Tech. J. River Res. Inst. 14(1): 54-61, 2018 (December), ISSN: 1606-9277

COMPARISON OF POLLUTANT REMOVAL EFFICIENCY BETWEEN SUB-SURFACE FLOW WETLANDS FOR MUNICIPAL WASTEWATER

U. Habiba[1], P. Sarker[1*] and F. R. Rubaba[1]

Abstract

Constructed wetlands have been used for decades mostly for the treatment of domestic or municipal wastewater. It is a treatment system that uses natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality, which is low in energy consumption, requiring minimal maintenance. The overall objective of this study was to assess the performance of two subsurface flow constructed wetland to treat municipal wastewater. The specific objectives were a comparative study of pollutant removal efficiency between horizontal and vertical flow wetland system using stone chips, coal and sawdust as media evaluate the removal performance of pollutants from municipal wastes such as pH, alkalinity, turbidity, TSS, TDS, BOD_5, fecal coliform, $NO^{-2}$and NO^{-3}. The two systems had an identical configuration; each consisted of a subsurface vertical flow (VF) wetland and a horizontal flow (HF) wetland. The wetlands were planted with *Canna indicia* and employed with stone chips, coal and sawdust media. The results were impressive. Vertical flow constructed wetlands are more efficient in reducing pH, turbidity, and E.coli from water than horizontal flow systems. The removal efficiency of total suspended solid varies in the range from 30-40%, BOD_5 ranges from 75-90%. Horizontal flow constructed wetlands are more efficient in removing dissolved solids from water and provide efficient color removal under predominantly anaerobic condition. The results provided a strong evidence to support widespread research and application of the constructed wetland as a low-cost, energy-efficient, wastewater treatment technology in Bangladesh.

Keywords: *coal, constructed wetland, horizontal flow, removal efficiency, sawdust, stone chips, vertical flow*

Introduction

Constructed wetlands are engineered to duplicate the processes occurring in natural wetlands, where the main purpose of the structure is to remove the contaminant or pollutant from the wastewater (Aremu and Ojoawo, 2012). The constructed wetland is an integrated system consisting of water, plants, microorganisms and the environment, which can be manipulated to improve water quality. It has been widely used for treating a variety of wastewater in many sectors because of its multiple values and functions. Constructed wetlands are artificial wastewater treatment system consisting of shallow (usually less than 1 m deep) ponds or channels, which have been planted with aquatic plants, and rely upon natural microbial, biological, physical and chemical processes to treat wastewater (Sandeep *et al.,* 2005). These systems of wastewater treatment offer several potential advantages as compared to the conventional treatment system, this includes; simple construction (can be constructed with local materials), require less skill to operate and maintain, process stability under varying environmental conditions.

As the nation's population continues to grow, development is pushed further into rural areas where septic systems must be used for wastewater treatment. Constructed wetlands for wastewater treatment are an inexpensive and technologically appropriate solution for wastewater treatment in developing countries (El-Bahrawy, 2013). There are two basic types of constructed wetland namely; free water surface flow constructed wetland in which the flow of water is above the sediment surface, and subsurface flow constructed wetland in which the flow of water is primarily below the sediment surface. These systems use wetland plants, soils, and their associated microorganisms to remove contaminants from wastewater (Baskar, 2008). In developed temperate-climate countries, the horizontal sub-surface flow constructed wetlands (HSF-CWs) have been successfully used for the treatment of various types of wastewater for more than four decades (Vymazal, 2010). However, to date, there has been limited information about CWs in developing countries (Zhang *et al.,* 2014). The adoption of

CWs has been surprisingly slow there due to the lack of understanding of CW's potential benefits, actual performance, and appropriate design features (Zhang *et al.,* 2014).

Bangladesh is the ninth most populous country & twelfth most densely populated countries in the

[1] Dept. of Civil Engineering, Ahsanullah University of Science & Technology, Dhaka-1208.
[*]Corresponding Author (Email: pubali777@gmail.com)

world. With the population growth, there is an increasing problem of wastewater management. Currently, according to a UNFPA report, Dhaka is one of the most populated cities in the world and one of the issued concerned in the management of municipal wastewater. An easy, cheap and efficient water purification system is needed to resolve this problem. Constructed wetlands have shown to successfully control organic material, nutrients, and pathogens (Greenway, 2005). It is reported that constructed wetland technology is a viable option that not only reduces nutrients but it performs the function of disinfection, rendering the treated wastewater a resource to irrigate crops, playing arenas, gardens or golf courses. Constructed wetlands are achieving prominence as an active and low-cost alternative for the treatment of wastewater in both the developed and developing world (Mustafa, 2013).

For this assessment, the actual source of the influent water is the municipal wastewater from Babu Bazar canal which is connected to Buriganga River. The Buriganga River is witness to many historic and cultural events of the capital city which thrive on the banks of its water. It stretches only 27 kilometers originating from the Dholeshwary (also known as Shitalakkhya) near Kalatia and meeting Turag at Kamrangirchar, near Hazaribagh. Because of its course, the Buriganga receives all the wastewater from Turag, which flows through industrial Tongi, Savar and Hazaribagh areas and receives it also from households besides industries and vessels. The Buriganga river is afflicted by the noisome problem of pollution. The city of Dhaka discharges about 4,500 tons of solid waste every day and most of it is released into The Buriganga. A recently published report has pointed out that there are over 7,000 industrial units including- dyeing mills, tanneries, rubber and plastic product factories, pesticide factories in the Dhaka metropolitan area. Of these, the dyeing factories and the tanneries are the biggest polluters. Each day about 900 cubic meters of untreated domestic and industrial effluents are discharged into the Buriganga-Turag system. Industries at these areas discharge untreated washing and clinical wastes, used batteries, plastic bottle sand containers, and other discarded plastic materials and burnt oil into the river water. At present, Buriganga is the most polluted river in Bangladesh.

The rationale of this paper is to advance the use of constructed wetland technology for wastewater treatment and reuse in developing countries like Bangladesh. The overall goal of this paper is to assess the performance of a pilot-scale constructed wetland through studying its treatment performance. And the specific objectives are to notify the capacity of removal of the various wastewater parameters from the horizontal subsurface flow and vertical subsurface flow using coal, stone chips, and sawdust media and to compare the removal percentage of various wastewater parameters between horizontal and vertical subsurface flow.

Methodology

The methodological approach of this study consists of the description of the experimental area, equipment and elements.

Source area and water

Babu Bazar Khal which comes from Buriganga River was the source of municipal wastewater. Sample water was collected from Babubazar Khal at Old Dhaka in 40 sunlight insulation barrel drum which contains 30 liters of municipal wastewater. It was collected in every Saturday morning and the drums were filled up by labors. It was transported from collection point to Bangladesh University of Engineering and Technology.

Dosing system

The outlet of the tank was being opened for 1.5-2 minutes to check the whole system and workability of the filtering process. Each tank received a container of wastewater. This process was continuously repeated 3 times a week.

Description of tanks

Two rectangular steel tanks were used to replicate the lake on a large scale. A media is used for the growth of the microbial community. It was constructed in such a way, so as to facilitate the growth of roots underwater.

Horizontal tank

The HF had a rectangular shape tank. This tank is made with high strength steel materials. The dimension consist depth of 3'5", a width of 1'8", a length of 3'4" shown in fig1. The outlet was located at the 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. In outlet, the water came out and passed into the farther stage of the hybrid system. Another outlet pipe is used to remove excess water from the tank and to provide a certain level of water for the research.

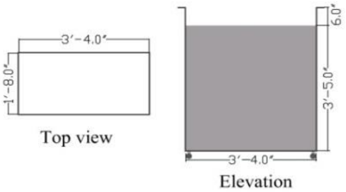

Fig. 1. The dimension of horizontal sub-surface flow tank

Vertical tank

The HF had rectangular shape also made with high strength steel materials. The dimension consist depth of 3'11", a width of 1'8", a length of 1'8" shown in fig 2. The outlet was located at the 1m from the bottom of the reactor. Two-inch valve is used as the outlet of the reactor. In outlet, the water came out and passed into the farther stage of the hybrid system.

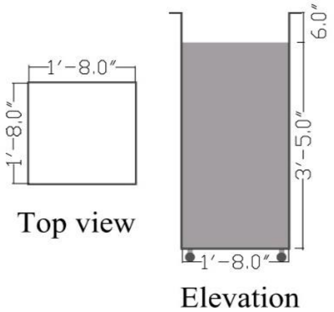

Fig. 2. The dimension of vertical subsurface flow tank

Preparation of coal media bed

Two constructed wetlands consist of coal as the media. It is available almost everywhere. It is an organic material which is used in two tanks. At first, we took a sufficient amount of coal and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Next, we crushed the coal into small pieces of 9.5mm to 2.75mm. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put all the coal into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the coal media. After all this, we filled the tank with our collected municipal wastewater from Babu Bazar canal up to a certain level. Canna indica is collected from the local market. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Preparation of stone-chips media bed

Two constructed wetland is consists of Stone chips as the media. Crushed stone is one of the most accessible natural resources, and is a major basic raw material used by construction, agriculture, and other industries. It is an organic material which is used in two tanks. At first, we took a sufficient amount of stone chips and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Next, we crushed them into small pieces. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put those crushed stone chips into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the media. After all this the tank was filled with collected municipal wastewater from Babu Bazar canal up to a certain level. In this project, stone chips are collected from a construction site of Mahakali. It was collected from a river bank in Sylhet. At least 20 kg of stones are used in each container of both vertical and horizontal flow. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Preparation of sawdust media bed

Two constructed wetland is consists of sawdust as the media. At first, we took a sufficient amount of sawdust and washed it with clean water to remove other organic and inorganic substances, harmful elements, oils, and impurities. Then a thin shit of wooden board is placed under the tank below the outlet. After that, we put all the sawdust into the tank and filled it, for horizontal tank we filled 2'11" and for vertical tank 3'2". The top of the tank left open and planted Canna Indica plant above the media. After all this, we filled the tank with our collected municipal wastewater from Babu Bazar canal up to a certain level. Canna indica is collected from the local market. This constructed wetland technology is based upon the treatment power of three main mechanisms: microorganism, optimizing the system, the physical and chemical properties of the media and finally the plants themselves.

Wetland vegetation

Constructed wetlands can be planted with a number of adapted, emergent wetland plant species. Wetlands created as part of compensatory mitigation or for wildlife habitat typically include a large number of planted species. Commonly used plants are Phalarisarundinacea (reed canary grass), Typha spp. (cattails), Scirpusspp, (bulrushes) and Glyceria maxima (sweet mannagrass) (Chadde, 2011). However, the most frequently used plant species worldwide is Phragmites australis (common reed) (Wallace, 2009). Canna Indica is the plant which was used for our experiment. These plants are used because they help transform wastewater constituents so that quality standards for their discharges are met. Macrophytes play an important role in the treatment of wastewater. The biomass of the plants shows the pathway of the wastewater enhancing sedimentation of solids. There is also uptake of some pollutants in wastewater as nutrients by these plants. The extensive root system provides a huge surface area to act as a filter for suspended solids and debris. The root zone also provides an extensive surface area for attached growth of microorganisms, which in turns are involved in the transformation of pollutants. Oxygen diffused through the root zone membranes into the surrounding water environment creates an oxygen-rich area around the root zone of the plants that drive many chemical transformations and results in the degradation of the pollutants. Diffusions of oxygen through the root zone also helps to maintain a partially aerobic condition in the water columns

Operation and maintenance

After the preparation for bed for the constructed wetland, the actual performance of the bed was started. The raw wastewater is collected from a drain beside BUET and put them into the wastewater container. The raw wastewater characteristics were determined using procedure mentioned in standard methods. After the analysis, wastewater was allowed to pass through the reactor, as the time progress the percolation of wastewater start into the reactor. Percolated water from the bed passed into the next stage of the hybrid system and finally collected into the effluent container. The dosing frequency of wastewater is two times a day with four hours' interval. The purified wastewater characteristics also studied by using standard methods.

Results and Discussion

During the three weeks, monitoring period samples were collected from the constructed wetland system and analyzed for each of the various physical, chemical, and microbiological parameters. Table 1, Table 2 and Table 3 represents the inlet and outlet concentrations of each monitored parameter of coal, stone chips, and sawdust media.

Analysis of pH

The pH values of effluent in coal media, from 6.7 to 7.1 meets up with WHO standard from drinking water which is between the ranges of 6.5-8.5 and for stone chips media the values, from 6.5-8 are also in WHO standard for both horizontal and vertical flow. It also meets up with the irrigation standard. If pH is less than 6.5 in crop yield, there would be increased foliar damage and may corrode irrigation equipment. But for sawdust media, though the vertical flow pH values were within WHO standard for horizontal flow, it exceeded the WHO range. It was reported that vegetated free-water surface wetlands produce effluent with pH just above neutrality (Wallace, 2009).

Table 1. Summary of the test scenarios of coal media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw	7.1	8	7.3
			Horizontal	7.1	7	6.7
			Vertical	6.9	7.1	6.5
Color	Pt-co	15	Raw	40	10	60
			Horizontal	25	30	30
			Vertical	20	28	35
Turbidity	NTU	10	Raw	0.91	1.05	8.9
			Horizontal	2.36	4.58	10.25
			Vertical	1.6	3.32	9.6
Alkalinity	mgL^{-1}		Raw	364	236	260
			Horizontal	236	212	204
			Vertical	208	212	208
TSS	mgL^{-1}	10	Raw	.001	.002	.001
			Horizontal	.002	.003	.003
			Vertical	.002	.001	.001
TDS	mgL^{-1}	1000	Raw	.032	.033	.028
			Horizontal	.027	.023	.035
			Vertical	.021	.030	.024
BOD_5	mgL^{-1}	0.2	Raw	16	14	19
			Horizontal	14	10	12
			Vertical	6	7	8
Fecal coliform (20ml)		0 CFU (N/100mL)	Raw	30	26	37
			Horizontal	Uncountable	Uncountable	14
			Vertical	11	7	4
Nitrate (NO^{-3})	mgL^{-1}	10	Raw	5.9	7.5	9
			Horizontal	1	3.2	2.4
			Vertical	3.6	2.9	2
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw	11	9	13
			Horizontal	13	6	3
			Vertical	4	1.7	2.5

Table 2. Summary of the test scenarios of stone chips media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw	7.1	8	7.3
			Horizontal	6.9	6.5	6.8
			vertical	7.2	7.4	6.7
Color	Pt-co	15	Raw	36	10	60
			Horizontal	47	70	20
			vertical	26	20	20
Turbidity	NTU	10	Raw	0.91	1.05	8.9
			Horizontal	25.36	20.87	19.23
			vertical	0.29	0	.36
Alkalinity	mgL^{-1}	- -	Raw	364	236	260
			Horizontal	240	280	215
			vertical	216	320	210
TSS	mgL^{-1}	10	Raw	.001	.002	.001
			Horizontal	.001	.003	.002
			vertical	.002	.001	.001
TDS	mgL^{-1}	1000	Raw	.033	.035	.029
			Horizontal	.026	.022	.020
			vertical	.026	.037	.022

BOD_5	mgL^{-1}	0.2	Raw Horizontal vertical	16 2 1	14 3 1	19 2 2
Fecal coliform (20ml)		0 CFU	Raw Horizontal vertical	30 38 16	26 50 11	37 59 19
Nitrate (NO^{-3})	mgL^{-1}	10	Raw Horizontal vertical	5.9 1.8 5.5	7.5 2.1 3.7	9 1.3 2.6
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw Horizontal vertical	11 1.8 6	9 1.2 5	13 2.7 8.4

Table 3. Summary of the test scenarios of sawdust media and key results

Parameter	Unit	Bangladesh standard	Sample type	Week 1	Week 2	Week 3
pH		-	Raw Horizontal Vertical	7.1 9.3 7.3	8 9.7 7.5	7.3 9.6 7.6
Color	Pt-co	15	Raw Horizontal Vertical	36 21 29	10 30 33	60 35 35
Turbidity	NTU	10	Raw Horizontal Vertical	0.91 0.08 1.98	1.05 1.62 5.32	8.9 2.10 0.94
Alkalinity	mgL^{-1}		Raw Horizontal Vertical	364 128 380	236 120 244	260 126 460
TSS	mgL^{-1}	10	Raw Horizontal Vertical	.001 .001 .002	.002 .003 .001	.001 .002 .001
TDS	mgL^{-1}	1000	Raw Horizontal Vertical	.033 .025 .041	.035 .020 .038	.029 .021 .033
BOD_5	mgL^{-1}	0.2	Raw Horizontal Vertical	16 3 2	14 2 2	19 3 2
Fecal coliform (20ml)		0 CFU	Raw Horizontal Vertical	30 Uncountable Uncountable	26 13 4	37 6 4
Nitrate (NO^{-3})	mgL^{-1}	10	Raw Horizontal Vertical	5.9 1.2 4.3	7.5 2.8 5.1	9 1.5 3.4
Nitrite (NO^{-2})	mgL^{-1}	<1	Raw Horizontal Vertical	11 2 8	9 2.7 7	13 2.5 8.1

Analysis of color

Spatially within each treatment, the performance of both coal media and sawdust media was not up to the mark as demonstrated in table1 and 3, the highest removal efficiency was 50% for vertical flow. In 2nd week, coal media failed to decrease color concentration but increased the concentration. For stone chips, the highest removal percentage was 66% for horizontal flow. The effluent values of this parameter were higher than Bangladesh standard which is 15 Pt-co.

Analysis of turbidity

For coal media, the turbidity value has been seen increasing throughout the monitoring period. For stone chips, the turbidity effluent value was higher than the influent value in case of horizontal flow. But in vertical flow, the removal percentage was very impressive. Removal percentage range for the stone chips vertical flow was between 68-100%. For sawdust media, the removal efficiency was insignificant except 3rd week where horizontal flow had up to 76% and vertical flow had up to 89% maximum efficiency rate.

Analysis of alkalinity

Alkalinity removal rate was around 35-43% for coal media for the observation period. Highest removal percentage was 42.23% for vertical flow as a reference to table 1. For stone chips, the removal range was between 35-41%, where the highest removal rate was 40.65% for vertical flow. The removal rate was good in saw dust media, ranged between 49-65%, having the maximum removal rate of 64.83% as demonstrated in table 3.

Analysis of TDS and TSS

TSS removal rate was not good in coal media as for table1, removal percentage rate was between 0-50% for both horizontal and vertical flow. The effluent TDS values were consistently low, degrading the removal rate between 9-35%, having the highest value of only 34.38%. The TSS effluent value of stone chips media showed no greater difference than coal media effluent value. For TDS, the removal rate was not satisfactory, as the removal percentage range was between 21-38%, the highest removal rate was 37.14%. For saw dust, the TSS removal percentage is below average as the range was 21-49% with highest removal percentage of 85% for horizontal flow. As for TDS effluent values, they were not significantly higher than TDS influent values.

Analysis of BOD_5

The reduction in BOD_5 concentrations over the monitoring period was reasonable, 62.5% for vertical flow of coal media, while horizontal flow was not much productive in reducing BOD_5concentrations. For stone chips, BOD_5 removal percentage was eminent as the range was between 89-93% with the highest percentage rate of 92.85% for vertical flow. For sawdust, degradation of BOD_5 ranged between 84-90% where the highest removal efficiency was found 89.47% for vertical flow. Performance of these constructed wetland showed that the system had a good buffer capacity and was able to tolerate organic shock loads.

Analysis of fecal coliform

Fecal coliform for coal media had the highest value of removal percentage of 89.78% for vertical flow but for horizontal flow, the removal percentage was dissatisfactory. Stone chips were not that successful in removing fecal coliform as compared to the other parameter. The highest percentage was 57.69% for vertical flow. For sawdust the values were unexpectedly good as the highest percentage was 89.18% for vertical flow.

Analysis of nitrite (NO^{3-}) and nitrate (NO^{-2})

Coal media showed better performance in removing NO^{3-} because removal percentage ranged from 38-84% with the maximum percentage of 83.05%. NO^{2-} removal percentage was also good, had the highest rate of 81.11% for a vertical flow having a range of 18-82%. For stone chips media NO^{3-} removal range was from 8-86% with a peak rate of 85.55%. NO^{2-} removal range was from 35-87%, had the highest rate of 86.67% for horizontal flow. For sawdust media, NO^{3-} had a removal percentage rate of 27-84% and the maximum value was 80.77% for horizontal flow.

Conclusion

The monitoring of horizontal flow constructed wetland shows that the general performance of the system was good and it successfully reduced contaminants system so, constructed wetlands. clearly can be an effective treatment facility for polluted water. The initial result of this research work, however, found that the ability of a wetlands system to treat such polluted water is highly influenced by the media and the flow pattern used in it. After observing the tanks performance, it can be highlighted that stone chips media and coal media performs exceedingly well in vertical flow wetland when saw dust media is highly appreciable in horizontal flow wetland, especially stone chips media with vertical flow showed a prominence performance for maximum water quality parameters. The results indicate that if constructed wetlands are appropriately designed and operated, they could be used for secondary and tertiary wastewater treatment under local conditions, successfully. The main advantage of these systems is they do not require any power as well as addition of chemicals. Hence constructed wetlands can be used in the treatment train to upgrade the existing malfunctioning wastewater treatment plants, especially in developing countries. The treated wastewater from these wetlands can be used for landscape irrigation and also for other beneficial uses. The goal of this study was to explore the potential public benefits and quality improvement of wastewater by the constructed wetland. The result provides an easy and low-cost way of treating wastewater from environmentally friendly elements and a certain process that is reliable to all kind of people.

Acknowledgment

The authors acknowledge Ahsanullah University of Science and Technology for supporting this research study. The authors also wish to express their special gratitude to supervisor Mrs. Rumana Afrin for her guidance and valuable time.

References

Aremu, S. A. and Ojoawo, S. O. (2012). Water hyacinth (eichhornia crassipes) culture in sewage: nutrient removal and potential applications of bye-products. *Trans. J. Sci. and Tech. Edit.* 2(7): 103-114.

Baskar, G., Deeptha, V. T., Rahman, A. A. (2008). Root zone technology for campus wastewater treatment. *J. Env. Res. and Dev.* 3(3): 695-705.

Chadde, S. W. (2011). *Wetland Plants of Wisconsin: A Complete Guide to the Wetland and Aquatic Plants.*

El-Bahrawy, M. E. (2013). Extensive Post Treatment Using Constructed Wetland. *Lif. Sci. Jour.* 10(2): 560-568.

El-Khateeb, M. (2003). Extensive Post Treatment Using Constructed Wetland. *Lif. Sci. Jour.* 10 (2):

Greenway, M. (2005). The role of constructed wetlands in secondary effluent treatment and water reuse in subtropical and arid Australia. *Ecol. Engg.* 25(1): 501-509.

Jayakumar, K. V. (2003). A Cost-Effective Environmental Friendly Treatment of Municipal Wastewater Using Constructed Wetlands for Developing Countries.

Mustafa, A. (2013). Constructed Wetland for Wastewater Treatment and Reuse: A Case Study of Developing Country. *Intl. J. of Env. Sci. and Dev.* 4(1): 20-24.

Tayade, S. T., Ojha, A. R., Kumar, R., Sing, R. N. (2005). *Feasibility study of constructed wetland for treatment of municipal wastewater*, Mumbai: National Environmental Engineering Research Institute (NEERI).

Vymazal, J. (2010). Constructed wetlands for wastewater treatment: Five decades of experience. *Env. Sci. & Tech.* 45: 61-65.

Kadlec, R. H. and Wallace, S. (2009). *Treatment Wetlands.* CRC press, Taylor & Francis Group, Boca Raton, London, New York.

Zhang, D. Q., Jinadasa, K. B. S. N., Gersberg, R. M., Liu, Y., Ng, W.J., Tan, S. K. (2014). Application of constructed wetlands for wastewater treatment in developing countries—A review of recent developments (2000–2013). *Ecol. Engg.*141: 116–131.