An approach for polishing drainage water using microcosm constructed wetland units

Ahmed A. Rashed and Hussein A.A El Gammal

National Water Research Center, P. O. Box 74, Cairo, Egypt
E-mail: Ahmedrashed2002@hotmail.com

Abstract: Egypt is among the most global countries which are facing severe escalating water shortage problems in the coming decades. The idea of using constructed wetlands for the treatment and improving of wastewater emerged in the second half of the last century. The main objectives of this study are; to compare the performance of floating treatment wetlands (FTW) with both plastic and gravel bed subsurface flow (SSF) CWs, to make a configuration of using shredded Polyethylene plastic water bottles as a SSF CW substrate, and to investigate the capabilities of using small scale low costs treatment wetlands in drainage water treatment as an unconventional irrigation water resource. To achieve these objectives, three microcosm constructed wetland cells made from one-m^3 recycled plastic tanks were investigated in its early stage operation to treat agriculture drainage water as a low cost unconventional irrigation water source. Shredded Polyethylene Terephthalate (PETE) water bottles, natural gravel and foam floating reeds mats were used to produce 0.5 m^3/day and 1.0 m^3 /day of treated water. The three cells managed to treat the drainage water according to the Egyptian standards of discharging drainage water at fresh water courses. The results showed that the treatment efficiency of PETE bed cell obtained the best removal performance followed by the gravel bed cell then the floating bed except for ammonia where floating beds acted better than the others. The one-day treatment detention time batch flow operation had nearly twice the removal efficiency of the half-day batch flow. These microcosms may offer a low cost clean irrigation water source for small landowners. It is recommended to apply more investigations to examine the operation, maintenance and economic visibility of such microcosms in a long run scale.

[Ahmed A. Rashed and Hussein A.A El Gammal. **An approach for polishing drainage water using microcosm constructed wetland units.** *Nat Sci* 2018;16(3):90-97]. ISSN 1545-0740 (print); ISSN 2375-7167 (online). http://www.sciencepub.net/nature. 10. doi:10.7537/marsnsj160318.10.

Keywords: Microcosm constructed wetland, Floating Treatment Wetland, Drainage Water, Lake Manzala, Shredded water bottles.

1. Introduction

Degradation of water resources has become one of the most pressing global concerns currently facing manhood and the environment. Egypt is among the global countries which are facing severe escalating water shortage problems in the coming decades. Lack of sanitation services mainly in rural areas and parts of the urban areas formed another stress on the available agriculture drainage water preventing its large scale reuse in crops production due to receiving loads of untreated sewage. The available irrigation water in the fringes of Lake Manzala, Northeastern Nile Delta, Egypt is polluted saline drainage water. The owners of such lands are poor fishermen growing some cattle and poultry to safe their food needs. They are buying almost all their food and animal fodder from markets since such deteriorated lands are currently suitable only for fish farming. Networked clean drinking water and sanitary services are absence over there and instead polluted potable water are bought from water tankers by 10 times the national fare. Therefore, production of cash crops will help them to earn more income and satisfy their requirements (Rashed, 2016).

Conventional sewage water treatment systems are very expensive in construction, operation and maintenance and does not work well on a small scale (EPA, 1993). Oppositely, constructed wetlands (CWs) can minimize these high expenses with better performance on both big and small scale specially for small communities in urban and rural areas remote from public sewage systems (Vymazal, and Kröpfelová, 2008). In the last decades, accumulating researches have shown that wetlands may improve water quality at lower capital costs, operation and maintenance expenses compared to other water treatment methods (Ko et al. 2012). Via high microbiological productivity, supported by sunlight, wind and soil, wetlands can transform a diversity of pollutants into less harmful by-products or life-supporting nutrients. Nowadays, CWs are used as a processing technology in many countries for the treatment of municipal wastewater, industrial wastewater, landfill leachates, etc. Due to their simplicity and low operational cost, proving to be more prevalent in wastewater treatment all over the world.

In subsurface flow, (SSF) CWs, the water surface is kept below the surface of the substrate media, which may support different types of emergent plants. The SSF CW type may be further divided into vertical and horizontal flow systems (Kadlec and Wallace 2009). Vertical flow, (VF) CWs consist of sand or gravel beds with planted emergent macrophytes. The wastewater is distributed on the surface of the bed and it percolates through the porous media down to the outlet zone usually placed on the bottom of the bed. Less-degradable pollutants require a combination of anaerobic and aerobic processes for biodegradation (Yamagiwa and Ong, 2007). In Egypt, 2*1-m3 microcosm gravel reeds bed CW cells (VF and HSSF) were implemented to polish irrigation water of El-Salaam Canal at eastern Nile Delta for vegetables production at an private farm investor (Ghada et al., 2004).

Using different substrates in CWs rather than sand and gravel is ve ry rare. Shredded tires as a medium for HSSF CWs for treating domestic wastewater were investigated by Collaço and Roston (2006) finding a potential use of tires chips to substitute the conventional media (gravel). The destination of used drinking water bottles has been defined as a great environmental problem, as it is not degradable, and thus cannot be disposed in landfills and end up accumulating in rivers and public designations or burned releasing contaminated gases into the atmosphere. According to an essay at the Guardian; (Laville and Taylor, 2017); annual consumption of plastic bottles is set to top half a trillion by 2021, far outstripping recycling efforts and jeopardizing oceans, coastlines and other environments. A million plastic bottles are bought around the world every minute and the number will jump 20% by 2021, creating an environmental crisis some campaigners predict will be as serious as climate change.

Health studies on Polyethylene Terephthalate (PETE) drinking water bottles, which are labeled Number 1 on plastics recycling standards, have found levels of antimony leaching from bottles that have been placed in heat for long times but it does not contain Phthalates (Westerhoff et al., 2008). As PETE plastic is only intended for one-time use, it should not be home reused because cleaning detergents and high temperatures can cause chemicals to leach out of the bottles.

Cordesius and Hedström (2009) investigated the use of two types of bed media (gravel and plastic pieces) on treating domestic wastewater. Their analyses showed a little increase in treatment efficiency for plastic pieces (larger surface area) than gravel media.

Headley and Tanner, (2008) stated that Floating Treatment Wetlands (FTWs) are an innovative variant of the well-known CW and pond technologies that offer great potential for treatment of urban storm waters. FTWs are a hybrid between a pond and a wetland; they behave hydraulically similar to a storm water detention pond, as well as mimicking treatment processes of a treatment wetland (David, et al. 2013). The rooted, emergent macrophytes like in surface and SSF wetlands are growing on a mat floating on the surface of the water rather than rooted in the sediments. FTW can tolerate the fluctuations of water depth as in storm water systems, preventing risks of inundating its plants. Roots of FTW plants are always in the water, and the plants can continuously take up nutrients from the water. Much of the nutrient assimilating strength of FTWs comes from the interaction between the plants and the microbes that live on and among the plants and mats, giving much more surface area for processes such as nitrification, denitrification and phosphorus adsorption to take place (Tanner and Headley 2011, Wang and Sample 2014).

An outdoor experiment where three 5 m^3 FTWs setup for a one-year period using water from three different local rivers gaining high removal rates in river storm water for Nitrogen and Phosphorus compounds and the different levels of nutrient concentrations did affect the plants' growth recommending using only one plant species (Islam, 2011). Sleeth (2014) reported that FTWs have developed as a novel method of reducing the negative impacts of these nutrient inputs by using artificial rafts to float emergent plants on the surface of water bodies to assimilate excess nutrients. Canna and iris plants were found to significantly overtake arrowhead in terms of biomass gains and the plants size had great potential in the ability of FTWs to limit algal development.

Lake Manzala Engineered Wetland Project (LMEWP) is one of the most pioneering CWs in Egypt and the Middle East. On more than 100 hectares, a mega research station was conducted at the fringes of Lake Manzala, (LM) is containing a 25000 m^3/ day free water surface CW, a reciprocating gravel bed wetland and several hybrid wetland microcosms. These microcosms investigated how to apply CW in different scales, pollutants sources and footprints. Moreover, agriculture, aquaculture and fish farms are established to demonstrate the recycling of treated water via low cost CW technology for good quality food production and to reduce the pollutant loads entering the LM. Several CW projects were conducted in Egypt depending on the gained experiences such as polishing of El-Salaam Canal water and Edfina and Al-Bahow drains in-stream treatment projects (Ghada et al. 2004 and Rashed and Abdel Rasheed, 2008). The LMEWP belongs to and operates by the National Water Research Center, (NWRC), Egypt (Rashed, 2016). This study is one of the LMEWP research facilities and its objectives are; (i) to compare the performance of FTW with both plastic and gravel bed

SSF CWs (ii) to make a configuration of using shredded plastic water bottles as a SSF CW substrate, and (iii) to investigate the capabilities of using small scale treatment wetlands in drainage water treatment as unconventional irrigation water resource.

2. Materials and Methods

Three one-m^3 recycled High Density Polyethylene (HDPE) tanks were placed at LM fringes, North East Nile delta, Egypt (31º 09' 50'' N, and 32º 11' 50'' E) adjacent to Bahr Baqar drain out fall. These tanks were originally industrial standard tanks suitable for a multitude of liquid storage uses with excellent stability for stacking and stiffened with an outer metallic frame that supports the weight and keeps the tank in shape. Each tank has a 0.5 HP feeding pump to lift the drain water (Figure 1). The 1st tank (A) is provided with 0.5-m layer of well graded gravel. The 2nd tank (B) provided with 0.5-m Shredded Polyethylene Terephthalate (PETE) water bottles of (Number 1 type) chips top fixed with plastic anchors to prevent its floating. The 3rd tank (C) provided with a foam floating board 0.90 L*0.90 W*0.05 H m with 25*0.05 m diameter holes. The board size is easy for freely moving up and down in the tank during the batch filling and the gradual water empting cycle. Twenty-five reed plants (*Phragmites Australis*) with healthy long rhizomes were transplanted at each tank media. In the pre-treatment stage, reeds were irrigated for six months to grow its roots and rhizomes. Each tank had an outlet equipped with water gauge to adjust the effluent discharge.

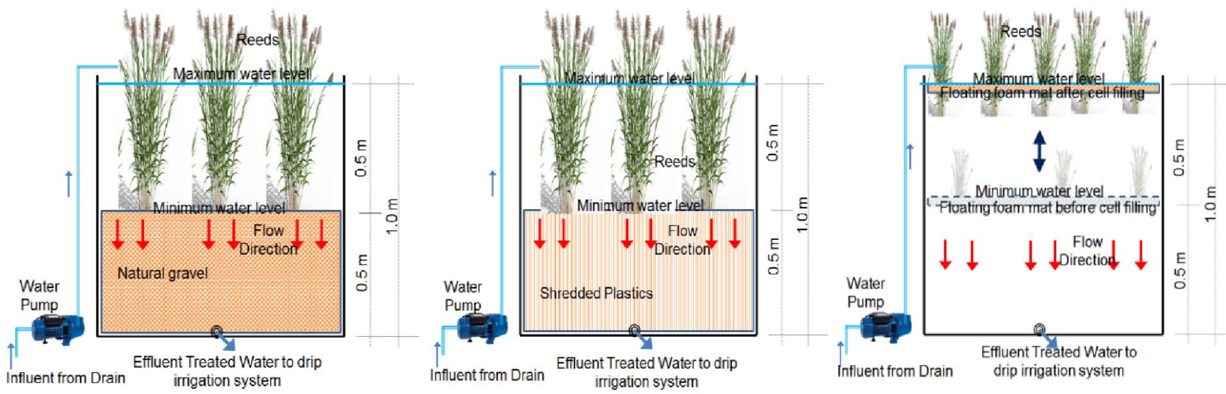


Figure (1) Sketches of the 3 microcosm tanks with natural gravel (A), shredded PETE (B) and floating foam mat (C)

The influent water is the agriculture drainage water of Bahr Baqar drain that receives drainage of newly reclaimed lands irrigated with a mixture of fresh and drainage water and loaded with portions of untreated municipal and industrial effluents. Water was pumped from the drain directly to fill the tanks then leaving the water draining from the outlets to reach the bed top layer at 0.5 m depth. The FTW full tank was also adopted to move down gradually and to stop at the same 0.5-m water depth. Tanks operation was adjusted at two flow rates, the 1st flow rate was 0.5 m^3 /day in one filling batch every 6:00 AM during August-September 2017, while in the 2nd flow rate two batches of 0.5 m^3/ day were applied as the filling at 6:00 AM and 6:00 PM daily during October-November 2017. The effluent from the two operation rates were adopted via the outlet gauge on equal effluent discharges to unify the treatment detention time at one and half day for the two operation rates respectively. The effluent water is being used in irrigating a research vegetables farm via drip emitters.

Treated water samples were collected after one month of the full microcosms operation considering this month as a pre-stability stage. Water samples were collected manually in 500 ml sterile bottles from each tank inlet and outlet at 12:00 PM. Water samples were stored in ice boxes, sent to laboratory and analyzed for Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Nitrate Nitrogen (NO_3-N), Ortho-Phosphate (PO_4), Total Coliform (TC) and Fecal Coliform (FC) as well as four heavy metals ((Iron (Fe), Cubber (Cu), Manganese (Mn), and Lead (Pb)). The influent and effluent pollutants concentrations were analyzed according to Standard Methods (APHA, 2012). The removal efficiency (RE) of the treatment cells was calculated from the pollutant influent concentration C_i and the pollutant effluent concentration C_o according to the following equations (Kadlec and Wallace, 2009):

$$RE\% = \left(\frac{(C_i - C_o)}{C_i}\right) * 100$$

Statistical Analysis

One-way analysis of variance (ANOVA) was applied using Minitab 17 statistical software (2010) to show the difference among the three microcosm constructed wetland cells treatment. One-way analysis of variance (ANOVA). It is a statistical procedure that ensures difference testing between several arithmetic means. In this study, one way ANOVA applied to show the difference among the three microcosms treatment method.

3. Results and Discussions

The three microcosms were operated for six months after the other initially six months' setup/stability period to enhance rooted reeds and to develop the bacterial biofilm layers covering substrates and reeds rhizomes at both gravel, plastic and floating foam board. The early stage operation performance of the three microcosms in treating drain water pollutants during the two batch loads are presented in Figure (2) and the averages of the two operation cycles are summarized in Table (1).

Detention time and microcosms treatment efficiency

The three microcosms were operated at two flow rates/detention times (two cycles); 0.5 m^3/day (1^{st} cycle) and 2* 0.5 m^3/day (2^{nd} cycle) as batch loads (Table1). In other words, two detention times; one-day and half-day were applied. The one-day detention time selection was chosen from an economic point of view in order to produce 0.5 m3/ day of treated water in one filling batch as a suitable daily practice for small land owners to supply drip irrigation system for about half acre. Generally, the one-day treatment cycle had a better treatment performance than the half -day cycle. The TSS RE range was 86-90% in the one-day cycle and 75-86% in the half-day cycle. The BOD RE range was 61-88% in the one-day cycle and 46-70% in the half-day cycle.

The same performance was recorded for all the other chemical pollutants except for COD. In both cycles, the COD RE ranges were nearly similar as it was 47-65% in the 1^{st} cycle and 49-67% in the 2^{nd} cycle even at 16% COD higher influent concentration in the 2^{nd} cycle (78.4 mg/l) than that of the 1^{st} cycle (67.0 mg/l). The treatment of TC and FC was very similar at both 2 cycles due to the very efficient treatment performance (about 3 logs) where the RE ratios were higher than 99.8%. The RE ratios of the four measured heavy metals were almost twice in the 1^{st} cycle comparing with the 2^{nd} cycle. This may be due to the high influent particulate contents of heavy metals which could be filtered at plastic and gravel beds pores and suspended at the FTW cell bottom. The three microcosms give quiet satisfactory results after six months of early stable stage of operation compared to literature. Sekiranda and Kiwanuka, (1998) reported that FWT removal of 33-68% COD, 66-95% SS, and 24-61% TP, but variable TN removal. It was noted that the water beneath the floating wetland was anaerobic, which is likely to be limiting nitrogen removal in particular. Most of the commercially available floating wetland systems incorporate mechanical or fine-bubble aeration systems to enhance aerobic treatment processes.

Triantafyllos et al., (2017) examined four horizontal flow CWs with different substrate including HDPE to treat wastes of a cheese factory. After a two-year operation, pollutant removal rates were approximately 80%, 75% and 90% for COD, ammonium and ortho-phosphate, respectively, while temperature and detention time had no significant effect on pollutant removal.

Treatment through the rooted beds and the FTW

The three CW microcosms were studied to compare the performance evaluation of polishing agriculture drainage water aiming safely use the effluent water for vegetables and crop production. For example, TSS effluent results were stable at the three cells even with the big variation of the TSS in the drain water (102-238 mg/l) (Figure 2). TSS effluent ranges were (12-22), (14-27) and (16-42) mg/l for PETE bed, gravel bed, and FTW respectively. Similarly, the TC bacteria effluent ranges were (14-68), (8-38) and (0-89) MPN/100 ml, for PETE bed, gravel bed, and FTW in turn corresponding to (26000-41000) MPN/100 ml TC influent rage. respectively, the PETE bed showed the best drainage water treatment followed by the gravel bed, then the FTW. This was existed for all pollutants except for the NH_4, where the FTW performed better treatment than the PETE beds followed by the gravel bed. This is opposite to some published works such as Sekiranda and Kiwanuka (1998) who stated the NH_4 increase under FTW beds. The reason was the absence of anaerobic condition that usually associated with FTW due to oxygen lack below the floating mats. Microcosm floating board was dynamic and was continuously moving up and down with the water batching cycles which enrich the beneath water oxygen content. This aerobic state transform NH_4 into other oxygenated nitrogen compounds. Sekiranda and Kiwanuka (1998) conducted a microcosm study comparing FTW with gravel-rooted bed CW. They found very little difference between the gravel-rooted and floating microcosms in terms of nitrogen removal, with both systems achieving greater than 60% reduction in the concentration of NH_4-N.

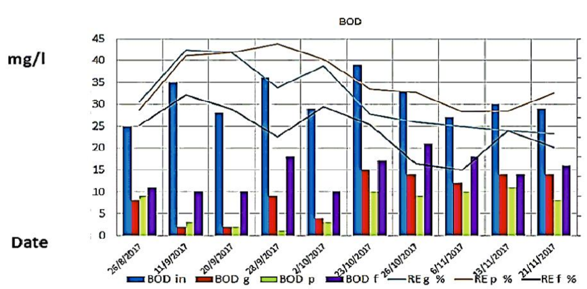
Table (1) Average pollutant concentrations of the three microcosms at two detention times (RE% in brackets)

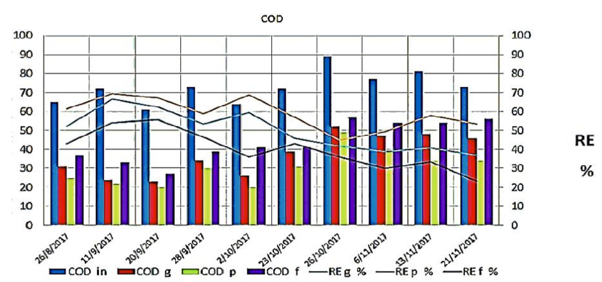
Parameter (Units)	Influent from Bahr Baqar Drain	one-day detention time (1st cycle)			Influent from Bahr Baqar Drain	half-day detention time (2nd cycle)			Standards of dumping drainage water at fresh water courses*
		Gravel bed	PETE bed	Floating bed		Gravel bed	PETE bed	Floating bed	
TSS (mg/l)	165.00	20.4 (88)	16 (90)	23.6 (86)	140.80	24.4 (83)	20.25 (86)	35.2 (75)	
BOD (mg/l)	30.60	5 (84)	3.6 (88)	11.8 (61)	31.60	13.8 (56)	9.50 (70)	17.2 (46)	< 30
COD (mg/l)	67.00	27.6 (59)	23.4 (65)	35.4 (47)	78.40	37.8 (52)	25.6 (67)	40.2 (49)	< 50
$NO_3 - N$ (mg/l)	38.200	2.102 (93)	1.144 (96)	1.702 (94)	27.200	2.200 (92)	1.500 (94)	1.700 (93)	------
NH_4 (mg/l)	3.154	1.706 (46)	0.766 (76)	0.615 (81)	2.144	1.604 (25)	1.200 (44)	1.010 (53)	------
PO_4 (mg/l)	2.212	0.946 (57)	0.812 (63)	1.554 (30)	2.192	1.400 (36)	1.105 (50)	1.598 (27)	------
Pb (mg/l)	0.066	0.041 (38)	0.032 (52)	0.048 (27)	0.077	0.053 (31)	0.039 (49)	0.066 (14)	< 0.1
Mn (mg/l)	0.222	0.082 (63)	0.055 (75)	0.115 (48)	0.317	0.212 (33)	0.156 (51)	0.247 (22)	< 2
Fe (mg/l)	0.341	0.129 (62)	0.051 (85)	0.134 (61)	0.317	0.282 (11)	0.208 (34)	0.287 (9)	< 3
Cu (mg/l)	0.19	0.082 (57)	0.048 (75)	0.089 (53)	0.0752	0.053 (30)	0.043 (43)	0.060 (20)	< 1
TC (MPN/100 ml)	31600	10.6 (99.97)	13.6 (99.96)	5.2 (99.98)	32600	28 (99.91)	34 (99.90)	63 (99.81)	5000
FC (MPN/100 ml)	14400	3 (99.98)	2.6 (99.98)	2.4 (99.98)	18400	13 (99.93)	16 (99.91)	33 (99.82)	------

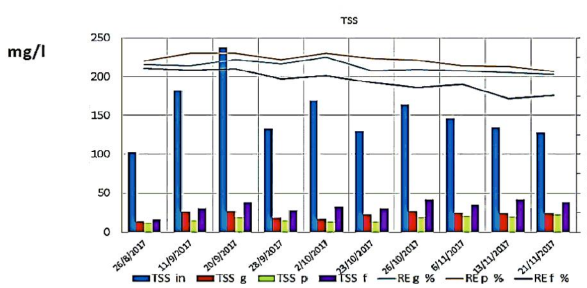
** Law 48, 1982 and its amendment decree 92/2013 (Article 51) (MWRI, 2013).*

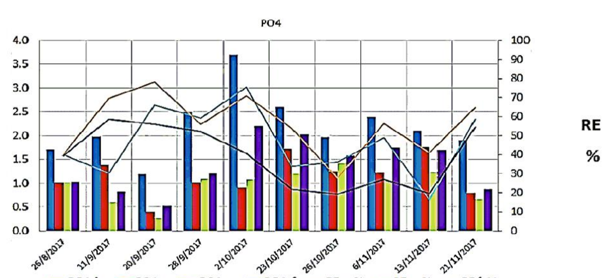
The PETE bed CW performed better water treatment than both gravel bed and FTW CWs. Reasons of this enhanced performance was the very high porosity of PETE bed comparing with gravel beds. Porosity of both tanks were measured on Dec. 2017 via empting the tanks starting from the media surface levels up to the tanks bottoms (0.5 m^3 media volume) and measuring displaced water volume. Collected water volumes were 332 and 118 liters that equivalent to 66.4% and 23.6% porosity for PETE and gravel beds respectively. The relative high porosity of PETE shredded chips had more than twice the gravel bed surface area and many folds of the bacterial biofilm layers. This enhanced the contact area of biofilm layers and the percolation from top to down increasing possibilities of trapping particulate parts of TSS, BOD and COD and bio-degrade other organic and soluble substances such as, heavy metals, nitrogen and phosphorus compounds. Other new noticed advantage for the PETE beds was its elasticity during the sudden batch filling and the low speed water exiting. The plastic bed was compressed after batch filling then it gradually expanded with time during treatment and water empting. These compression expansion cycles may prevent the usually clogging problems of gravel bed CWs.

Irrigation canal water were evaluated according to the Egyptian water reuse law (Law 48, 1982 and its amendment by decree 92/2013 Article 51), (MWRI, 2013). This decree identified the maximum permissible limits of some pollutant concentrations in the treated drainage water as a condition to be dumped at the irrigation fresh water canals. Table (1) indicated that all treated water samples collected from the three microcosms were compatible with the law standards in both operation cycles (one-day and half-day detention time). The maximum effluent concentrations produced from the FTW cell were also safely below these limits. The BOD, COD, and Pb concentrations were 17.2, 40.2, and 0.066 mg/l which was smaller than the 30, 50, and 0.1 mg/l of the law standards respectively. Similarly, the average FTW cell TC bacteria was 63 MPN/100 ml while the maximum permissible limits are 5000 MPN/100.









N-NO3 NH4

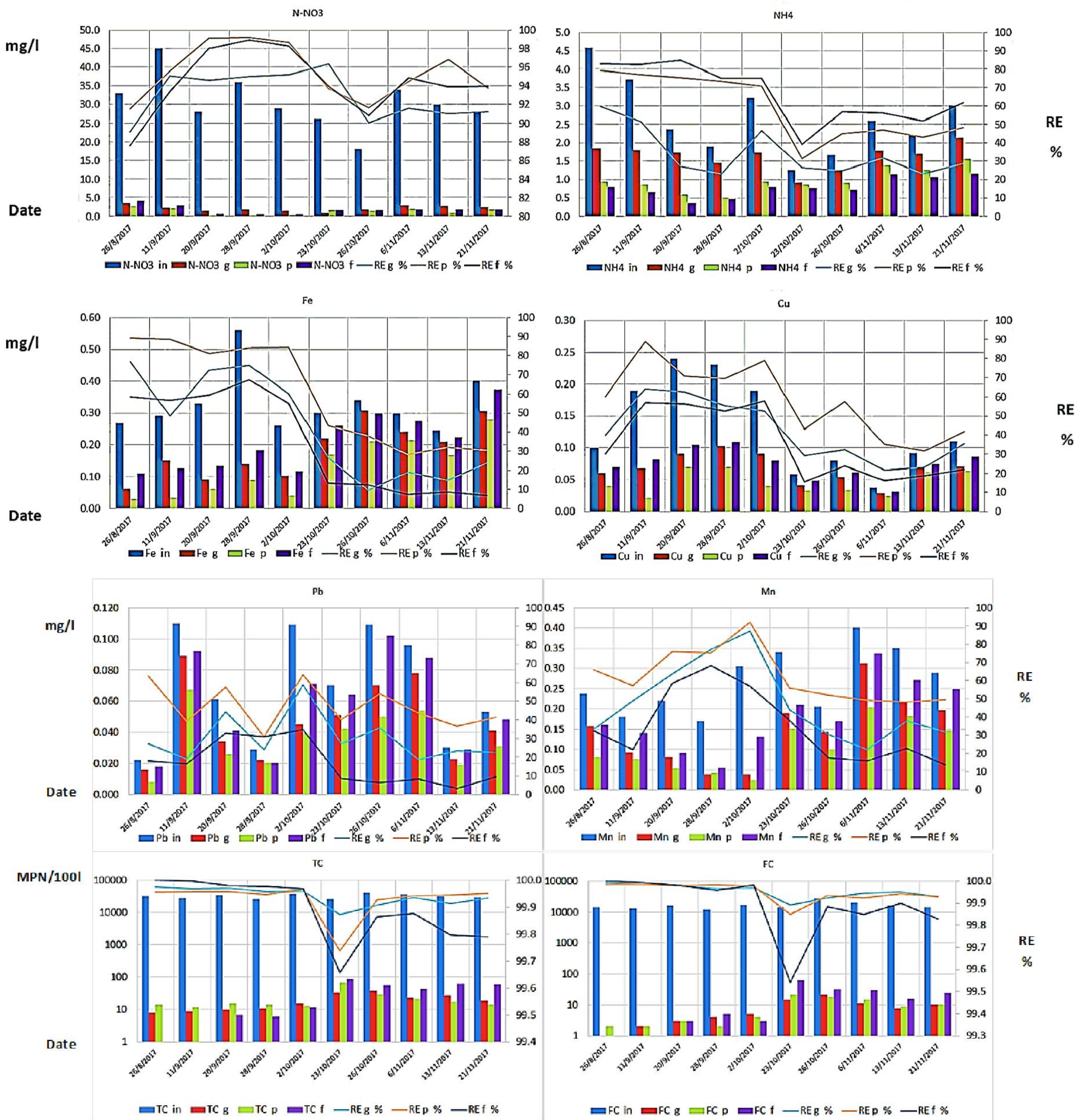


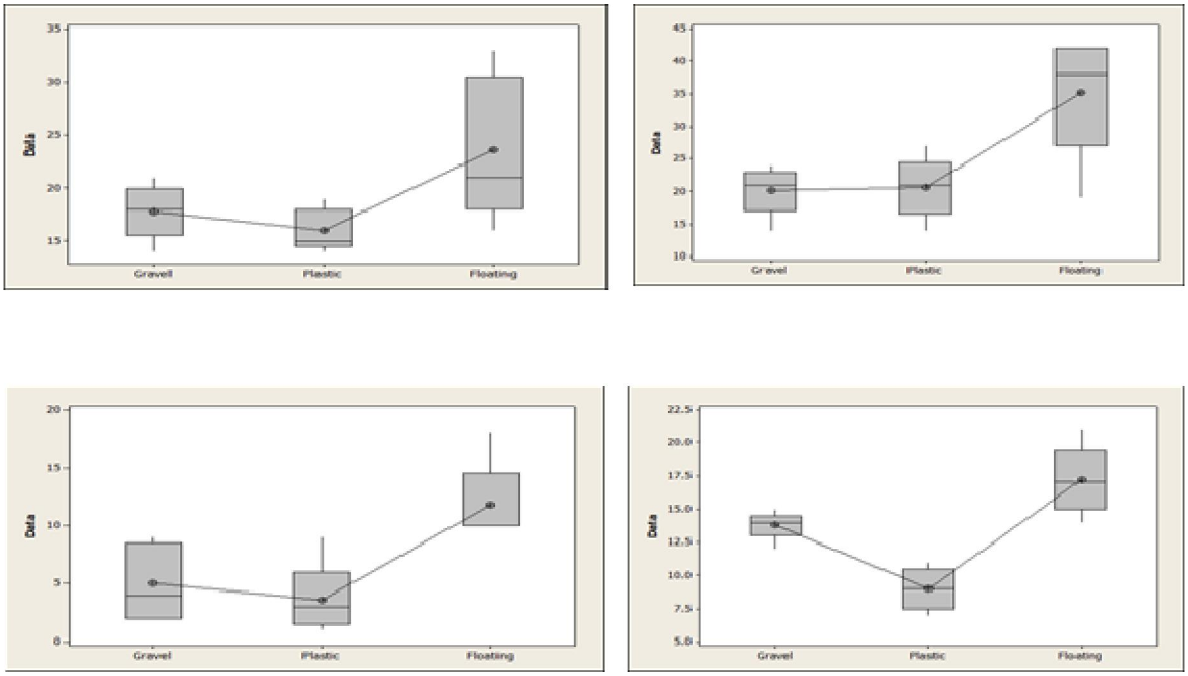
Figure (2) Influent (in), effluent and % removal rates of BOD, COD, TSS, PO_4, NO_3-N, NH_4, Pb, Mn, Fe, and Cu (mg/l) and TF, and FC (MPN/100 ml) of the gravel, (g), plastic (p) and floating (f) wetland cells during one-day detention time Aug.–Sep. 2017 and half-day detention time Oct.-Nov. 2017.

Statistical Analysis

The One-way analysis of variance (ANOVA) results showed that, there is a significant difference among the three microcosms treatment cells ($P < 0.05$) for TSS and BOD during both two detention times (one day and half day) as shown in Table (2). The results also showed that, the PETE beds shredded water bottles microcosm cell is the best for treatment where its recoded mean value is less than that recorded using the other bed microcosm cells as shown in Figures (3 & 4).

Table (2): Comparison between gravel, Plastic and floating methods using ANOVA

Parameters	P value (one- day)	P value (half- day)
TSS	0.043	0.005
BOD	0.005	0.000
Nitrate	0.897	0.318
Ammonium	0.210	0.101
FC	0.824	0.028



One- day detention time half- day detention time

Figure (4): Boxplot of BOD for different microcosm treatment cells

Conclusions

From this study we can conclude that, novel microcosm CWs were introduced using recycled one-m^3 HDPE tanks, filled with shredded PETE water bottles or dynamic floating foam boards. Comparing with rooted gravel beds; these batch flow microcosms managed to treat the un-usable drainage water to the limit that it either could be mixed with the canals fresh water or directly used for crops production. Treatment performance of rooted PETE bed microcosm was better than gravel bed followed by FTW microcosms. The elasticity and high porosity and surface area might be of the reasons of PETE microcosm good treatment performance. Two investigated batch flow treatment cycles; 1.0 m^3/day and 0.5 m^3/day managed to produce treated drainage water according to Egyptian standards. These small scale microcosms were suitable for small size landowners facing shortage of irrigation clean water. More investigations are required to examine the operation, maintenance and economic visibility as well as media material significance on pollutants treatment through such microcosms in the long run scale. The results also revealed that, as detention time increase the removal efficiency increase.

Corresponding author
Ahmed A. Rashed
Drainage Research Institute, National Water Research Center, Cairo, Egypt
E-mail: Ahmedrashed2002@hotmail.com

References

1. APHA, AWWA, and WEF. (2012). “Standard methods for the examination of water and wastewater”, 22nd edition, American Public Health Association, American Water Works Association, and Water pollution Control Federation, Washington D.C,.
2. Collaço A. B. and Roston D. M. (2006). “Use of Shredded Tires as Support Medium for Subsurface Flow Constructed Wetland”. Engenharia Ambiental - Espírito Santo do Pinhal Vol. 3, No. 1, pp 21 - 31.
3. Cordesius H. and Hedström S. (2009). “A Feasibility Study on Sustainable Wastewater Treatment Using Constructed Wetlands, An Example from Cochabamba, Bolivia”. M. Sc. Thesis, Division of Water Resources Engineering, Department of Building and Environmental Technology, Lund University, Sweden, TVVR-09/5004, ISSN-1101-9824 Minor Fiel d Study.
4. David J., Chih-Y. W., and Laurie J. F., (2013). “Innovative Best Management Fact Sheet No. 1: Floating Treatment Wetlands” Publication BSE-76P, College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University.

https://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/BSE/BSE-76/BSE-76-PDF.pdf.

5. EPA, Environmental protection Agency, (1993). “Subsurface flow constructed wetlands for wastewater treatment and wildlife habitat”. EPA 832-R-93-005. Washington, DC (USA): Office of Wastewater Management.
6. Ghada G. El Refaie and Ahmed Rashed, and M Abdul Khaleq, (2004). "Microcosm constructed wetland for improving mixed irrigation water of El Salam Canal, Egypt", The 7th INTECOL International Wetlands Conf., Utrecht, Nederland, July, 2004.
7. Headley, T.R., C.C. Tanner, (2008). “Floating Treatment Wetlands: An Innovative Option for Stormwater Quality Applications” 11th International Conference on Wetland Systems for Water Pollution Control, November 1-7, 2008 Indore, India.
8. Islam M. D. Kamrul, (2011) “Nutrient removal from urban stormwater using floating treatment wetland system”. M. Sc. Thesis, Montana State Univ., Bozeman, Montana.
9. Kadlec, R. H. and S.D. Wallace. 2009. “Treatment Wetlands” 2nd ed. CRC Press, Boca Raton, FL, USA, 662 pp.
10. Ko, J.Y., Day, J. W., Lane, R.L., Hunter, R., Sabins, D., Pintado, K.L. and Franklin, J. (2012). “Policy adoption of ecosystem services for a sustainable community: A case study of wetland assimilation using natural wetlands in Breaux Bridge, Louisiana”. Ecol. Eng. 38, 114–118.
11. Laville, S., and Taylor, M. (2017 June 11th) “A million bottles a minute: world's plastic binge 'as dangerous as climate change“. The Guardian, International edition. Retrieved from: https://www.theguardian.com/environment/2017/jun/28/a-million-a-minute-worlds-plastic-bottle-binge-as-dangerous-as-climate-change.
12. Minitab 17 Statistical Software (2010). [Computer software]. State College, PA: Minitab, Inc. (www.minitab.com).
13. MWRI, (2013). “Ministry of Water Resources and Irrigation ministerial decree 92/2013 for the amendment of Low 48/1982”. The Egyptian Chronicle, Vol. 22 (Continued), 28/01/2013. https://www.mwri.gov.eg/images/pdf/law48.pdf (in Arabic).
14. Rashed, A. A. (2016). "Vegetable Production on Rice Bales Using Brackish Treated Drainage Water", Irrig. and Drain. 65, (664-672), doi: 10.1002/ird.1994 ISSN: 1531-0353.
15. Rashed, A. and Abdel Rasheed A., (2008). "Polluted Drainage Water Natural On-Stream Remediation" The 26th Annual Water Treatment Technologies Conference, Alexandria, June, 2008.
16. Sekiranda, S. B. K. and Kiwanuka, S., (1998). “A study of nutrient removal efficiency of Phragmites mauritianus in experimental reactors in Uganda”. Hydrobiologia 364: 83-91.
17. Sleeth, Bradley L. (2014). "The Performance of Simple Artificial Floating Wetland Communities and Their Effects on Aquatic Nutrient Levels and Algal Abundance". UNF Thesis and Dissertations. Paper 547. http://digitalcommons.unf.edu/etd/547.
18. Tanner C. C. and Headley T. R. (2011). “Components of floating emergent macrophytes treatment wetlands influencing removal of stormwater pollutants”. Ecological Engineering 37: 474-486.
19. Triantafyllos T., Christos S. A., Athanasia G. T., Dimitrios V. V., and Alexandros I. S., (2017). “A novel horizontal subsurface flow constructed wetland: Reducing area requirements and clogging risk”, Chemosphere: Volume 186: 257-268, November 2017,, https://doi.org/10.1016/j.chemosphere.2017.07.151.
20. Vymazal, J. and Kröpfelová, L., (2008). “Wastewater Treatment in Constructed Wetlands with Horizontal Sub-Surface Flow”. Library of Congress Control Number: 2008931478, ISBN 978-1-4020-8579-6, e-ISBN 978-1-4020-8580-2, Springer Science + Business Media B.V.
21. Wang C.Y. and Sample D.J. (2014). “Assessment of the nutrient removal effectiveness of floating treatment wetlands applied to urban retention ponds”. J. of Environ. Management 137: 23-35.
22. Westerhoff P., Prapaipong P., and Shock E. H. A. (2008) “Antimony leaching from polyethylene terephthalate (PET) plastic used for bottled drinking water “. Water Res. 2008 Feb;42(3):551-6. doi: 10.1016/j.watres.2007.07.048.
23. Yamagiwa, K. and Ong, S.A., (2007). “Upflow constructed wetland for on-site industrial wastewater treatment”. Intern. Conf. Proceedings, Intern. Forum on Water Environmental Governance in Asia, pp.87-91.

2/11/2018