Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268 e-ISSN: 2395-3454	Vol. 16	No. 2	pp. 569-577	2017

Original Research Paper | Open Access

Nutrients and Pollutants Removal in Small-Scale Constructed Wetland in Frangipani Resort Langkawi, Malaysia

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 18-03-2016
Accepted: 16-04-2016

Key Words:
Eco-technology
Constructed wetlands
Sewage treatment system
Wastewater
Water quality

ABSTRACT

Constructed wetlands are the man-made system that mimics the function and structures of natural wetland and manipulated for wastewater treatment. The aim of the present study is to investigate the feasibility of using the small scale constructed wetland (CW) that is integrated with six species of plants to treat municipal wastewater in a hotel. The annual water quality improvement performance of four sampling points in the CW cells is described once in mid-January and mid-September from 2009 until 2013. The parameters studied were pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammoniacal nitrogen (AN), nitrate nitrogen (NN) and total phosphorus (TP). The removal percentage of each parameter was calculated and described as removal efficiency. Loading capacity of nutrients was also calculated using models. Removal percentage of pollutants and nutrients was higher in January compared to September in average due to some factors that are already explained. However, the results proved that the small scale CW can be one of the best alternatives to be used in hotels and resorts among modern and conventional treatments.

INTRODUCTION

Hotels, motels, serviced apartments and hostels provide great services to people on business or holidays. In this case, hotels and resorts are, among others, that actively introduce their waste into the surroundings and possess water disposal issues worldwide. Lodging industry in Malaysia, like most of the developing countries, is facing an increase in the generation of waste and of accompanying problems with the disposal of this waste. The wastewater from the hotels and resorts usually disposed with little or no treatment. Most hotel owners have their hotels installed with septic tank. Septic tanks are usually installed underground and the wastewater is only partially treated by infiltrating into the ground. Some other owners have taken initiatives to install conventional wastewater treatment plant to treat their wastewater.

However, the application of conventional system has a disadvantage. The treatment methods of this system may be highly effective, but it also involves too much unnecessary expense (Nelson & Tredwell 2002). It may require high financial investment to be constructed and high energy consumption during operation which can lead to more financial wastage. The use of high-tech machineries will also need frequent technical supervision and maintenance.

This is where the use of ecological based approach plays an important role. One of the effective methods of this approach is constructed wetlands. Constructed wetlands are manmade system that imitate the natural wetlands in the aspects of structure and function. They are built mainly for the purpose of pollutant removal from the wastewater. The system uses aquatic plants and microorganisms as active agents in treatment processes (Kaldec & Knight 1996). CW has potential to treat pollutants from various kinds of sources including surface runoffs, agricultural and industrial effluents, and polluted water from rivers and lakes (Sekiranda & Kiwanuka 1998). Apart from that, CW also can serve as a garden to attract tourist or the public that wish to explore the environment or educational purposes.

The objective of the present study is to assess the wastewater quality performance in a small-scale constructed wetland system which examines the role of constructed wetland in providing an efficient and economical means for treating wastewater. The study was carried out at The Frangipani Resort & Spa using a mixed wastewater including, drains from kitchens, laundries and bathrooms and sewage which has previously undergone a primary treatment. A surface flow constructed wetland planted with six species of plants was constructed to treat the hotel's sewage. It was supposed that the use of these plants will reduce the BOD, COD, TSS, AN, NN and TP load in the wastewater.

MATERIALS AND METHODS

Description of site: A small scale CW system with integration of six species of floating and submerged plants was built at the abandoned pond behind The Frangipani Resort & Spa. This resort is located at Pantai Tengah, Langkawi Island, Malaysia (6°16'43.7"N, 99°43'50.6"E). Fig. 1 illustrates the location of Frangipani Resort in Malaysia and the location of their CW system. The climate of this region is tropical with an average annual rainfall of 1300-1400 mm. The average minimum and maximum temperatures during the study period were 24 and 33 respectively.

Wetland design: The size of the CW system is approximately 0.1363 hectare (0.3369 acre) with a maximum depth of 1.2 meters to 1.7 meters depending on the season. The system was divided into five cells and two retention ponds. Crested weirs were installed between the first retention pond and the first treatment cell and between the last treatment cell and the second retention pond to ensure the surface flow of the wastewater. There were two inlet chambers carrying wastewater from Imhoff tank (storing sewage) and storage tank (storing kitchen and laundries drains) into the first retention pond. Both inlet chambers are made up of a PVC pipe of 12.5 cm in diameter connected to an electric pump.

Wetland vegetation: The study was carried out with six species of aquatic macrophytes. They were water mimosa (*Neptunia oleracea*), water hyacinth (*Eichhornia crassipes*), water spinach (*Ipomoea aquatica*), arrowroot (*Thalia geniculata*), vetiver (*Chrysopogon zizanioides*) and water lily (*Nymphaea caerulea*) which are known to be used in constructed wetlands. They were collected from local natural wetlands. The plants were transferred into the treatment cells in orders.

Wetland operation: The treatment process began with collection of wastewater in the first retention pond. The black water is generated from the sewage that has undergone the primary treatment in the septic tanks to separate the water from the sludge. On the other hand, the gray water from kitchen, laundry and bath drains was filtered with net to separate the water from rubbish and solids in the other storage tanks. The oil and grease trap were installed in the kitchen system to separate the wastewater from grease. Both gray water and black water were pumped into the first retention pond once a day using electric pump that is equipped with a timer. After that the wastewater was channeled through a series of plants for secondary treatment and being collected in the second retention pond at the end of the CW for storage and supply. Fig. 2 illustrates the system and its major components.

Sampling and analysis: The study was performed in two sets which were run once in mid-January and mid-September of each year from 2009 until 2013. The two set method was carried out to determine the performance of the CW in dry and wet season. Three replicates of wastewater samples were collected from four sampling points identified along the CW system. They are the inlet discharge point of first retention pond (S1), the outlet point of the water hyacinth

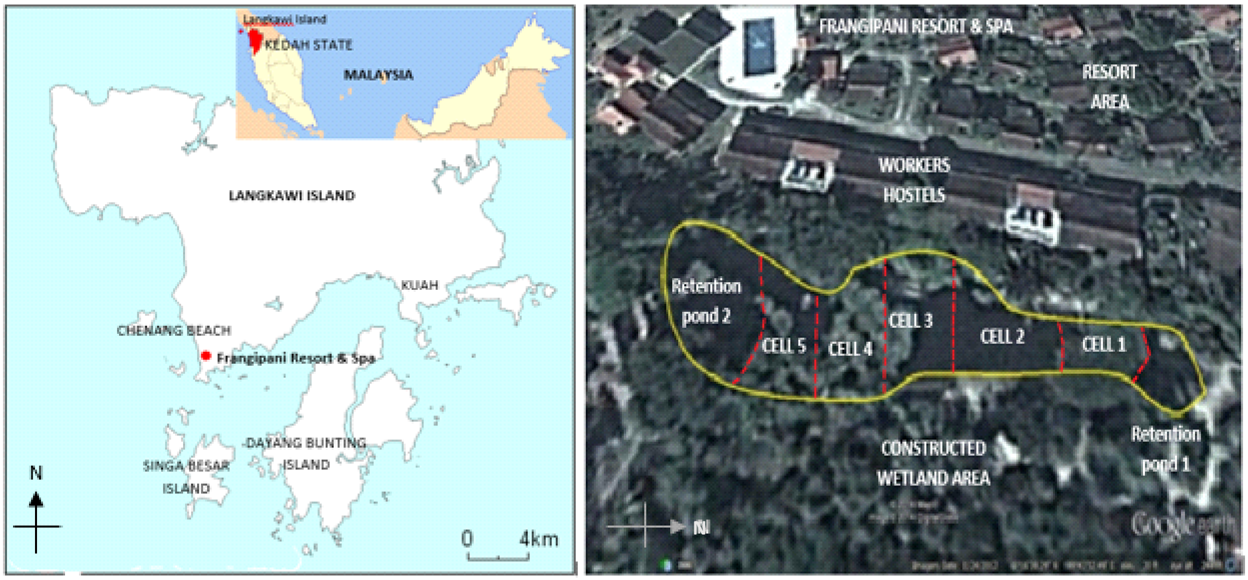

Fig. 1: Left: The location of Frangipani resort & spa at Langkawi Island; Right: The CW system at the backyard of the resort (Source: Google Earth & Google Maps).

cell (S2), the outlet point of the water spinach cell (S3) and the outlet of water lily cell (S4). Fig. 2 shows the location of sampling points within the system. The parameters analysed in the study were pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), ammonia nitrogen (AN), nitrate nitrogen (NN) and total phosphorus (TP). All the analysis was carried out by standard methods (APHA 1999).

The flow rates (Q) of each of the outlet point were measured using flow meter. The estimated loadings of nutrients of each point were calculated by multiplying the flow rate and nutrient concentration. This calculation is used to assess the influence of wastewater flow rates and concentration of nutrients to the nutrient loading capacity. The nutrient and pollutant removal percentage was also calculated.

RESULTS AND DISCUSSION

Mean values of various parameters of January 2009-2013 and September 2009-2013 data set are depicted in Figs. 3-14. The overall system treatment performance was moderate and stable during the observation period. The use of wetland macrophytes is essential for wastewater treatment. Generally, the plants produce significant amount of oxygen in the zone of their root system, enabling development of aerobic bacteria colonies in the root zone. These bacteria use the pollutants and nutrients for their nutrition. Part of the nutrients are used by plants for their growth.

The final result of the parameter studied showed that both sets of data varied within the standards for wastewater released by the Department of Environment, Malaysia (Table 1 and Table 2). The initial reading at S1 showed high variability of pollutant and nutrient content as it was only primarily treated. The initial reading of most of the September data set was higher compared to January data set. Some parameters showed continuous and non-continuous reduction in the next three sampling stations, which indicates that the pollutants and nutrients were removed or absorbed during the treatment process. Some parameters also showed addition to the initial reading in the middle of the treatment. This indicates that the pollutants were added into the wastewater from non-point source or released back biologically.

pH: The range of pH at S1 is 6.20 to 6.66 for the January data set (6.44 ± 0.128) and 6.26 to 6.60 for September data set (6.37 ± 0.111). pH reading of the wastewater showed an increase throughout the system for both the data sets. Average increase percentage of pH was 1.2% in January (6.59 ± 0.157) and 5.3% in September (6.73 ± 0.141). The increase of pH might be due to green algae formation in the wastewater. The green algae absorbed a substantial amount of carbon dioxide before it can be replaced by its respiration process and will lead to excessive formation of hydroxyl ion and the increase of pH readings (Barsyal 2010). The range of pH between 6.10 and 6.95 shows the neutral nature of the wastewater.

Biochemical oxygen demand (BOD): In the present study, it was observed that the BOD level of Frangipani Resort's wastewater at S1 ranged between 13 mg/L and 50 mg/L in January data set (39.646 ± 12.215) and between 43.3 mg/L and 51.3 mg/L in September data set (46.282 ± 3.01). The

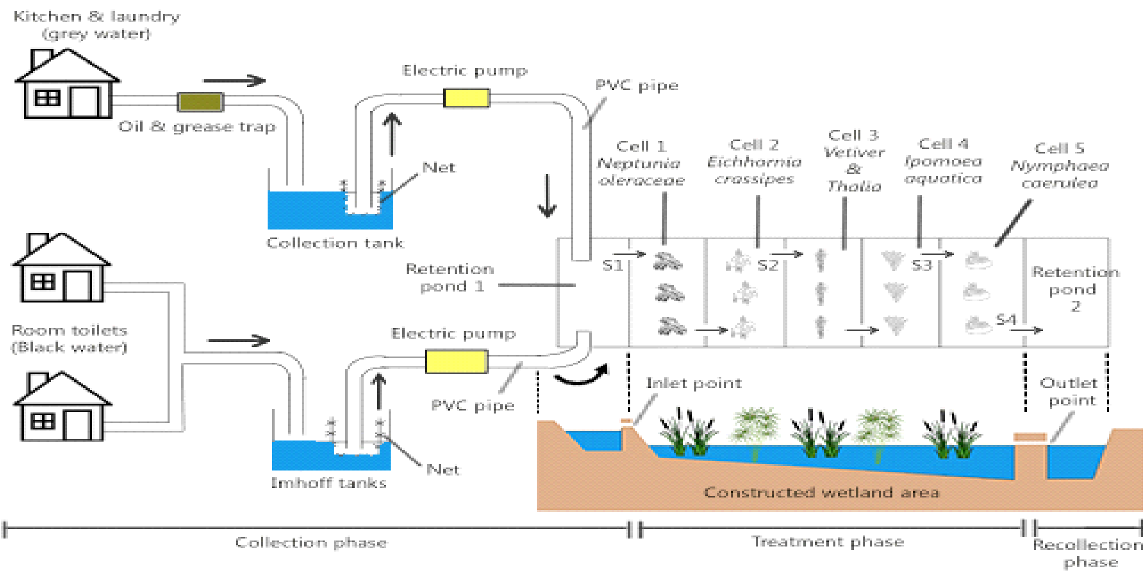

Fig. 2: Layout and wastewater flow of Frangipani Resort constructed wetland system.

Table 1: Comparison between January data set of S1 and S4 at Frangipani CW system and wastewater standards by DOE Malaysia.

Parameter	Unit	DOE Standard A	DOE Standard B	Inlet (S1)		Outlet (S4)	
				Mean	Range	Mean	Range
Temperature	°C	40	40	26.62	25.6-29.0	25.94	24.5-27.0
pH	-	6.0-9.0	5.5-9.0	6.43	6.3-6.56	6.584	6.4-6.77
BOD	mg/L	20	50	33.00	13-48	15.80	10.5-20.0
COD	mg/L	50	100	113.88	41.2-173.0	62.92	40-130
Suspended solids	mg/L	50	100	34.60	17-78	29.20	26-30
Ammonical nitrogen	mg/L	10	20	16.5	15.1-18.3	4.6	2.5-8.0
Nitrate nitrogen	mg/L	-	-	19.88	16.40-24.50	9.81	4.55-16.60
Phosphorus	mg/L	-	-	3.8	1.6-7.2	1.6	1.2-2.1

Table 2: Comparison between September data set of S1 and S4 at Frangipani CW system and wastewater standards by DOE Malaysia.

Parameter	Unit	DOE Standard A	DOE Standard B	Inlet (S1)		Outlet (S4)	
				Mean	Range	Mean	Range
Temperature	°C	40	40	25.4	23.7-28.4	24.7	23.2-26.9
pH	-	6.0-9.0	5.5-9.0	6.37	6.26-6.60	6.73	6.55-6.93
BOD	mg/L	20	50	46.28	41.30-51.30	39.50	32.60-44.90
COD	mg/L	50	100	162.58	123.30-186.0	53.70	32.50-78.60
Suspended solids	mg/L	50	100	36.58	18.60-80.30	29.16	25.50-36.0
Ammonia nitrogen	mg/L	10	20	10.70	7.90-13.60	11.24	8.40-20.30
Nitrate nitrogen	mg/L	-	-	28.13	21.30-34.60	15.54	13.80-17.30
Phosphorus	mg/L	-	-	15.32	12.30-19.70	14.66	10.80-20.80

removal of BOD at the end of the treatment is slightly higher in January data set in average which is 52.1% (15.906 ± 3.4) compared to 14.5% (39.5 ± 4.28) in September data set. The photosynthetic activities in plants increase the dissolved oxygen in wastewater, thus creating an aerobic condition which favours the aerobic bacterial activity to reduce BOD. However, these variations might be due to different bioactivity of microbes with temperatures. According to Steinmann et al. (2003), the increase in temperature (referring to January data set) will help to increase the biomass and activity of microbes in high speed and therefore result in higher BOD removal.

Chemical oxygen demand (COD): The level of COD at S1 ranged between 41.0 mg/L and 175 mg/L for January data set (114.326 ± 57.435) and between 123.3 mg/L and 186 mg/L for September data set (162.58 ± 21.243). The September data set showed a higher COD reading with less variations of the data. The higher COD level compared to BOD levels in Frangipani Resort's wastewater may be due to the presence of more organic material that are not easily biodegraded. The average removal of COD at the end of the treatment was 49.7% (60.4 ± 34.99) in January and 66.9% (53.0 ± 13.27) in September which is slightly higher than in January. COD removal trend is expected to be similar to BOD due to the influence of temperature. However, both data sets showed moderate removal of COD compared to the other studies on constructed wetlands as higher COD removal percentage recorded by Saeed & Sun (2013) when 90% of COD removed from textile wastewater and Sudarsan et al. (2015) recorded more than 80% COD removal in treating industrial wastewater.

Total suspended solids (TSS): Surface flow constructed wetland has low water velocities and appropriate composition of nutrient solids which allow the suspended solids to settle from the water column within the wetland. However, sediment resuspension not only releases pollutants from the sediments, but also increases the turbidity and reduces light penetration. The level of TSS at S1 ranged between 17 mg/L and 80.3 mg/L in January data set (35.233 ± 23.516) and between 18.6 mg/L and 80.3 mg/L in September data set (36.586 ± 22.305). At the end of the treatment, the removal percentage of TSS was 15.6% in January (29.146 ± 3.359) and 20.2% in September (29.166 ± 3.405). The removal of TSS was the lowest among all parameters. This result might be due to lateral inflows in the treatment cells and resuspension of bottom sediments during rainfall.

Nitrogen and phosphorus: Nitrogen and phosphorus are important pollutants in wastewater because of their role of algal growth and eutrophication in the water bodies. Nitrogen is present in organic form in sewage. Nitrate nitrogen and ammonia nitrogen are common types of organic nitrogen in wastewater. The removal of organic nitrogen is usu-

Table 3: Average removal percentage of nutrients and pollutants from the wastewater of Frangipani Resort's CW system.

Data sets	Sampling sites	Removal rate (%) BOD	COD	Suspended solids	Nitrate Nitrogen	Ammonia nitrogen	Phosphorus
January	S1 – S2	18.7	36.6	9.8	70.8	30.5	26.4
	S2 – S3	30	3.5	11.5	66	14.8	24.0
	S3 – S4	15.6	9.7	-5.7	-2.95	50.4	45.7
	S1 – S4	52.1	44.7	15.6	0.5	84.4	60.8
September	S1 – S2	8.2	17.2	3.5	11.7	-7.3	-16.8
	S2 – S3	2.3	25.0	-4.3	23.7	-12.8	11.9
	S3 – S4	4.5	46.6	20.9	17.9	15.1	9.8
	S1 – S4	14.5	66.9	20.2	44.7	-4.8	4.3

Table 4: Flow rates of wastewater and loading capacity estimation of nutrients in S1-S4.

Data set		Flow rate, $Q(m^3/s)$	NO_3-N (mg/L)	NH_4-N (mg/L)	P (mg/L)	Loading NO_3-N (kg/day)	Loading NH_4-N (kg/day)	Loading P (kg/day)
Jan.	S1	0.0033 ± 0.00019	19.88 ± 3.02	0.608 ± 0.295	10.21 ± 1.94	0.065	0.002	0.033
	S2	0.0032 ± 0.00018	15.23 ± 3.47	0.342 ± 0.167	7.51 ± 1.54	0.048	0.001	0.024
	S3	0.0023 ± 0.00015	13.59 ± 3.85	0.188 ± 0.088	5.77 ± 2.53	0.031	0.0004	0.013
	S4	0.0016 ± 0.00013	9.81 ± 4.26	0.092 ± 0.042	4.00 ± 1.64	0.015	0.0001	0.0064
Sep.	S1	1.347 ± 0.708	28.13 ± 4.527	10.70 ± 2.092	15.32 ± 2.224	37.89	14.41	20.63
	S2	0.746 ± 0.032	24.82 ± 2.911	11.54 ± 3.129	18.40 ± 4.522	18.51	8.60	13.72
	S3	0.553 ± 0.015	18.98 ± 2.340	13.25 ± 1.621	16.29 ± 5.700	10.49	7.32	9.00
	S4	0.351 ± 0.062	15.54 ± 1.116	11.24 ± 3.776	14.66 ± 2.961	5.45	3.94	5.14

Table 5: Nitrate nitrogen and phosphate removal rate during two sampling periods from sampling sites S1-S4/S1-S5 in Putrajaya wetland (Cheng et al. 2007).

Sampling stations	Removal rate (%) Nitrate nitrogen		Phosphate	
	Oct 2001 – Dec 2002	Apr – Dec 2004	Oct 2001 – Dec 2002	Apr – Dec 2004
S1 – S2	6.4	69.2	39.0	64.4
S2 – S3	36.0	-174.9	24.3	-152.6
S3 – S4	-45.3	24.7	-44.8	33.8
S4 – S5	-	54.1	-	73.7
S1 – S4	12.9	36.3	33.2	40.4
S1 – S5	-	70.0	-	84.3

ally assisted by chemical and physico-chemical processes of plants.

According to Breen (1990), nitrogen was removed by volatilization of NH_3 assisted by the increase of pH level, nitrification in aerobic condition, denitrification in anaerobic condition and organic film formation. Sommer & Olesen (2000) also suggested that nitrogen removal involved three main processes; hydrophytes uptake, volatilization and nitrification/denitrification. It is suggested that in Frangipani CW case, removal of nitrogen is due to the volatilization of NH_3 that is assisted by the increase of pH along the system. However, Al-Omari & Fayyad (2003) stated that normally, total nitrogen is reduced by denitrificaion, adsorption and incorporation into cell mass. According to Baskar (2009), plants need nitrogen for their growth and will uptake it using their roots and incorporate it in the form of biomass.

In the present study, it was observed that the ammoniacal nitrogen of Frangipani Resort's wastewater at S1 ranged between 0.2 mg/L and 1.0 mg/L in January data set (0.608 ± 0.295) and between 7.9 mg/L and 13.6 mg/L in September data set (10.70 ± 2.092). While nitrate nitrogen ranged between 16.4 mg/L and 24.5 mg/L in January (19.889 ± 3.022)

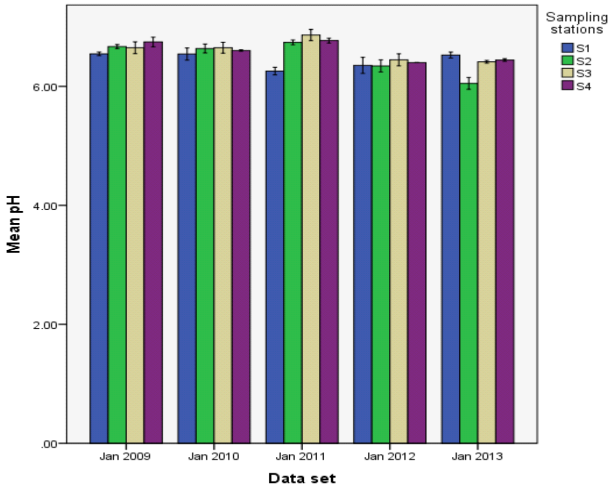

Fig. 3: Mean of pH of January 2009-2013 data set.

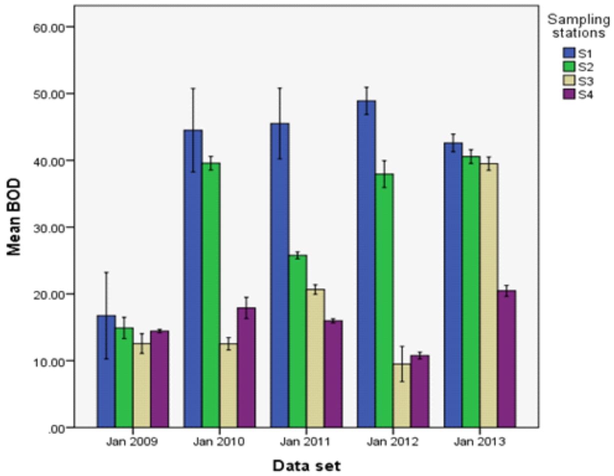

Fig. 4: Mean of BOD of January 2009-2013 data set.

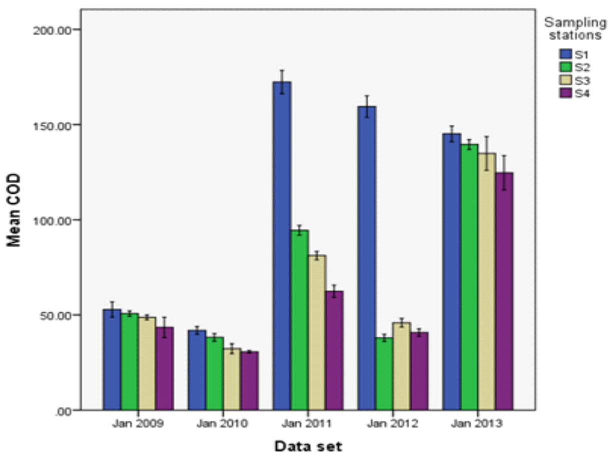

Fig. 5: Mean of COD of January 2009-2013 data set.

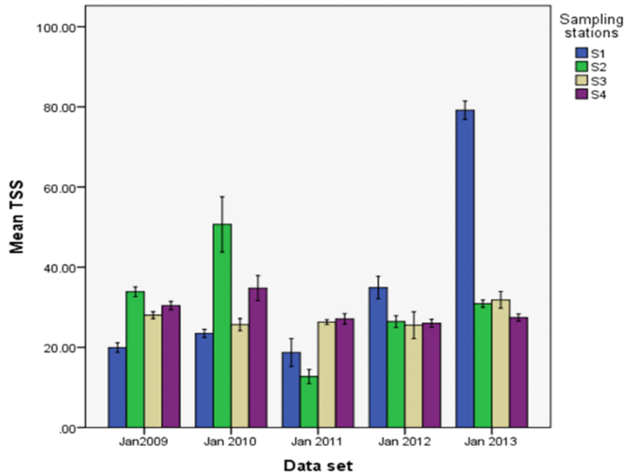

Fig. 6: Mean of TSS of January 2009-2013 data set.

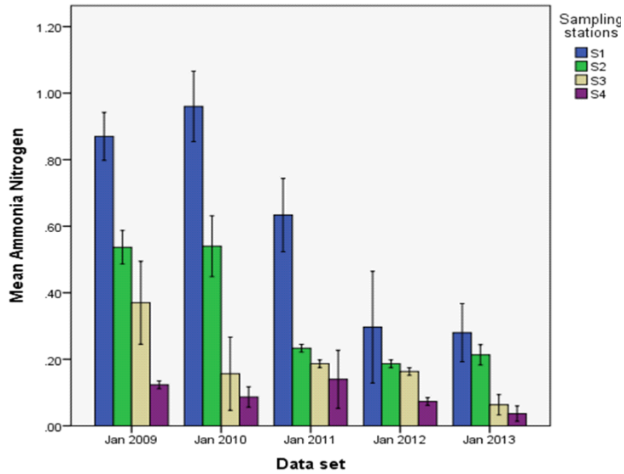

Fig. 7: Mean of ammonia nitrogen of January 2009-2013 data set.

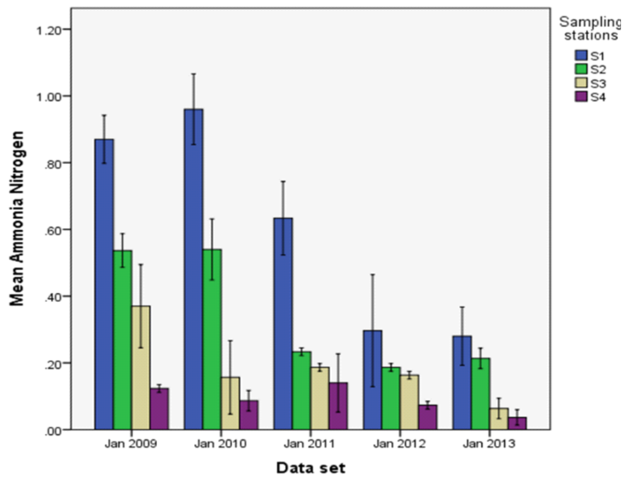

Fig. 8: Mean of ammonia nitrogen of January 2009-2013 data set.

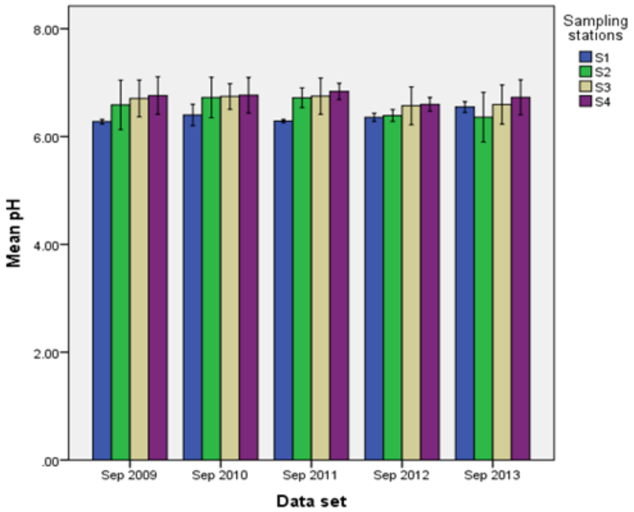

Fig. 9: Mean of pH of September 2009-2013 data set.

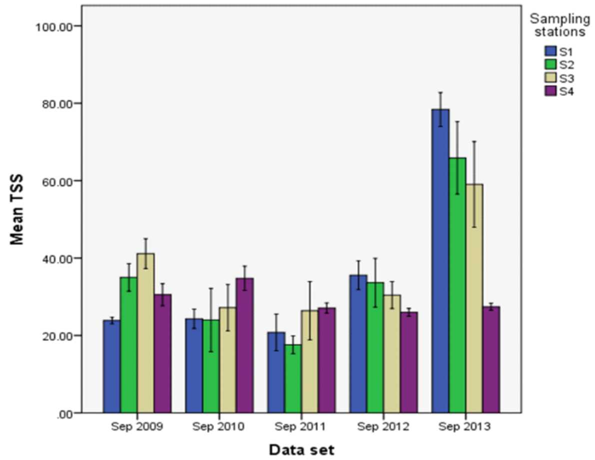

Fig. 12: Mean of TSS of September 2009-2013 data set.

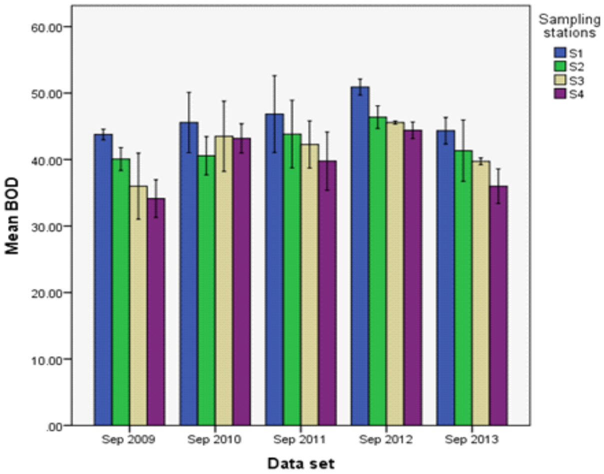

Fig. 10: Mean of BOD of September 2009-2013 data set.

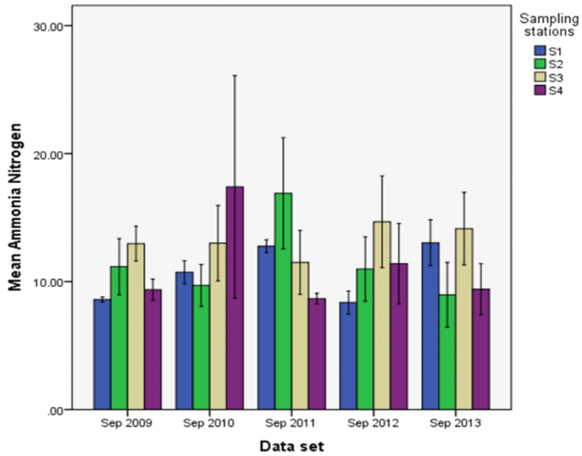

Fig. 13: Mean of ammonia nitrogen of September 2009-2013 data set.

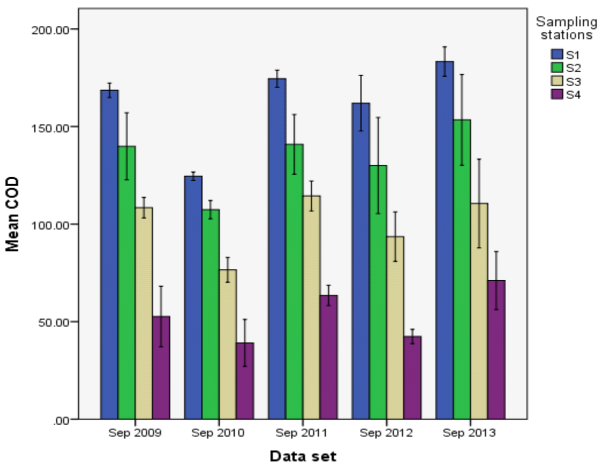

Fig. 11: Mean of COD of September 2009-2013 data set.

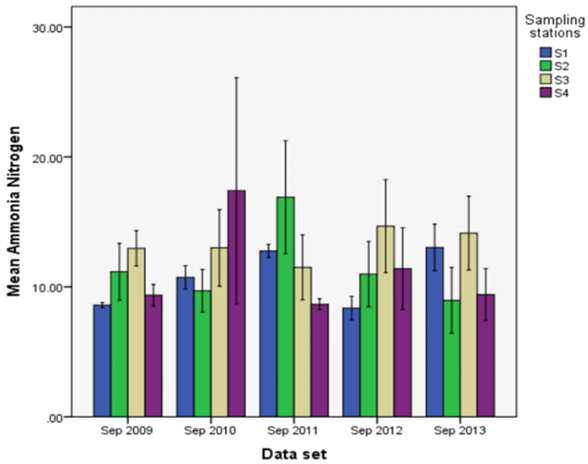

Fig. 14: Mean of ammonia nitrogen of September 2009-2013 data set.

Table 6: Ranges of water quality data during two sampling periods from sampling sites S1-S4 in Putrajaya wetlands (Cheng et al. 2007).

Water quality parameters	Sampling period	
	Oct 2001 – Dec 2002	Apr 2004 – Dec 2004
***In-situ* parameter**		
pH	5.5-7.4	6.85-7.65
Dissolved oxygen	0.78-13.25	2.5-5.02
Water transparency	0.069-0.51	0.098-0.51
Turbidity	21.7-284.3	18.7-134.2
Laboratory analyzed parameter		
Ammoniacal nitrogen	0.13-0.72	0.21-1.67
Nitrate nitrogen	0.07-2.23	0.7-1.78
Phosphate	0.07-0.32	0.05-0.28
Total suspended solids	10.25-137.5	7.2-73.2
COD	24-48.75	-
BOD	0.38-1.65	-

and between 21.3 mg/L and 34.6 mg/L in September (28.133 ± 4.574). Total nitrogen was higher in September data set compared to January data set. 84.8% of ammonia nitrogen was removed in January (0.092 ± 0.042), while there was 4.8% addition recorded in September (11.246 ± 3.776) at the end of treatment. However, 50.6% (9.814 ± 4.269) and 44.7% (15.546 ± 1.116) of nitrate nitrogen were removed in January and September respectively.

Phosphorus on the other hand is naturally more attracted to organic and soil particles (Brix 1987) that lead to its low presence in the open field CW system wastewater. Excess dissolved phosphorus was removed through absorbance by plants and algae. The removal of phosphorus is important since it is known to be major limiting nutrient for algal growth in freshwater ecosystems (Wetzel 2001).

Similarly, phosphorus ranged between 7.2 mg/L and 13.4 mg/L in January data set (10.212 ± 1.941) and 12.3 mg/L and 19.7 mg/L in the September data set (15.32 ± 2.244). Total phosphorus also found to be higher in September data set compared to January data set. 60.8% (4.00 ± 1.649) and 4.3% (14.666 ± 2.961) phosphorus were removed at the end of the treatment in January and September respectively.

Overall performance: September data set showed more frequent negative removal during the treatment and low overall performances compared to January data set (Table 3). The low nutrient removal in September is due to intermittent addition from lateral sources into the CW cells. High annual precipitation rates in Langkawi within September and mid-November would increase the side inflows into the wetland, and therefore decrease the hydraulic retention time and increase the nutrients load in the wastewater. Subsequent testing also showed that the estimated loading capacity of nutrients was higher in September due to faster flow rates of wastewater during rainy season and higher concentration of nutrients (Table 4). Besides, siltation due to heavy rainfall would also be the reason of low nutrient and total suspended solids removal. Siltation will wash away the sediments from the side inflows into the wetland and damage its capability to remove pollutants (Tanner et al. 2002).

Constructed wetland built on the field in Malaysia seems to be facing the same problem with the instability of overall pollutant removal efficiency due to high precipitation, evaporation and evapotranspiration rate throughout the year. For example, the Putrajaya wetland showed a generally high efficiency in removal of nutrients and pollutants from the wastewater, but high variability of TSS and turbidity (Table 6) and negative nutrient removal (Table 5) was also recorded due to the addition of lateral inflows into the wetland assisted by the rainfall (Cheng et al. 2007).

CONCLUSION

The small-scale constructed wetland system using six species of plants in Frangipani Resort was found proper for the removal of monitored pollutants and nutrients to the intermediate yet satisfactory quality in this study. However, the addition of nutrients and pollutants from lateral sources was suspected to be the reason of negative removal recorded by certain parameters in the middle of the treatment and affected the overall performance of the system. Therefore, a better result might be predicted if there is longer flow length in the constructed wetland to allow more intense treatment and the design is upgraded to mitigate the lateral leakage of storm water and surface runoff from entering the system. The treated effluent values obtained at the end of the treatment were convenient with current Department of Environment standards for domestic wastewater discharge. Proven to be a reliable treatment alternative, especially for a small area that have decentralized sanitation approach, this simple configuration permits a considerable reduction of surface area needed for treatment and less technical supervision that will lead to a saving of financial expenses. This design seems to be a viable alternative for reducing the organic matter from a small and medium size lodging facilities and settlements. Applying wastewater treatment system within these facilities will support to enhance the sustainable environmental consciousness besides being readily functional on educational purposes. Therefore, more studies should be conducted especially on the performance of the CW system in higher nutrient loading situation to determine its maximum capacity to treat various types of wastewaters and the designs of sanitation system that can promote reuse of the treated wastewater within the facility.

ACKNOWLEDGEMENT

The authors would like to thank The Frangipani, Resort & Spa for providing a land within their facility for constructing a constructed wetland system. Sincere thanks are also due to the Institute for Environment and Development, Universiti Kebangsaan Malaysia for providing facilities for research.

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