PERFORMANCE OF CONSTRUCTED WETLAND ON STORMWATER QUALITY CONTROL

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Abstract
Constructed wetlands as the best management practices can be explicitly designed to aid in pollutant removal from stormwater. The treatment in constructed wetlands involves several mechanisms, namely, coagulation, filtration, sedimentation and sorption. The operation and maintenance costs for constructed wetlands is lower compared to alternative treatment options, necessitating a superior operation for constructed wetland to achieve optimum performance of stormwater treatment. A study was conducted based on actual constructed wetland located in Universiti Sains Malaysia (USM) Engineering Campus, Penang, Malaysia, focusing on the changes of the newly rehabilitated wetland performance in enhancing the stormwater quality. The parameters that investigated were pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniacal nitrogen (AN) and total suspended solid (TSS). The Water Quality Index (WQI) and National Water Quality Standards for Malaysia (NWQS) were studied for the year of 2013 and 2014. The results showed that the performance of constructed wetland was maintained after one year. These results were explained further by the treatment media in constructed wetland throughout the study period. Therefore, an appropriate design of constructed wetland with the consideration of long term performance definitely can contribute the stormwater runoff quality enhancement.
Key Words: Newly rehabilitated wetland, Performance, Water quality control

1. INTRODUCTION
Constructed wetlands as the best management practices can be explicitly designed to aid in pollutant removal from stormwater. Stormwater runoff will carry pollutant such as suspended solid, oil and grease, phosphorus and ammonia [14]. Thus, can deteriorate the water quality and can lower the usage of river water.

In Malaysia, the water quality level and class of pollutant can be measured by using Water Quality Index (WQI) while the usage of water can identify by comparison the concentration to the National Water Quality Standards for Malaysia (NWQS) [4]. Six sub-indexes that consist in WQI was dissolved oxygen (SIDO), biochemical oxygen demand (SIBOD), chemical oxygen demand (SICOD), ammoniacal nitrogen (SIAN), suspended solid (SISS) and pH (SIpH) where was involved with physical, chemical and biological reaction in the water body.

Constructed wetland consists two types, namely, horizontal flow and vertical flow. According to the Urban Stormwater Management Manual for Malaysia or “Manual SaliranMesraAlam” (MSMA 2nd Edition), constructed wetlands comprising of three main zones, namely, inlet zone, macrophtye zone and open water zone [3]. The treatment in constructed wetlands involves several mechanisms, namely, coagulation, filtration, sedimentation and sorption where macrophyte was present as the main part of the treatment media in constructed wetland[8].According to [2], macrophyte was proven play an essential role as pollutant removal in constructed wetland. This is due to a large surface area provided by macrophyte for microbial growth and supply oxygen in the rhizosphere.

The operation and maintenance costs for constructed wetlands is lower compared to alternative treatment options, necessitating a superior operation for constructed wetland to achieve optimum performance of stormwater treatment. Many studies conducted in constructed wetland on the pollutant removal [9, 10, 11, 12]. However, less information on the performance of the newly rehabilitated wetland for water quality enhancement. Therefore, this study was conducted to evaluate the changes of the newly rehabilitated wetland performance in enhancing the stormwater quality via WQI and NWQS.

2. METHODOLOGY

This study was conducted in actual constructed wetland where was newly rehabilitated according to the design criteria and requirement as specified in MSMA 2nd Edition located in Universiti Sains Malaysia (USM) Engineering Campus, NibongTebal, Penang, Malaysia as shown in Fig1. 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.

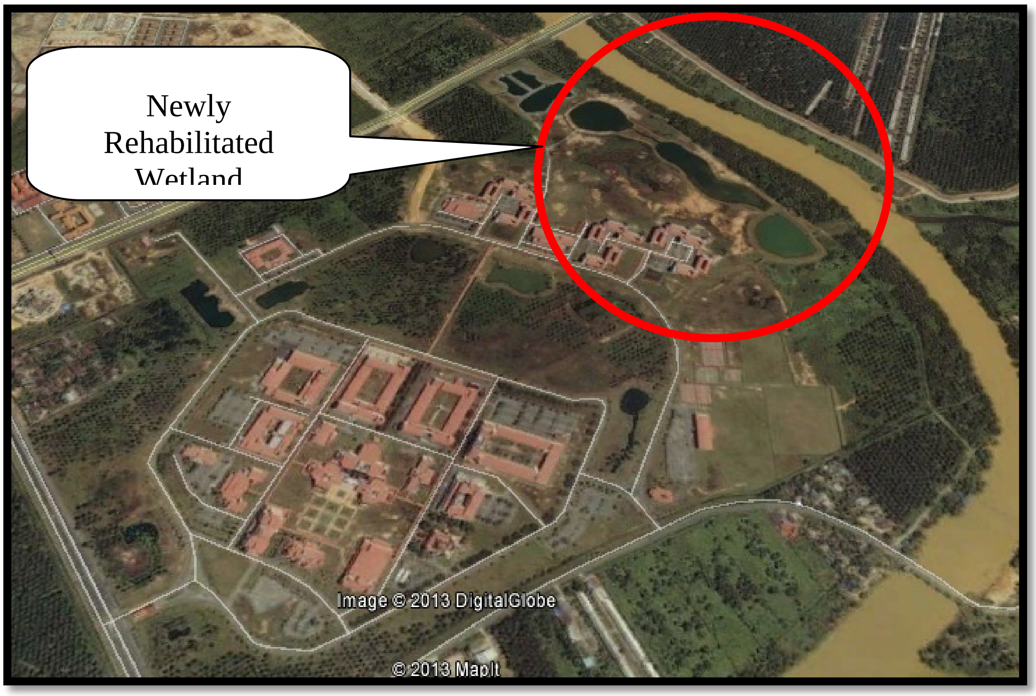

Fig 1: Map of Universiti Sains Malaysia Engineering Campus [5]

Six species of macrophyte had been selected, namely,*Elocharis variegate*, *Scirpusgrossus*, *Phragmitekarka*, *Typhaangustifolia*, *Lepironia articulate* and*Hanguanamalayana*had been cultivated at the newly rehabilitated wetland via high marsh or low marsh as in Table 1.The water sampling were conducted from year 2013 until 2014. Grab sampling method was being applied for 14 sampling stations and preservation of the sample was made. The parameters that investigated were pH, 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 2. 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 - 1Macrophyte cultivated in newly rehabilitated wetland

	Macrophyte	Marsh
Inlet zone		
Cell 1	*Eleocharisvariegata*	High
Cell 2	*Scirpusgrossus*	High
	Phragmiteskarka	Low
Cell 3	*Typhaangustifolia*	Low
	Scirpusgrossus	High
	Lepironiaarticulata	High
Cell 4	*Lepironiaarticulata*	Low
	Eleocharisvariegata	Low
	Eleocharisvariegata	High
	Hanguanamalayana	Low
Outlet zone	*Typhaangustifolia*	High

Table - 2 Standard Method [1,6]

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^oC)	APHA-5210B
Chemical Oxygen Demand (COD)	HACH-8000
Ammoniacal Nitrogen (AN)	HACH-8038

The percentage of reduction,WQIand NWQSwere used to determine the performance of the newly rehabilitated wetland in enhancing the stormwater quality. The percentage of reduction on each sampling was determined using the Eq. [1] as follow:

Percentage of removal, % = $\frac{C_{in} - C_{out}}{C_{out}} x100$ [1]

where C_{in} and C_{out} are the concentration of influent and effluent of the cell.

The 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. [2].

WQI= 0.22(SIDO) + 0.19(SIBOD) + 0.16(SICOD) + 0.15(SIAN) + 0.16(SISS) + 0.12(SIpH)[2]

Then, the WQI result will be compared to the values shown in Table 3 and Table 4.

Table - 3 Water Quality Index [4]

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 - 4 Water Quality Index Range [4]

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

The NWQS was determined by the individual classification water quality parameter.The NWQS was a set of standards derived based on beneficial uses of water as in Table 5. It consist of 72 parameters and designation into 6 classes as shown in Table 6. In this study, only six parameters that compared to the NWQS, namely, DO, BOD, COD, AN, SS and pH.

Table - 5 Class of water quality and uses [4]

CLASS	USES
Class I	Conservation of natural environment. Water Supply I - Practically no treatment necessary. Fishery I - Very sensitive aquatic species.
Class IIA	Water Supply II - Conventional treatment. Fishery II - Sensitive aquatic species.
Class IIB	Recreational use body contact.
Class III	Water Supply III - Extensive treatment required. Fishery III - Common,of economic value and tolerant species; livestock drinking.
Class IV	Irrigation
Class V	None of the above.

Table - 6 National Water Quality Standards for Malaysia [4]

PARAMETER	UNIT	CLASS					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Biochemical Oxygen Demand	mg/l	1	3	3	6	12	> 12
Chemical Oxygen Demand	mg/l	10	25	25	50	100	> 100
Dissolved Oxygen	mg/l	7	5 - 7	5 - 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Total Suspended Solid	mg/l	25	50	50	150	300	300

All the data analysis was conducted using Microsoft Excel 2010.

3. RESULT AND DISCUSSION

The assessment of water quality in stormwater runoff shown an improvement through the newly rehabilitated wetland. Table 7 showed the mean concentration for all the parameters of study at the newly rehabilitated wetland.

Table - 7 The mean concentration of Inlet zone and Oulet zone via season

Parameter	Inlet zone		Outlet zone	
	Wet season	Dry season	Wet season	Dry season
DO (mg/L)	5.60	4.21	5.38	3.99
BOD (mg/L)	1.82	3.12	1.73	2.94
COD (mg/L)	18.00	18.91	13.82	16.48
AN (mg/L)	0.33	0.28	0.11	0.10
TSS (mg/L)	30.60	15.67	12.70	3.33
pH	8.44	8.09	7.55	7.88

The mean concentration for DO in the wet season was slightly higher than dry season for Inlet zone and Outlet zone. The obtained result indicated 3.93% of reduction in the wet season while inthe dry season, the percentage of reduction obtained was 5.33%.The mean concentration for the wet and dry season were higher in Inlet zone compared to Outlet zone was because of the turbulence flow from incoming pollutant compared to the nearly stagnant flow before discharge. The incoming pollutant via stormwater required microorganism to degrade the organic matter was highly consumed the dissolved oxygen. In newly rehabilitated wetland consist aquactic animal like phytoplankton and fish that also consumed the dissolved oxygen[10]. Therefore, the dissolved oxygen level was low.As compared to the NWQS, the effluent for DO concentration was in Class IIA/B for wet season while in Class III for dry season.

The mean concentration of BOD_5 and COD was higher in dry season compared to the wet season for both Inlet and Outlet zone. The data obtained showed the percentage of reduction for BOD_5 mean concentration was 4.95% and 5.77% for the wet and dry season, respectively. As for COD mean concentration, approximately 23.22% and 12.85% of reduction obtained from the wet and dry season, respectively. The mean concentration for the wet and dry season were higher in Inlet zone compared to Outlet zone was because of the incoming pollutant for both BOD_5 and COD, respectively. The incoming pollutant via stormwater runoff carried pollutant such as suspended solid and nutrient. The microorganism was demanded the oxygen to degrade the organic matter. This will increase the BOD_5concentration. The COD concentration also was increasing because of the incoming pollutant as the present of organic and inorganic pollutant that need to chemically oxidize also required the dissolved oxygen. Therefore, as at Outlet zone the concentration of BOD_5 and COD were decreased as all the process took part more at beginning, Inlet zone. As compared to the NWQS, the effluent for BOD_5concentration was in Class IIA/B for wet and dry season while the effluent for COD concentration also was in Class IIA/B for wet and dry season.

Based on the data obtained, the mean concentration for AN in the wet season was slightly higher than dry season for Inlet zone and Outlet zone. The obtained result indicated 66.67% of reduction in the wet season while inthe dry season, the percentage of reduction obtained was 64.29%.The mean concentration for the wet and dry season were higher in Inlet zone compared to Outlet zone was because of the incoming pollutant. The incoming pollutant via stormwater runoff carried pollutant such nutrient.The high concentration of ammonia can be found in the landscaping area from fertilizer. The newly rehabilitated wetland was cultivated with six species of macrophyte via a variety of marsh. According to [7], the highest reduction of AN concentration was from Cell 4 were contained three species of macrophyte, namely, *Lepironia articulate*, *Eleocharisvariegata* and *Hanguanamalayana*. The ammonia-nitrogen was uptake by macrophyte and convert the nitrogen into organic compound to be used as a wall for cells and tissues [13].As compared to the NWQS the effluent for AN concentration was in Class I for wet and dry season.

The data obtained for Inlet zone and Outlet zone was higher in wet season than dry season for the TSS mean concentration. However, the percentage of reduction was indicated 58.50% and 78.75% reduced in the wet season and dry season, respectively.The mean concentration for the wet and dry season were higher in Inlet zone compared to Outlet zone also was because of the incoming pollutant. The incoming pollutant via stormwater runoff carried pollutant such suspended solid. The study reported by[7], indicated the highest reduction of TSS concentration was from Cell 4 were contained three species of macrophyte, namely, *Lepironia articulate*, *Eleocharisvariegata* and *Hanguanamalayana*. Macrophyte will influence the suspended solid to settle down and trap in constructed wetland [13].As compared to the NWQS the effluent for TSS concentration was in Class I for wet and dry season.

The data obtained for pH value at Inlet zone was higher for wet season while for dry season, the pH value was slightly higher in Outlet zone comparatively to Inlet zone. The percentage of reduction of pH value was indicated 10.55% and 2.60% reduced in the wet season and dry season, respectively.The mean concentration for wet and dry season were slightly reduced when in the Outlet zone.This can be related to the low of DO concentration and high of $BOD_5$and COD concentration where the breakdown of organic matter and oxidation was occurring. As compared to the NWQS the effluent for pH value was in Class Ifor wet and dry season.

The WQI for the newly rehabilitated wetland was shown in Figure 2. Overall, the WQI value for wet and dry season showed enhancement after throughout the newly rehabilitated wetland. However, on February 2014 the WQI value showed declination. Based on results obtained, the mean of WQI at Inlet zone was 78.6 and 78.7 for wet and dry season, respectively indicated as slightly polluted at Class II. Meanwhile, 84.6 and 81.1 of the mean WQI values were achieved at the Outlet zone for the wet and dry season, respectively was indicated as clean and also at Class II. The result obtained also was compared to the NQWS.

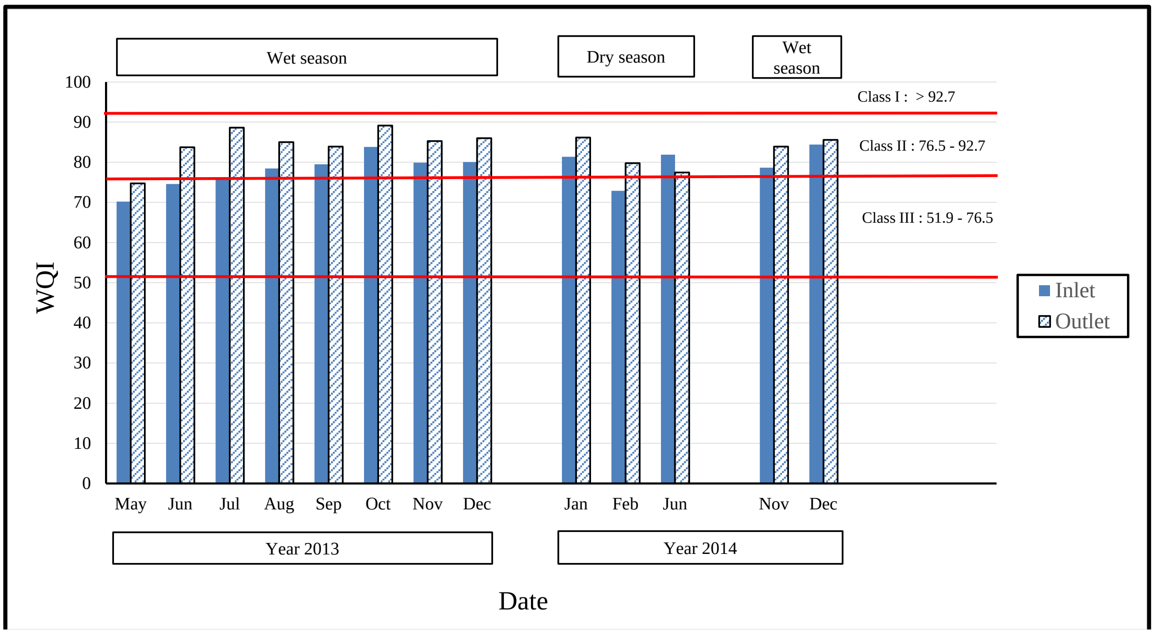

Fig2. Water Quality Index for the newly rehabilitated wetland

As overall, for wet season, the water quality was under Class 1 where the water can be used for water supply without any necessary treatment and also can be used as a fishery for very sensitive aquatic species. As for the dry season, the water quality was under Class II when compared to NWQS. The conventional treatment is needed when as water supply while, also can be used as a fishery for sensitive aquatic species and for recreational usedas much as body contact.

4. CONCLUSIONS

In conclusion, the newly rehabilitated wetland had the potential in enhancing the stormwater runoffquality. The value of WQI was increasing after passing through the constructed wetland from slightly polluted to clean. After compared to the NWQS, the water quality was in Class I and Class II for wet and dry season where can be used as water supply, fishery and also recreational for water body contact. As overall, the performance of the newly rehabilitated wetland was maintained after one year.

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