Constructed Wetlands for Urban Wastewater Treatment in Egypt

Results shown in this paper reveal that the investigated CW is capable of treating domestic wastewater in Egypt up to an acceptable environmental level suitable for agricultural reuse.

Authors: Hussein I. Abdel-Shafy, Ahmed Dewedar

Abstract

Constructed-Wetlands (CWs) with horizontal subsurface flow (HSSF) have been implemented as secondary treatment of urban wastewater at Ismailia. The system consists of two treatment stages in sequences. Each stage consists of 6 channels. Raw wastewater was subjected to sedimentation followed by a trickling filter and then to the CW system with a flow rate of 20 L/min to each CW bed. The total treated volume was 100 m^3/d. The CWs have been operated intermittently; the flow of wastewater was 18 hours. The daily cycle provides sufficient time for the channels to dry and allow atmospheric oxygen to diffuse into the root zone. Physical, chemical and biological characteristics of the wastewater influent and effluent were studied for a period of eight months. Removal of BOD_5, Suspended Solids and Ammoniacal-N ranged from 70 % to 93 %. Effective elimination of the pathogenic bacteria was achieved. Overall results reveal that the CW is capable of treating domestic wastewater in Egypt up to acceptable environmental level suitable for reuse in agriculture purposes.

Introduction

Within the last 30-35 years various types of constructed wetlands (CWs) have been developed in different countries. There is a wide international acceptance and interest because of many advantages of this system including low cost to build compared to other treatment options, simple construction, operation, maintenance, and very low energy consumption (Hammer, 1989; Cooper et al., 1996). CWs have other advantages including high ability to tolerate fluctuations in flow and inlet quality, high process stability due to a high buffer capacity (Crites and Tchobanoglous, 1998; Abdel-Shafy et al., 2008). Sludge is produced only in the primary treatment stage (Masi et al. 2010). CW systems proved to be an efficient technology for physical, chemical and biological treatment of wastewater (Kadlec and Knight, 1996, Masi et al., 2008).

Treatment of domestic or municipal wastewater and ecological sanitation is currently a conventional application (Crites and Tchobanoglous, 1998, Kadlec and Knight, 1996, Otterpohl, 2004). There are several thousands of operating wetlands worldwide, the most used are the subsurface flow systems (Masi et al. 2010, Bulc et al., 2003). The most available monitoring data are related to this kind of application. Meanwhile, there are numerous possibilities also for industrial wastewater like heavy metals, chemical industry, laboratory effluents, landfills, acid mines, endocrine disrupting chemicals (EDCs) as well as agricultural or agro-food wastewaters in general that is characterised by high organic content like wineries, olive oil mills and dairy (Abdel-Shafy et al., 1986; Crumpton, 2001; Revitt et al., 2001; Masi et al., 2004).

The importance of CWs mainly depend on the effectiveness in the removal of nutrients (nitrogen and phosphorous) and micropollutants, like persistent organic compounds and elimination of heavy metals (Abdel-Shafy et al., 1994; Masi et al., 2004; Vymazal, 2001). CWs that

Key factors:

- Constructed treatment wetlands have been shown to be a suitable technology for treating wastewater in Egypt.
- Horizontal subsurface flow CWs with intermittent loading have been investigated.
- The CW system proved to be an efficient for treating wastewater in hot climate as it exhibited effective removal of the pollution parameters including pathogenic bacteria.
- Horizontal subsurface flow CWs with intermittent loading can treat domestic wastewater in Egypt up to levels suitable for reuse in agriculture purposes.

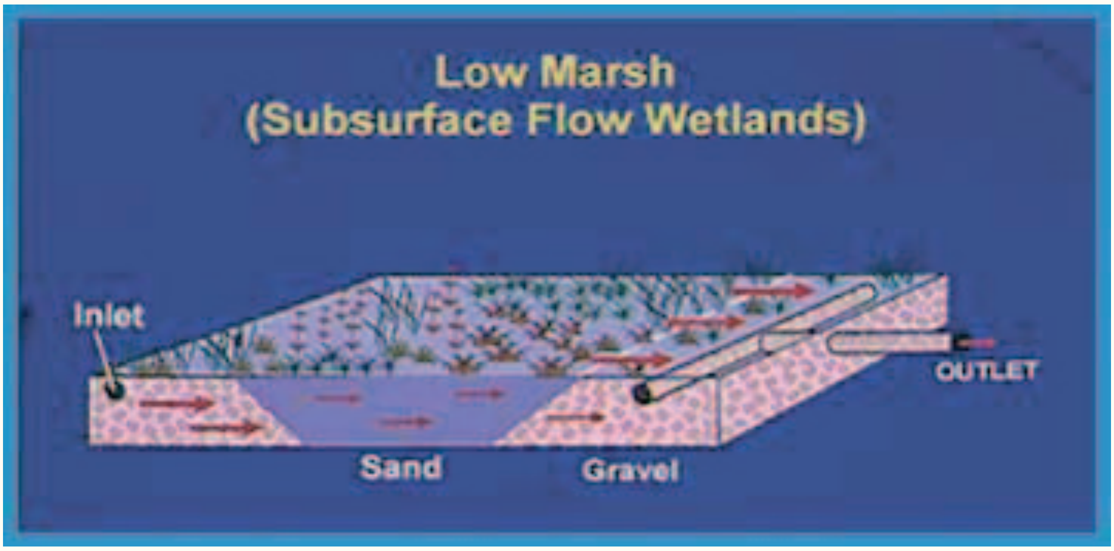

Figure 1: Schematic sketch of a CW bed with HSSF

consist of inclined channels lined with an impermeable geomembrane and filled with flint, can treat wastewater effluents depending on several factors including bed length, depth, gradient, retention time as well as type of aquatic plant and aggregate (Masi et al., 2008, Revitt et al., 2001, WateReuse Research Foundation, 2011).

A field-scale CW with horizontal subsurface flow (HSSF) was established in Ismailia, Egypt, to study the success factors, performance and effects on the characteristics and effluent quality produced by the system in sub-tropical climate areas. The main aim was to evaluate the efficiency of CWs as secondary municipal treatment process in terms of physical, chemical and biological parameters. Different media for the CW main layer were implemented for the purpose of studying their effect on the CW treatment performance.

Materials and Methods

A field-scale CW system with HSSF (Figure 1) was designed and constructed in Ismailia, Egypt, to treat 100 m^3/d of primary treated municipal wastewater. Raw wastewater was subjected to sedimentation followed by a trickling filter, then finally to the CW system. The CW system comprised 6 parallel channels with 2 HSSF beds in series each (Figure 2). The HSSF beds of the 1st stage had different lengths (50 m and 100 m), 2.5 m width and different depths (300 mm and 600 mm). The dimensions of the beds of the 2nd stage were: 40 m length, 2.5 m width and 300 mm depth. The gradient of the channels ranged from 1:20 to 1:50. The flow rate for each channel was controlled by a mean V-notch and was adjusted daily to 20 L/min to each bed. The loading of the CW system was for 18 hours per day, to leave the channels free of wastewater for the rest of the day by night time (i.e. 6 hours), to allow atmospheric oxygen to diffuse into the root zone. The first stage represents the treatment phase which was filled with various types of aggregates (flint gravel, limestone and basalt each with grain size of 4-6 cm). These channels were planted with *Phragmites australis* and *Napier grass* (Figure 3). The channels of the second phase were cultivated with appropriate seasonal crops. Details of design and construction as well as sampling position are summarized in Table 1.

Figure 2: 1st stage HSSF beds, CW system in Ismailia, Egypt

Figure 3: Effluent sampling points at the 6 1st stage HSSF beds

Table 1: Detailed description of the two stages CW system.

Stage	Channel	Type of Plant	Length (m)	Width (m)	Depth (mm)	Type Of Media (4-6 mm)
1	1	*Phragmites australis*	100	2.5	600	Flint
	2	*Napier grass*	100	2.5	600	Basalt
	3	*Phragmites australis*	100	2.5	600	Limestone
	4	*Phragmites australis*	100	2.5	300	Flint
	5	*Napier grass*	50	2.5	300	Basalt
	6	Papyrus	50	2.5	300	Limestone
2	1	seasonal crops	50	2.5	300	Flint
	2	seasonal crops	40	2.5	300	Basalt
	3	seasonal crops	40	2.5	300	Limestone
	4	seasonal crops	40	2.5	300	Flint
	5	seasonal crops	40	2.5	300	Basalt
	6	seasonal crops	40	2.5	300	Limestone

Wastewater inlet and outlet to the CW were sampled weekly for continuous period of eight months for the determination of the physical, chemical and biological characteristics (total coliform, faecal coliform and faecal streptococci) according to APHA (2005). Sodium, calcium and magnesium were determined in the influent and effluent using Flame Photometer in the same samples of the wastewater. The samples were filtered through Whatmann No.4 and acidified by A.R. nitric acid to a pH value below 2.0 before determination.

Results and Discussion

The physical and chemical characteristics of the primary treated municipal wastewater are given in Table 2. The results show that primary treatment process was efficient. The concentrations of COD, BOD, TSS, and total nitrogen in the influent of the CW system were 220, 126, 195 and 76 mg/L, respectively. The TKN and ammonia nitrogen concentrations were 41 and 23 mg/L. The influent wastewater was anaerobic, no nitrates could be detected and the sulphides concentration were 2.4 mg S/L.

Table 2: Physical and chemical characteristics of the primary treated municipal wastewater, i.e. the influent to the CW system.

Parameters	N	Min.	Max.	Mean value
pH	32	7.1	7.5	7.1 - 7.5
Turbidity	32	160	280	220.1
Dissolved Oxygen (mg/L)	32	0.00	0.20	0.15
COD (mg/L)	32	188	320	220
BOD (mg/L)	32	101	187	126
TKN (mg/L)	32	28	49	41
Ammonia N (mg/L)	32	16	24	23
TN (mg/L)	32	52	89	76
Organic N (mg/L)	32	17	37	28
Nitrates N (mg/L)	32	n.d.	n.d.	n.d.
TSS (mg/L)	32	230	121	195
VSS (mg/L)	32	98	57	79
TDS (mg/L)	32	1176	1788	1474
TR (mg/L)	32	107	188	129
VR (mg/L)	32	87	125	107
Oil & Grease (mg/L)	32	37	67	48
Sulphides S (mg/L)	32	1.2	4.4	2.4

N = number of samples; n.d. = not detected

Table 3: Physical and chemical characteristics of the inlet and outlet of the Ismailia CW system (N = number of samples).*

Sampling position	N	pH	DO (mg/L)	TSS (mg/L)	BOD (mg/L)	NH_4-N (mg/L)	NO_3-N (mg/L)
Inlet	25	7.1 - 7.5	0.15	195	126	23	0.00
Outlet short bed (50 m)	25	7.1 - 7.5	1.90	30	25	17	0.51
Outlet long bed (100 m)**	25	7.1 - 7.5	3.90	20	14	12	0.94
Outlet long bed (100 m)***	25	7.1 - 7.5	3.15	22	15	12	0.92
Crop bed (40 m)	25	7.1 - 7.5	4.19	12	11	10	2.16

* presented values are the averages of all studied samples.
** Channel planted with *Phragmites australis*.
*** Channel planted with *Napier grass*.

Table 4: Total coliform, faecal coliform and faecal streptococci contamination in the inlet and outlet of the Ismailia CW system (mean values, N = number of samples).

Sampling position	N	Total coliforms (10^3 CFU/mL)	Faecal coliforms (10^3 CFU/mL)	Faecal streptococci (10^3 CFU/mL)
Inlet	21	497	129	28.3
Outlet planted bed	21	34.6	6.91	0.0995
Outlet crop bed	21	1.53	0.080	0.0994
Outlet non-vegetated bed	21	4.6	0.091	0.029

The physical and chemical characteristics of the municipal wastewater inlet and outlet of the variable CW channels are presented in Table 3 as mean values. The pH values showed no variation in the long or short channel. This indicates a buffering capacity of the system. For the dissolved oxygen (DO) gradual increase towards the outlet could be observed. The effluent from the short channel had lower DO (1.90 mg/L) in correlation to the effluent from the long one (3.91 mg/L) that planted with *Phragmites australis*, and (3.15 mg/L) that planted with *Napier grass*. The value of the D.O. increased to (4.19 mg/L) in the outlet of the crop channel.

The removal efficiencies calculated from Table 3 for total suspended solids (TSS) have been 84.6 %, 89.7 %, 88.7 % and 93.8 % for short channel, Phragmites long channel, Napier long channel and crop channel respectively. BOD removal was 80.2 % for the short channel, 88.9 % for both long channels, and 92.1 % for crop channel. Remarkable improvement was achieved in terms of the ammonium and nitrate nitrogen. The short beds showed little changes for NH_4-N (26.1 % removal). However, better improvement was recorded in the effluent of the long beds as well as the crop channels (47.8 % and 56.5 % respectively). The nitrate-nitrogen (NO_3-N) exhibited increase from zero to 0.51 mg/L in the short bed outlet then slight improvement was achieved in long channels. Further increased was reached in the effluent of the crop channel (2.16 mg/L).

Furthermore, the CW system was effective in eliminating pathogenic bacteria as indicted by total coliforms, faecal coliforms and faecal streptococci (Table 4). The die-off rates of microbial groups were calculated for the determination of the removal rates. The results indicate that the mean bacterial count is the highest die-off rates in all the studied cases. However, increasing the bed length showed no importance effect on the removal of bacterial indicators. The general observation shows that effective removal of indicator bacteria, namely total coliform, faecal coliform and faecal streptococci, was achieved in all cases due to the long retention time. Higher removal was achieved in the second stage for the same reason; namely longer duration time of wastewater in the CW.

Concentrations of Na, Ca and Mg in the influent and effluent of the 6 CW channels are given in Table 5. The results indicated that the level of the studied metals increased in the effluent. This can be attributed to the partial evaporation of the wastewater on the surface of the CW during the long retention time of the treatment process. It is worth noting that the level of Ca and to less extend Mg in the limestone channels numbers 3 and 6 exhibited slight higher increase as indication of slow release of Ca and Mg from the limestone media of these channels. On the contrary, the other channels; namely flint and basalt; did not exhibit any release of Na, Ca or Mg as indication that these materials are stable and inert with wastewater. However, flint was

Table 5 : Concentrations of Na, Ca and Mg in the municipal wastewater in the inlet and outlet of the Ismailia CW system (N = number of samples, in mg/L).

Channel	N	Na		Ca		Mg	
		IN	OUT	IN	OUT	IN	OUT
1	16	56	63	56	59	44	55
2	16	68	70	68	75	50	54
3	16	65	80	65	79	50	68
4	16	60	74	66	70	42	60
5	16	63	74	62	70	49	55
6	16	62	69	67	81	43	59

Table 6: Effluent concentrations of the Ismailia CW system and Egyptian regulation* for wastewater reuse

Parameter	Unit	1st group Primary treated water	2nd group Secondary treated water	3rd group Advanced treated water	Effluent of the CW system
BOD_5	mg/L	300	40	20	11 - 25
COD (dichromate)	mg/L	600	80	40	28 - 76
TSS	mg/L	350	40	20	12 - 30
Oil and grease	mg/L	Not limited	10	5	3 - 5
Number of cells or eggs of Nematodes	Counts/L	5	1	1	-
E.Coli	100/mL	Not limited	1000	100	< 100
TDS	mg/L	2500	2000	2000	998 - 1763
Na absorption ratio	%	25	20	20	12 - 19
Cl-	mg/L	350	300	300	84 - 121
B	mg/L	5	3	3	2 - 3

* The permissible limits for irrigation according to the Egyptian Law 48, No.61-63, Permissible values and Law of the Environmental Protection (1994); updated by No.44, (2000).

circular or curved shape, but basalt was sharp edged. This means that flint has an advantage over the basalt for supporting larger surface area.

The average final effluent concentrations of BOD_5, COD, TSS, oil & grease, TDS, chloride and Boron of the CW system ranged from 11 - 25, 28 - 76, 12 - 30, 3 - 5, 998 - 1763, 84 – 121, and 2 – 3 mg/L, respectively (Table 6). The calculated Na absorption ratio ranged from 12 - 19 and the E.Coli count were less than 100 MPN/100 mL. Such quality of treated effluent is accepted as “3rd group advanced treated water” classified as “Class Excellent” according to the Egyptian irrigation regulation (EEAA, 2000).

The overall results reveal that a CW system with HSSF and intermittent loading is capable of treating the domestic wastewater in Egypt up to acceptable environmental level suitable for irrigating agriculture products where the crops are not intended for immediate human consumption without further processing. The treatment process provides effluent appropriate for crop irrigation with acceptable level of nitrogen as NH_4-N (7.8 mg/L) and NO_3-N (2.2 mg/L) and dissolved oxygen (3.8 mg/L) as good indicator of adequate treatment. Slight release of Ca from the channels using limestone as filter media was confirmed.

Conclusions

The following conclusions can be drawn:

1. Constructed wetlands (CWs) with horizontal subsurface flow and intermittent loading showed efficient treatment of primary treated municipal wastewater.
2. Removal efficiencies for BOD_5, total suspended solids and ammoniacal-N were 90 %, 93 % and 54 to 70 %, respectively.
3. Effective elimination of the indicator bacteria (total coliforms, faecal coliforms and faecal streptococci) was achieved. However, increasing the bed length showed no importance effect on the removal of bacterial indicators.

4. Longer beds up to 100 m were more efficient than shorter beds (50 m) as indicated by the quality of the effluent.
5. Beds planted with papyrus showed similar treatment efficiency as beds planted with *Phragmites australis* and *Napier grass*.
6. Concentration of Na, Ca and Mg is slightly increased in the effluent due to the high evaporation rate in Egypt's hot climate. In addition, release of Ca and Mg from the limestone channels may occur. Therefore, it is recommended to avoid using limestone as filter media in CWs.
7. Using flint as filter media in CWs has advantage over the basalt for supporting larger surface area.
8. The overall results reveal that the CW system is capable of treating the domestic wastewater up to an level suitable for irrigating agriculture products where the crops are not intended for immediate human consumption without further processing.

Acknowledgement

The full financial support of the UK Overseas Development Administration (ODA) to construct and conduct this project is greatly appreciated. The authors are in debt to the National Research Centre, Suez Canal University and the Ismailia Sewage Works Authorities for the facilities provided.

References:

Abdel-Shafy, H.I., Cooper, W., Handley-Raven, L., Casey, L. (1986): Short-Term fate of heavy Metals in the Gravel Bed Hydroponics wastewater treatment system, J Environ. Protection Eng 12(1), 61-80.

Abdel-Shafy, H.I., Hegemann, W., Teiner, A. (1994): Accumulation of metals by Vascular plants. J. Environ. Management Health 5(2), 21-24.

Abdel-Shafy, H.I., Regelsberger, M., Masi, F., Platzer, C., El-Khteeb, M.A. (2008): Constructed Wetlands in Egypt. Sustainable Water Management, Journal of the EU project Zer0-M 3/2008, 10-14.

APHA (2005): Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, D.C., USA.

Bulc, T., Zupancic, M., Vrhovsek, D. (2003): Constructed Wetland experiences in Slovenia: development and application. In: Proceedings of the Conference on Constructed-Wetlands: Applications and Future Possibilities, 2003, Volterra, Italy, pp.90–105.

Cooper P.F., Job G.D., Green M.B., Shutes R.B.E. (1996): Reed beds and constructed wetlands for wastewater treatment. WRc plc, Swindon, UK.

Crites, R., Tchobanoglous, G. (1998): Small and decentralized wastewater management systems, 2nd edition, McGraw-Hill, N.Y.C., USA.

Crumpton, W. (2001): Using wetlands for water quality improvement in agricultural watersheds: the importance of a watershed scale approach. Water Sci Technol 44(11/12), 559-564.

EEAA (2000): Egyptian Environmental Association Affair, Law 48, No.61-63, Law of the Environmental Protection (1994) - updating No.(44), (2000), Cairo, Egypt.

Hammer, D.A. (1989): Constructed Wetlands for Wastewater Treatment Municipal, Industrial and Agricultural. Lewis Publishers, Michigan, USA.

Kadlec, R., Knight, R. (1996): Treatment Wetlands. Lewis Publisher CRC press, Boca Raton, Florida, USA.

Masi, F., Conte, G., Lepri, L., Martellini, T., Del Bubba, M. (2004): Endocrine disrupting chemicals (EDCs) and pathogens removal in the hybrid CW system for a tourist facility wastewater treatment and reuse. In: IWA (eds.): Proceedings of the „9th IWA International Conference on Wetland Systems for Water Pollution Control“ – Vol.2, 26 September - 1 October 2004, Avignon, France, pp.461-468.

Masi, F., Conte, G., Martinuzzi N. (2008): Sustainable Sanitation by Constructed Wetlands in the Mediterranean countries: experiences in small/medium size communities and tourism facilities. In: Al-Baz I., Otterpohl, R., Wendland, C. (Eds.): Efficient Management of Wastewater, Its Treatment and Reuse in Water Scarce Countries. Springer, New York, USA, ISBN 978-3-540-74491-7, pp.125-138.

Masi, F., El-Hamouri, B., Abdel-Shafy H.I., Baban, A., Ghrabi, A., Regelsberger, M. (2010): Treatment of segregated black/grey domestic wastewater using Constructed Wetlands in the Mediterranean basin - the Zer0-m Experience. Water Sci Technol 61(1), 97-105.

Otterpohl R. (2004): New technological developments in ecological sanitation. In: Werner, C., et al. (Eds.): „Ecosan - closing the loop“ - Proceedings of the 2nd International Symposium on ecological sanitation, 7-11 April 2003, Lübeck, Germany, pp.455-462.

Revitt, D., Worrall, P., Brewer, D. (2001): The integration of constructed-wetlands into a treatment system for airport runoff. Water Sci Technol 44(11/12), 469-476.

Vymazal, J. (2001): Transformation of Nutrients in Natural and Constructed-Wetlands. 1st edition, Backhuys Publisher, Leiden, Netherlands.

WateReuse Research Foundation (2011): Evaluate Wetland-Systems for Treated Wastewater Performance to Meet Competing Effluent Quality Goals. Publication Number 05-0061-1, Washington, D.C., USA.

Name: Hussein I. Abdel-Shafy
Organisation: Water Research & Pollution Control Department, National Research Centre
Town, Country: Cairo, Egypt.
eMail: hshafywater@yahoo.com

Name: Ahmed Dewedar
Organisation: Suez Canal University
Town, Country: Ismailia, Egypt