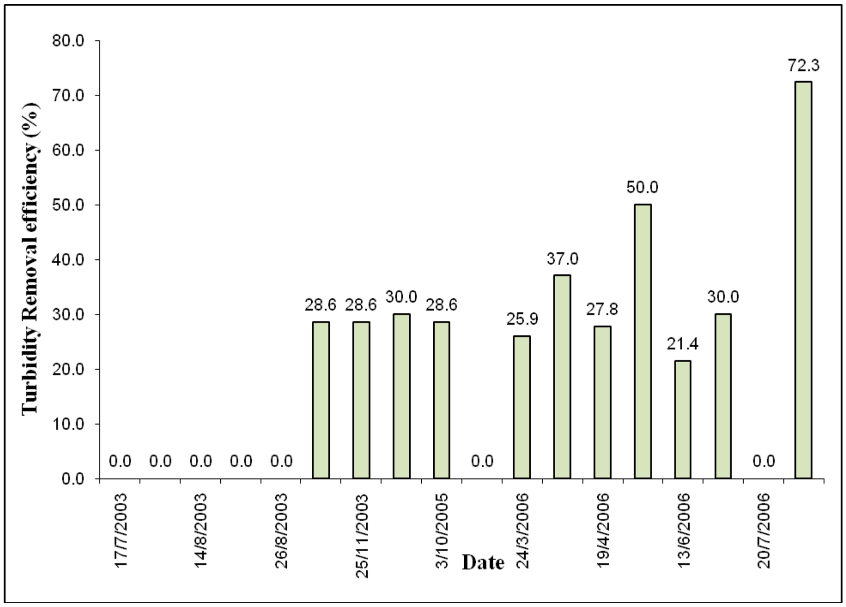

Figure 9: Turbidity Removal Efficiency

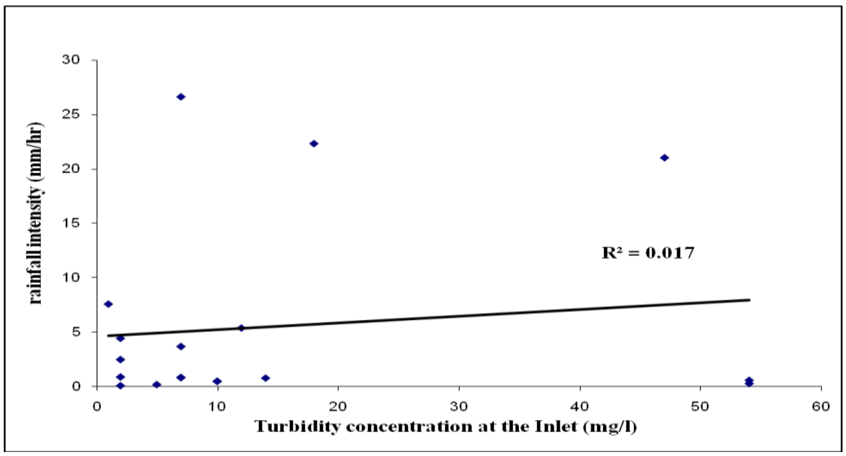

Figure 10: Correlation of Turbidity concentration at the inlet with various rainfall intensity

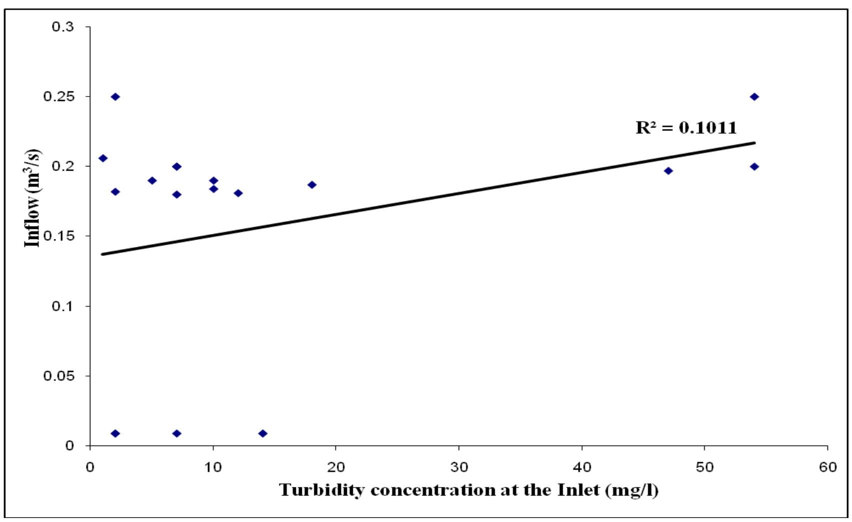

Figure 11: Correlation of Turbidity concentration at the inlet with various inflow

2.4 Total Phosphorus

Phosphorus transformations and retention in wetlands are controlled by the interaction of redox potential, pH values, Fe, Al, and Ca minerals, organo-metallic complexes, organic matter content,clay minerals, hydraulic loading, and the amount of native soil P (Richardson, 1985; Faulkner and Richardson, 1989; Vymazal, 1995;Dunne and Reddy, 2005). A theoretical hierarchy of the processes that control P retention in wetlands is as follows (Richardson and Craft, 1993; Richardson et al., 1997; Richardson, 1999): peat/soil accretion (high magnitude, very slow rate), soil adsorption (low to moderate magnitude, moderate rate), precipitation (moderate magnitude, fast rate), plant uptake (low to moderate magnitude, slow rate), detritus sorption (low magnitude, fast rate) and microbial uptake (very low magnitude, very fast rate). The average removal efficiency TP for this constructed wetland was 24% to 46% and this can be seen in Figure 12 where showed the TP removal efficiency for selected storm event. One of the factors that might be reduced the TP concentration in constructed wetlands 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 (HLA, 1999). Figure 13 showed the correlation of TP concentration at the inlet with various rainfall intensity with the positive correlation ,R^2= 0.0106 and it strongly agree that the rainfall intensity had effected the TP concentration in the constructed wetland. While Figure 14 showed the correlation of TP concentration at the inlet with various inflow with correlation of TP concentration at the inlet with various inflow, R^2= 0.0228. For statistical analysis, the P value gained from paired sample test was 0.7461 which greater than 0.05.

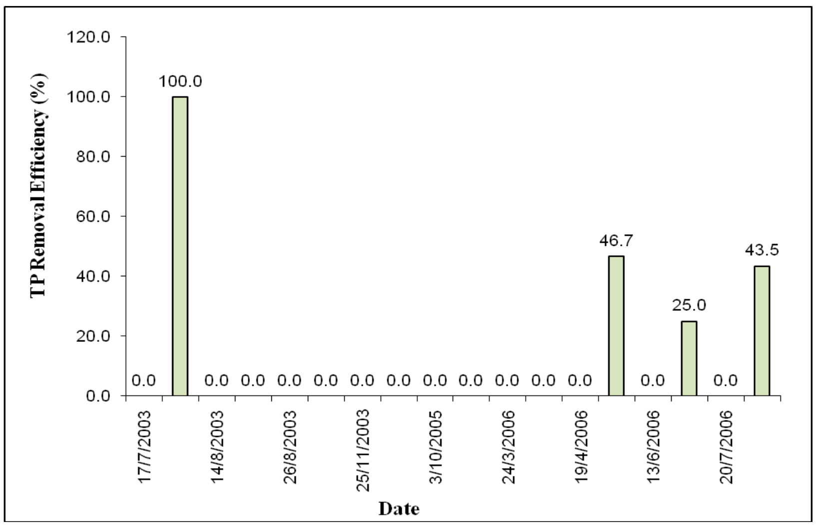

Figure 12: TP Removal Efficiency

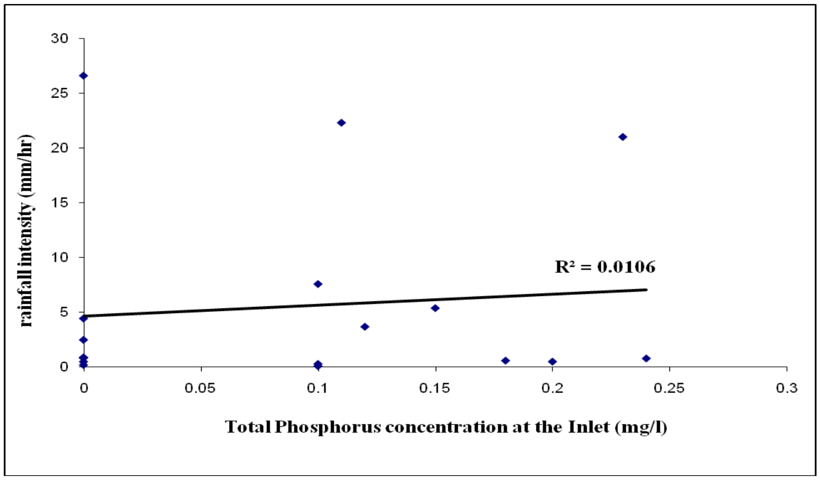

Figure 13: Correlation of TP concentration at the inlet with various rainfall intensity

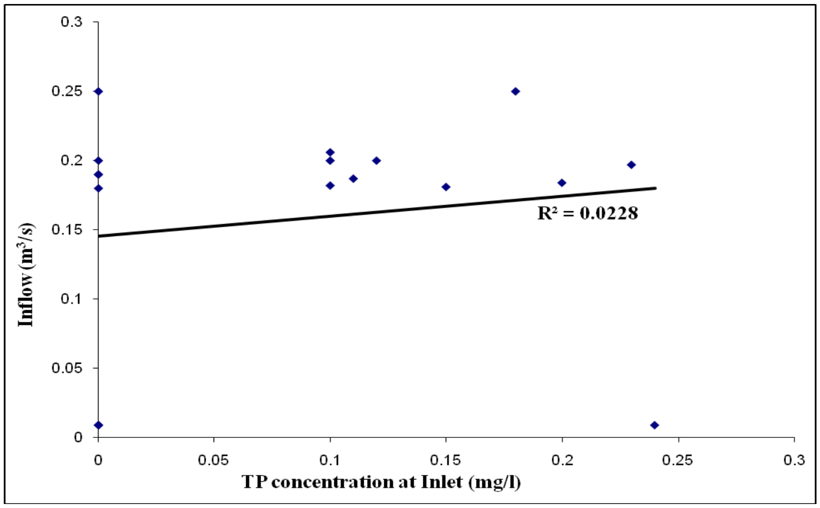

Figure 14: Correlation of TP concentration at the inlet with various inflow

2.5 Conclusion

In conclusion, the results showed that most of the parameters such as DO, BOD, TP and turbidity comply with Class IIB, Interim National Water Quality Standard for Malaysia (INWQS). However, the finding suggested that there are no significant differences ($P > 0.05$) for BOD, DO, TP and turbidity. The analysis proved that the water quality at inlet point has no significant effect to the outlet point. The study indicated that the suitable design features of the constructed wetland, suitable plants and details monitoring are important elements to achieve the objectives of constructed wetland as water quality improvement.

2.6 Acknowledgement

The authors would like to express their gratitude to all REDAC's staffs that helped to conduct this study.

3.0 REFERENCES

American Public Health Association, American Water Works Association and Water Environment Federal, 1995: Standard Methods for the Examination of Water and Wastewater 19th Edition APHA. Washington DC

Babatunde, A.O., Zhoa, Y.Q., Neill, M.O. and Sulivan, B.O, 2008: Constructed Wetland for Environment Pollution Control: A Review of Development, Research and Practice in Ireland. *Environment International* 34, 116-126.

DID, 2001: Stormwater Management Manual for Malaysia, Percetakan Nasional

Dunne, E.J., Reddy, K.R., 2005: Phosphorus biogeochemistry of wetlands in agricultural watersheds. In: Dunne, E.J., Reddy, K.R., Carton, O.T. (Eds.), Nutrient Managementin Agricultural Watersheds:A Wetland Solution. Wageningen AcademicPublishers, Wageningen, The Netherlands, pp. 105–119.

Faulkner, S.P., Richardson, C.J., 1989: Physical and chemical characteristics of freshwater wetland soils. In: Hammer, D.A. (Ed.), Constructed Wetlands for Wastewater Treatment. Lewis Publishers, Chelsea, MI, pp. 41–72.

Fleet, K., 2002: The Use of Constructed Wetland to Improve the Water Quality of Bourne Stream Dorset. Disertation BSc. *(Hons) Environmental Protection*, Bournemouth University

Geary, P., Saunders, M., & Waters, D., 2003: Stormwater Runoff Treatment Using Constructed Wetlands. *Water*

Greenway, M. and Woolley, A., 1999: Construction Wetland In Queensland: Performance Efficiency And Nutrient Bioaccumulation. *Ecological Engineering 12*, 39-55

HLA Associates BHD, 1999: Laporan EIA untuk Pembangunan Universiti Sains Malaysia Kampus Kejuruteraan

Li, X., Chen, M. and Anderson, B.C., 2009: Design and Performance of A Water Quality Treatment Wetland In Public Park In Shanghai China. *Ecological Engineering* 35, 18-24.

Lim, P.E., Wong, T.F. and Lim, D.V., 2001: Oxygen Demand, Nitrogen and Copper Removal by Free Water Surface and Subsurface Flow Constructed Wetland Under Tropical Condition. *Environment International* 26, 425-431

Mitch & Gosselink, 2000: Wetlands. 3rd. Edition, *John Willey and son*.

Shatwell, T., & Cordery, I.,1998: A Phosphorus and Sediment Balance of an Urban Pond. Paper presented at the *HydraStorm 98, 3rd International Symposium on Stormwater Management*, Adelaide, South Australia

Sim, C.H., Yussof, M.K., Shutes, B., Ho, S.C. and Mansor, M., 2007: Nutrient Removal in A Pilot And Full Scale Constructed Wetland Putrajaya City Malaysia. *Journal Environmental Management*, 1-10.

Stewart, J., & Hackney, P., 2002: Water quality of stormwater treatment wetlands at Riverside Park,Chipping Norton. Liverpool, NSW: Liverpool City Council.

Richardson, C.J., 1985: Mechanisms controlling phosphorus retention capacity in freshwater wetlands. *Science* 228, 1424–1427.

Richardson, C.J., 1999: The role of wetlands in storage, release, and cycling of phosphorus on the landscape: a 25-year retrospective. In: Reddy, K.R.,OˇıConnor, G.A., Schelske, C.L. (Eds.), *Phosphorus Biogeochemistry in Subtropical Ecosystems*. CRC Press, Boca Raton, FL, pp. 47–68.

Richardson, C.J., Craft, B.C., 1993: Effective phosphorus retention in wetlands-fact or fiction? In: Moshiri, G.A. (Ed.), *Constructed Wetlands for Water Quality Improvement*.CRC Press/Lewis Publishers, Boca Raton, FL, pp. 271–282

Richardson, C.J., Qian, S.S., Craft, B.C., Qualls, R.G., 1997: Predictive models for phosphorus retention in wetlands. *Wetlands Ecol. Manage.* 4, 159–175.

USEPA, 1999: Free Water Surface Wetland For Waste Water Treatment.

Vymazal, J., 1995: Algae and Element Cycling in Wetlands. *Lewis Publishers*, Chelsea, MI.

Zakaria, N.A., Abdul Ghani, A., Abdullah, R., Mohd Sidek, L. and Ainan, A., 2003: Bio-Ecological Drainage System (BIOECODS) For Water Quality and Quantity Control. *International Journal River Basin Management, International Association of Hydraulic Engineering Research (IAHR)*, 1:3, 237-251.

Zhang, D., Richard, M.G. and Tan, S.K., 2009: Constructed Wetland in China. *Ecological Engineering* 35, 1367-1378.