Impact on the distribution of freshwater phytoplankton from the urban stormwaterrunofftreatment in constructed wetland

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Abstract

The issues of stormwater runoff had become one of the priority agenda of government and non-government body in Malaysia. Impact from stormwater runoff not only on water quality degradation, also habitat-destroying, which can cause harm to many wildlife population such as fish and birds, and also can kill the native vegetation, which is the primary building in the pyramid chain. Thus the aim of the study to understand the impact of biotic component through assessment of primary producer in the food web, phytoplankton from the urban stormwater runoff treatment in the free water surface (FWS) constructed wetland. The results showed that freshwater phytoplankton was significantly negative relationship (p=0.01) with water quality index (WQI) as well as certain parameters measured such as dissolved oxygen and water temperature. The WQI value showed that the macrophytes zone was low as compare to forebay zone and micropool zone. The distribution of phytoplankton was high at macrophytes zone, whereas the wetland plant expected to contribute high favourable nutrientand other environmental variables for the high abundance of phytoplankton density. Through regression, phyla Chlorophyta showed dominance as well as high R^2 value, more 0.7. The constructed wetland was able to retain the sufficient amount of distribution of freshwater phytoplankton at the outlet zone, micropool, for the source of food for higher trophic level.

Key Words: Stormwater, water quality, phytoplankton, constructed wetlands, free water surface

1. INTRODUCTION

Rapid urban growth in Malaysia over the last 30 years has resulted in increased stormwater flow into receiving waters, increases in flood peaks, and degraded water quality.In the past, stormwater runoff has been generally regarded as a nuisance that must be disposed of as quickly and efficiently as possible. The consequence of removing the stormwater from the land surface so quickly is to increase volumes and peak rates of flow discharge and finally overloading conventional drainage system. This results in a greater runoff that generally requires expensive enhancement of drainage network to reduce severity and frequency of flooding in urban areas. This also results in a higher pollutant wash off from the urban areas leading to deteriorate water quality in the receiving water bodies [1].

Constructed wetlands are engineered systems that had been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and their associated microbial assemblages to assist in treating pollutant and wastewater [2]. Constructed wetlands generally used to treat various types of wastewater [3] such as stormwater runoff-residential [4] and stormwater runoff-highway [5]. Free water surface (FWS) is a one of the type of constructed wetland with emergent macrophytes is a shallow sealed basin or sequence of basins, containing 20-30 cm of rooting soil, with a water depth of 20-40 cm. The treatment studies from FWS constructed wetlands are also well documented in tropical climate region, especially in Malaysia [6-8]. However in Malaysia, the study on how well constructed wetlands can contribute and give impact to the biodiversity is scares. Semeraro et al. [9] had shown the ability of constructed wetland in sustaining wildlife habitats and biodiversity at local and global scales. Hsu et al. [10] also suggested that wetland area, cover of aquatic macrophytes and water quality are the most important factor contributing in diversity in constructed wetland. The understanding diversity in the constructed wetland had to be consider the initial stage of whole food web systems, which is phytoplankton or algae. Phytoplankton is a main source of foods to the zooplanktons, invertebrates and fish, which later affected the distribution of birds. Eventhough the role of phytoplankton is not only to act as a primary producer in food chains, but if it present in the highly abundance in numbers and density, it can cause eutrophication. Eutrophication is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis [11], such as sunlight, carbon dioxide, and nutrient fertilizers. Recently, a few studied had been conducted to start to use the constructed wetland as a new approached and sustainable solution to solve the eutrophication problem [12-13]. The purposed of this paper to see how the constructed wetland, free water surface design, can help to reduce the phytoplankton distribution (solve eutrophication) and at the same time, retained adequate amount of density to support source of food for the higher trophic level (biodiversity purposes).

2. MATERIAL AND METHODS

2.1 Site description

The constructed wetland of this study is located in the Universiti Sains Malaysia (USM) Engineering Campus, SeberangPerai Selatan District, Pulau Pinang. (Figure 1). The area of the campus is about 320 acres and made up of mainly oil palm plantation land and is fairly flat. This constructed wetland was built to receive 0.0712 km^2 catchment area, which comprises of faculty buildings and car park areas.

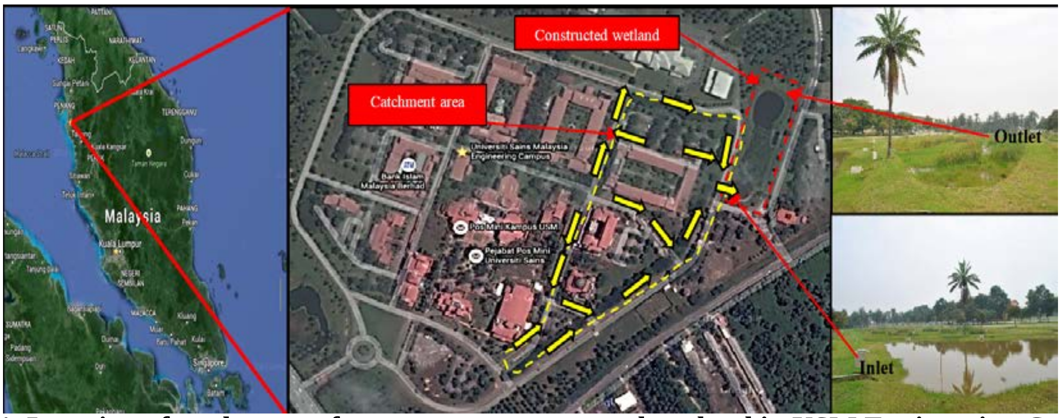

Fig 1. Location of study area of stormwater constructed wetland in USM Engineering Campus

2.2 Sampling and analysis

The constructed wetland consists of three zones and design based on MSMA 2nd Edition [14]. The forebay zone is the first zone to receive the discharge from drainage/swales (Table 1). The macrophyte zone consists of three main sub-zones, high marsh, low marsh and deep marsh. In this zone, most of the species are emergent macrophytes. The last zone before the water is discharged from the constructed wetland is called the micropool zone (Table 1). Sampling was conducted from November 2014 until March 2015, once a month throughout the sampling period. Four sampling points were selected in the forebay, seven points were selected at the macrophytes zone and three sampling points were selected at micropool (Figure 2). Sampling time was between 9 am and 12 pm (3 hours) using grab samples 0.5m below the water surface.

The phytoplankton was sampled using plankton net 35 µm mesh size, filtered 40L samples and preserved using formalin 5% solution and Lugol. Phytoplankton identification was done using taxonomic keys references [15-16]. Enumeration of phytoplankton samples was done according to Leupold [17]. The in-situ water quality parameter was taken at the sampling point during the sampling using a YSI Pro Plus multiparameter water quality sonde and laboratory analyses followed HACH procedure [18]. Rainfall data were collected using a rain gauge located at the constructed wetland. Pearson correlation will be used to identify the relationship of phytoplankton abundance (cell/ml) and WQI.

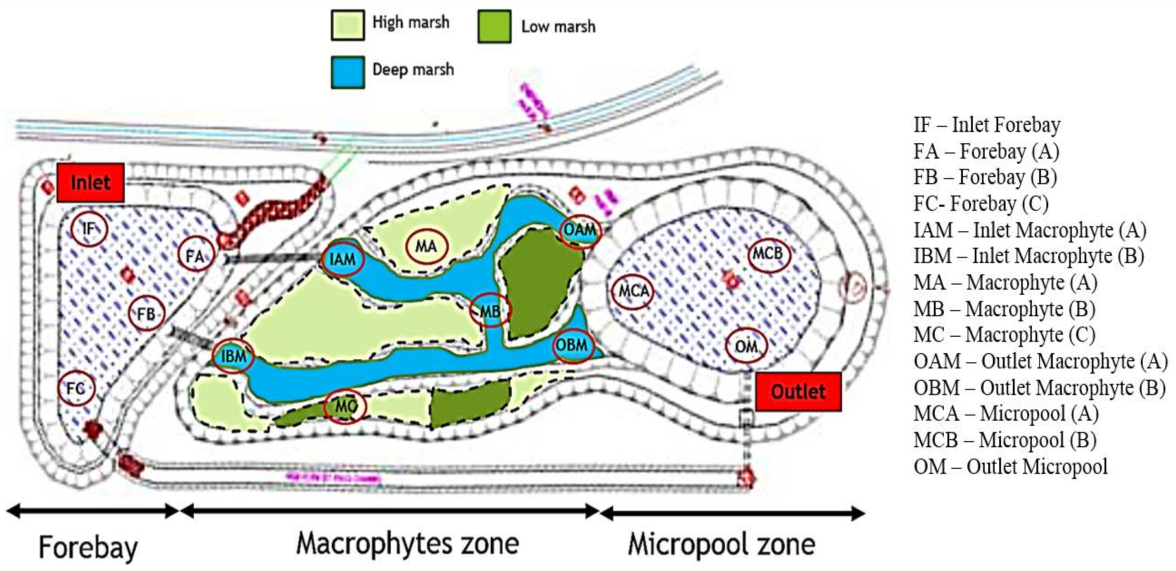

Fig 2. The sampling point and zonation of constructed wetland

Table-1. Zone characteristics (water depth and plants/macrophytes) in the constructed wetland.

Zonation		Water depth (min-max) (m)	Types of plants	Plant Density
Forebay		0.6-1.0	-	-
Macrophyte	High marsh	0-0.3	*-Donaxgrandis,* *-Eleocharisvariegata*	1.63 ind/m^2
	Low marsh	0.3-0.5	*Phragmateskarka*	58 ind/m^2
	Deep marsh	0.6-1.0	*Typhaangustifolia*	29 ind/m^2
Micropool		0.7-1.4	-	-

The WQI will be adopted from the Department of Environment (DOE) [19] based on the given formula;

WQI = (0.22* SIDO) + (0.19*SIBOD) + (0.16*SICOD) + (0.15*SIAN) + (0.16 * SISS) + (0.12 * SIpH)

Where;
SIDO = Sub-index DO (% saturation); SIBOD = Sub-index BOD; SICOD = Sub-index COD
SIAN = Sub-index NH3-N; SISS = Sub-index SS/TSS; SIpH = Sub-index pH

The classification of water quality concentration was based on the Table 2;

Table-2. DOE Water quality index classification [19]

Parameters	Unit	Classes				
		I	II	III	IV	V
Ammoniacal nitrogen	mg/L	<0.1	0.1-0.3	0.3-0.9	0.9-2.7	>2.7
Biochemical oxygen demand (BOD_5)	mg/L	<1	1-3	3-6	6-12	>12
Chemical oxygen demand (COD)	mg/L	<10	10-25	25-50	50-100	>100
Dissolved oxygen (DO)	mg/L	>7	5-7	3-5	1-3	<1
pH	-	>7	6-7	5-6	<5	>5
Total suspended solid (TSS)	mg/L	<25	25-50	50-150	150-300	>300
Water quality index (WQI)	mg/L	>92.7	76.5-92.7	51.9-76.5	31.0-51.9	<31.0

3. RESULTS AND DISCUSSION

3.1 Monthly and zone variation of phytoplankton abundance

Figure 3 shows the distribution of phytoplankton phyla throughout the sampling period. Four main phyla were observed, with Chlorophyta being the most abundant, followed by Bacillariophyta, Cyanophyta, Chrysophyta, and Pyrrhophyta. Chlorophyta is the most common phyla in the freshwater and marine ecosystems [20]. A few examples species observed and obtained in the constructed wetland such as *Closteriumparvulum*, *Nitzschialonggisima*, *Lyngbyaconfervoides*, *Stauroneis anceps* and *Straurastrum sp.* The identity of species of is important because of their specificity as food sources for herbivorous species [21]. Olurin and Awolesi [22] found that the fish species *Tilapia mariae* and *Chromidotilapiaguntheri*, fed mainly on phytoplankton largely consisting of the desmid genera *Closterium* and *Cosmarium*. Thus, *Closterium*sp is a desirable species in this wetland because of the dominance fish such as *Tilapia sp.*

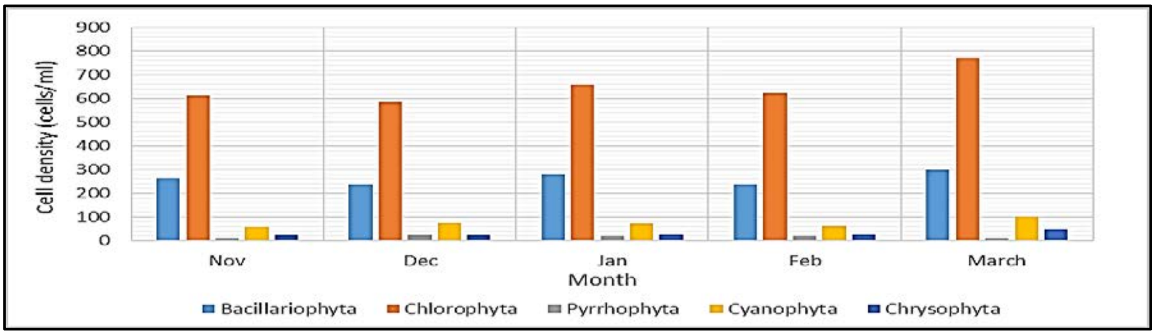

Fig 3. Monthly distribution of phytoplankton density by phylum in the constructed wetland from November 2014 until March 2015

3.2 Correlation between phytoplankton and WQI and water quality parameters

Based on the Table 3, DO concentration showed significant negative relationships (p=0.01) with all phytoplankton phyla, except for Pyrrhophyta. The pH value showed only significance positive relationship (p=0.05) with Chrysophyta. Phytoplankton density had affected the oxygen concentration in the water through decomposition by the bacteria present in the constructed wetland. As the density of phytoplankton was high, the decomposition rate may be high. The amount of oxygen used by the bacteria will be high and cause DO concentration to drop in the macrophytes zone. For the nutrients, TN showed significance positive relationship (p=0.05) with Cyanophyta and Chrysophyta. TN typically stimulates phytoplankton growth in freshwater ecosystems such as lake and wetlands [5]. However the TP showed no significant relationships for all phytoplankton phyla, and it suggest that the TN is the limiting nutrient to the phytoplankton, not the TP in this constructed wetland. Based on the Figure 4, the WQI value developed from the six main parameters had showed significant negative relationships (p=0.01) with Bacillariophyta, Chlorophyta and Chrysophyta. As the WQI value drops in the macrophytes zone, with the range of 71.6-77.9, for mostly Class III, the phytoplankton density increased, which may be due to several factors.The source of nutrient, come through natural processes from the decomposition of plants and animals materials as well as surface water runoff that enters this zone from the forebay, had decrease the WQI value, and at the same time trigger the growth and numbers of density of phytoplankton. The macrophytes zone experience low water depth and received direct sunlight for phytoplankton to undergo photosynthesis process. The WQI of the outlet of this constructed wetland is high, with the range in between 83.7-85.5, Class II, which shows that the constructed wetland has improved the water quality received from the catchment area. The most important parameters for the abundance of phytoplankton based on Table 3 were DO and water temperature. The relationship in DO and water temperature involved a lot of other factors such as the respiration and decomposition rate of bacteria, which affected the concentration level of oxygen in the water. The more plants, the more places for the bacteria to inhabit. As the macrophytes zone consist high density of plants compared to other zones, most probably the amount of bacteria was high. The zone would thus have a high decomposition rate, which also involved decomposition of phytoplankton.

Table-3. The relationship (in Pearson correlation coefficient) between phytoplankton phylum and WQI and environmental variables

Parameters	Pearson correlation coefficient				
	Baci.	Chlo	Pyrr	Cyan	Chry
BOD	-0.309	-0.253	-0.089	-0.29	-0.263
AN	0.336	0.339	0.196	0.091	0.053
COD	-0.185	-0.201	-0.052	-0.406	-0.414
DO	**-0.723****	**-0.836****	-0.526	**-0.734****	**-0.836****
pH	0.430	0.477	0.115	0.380	**580***
TSS	0.236	0.144	0.336	-0.006	-0.005
TN	0.502	0.428	0.435	**0.629***	**0.623***
TP	-0.131	-0.097	0.133	-0.188	-0.117
Temp	**-0.794****	**-0.847****	**-0.729****	**-0.699****	**-0.721****
WQI	**-0.720****	**-0.852****	**-0.593***	**-0.650***	**-0.736****

** Statistically significant at the 0.01 level* Statistically significant at the 0.05 level

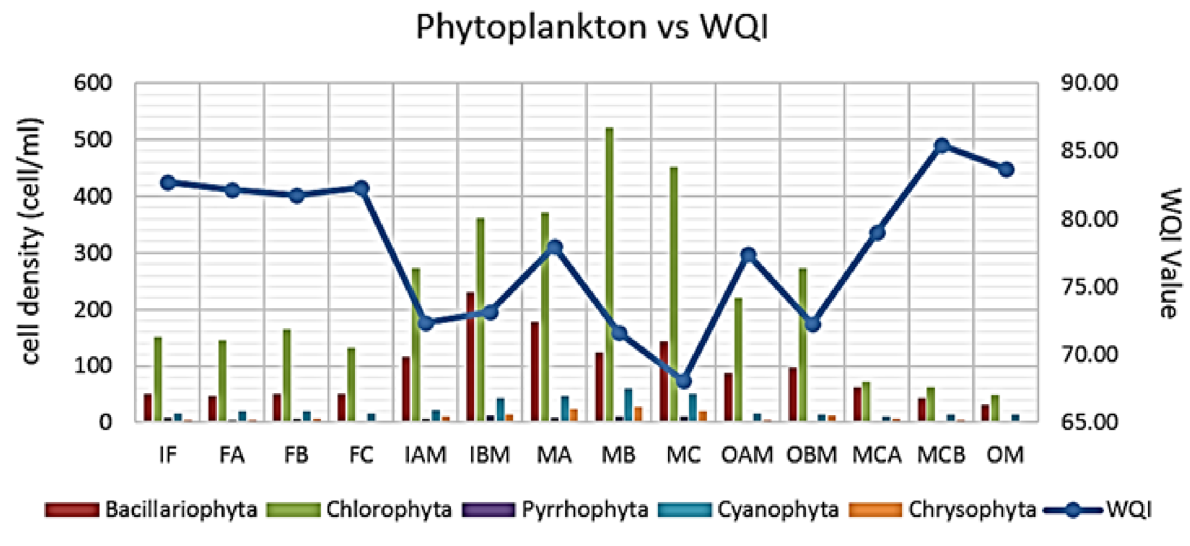

Fig 4. WQI and phytoplankton density pattern for sampling station in the constructed wetlands

4. CONCLUSION

As a conclusion, this free water surface constructed wetland was able to control the distribution of freshwater phytoplankton and at the same time capable to improve water quality up to Class II DOE standard. Slight variation on distribution during dry and wet season for phytoplankton as the water quality parameter also not so affected by monthly except for ammoniacal nitrogen. The introduction of this constructed wetland had overcome the problems of eutrophication, cause by highly abundance algae or phytoplankton. However, the macrophytes area had to be carefully monitored and suggested to have periodically harvesting the plants, once in six month, to avoid contribution of nutrient in which can affected the water quality. This relationship assessment will help to understand importance parameters for the phytoplankton in the constructed wetland for the sustainability habitat and biodiversity, ecological interaction and primary production in the food web under tropical climate condition in Malaysia.

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References

[1] Zakaria, N.A., Ab. Ghani, A., Abdullah, R., Mohd Sidek, L. &Ainan, A., (2003):Bio-Ecological Drainage System (BIOECODS) For Water Quantity and Quality Control. International Journal River Basin Management, IAHR & INBO, Vol. 1, No. 3, pp. 237-251

[2] Vymazal J., (2007), "Removal of nutrient in various type of constructed wetland" *Science of the Total Environment*, Vol.380, pp 48-65

[3] Vymazal J,(2010), "Constructed Wetland for Wastewater Treatment-Review" *Water*, Vol. 2, pp 530-549

[4]Bavor H.J., Davies C.M., Sakadevan K, (2001), “Stormwater treatment: do constructed wetlands yield improved pollutant management performance over a detention pond system?,*Water Science Technology*. Vol.44, pp.565-570

[5]LV J., Hongjuan W., Mengqiu C., (2011), “Effects of nitrogen and phosphorus on phytoplankton composition and biomass in 15 subtropical, urban shallow lakes in Wuhan, China”*Limnologica*, Vol. 41, pp 48-56

[6] Mohammadpour R., Shaharuddin S., Chang C.K., Zakaria N.A. & Ab Ghani A,(2014), “Spatial Pattern Analysis for Water Quality in Free Surface Constructed Wetland”, *Water Science and Technology*, Vol. 70, No.7, pp 1161-1167

[7] Mohammadpour R., Shaharuddin S., Chang C.K., Zakaria N.A., Ab Ghani A., Chan N.W, (2015), “Prediction of Water Quality Index in Constructed Wetlands using Support Vector Machine” *Environmental Science and Pollution Research*, Vol. 22, No.8, pp 6208-6219

[8] Mohd Noor N.A., Mohd Sidek L., Zainal Abidin M.R., Ab Ghani A, (2014), “Removal Efficiency Evaluation for Constructed Wetland in Tropical Climate” *Journal of Energy and Environment, Universiti Tenaga Nasional*, pp 1-6

[9] Semeraro, T., Giannuzi, C., Beccarisi,L., Aretano, R., De Marco, A., Pasimeni, M.R., Zurlini, G., Petrosillo, I., (2015), A Constructed Treatment Wetland as an opportunity to Enhance Biodiversity and Ecosystem Services, *Ecological Engineering,* Vol.82, pp 517-526

[10] Hsua, C.B., Hsieh, H.L., Yang, L., Wu, S.H., Chang, J.S., Hsiao, S.C., (2011). Biodiversity of constructed wetlands for wastewater treatment, *Ecological Engineering*, Vol.37, pp 1533-1545

[11] Schindler, D. W, (2006). Recent advances in the understanding and management of eutrophication. Limnology and Oceanography, Vol.51, pp 356-363

[12] Martin, M., Oliver, N., Crespo, C.H., Gargallo, S., Regidor, M.C., (2013), The Use of Free Water Surface Constructed Wetland to Treat the Eutrophicated Waters of Lake LÁlbufera de Valencia (Spain), *Ecological Engineering,* Vol.50, pp52-61

[13] Calero, S., Segura, M., Rojo, C., Rodrigo, M.A., (2015), Shifts in Plankton Assemblages Promoted by Free Water Surface Constructed Wetlands and Their Implication in Eutrophication Remediation, *Ecological Engineering,* Vol. 74, pp 385-393

[14] DID, “Urban Stormwater Management Manual for Malaysia (MSMA) 2th Edition”. (2012)

[15] Shamsudin, L. *Diatom marin di Perairan Malaysia*, Dewan Bahasa dan Pustaka, (1990)

[16] Tomas,C.R. *Identifying marine phytoplankton*. Academic Press, (1997)

[17] Leupold, M.A. Water quality assessment. In C.S. Lobban, D.J. Chapman & B.P. Kremer (Eds.), Experimental Phycology: A laboratory Manual, Cambridge Australia, (1998), pp.47-55

[18] Hach, *Water Analysis Handbook 5th Edition.* Hach Company, Loveland, CO, USA, (2013).

[19] DOE, “Malaysia Environmental Quality Report 2006”, In: Chapter 3: River Water Quality. Sasyaz Holdings SdnBhd, (2006), pp.24

[20] Graham L.E., Graham J.M., Wilcox L.W, "*Algae*", 2nd edition. Benjamin Cummings (Pearson), San Francisco, CA, (2008)

[21] Coesel P.F.M, "The edibility of Staurastrumchaetoceras and Cosmariumabbreviatum (desmidiaceae) for Daphnia galeata/hyalina and the role of desmids in the aquatic food web", *Aquatic Ecology*, Vol.31, (1997), pp 73–78

[22] Olurin KB and Awolesi O.O. "Food of some fishes of Owa Stream, south-western Nigeria", *ArchivfürHydrobiologie*, Vol. 122, (1991), pp 95–104