Advances in Recycling and Waste Management

Sirage Ali et al., Adv Recycling Waste Manag 2017, 2:3
DOI: 10.4172/2475-7675.1000138

Research Article Open Access

Purifying Municipal Wastewater Using Floating Treatment Wetlands: Free Floating and Emergent Macrophytes

Adane Sirage Ali[1*], Piet Lens PN[2] and Hans Van Bruggen JJA[3]

[1]*Department of Environmental Science, Kotebe Metropolitan University, Addis Ababa, Ethiopia*

[2]*Department of Environmental Science, IHE-Delft Institute for Water Education, Delft, The Netherlands*

[3]*Department of Environmental Science, IHE-Delft Institute for Water Education, Delft, The Netherlands*

[*]**Corresponding author:** Sirage Ali A, Department of Environmental Science, Kotebe Metropolitan University, Addis Ababa, Ethiopia, Tel: +251911149050; E-mail: adnansirage@gmail.com

Received date: July 26, 2017; **Accepted date:** August 01, 2017; **Published date:** August 07, 2017

Abstract

Wastewater treatment using natural systems such as ponds and constructed wetlands have faced several limitations. Floating treatment wetlands (FTWs) can offer potential solutions for these problems. However, there has been little information published to date about FTWs. This study was aimed to investigate the performance of various FTWs for domestic wastewater. Secondary and primary municipal wastewater effluents were used in five pairs of FTWs and a pair of control. Temperature, pH, electrical conductivity, dissolved oxygen, NO_3^--N, NH_4^+-N, TDN, PO_4^{3-}-P, total phosphorus, DOM fractions, DOC, TOC, COD and BOD were measured every week for four months. The presence of plants created optimum pH level and stimulated oxygen demanding activities in the FTWs. Mean removal efficiencies of the FTWs for NH_4^+-N, total dissolved nitrogen, PO_4^{3-}-P, and total phosphorus was 76%, 61%, 53% and 63% respectively. Mean NO_3^--N reduction in the secondary influent was 69% whilst during primary influent treatment phase, NO_3^--N concentration was increased in the effluent due to intensive nitrification in the system. Among the DOM fractions, fulvic acid was the most removed (84%) by all the FTWs. All FTWs perform better than the control and; among FTWs emergent macrophytes perform better than free-floating hydrophytes particularly under high pollutant loads and with respect to performance stability.

Keywords: Floating treatment wetland; Macrophytes; Free floating wetlands; Municipal wastewater, Hydrophytes

Introduction

The need for wastewater treatment is becoming mandatory throughout the world in all sectors which produce polluting agents at all scales. Wastewater treatment using pond and wetlands have become more popular and widely accepted over the past few decades and increasingly being integrated into water sensitive urban designs [1]. However, the application of wetland and pond treatment systems has several limitations including clogging problem [2], weak performance in the removal of fine particulate matter and dissolved contaminants and attenuating hydraulics [3]. Floating treatment wetland (FTW) systems that incorporate common wetland plants growing in a hydroponic condition on floating rafts offer a potential solution to all these problems by enabling the integration of treatment wetland characteristics into deeper pond systems exposed to water level fluctuations [4]. FTW innovation can be practiced at all levels, with very low expense in all types of water body and with ordinary engineering. The main applications of FTWs reported to date have been for the treatment of storm water [1], acid mine drainage [5], poultry processing wastewater [6]; water supply reservoir [7] and river water amelioration [8] using only the common types of emergent macrophytes.

Despite the potential advantages of FTWs for the treatment of various wastewaters, there has been little information published to date about their design, construction and performance [9]. Different authors have evaluated the effects of vegetation on the capacity of conventional constructed wetlands (CW) and reported their added values in polishing the wastewater [9,10]. However, the knowledge about the roles played by macrophytes in FTWs on the removal of pollutants is still limited [11]. Some of the studies focused on the effect of some plant species, which are commonly used in conventional CWs and the effect of their addition compared to a control system without floating macrophytes mat. Both free-floating and emergent macrophytes haven't ever tested for municipal wastewater treatment. In FTWs both naturally floating and emergent macrophytes can be employed and in few studies the uses of emergent macrophytes and natural floating macrophytes have been reported but none of them made comparison between their performances under similar conditions. For augmenting the treatment capacity and confidential dissemination of the innovation, there is a need to investigate the full treatment potential and full understanding of the system. In this study pollutant removal efficiencies of FTWs employing different types of macrophytes were assessed. Therefore, the objective of this study was to evaluate the pollutant removal performance of emergent macrophytes and naturally free-floating hydrophytes.

Research Design and Methods

Experimental set up

Twelve mesocosms were prepared from Twelve buckets and one 100 L influent tank was placed higher in the laboratory (Figure 1). The bottoms of every bucket were covered with gravels measuring about 2 Liters. Two pairs of suspending racks were prepared from white floater and several small holes were made to suspend the plants.

Citation: Sirage Ali A, Piet Lens PN, Hans Van Bruggen JJA (2017) Purifying Municipal Wastewater Using Floating Treatment Wetlands: Free Floating and Emergent Macrophytes. Adv Recycling Waste Manag 2: 138. doi:10.4172/2475-7675.1000138

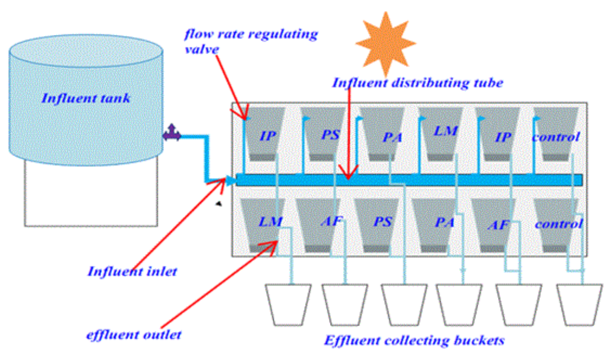

Figure 1: Schematic view of the experimental set up.

Two species of emergent macrophytes (*Iris pseudacorus* (IP) and *Phragmites australis*(PA)) and three species of free-floating hydrophytes (*Lemna minor* (LM), *Azoll afiliculoides* (AF) and *Pistia stratiotes* (PS)) were selected. The free-floating macrophytes were directly placed in the mesocosm surface water whilst the emergent macrophytes were placed on the suspending floater in such a way that the roots could suspend down to the water column. A pair of bucket was used as a control (without plant and floating mat). All of the mesocosms were prepared in duplicate. Twelve *Iris pseudacorus*, 12 *Phragmites australis*, 12 *Pistia stratiotes* and hundreds of *Lemna minor* and *Azolla filiculoides* macrophytes were placed. The influent tank was filled with primary wastewater (taken from primary sedimentation pond). The influent was allowed for 5 days retention time. The set up was run for about 5 months.

In situ physio-chemical measurements

The parameters pH, temperature, electrical conductivity and dissolved oxygen were measured *in-situ* in the mesocosms using portable digital meters/probes together with the weekly samplings for other chemical parameters. Electrical conductivity and pH were measured using portable digital conductivity meter and pH meter respectively. Dissolved oxygen was measured using WTW Oxi-340 portable oximeter integrated after calibrating at 100% oxygen saturation.

Measurements of nutrients

For chemical analysis, about weekly water samples were collected at the outlet of the influent tank and at the outlet of each of the floating systems. These samples were used for the analysis of BOD_5, COD, NO_3^--N, NH_4^+-N, TN, TOC, DOC, PO_4^{3-}-P and TP. All the parameters were analysed following the procedures of standard methods for examination of water and wastewater [12].

NH_4^+-N was measured using dicholorocyanurate method spectrophotometrically (UV-2501 PC spectrophotometer) at 655 nm using spectrophotometer. NO_3^--N and PO_4^{3-}-P were determined by ion chromatography (Dionex ICS-1000 with DV sampler) after filtration through 0.2 µm pore size IC filter. Total Phosphorous (TP) was estimated by hydroxylation of particulate organic phosphate by acid digestion followed by Ammonium molybdate method for determination TP as PO_4^{3-} ions (PO_4^{3-}-P determination). Absorbance was measured using spectrophotometer (UV-2501 PC spectrophotometer) at 880 nm.

Analysis of organic carbon

BOD was measured using the 5-day incubation period technique whereas; COD was determined using closed reflux colorimetric technique spectrophotometrically. DOC and TOC were measured by a total organic carbon analyzer (TOC-VCPN, Shimadzu, Japan). Fluorescence EEM spectra for the different samples were measured by FluoroMax-3 Spectro fluorometer (Horiba Jobin Yvon, Inc., USA) with xenon lamp as the excitation source.

Results and Discussion

Physicochemical parameters

Temperature: Temperature in all of the wetlands was almost similar throughout the study period. It ranged from a minimum of 18.9ºC to a maximum of 22.1ºC with maximum standard deviation of less than one (Table 1). Temperature in the FTWs was little bit higher than the control but stable.

The prevailed temperature variations between the influent, control and the FTWs was attributable to the influence of vegetation in all of the FTWs and suspending rack in the emergent macrophyte FTWs. Reports showed that the presence of macrophytes results in more stable temperature throughout the year, which in turn influences pollutant reduction in treatment wetlands [13].

Dissolved oxygen: The average DO concentration varied between different FTWs (Table 2). Dissolved oxygen in the FTWs was more depleted than the control implying that in the presence of plants, the consumption of dissolved oxygen was higher than oxygen input through plant roots and atmospheric diffusion.

Wastewater	Influent	Control	Floating systems				
			PA	IP	PS	LM	AF
Secondary	19.8 ± 0.9	20.4 ± 0.6	21.5 ± 0.5	21 ± 0.8	21.5 ± 0.6	21.5 ± 0.5	20.9 ± 0.1
Primary	21 ± 0.8	20 ± 0.6	21.67 ± 0.4	21.4 ± 0.4	21.7 ± 0.4	21.7 ± 0.3	21.6 ± 0.3

Table 1: Mean (+SD) values of temperature in the influents and effluents of the control and the FTWs(n=12).

Supply of oxygen through the plant roots is much higher than atmospheric diffusion and could stimulate oxygen consuming reactions in the system [11] and hence, this could ultimately leads to more depleted and anoxic microenvironments.

Wastewater	Influent	Control	Floating systems				
	In	C	PA	IP	PS	LM	AF
Secondary	8.3+1.5	6.2+1.3	6.1+1.7	3.4+0.9	5.1+2.1	4.5+2.4	5.5+2.5
Primary	0.20+0.2	0.80+0.7	0.80+0.5	0.70+0.6	0.70+0.2	0.30+0.3	0.60+0.2

Table 2: Mean, standard deviation values of DO concentration (mg/L) in the influents and effluents of the control and the FTWs (n=12).

Wastewater	Values	Influent	Control	Floating systems				
				PA	IP	PS	LM	AF
Secondary	Mean	7.3 ± 0.01	8.14 ± 0.3	7.1 ± 0.3	6.9 ± 0.1	7.4 ± 0.3	7.8 ± 0.8	7.6 ± 0.4
Primary	Mean	7.2 ± 0.1	7.6 ± 0.1	6.7 ± 0.1	6.8 ± 0.1	6.9 ± 0.1	6.9 ± 0.1	7 ± 0.2

Table 3: Mean+SD values of pH in the influents and effluents of the control and the FTWs (n=12).

Plants modify wetland environments by excreting protons, organic acids and carbon dioxide via their roots [14] and this maintains the pH below 7 which is favorable for several biochemical transformations. Lower pH in the presence of plants could also be related with the imbalances between nitrification and denitrification.

Electrical conductivity (EC): The mean EC in the secondary and primary influents was 1169 and 1391 μS/cm respectively (Table 4). In all of the FTWs, there was better regulation of conductivity (9.2-12.9% for secondary and 7.9- 17.8% for primary influents) than the control (8% for secondary and 5.3% for primary influents); and the FTWs' efficiency was increased with increasing conductivity levels in the influent. The removal of ions by the FTW, which was always less than 20% was not significant.

Since the highest proportion of the conductivity was due to chlorine and sulphate ions, removal by plant uptake is expected to be low. An increasing trend of ion removal overtime could be attributable to the developing substrate on the bottom with time and associated increment in ionic sorption capacity of the system.

Wastewater	Values	Influent	Control	Floating systems				
				PA	IP	PS	LM	AF
Secondary	Mean std	1168.8 36	1074.7 59	1017.7 82	1086.0 33	1028.0 87	1060.7 81	1061.0 104
	Efficacy		8.0	12.9	9.9	12.0	9.2	9.2
Primary	Mean std	1391 268	1318 247	1163 231	1282 239	1219 259	1222 280	1143 224
	Efficacy		5.3	16.4	7.9	12.3	12.1	17.8

Table 4: Mean and standard deviation of EC (μS/cm) in both secondary and primary influents and effluents of the control and the FTWs; and removal efficacy (%) (n=12).

Nutrient removal

Ammonium removal: The average ammonium removal efficiency of all the wetlands for secondary influent varied from 63% (AF) to 89.8% (PS) and for primary influent varied between 52.4% (PA) and 80.6%(*L. minor*) (Figure 2). During primary influent treatment the removal efficiency of all of the FTWs except free-floating hydrophytes, was decreased. FTWs with emergent macrophytes perform better at lower influent concentration than high concentration whilst FTWs with free-floating hydrophytes perform vice versa.

The higher variability of free-floating hydrophtes for ammonium removal (Figure 2) can be due to the fast growth rate and short life span of smaller hydrophytes such as *A. filiculoides* and *L. minor*; and could result in high turnover rate of biomass and enhanced die backs ultimately cause remobilization of nutrients. During peak growth, they can achieve high efficacy whereas during die back ammonium uptake will virtually be low and associated conducive conditions for microbial activities could be impacted. This condition makes these systems unpredictable and hardly possible to get the steady state conditions.

Nitrate: Nitrate concentration in the influent varied from a minimum of 0.05 to 1.13 mg/L and 5.5 to 7.7 mg/L in the primary and secondary influents respectively. At lower nitrate concentration, all of the FTWs perform better than the control. All of the FTWs perform very well with a mean removal efficiency of minimum 61.3% in *L. minor* and maximum 80.3% in *I. pseudacorus* (Figure 3). Even though nitrate concentration in the primary influent is naturally very low, during treatment process in the wetlands it was compensated by extremely high production of nitrate in all of the FTWs and the

Citation: Sirage Ali A, Piet Lens PN, Hans Van Bruggen JJA (2017) Purifying Municipal Wastewater Using Floating Treatment Wetlands: Free Floating and Emergent Macrophytes. Adv Recycling Waste Manag 2: 138. doi:10.4172/2475-7675.1000138

control; and hence, the FTWs actively transform organically bound nitrogen to nitrate up to a maximum of about 20 fold nitrate increase from the influent concentration, particularly in the FTWs with free-floating hydrophytes (*A. filiculoides* and *P. stratoites*) (Figure 3).

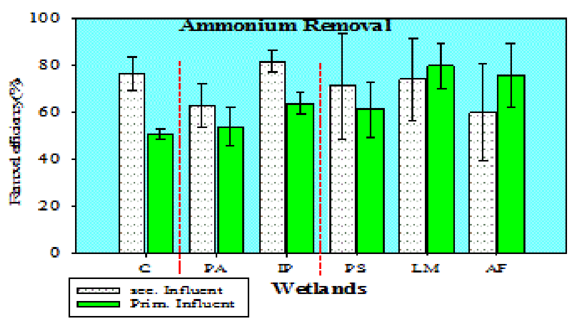

Figure 2: Mean Ammonium Removal efficiency in the FTWs and control.

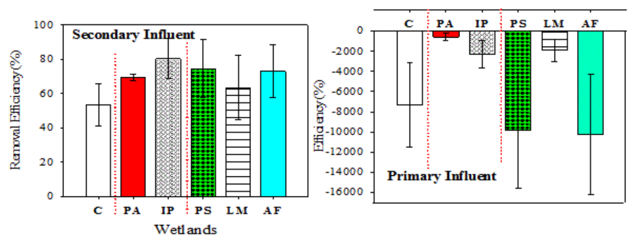

Figure 3: Mean nitrate removal efficiency of the FTWs and the control for secondary (left) and primary (right) influents.

The higher nitrate removal efficiency during secondary wastewater treatment could be due to plant and microbial uptake since ammonium concentration was low in the secondary influent, nitrate removal could be enhanced. It is known that in primary influent excessive nitrogen is bound organically and nitrate is normally produced from this organically bound nitrogen through biological transformation. Therefore, the high rate of organic nitrogen transformation through mineralization and nitrification should be the responsible factor for the increased nitrate concentration in the effluents of the FTWs.

Reports showed an increased level of nitrate in the effluents of FTWs due to more rapid nitrification rate than nitrate removal by dentirifiers and uptake by plants and microbes [15]. This phenomenon resulted in extreme oxygen depletion in all of the wetlands.

Total Dissolved Nitrogen (TDN): TDN concentration in the influent ranged from a minimum of 5.5 to 8 mg/L in secondary influent to a maximum of 15.5 to 21 mg/L in primary influent. There were statistically significant variations in the removal efficiencies of total nitrogen between the FTWs and the control; and among the FTWs ($F=11.2$, $df=5$, $P<0.05$). The removal efficacy for secondary influent ranged from a minimum of 56.7% in the A. filiculoides to a maximum of 76.2% in LM FTW; whereas for primary influent 44.9% in A. filiculoides FTW to a maximum of 82.2% in the P. Australis FTW (Figure 4). One-way ANOVA with pair wise grouping information using Tukey's Method confirmed the significance variations between the emergent macrophyte FTWs and free-floating hydrophytes in the processing of TDN ($F=11.2$, $df= 5$, $P<0.05$).

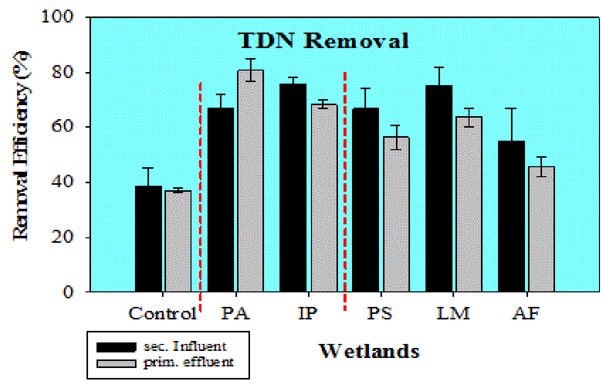

Figure 4: Mean TDN removal efficacy of FTWs and control for secondary and primary influents.

Dissolved organic nitrogen was the dominant form and hence, the main removal mechanism in the FTWs could be mineralization and nitrification processes, which was manifested as excessive nitrate production in the system (Figure 3, Right). Organic nitrogen cannot be taken up directly by plants and microbes rather it has to be transformed into inorganic form by ammonification and nitrification processes and hence, the high removal efficiency here is an indication the fact that FTWs create conducive environment for such chemical and biological transformations.

In the present study, the FTWs perform better than the control and compared with other study reports, they showed better performance. Low total nitrogen removal efficiencies (25.9%) of FTW that were used for domestic wastewater treatment, due to the reduction conditions and low nitrification processes [11].

Phosphorus removal

Soluble reactive phosphate: Soluble reactive phosphate in the secondary influent was mostly below 1 mg/L but it was a maximum of 5 mg/L in the primary influent. The removal efficiency of FTWs ranged between 36% (PA) and 64% (IP) for secondary influent and 35% (AF) and 63% (LM) for primary influent (Figure 5). There were no significant differences ($F=1.2$, $df=5$, $P=0.36$) in performance between the FTWs and the control and among the FTWs. However, all the FTWs showed better performance than the control.

Phosphate removal was variable in all of the wetlands including the control. The removal efficiency in the control may suggest the relevance of phosphorus removal mechanisms such as ion sorption and precipitation besides to plant and enhanced biofilm uptake. Unlike nitrogen removal, phosphorus removal is strongly effectuated by physicochemical process of sorption to the sediment [16]. The observed increasing efficacy through time may be attributed to an increasing level of adsorptive capacity of the substrate, which was very low at the beginning. Moreover, the development of the substrate might be a factor responsible for more stable removal efficiency and steady state of the system. Variability and poor performance of FTWs are common particularly depending on the substrate conditions and occurrence of remobilization of nutrients. Van de Moortel [11]

Citation: Sirage Ali A, Piet Lens PN, Hans Van Bruggen JJA (2017) Purifying Municipal Wastewater Using Floating Treatment Wetlands: Free Floating and Emergent Macrophytes. Adv Recycling Waste Manag 2: 138. doi:10.4172/2475-7675.1000138

reported variability of reactive phosphate removal efficiency between -13% and 39 % between seasons.

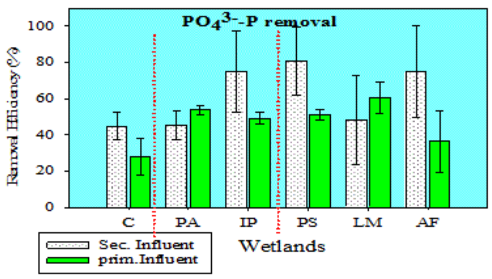

Figure 5: Mean soluble reactive phosphate removal efficacy of the FTWs and the control for secondary and primary influents.

Total phosphorus: Total phosphorus concentration ranged from 1.4 mg/L to 4.3 mg/L in the secondary influent and from 11 to 24.4 mg/L in the primary influent. All of the FTWs performed better than the control and their average efficacy ranged from 43.9%(*P. australis*) to 86% (*P. stratoites*) for secondary influent; and 58.3(*A. filiculoides*) to 81.3% (*I. psuedacorus*) for primary influent (Figure 6), but the variation among the wetlands was not significant (F=1.3, df=5, P=0.27).

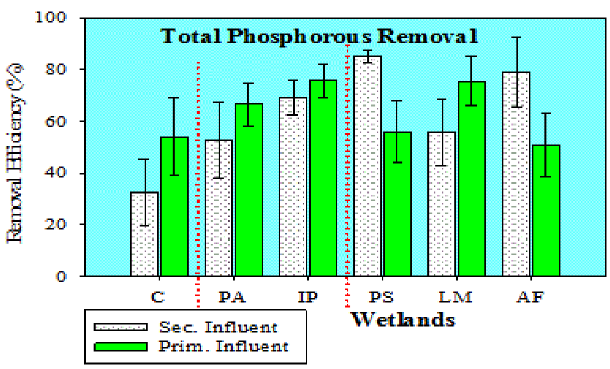

Figure 6: Mean Total phosphorus removal efficacies in the FTWs and control for secondary and primary influents.

Total phosphorus removal efficiency for both types of influents was almost the same as the removal efficiency for soluble reactive phosphate, which suggests the similarity of the removal mechanisms of FTWs for inorganic phosphate and total phosphorus. Total phosphorus removal is mainly dependent upon sorptive physicochemical processes taking place on the substrate. De Stefani [11] tested the performance of FTWs for tertiary urban wastewater treatment by using *T. latifolia*, *I. pseudacorus* and *P. australis* and the system showed total phosphorus removal performance of 13.3%. Hubbard et al. [17] used FTW for swine lagoon wastewater treatment and found total phosphorus removal efficiency of 34-41%. Performance variability in the free-floating FTWs was common between measurements.

Organic carbon removal

BOD removal: BOD in the influent varied from 7.2 to 16.8 mg/L in the secondary influent and 26.6 to 37.3 mg/L in the primary influent. The removal efficiency of the FTWs for the biodegradable organic matter varied between 29.4 and 56.3% for secondary influent whereas for primary influent, it was between 37.7 and 62.3% (Figure 7). The removal efficiencies of almost all of the FTWs were better than the control but there was no statistically significant differences between them and among the FTWs (F=0.95, df=8, P=0.46). Free-floating FTWs seem to perform better than emergent macrophyte FTWs at low and high organic matter load; however, performance variability was also evident for these FTWs particularly in the case of *L. minor* and *A. filiculoides* (Figure 7).

The higher BOD removal in the FTW suggests that the presence of the plants have an added value for enhanced organic biodegradation. The high-performance variability in the free-floating hydrophytes could be due to the influence of the rapid growth rate and dieback.

COD removal: COD varied from 28 to 43 mg/L and from 43 to 60 mg/L in secondary and primary influents respectively. The corresponding removal efficiency varied from 45.6 to 76.8% and 47.2 to 65% for secondary and primary influents respectively (Figure 8). One-way ANOVA demonstrated significant variations between the control and the FTWs (F=4.3, df=8, P<0.05). Moreover, grouping information using Tukey's method after ANOVA also displayed variations in removal efficiency between emergent FTWs and free-floating FTWs.

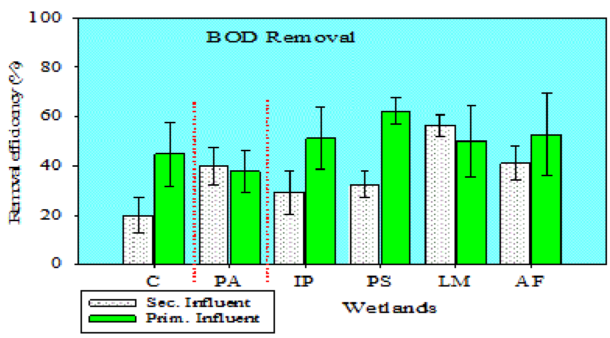

Figure 7: Mean BOD removal efficiency of the FTWs and control for secondary and primary influents.

COD removal in FTWs is suggested to be related with the process of filtration of organic particulates by the roots hanging down to the water column [18] and enhanced chemical processes in the system. Better COD removal efficiency in the free-floating hydrophytes can be explained by the relatively higher rates of potential nitrification occurred associated with these hydrophytes' water column. The performance variability of the free-floating hydrophytes can be resulted from the influence of the rapid biomass turnover rate and this suggests the difficulties of performance prediction on this type of FTWs.

TOC and DOC removal: Most of the non-purgeable organic carbon was found dissolved in the water as DOC and hence, the concentration and removal efficacy of the FTWs was almost similar. Mean FTWs' TOC removal efficiency ranged from 14 to 33% for secondary and 34-50% for primary influents whereas; for DOC, it ranged from 21 to

Citation: Sirage Ali A, Piet Lens PN, Hans Van Bruggen JJA (2017) Purifying Municipal Wastewater Using Floating Treatment Wetlands: Free Floating and Emergent Macrophytes. Adv Recycling Waste Manag 2: 138. doi:10.4172/2475-7675.1000138

26% and 39 to 54% for secondary and primary influents respectively (Figure 9). For both DOC and TOC, their performance under high organic load was almost double of the performance found for low organic loads. For all of the wetlands, the variability in removal efficiency at higher organic load was very low.

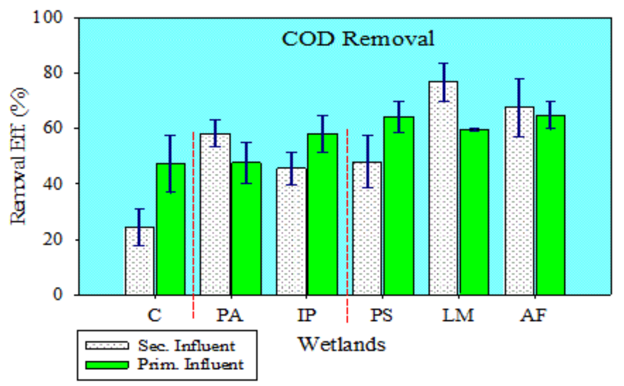

Figure 8: Mean COD removal efficacy of FTWs and control for secondary and primary Influents.

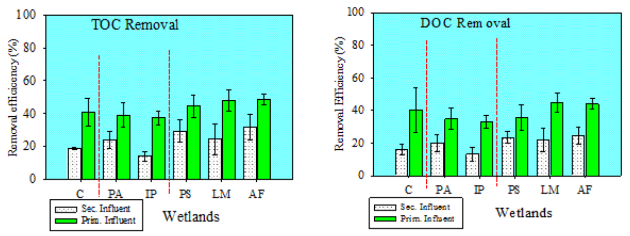

Figure 9: Mean TOC and DOC removal efficacy of the FTWs and control for secondary and primary influents.

The increased efficiency at high organic load is a direct indication of enhanced degradation of organic matter in the system, which could be due to the increasing biological and chemical transformation of organic matter. Since more than ninety percent of the TOC was found in dissolved form, there were no differences in the removal efficiency and hence, the removal mechanism involved could be the same in all of the wetlands.

Removal of DOM fractions: The fluorescence peaks for each effluent from all of the FTW and control together with the wavelength ranges of their maxima and their assignments according to what is reported in literatures [19,20]. In the influent, the typical three peaks were identified, each for humic acid, fulvic acid and protein-like substances. Humic acid, and protein peaks were obtained at Ex_{max}/Em_{max} of 240/430-438 and 270/312-318 nm respectively. Fulvic acid Ex_{max}/Em_{max} intensity peaks were observed at 370/330 and 496/422-424 nm, of which the later peak is not common in many environmental samples.

Based on the intensity reductions from the influent peaks, fulvic acid were most reduced, ranging from 56.2% in the control to 100% in most of the FTWs showing that this fraction of DOM was the most removable component of DOM in FTW systems (Figure 10). Humic acid was the least removed DOM components ranging from 13% in *L. minor* to maximum removal of 44.2% in *A. filicculoides* (Figure 10). The performance of all of the FTWs was better than the control. The removal characteristics of the free fractions of DOM in all of the wetlands were similar.

FEEM analysis showed considerable reduction of low molecular weight fractions (fulvic acid and protein-like) and less reduction of long wave length and high molecular weight components (humic-like) by the FTW. Reports showed that protein-like components, xenobiotics and fulvic acid are most removed components of DOM in conventional wastewater treatment whereas excited longer wave length humic-like fractions are the least degradable throughout the treatment system [21].

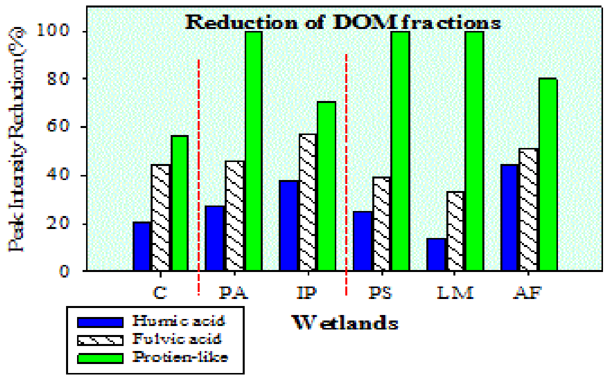

Figure 10: FEEM analysis results of peak intensity reduction for humic acid, fulvic acid and protein-like components of DOM in the FTWs and control.

Conclusion

FTWs displayed better pollutant removal performance for all measured parameters compared to control without macrophytes and suspending rack for both secondary and primary domestic wastewater. Under high organic load, rate of mineralization and nitrification was much higher than denitrification and biological uptake; and this always results in elevated nitrogen transformation in the system.

The presence of vegetation was the major responsible factor to the overall performance of the FTWs with few exceptions such as for TOC and DOC removal that they didn't show differences from the control mesocosm.

Emergent macrophytes (*I. pseudacorus* and *P. asutralis*) function better than free-floating hydrophytes (*P. stratoites*, *A. filiculoides* and *L. minor*) in many aspects. For many pollutants, emergent macrophytes in FTWs showed better performance both at lower and higher influent concentration. FTWs with Emergent macrophytes showed more stable performance than FTWs with free-floating hydrophytes, in which the later were characterized by fast growth rate and unsteady pollutant retention because of their differences in growth rate, life span and susceptibility to environmental changes such as increasing pollutant loads.

References

1. Headley T, Tanner CC, Council AR (2008) Application of Floating Wetlands for Enhanced for Storm water Treatment: A Review. Auckland Regional Council.
2. Knowles P, Dotro G, Nivala J, García J (2011) Clogging in subsurface-flow treatment wetlands: Occurrence and contributing factors. Ecologic Eng 37: 99-112.
3. Scholes L, Revitt DM, Ellis JB (2008) A systematic approach for the comparative assessment of stormwater pollutant removal potentials. J Environ Manag 88: 467-478.
4. Ash R, Truong P (2003) The use of Vetiver grass wetlands for sewerage treatment in Australia. In Proceedings of 3rd International Conference on Vetiver, Guangzhou, China, pp: 132-141.
5. Smith MP, Kalin M (2000) Floating wetland vegetation covers for suspended solids removal. Treatment wetlands for water quality improvement. InProceeding of Quebec 2000 Conference, CH2MHILL, Canada.
6. Todd J, Brown EJ, Wells E (2003) Ecological design applied. Ecologic Eng 20: 421-440.
7. Garbett P (2005) An investigation into the application of floating reed bed and barley straw techniques for the remediation of eutrophic waters. Water and Environ J 19: 174-180.
8. De Stefani G, Tocchetto D, Salvato M, Borin M (2011) Performance of a floating treatment wetland for in-stream water amelioration in NE Italy. Hydrobiologia 674: 157-167.
9. Headley TR, Tanner C (2008) Floating wetlands for storm water treatment: removal of copper, zinc and fine particulates. Technical Report 2008-030, Auckland Regional Council Auckland, NZ, p: 38.
10. Allen WC, Hook PB, Biederman JA, Stein OR (2002) Temperature and wetland plant species effects on wastewater treatment and root zone oxidation. J Environ Quality 31: 1010-1016.
11. Van de Moortel A, Meers E, De Pauw N, Tack F (2010) Effects of Vegetation, Season and Temperature on the Removal of Pollutants in Experimental Floating Treatment Wetlands. Water Air and Soil Pollu 212: 281-297.
12. APHA (2006) Standard methods for the examination of water and wastewater, (22nd edn). American Public Health Association, Washington, DC.
13. Hill DT, Payton JD (2000) Effect of plant fill ratio on water temperature in constructed wetlands. Biores Technol 71: 283-289.
14. Coleman J, Hench K, Garbutt AS, Bissonnette G, Skousen J (2001) Treatment of Domestic Wastewater by Three Plant Species in Constructed Wetlands. Water, Air and Soil Pollu 128: 283-295.
15. Belmont MA, Metcalfe CD (2003) Feasibility of using ornamental plants (Zantedeschia aethiopica) in subsurface flow treatment wetlands to remove nitrogen, chemical oxygen demand and nonylphenolethoxylate surfactants- a laboratory-scale study. Ecological Engineering, pp: 233-247.
16. Spieles DJ, Mitsch WJ (1999) The effects of season and hydrologic and chemical loading on nitrate retention in constructed wetlands: a comparison of low-and high-nutrient riverine systems. Ecologic Eng 14: 77-91.
17. Hubbard RK, Gascho GJ, Newton GL (2004) Use of floating vegetation to remove nutrients from swine lagoon wastewater. Transactions of the ASAE 47: 1963.
18. Revitt DM, Shutes RB, Llewellyn NR, Worrall P (1997) Experimental reedbed systems for the treatment of airport runoff. Water Sci and Technol 36: 385-390.
19. Marhaba TF, Kochar IH (2000) Rapid prediction of disinfection by-product formation potential by fluorescence. Environ Eng and Policy 2: 29-36.
20. Yamashita Y, Tanoue E (2003) Chemical characterization of protein-like fluorophores in DOM in relation to aromatic amino acids. Marine Chem 82: 255-271.
21. Guo W, Xu J, Wang J, Wen Y, Zhuo J, et al. (2010) Characterization of dissolved organic matter in urban sewage using excitation emission matrix fluorescence spectroscopy and parallel factor analysis. J Environ Sci 22: 1728-1734.