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Assessing the performance of constructed wetland for water quality management of a Southern Mediterranean river

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Abstract

Most of Southern Mediterranean water courses suffer from numerous types of pollution. This study presents a comprehensive performance assessment of a pilot CW system for removing various contaminants from the Litani River, Lebanon. The physico-chemical, pathogens and trace metal parameters were analyzed for river water as well as for the wetland effluent. Results revealed that the average removal efficiencies were 87.01% for COD, 64.99% for BOD_5, 86.18% for TSS, 43.11% for NO_3—N, 34.82% for NH_4—N, 55.07% for PO_4—P and 73.05% for K. The removal efficiency of faecal coliforms was around 99.84%. Influent and effluent heavy metal pollution (Cu, Pb, As and Ni) concentrations greatly exceeded the range of the environmental limit values due to industrial emissions in river water. CWs seem to be a promising green technology for Lebanon for the reduction of bacterial contamination. Further studies are required to improve treatment modules for different pollutants, including metals.

Introduction

The discharge of industrial and domestic wastewater into surface water destroys the quality of water resource. Constructed wetlands (CWs) have emerged and become a viable option for wastewater treatment, and are currently being recognized as attractive alternatives to conventional wastewater treatment methods (Zhang *et al*. 2014).

In Lebanon, to date, there has been little information about the application of CWs. The Litani River is the largest river in Lebanon suffering from extensive garbage dumping, direct release of urban wastewater uncontrolled industrial discharges, lack of riverbed maintenance and unauthorized diversions. In 2012, the Litani River Basin Management System (LRBMS) program aimed to develop a constructed wetland adjacent to the River. The wetland had to serve multiple objectives, including treating polluted Litani River water, restoring wetlands and riparian habitat, promoting environmental awareness and education regarding water resources and demonstrating an innovative, natural water treatment technology not yet implemented in Lebanon (LRMBS 2012). In the dry season, the constructed wetland is expected to treat on average 20% of the Litani River flow (up to the entire flow during dry years), and to remove 47% BOD_5, 81% TSS, 44% NH_4—N, 46% NO_3—N, 23% PO_4 and 99% faecal coliforms (LRMBS 2012).

Since the use of a CW improves the quality of contaminated water, the primary objective of this study is to present a comprehensive performance assessment of pilot CW system for removing various contaminants from the Litani River, within the overall context of the need for low-cost and sustainable wastewater treatment systems in the Southern Mediterranean. The emphasis is placed on the treatment performance including physico-chemical performance, pathogens and trace elements removal in order to check if the abovementioned expectations of removal rates will be met

Materials and methods

Location and description of constructed wetland system

A constructed wetland was present and developed on a plot belonging to the Litani River Authority (LRA) agricultural extension center along the Litani River near Joub Jannine

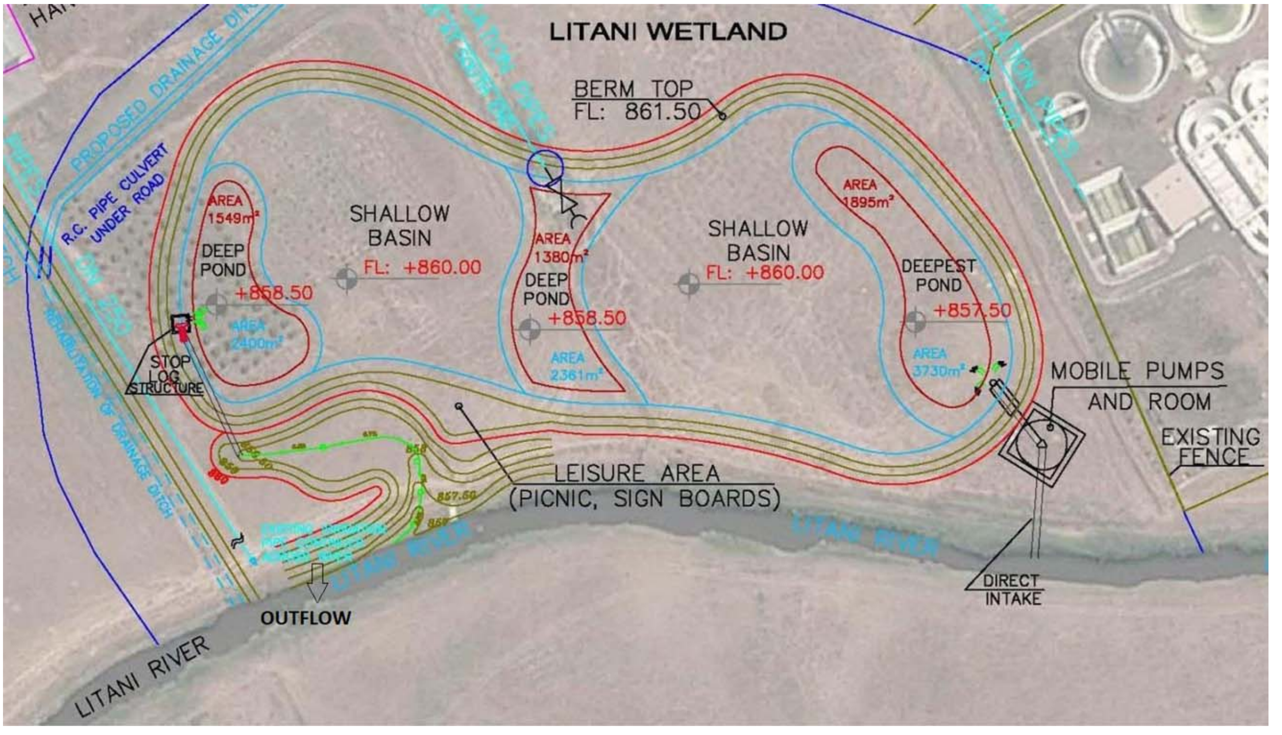

Fig. 1. Components of the constructed wetland (LRMBS 2012). [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

bridge in Khirbet Kanafar village (Lebanon, 33.63° lat, 35.77° long, 859 m elev.), being the only example. A treatment wetland sited here will provide improved water quality downstream to Qaraoun Lake and irrigation Canal 900. The wetland was constructed at approximately 2.5 ha in size and it was designed to receive 30 $L.s^{-1}$ of flow during the dry season and 60 $L.s^{-1}$ of flow during the rest of the year (LRMBS 2012).

The constructed wetland system comprises three main elements: the main constructed wetland itself, a pump station to provide inflow to the wetland from the Litani River and the discharge channel to convey treated wetland effluent back to the River (Fig. 1). The constructed wetland system consists of an alternating sequence of deep (2 m) and shallow (30–50 cm) zones. *Phragmites australis* provided an ideal primary species for the wetland because it is commonly found near the selected site (e.g., at the Aammiq wetlands). The hydraulic retention time was 5 days (LRMBS 2012).

Climatic characteristics of the site

The climate of the area is typically Mediterranean, characterized by a hot and dry season from April to September. The main weather parameters were collected from a standard agro-meteorological station located at the experimental station of the LRA agricultural extension center in Khirbet Kanafar that is 800 m far from the wetland site. The weather regime, in terms of precipitation (P), maximum temperature (*T*max) and minimum temperature (*T*min) from October 2015 until September 2016 are presented in Fig. 2. The overall average air temperature was 15.8 ± 6.78°C while the total precipitation amount was 970 mm. The precipitation was concentrated only during the winter-spring period, until May, and it was zero during the summer season (June–September).

The evaluation of the temperature data shows that the climatic conditions of the region are suitable for development and survival of plants grown in the constructed wetlands during at least 7 to 8 months of the year. The typical warm

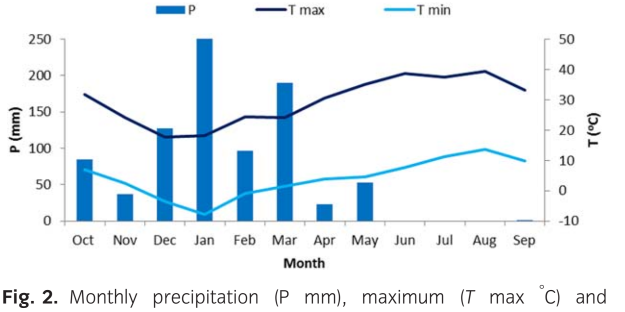

Fig. 2. Monthly precipitation (P mm), maximum (*T* max °C) and minimum (*T* min °C) temperatures at the wetland site from October 2015 until September 2016. [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

climate of Mediterranean areas, all year-round is suitable for using CW as wastewater treatment, since it is conducive to the plant growth and microbiological activity, which have a positive effect on treatment efficiency (Bojcevska & Tonderski 2007).

Water measurements, sampling and analysis

River flow was measured at a gauging station located immediately adjacent to the CW on the Litani River at the Joub Jannine bridge. The wetland inflow and outflow ($m^3.day^{-1}$) were monitored. Since the performance of a constructed wetland would be affected by evapotranspiration (ET), further knowledge on water losses could provide useful information. The estimate of ET is highly important for arid areas, especially where the water at the outflow of the CWs is required for reuse (Tuttolomondo *et al*. 2016).

The water budget was calculated according to IWA (2000) using the equation:

$$Qo = Qi + (P - ET) * A \quad (2)$$

where Qo is the output wastewater flow rate (m^3/d), Qi is the wastewater inflow rate (m^3/d), P is the precipitation rate (m/d), ET is the evapotranspiration rate (m/d) and A is the wetland top surface area (m^2).

Water samples for quality assessment were taken monthly (from March to September) during the spring/summer period of 2016. The samples were collected at the inflow and at the outflow of the wetland always at the same time in the morning as described by Leto *et al*. (2013).

Different parameters were measured along the wetland to assess the removal efficiency of contaminants. All analyses were performed according to the *Standard Methods for the Examination of Water and Wastewater* (APHA-AWWA-WEF 2005). Among them were; hydrogen ion concentration (pH), total suspended solids (TSS) analyzed gravimetrically (SM-2540 D), total dissolved solids (TDS), biological (biochemical) oxygen demand (BOD_5) determined by measuring oxygen depletion within 5 days at 20°C (SM-5210 B), chemical oxygen demand (COD) analyzed by open reflux method (SM-5220 B), ammonium nitrogen (NH_4—N) analyzed by distillation followed by titration (SM- 4500-NH3 B, C), nitrate-nitrogen (NO_3—N) and phosphorus (PO_4^{3-}) analyzed by ion chromatography (SM-4110 B), trace metals (Fe, Cu, Zn, Pb, Cd, etc.) detected through atomic absorption spectroscopy, total coliforms (TC), faecal coliform (FC; method SM-9220 B and D), *E. coli*, *Salmonella*, and so forth. Analyses were elaborated at the laboratories of the Lebanese Agricultural Research Institute (LARI).

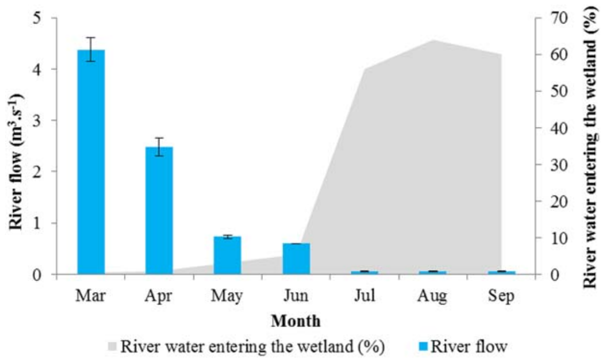

Fig. 3. Average flow rate in Litani River at Joub Jannine Bridge and percentage of water diverted to the wetland, spring/summer 2016. [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

Evaluation of the contaminant removal efficiency

The performance of the system as a whole was interpreted on the basis of computed removal rates. The percentage concentration decrease efficiency was evaluated according to the IWA recommended equation (2000). Removal rates (RR) of the major parameters such as TSS, COD, BOD_5, and so forth, were computed by the formula given below, as it was also presented in the study of Chang *et al*. (2007) and others.

$$RR(\%) = \frac{Ci - Ce}{Ci} 100 \quad (1)$$

where, Ci and Ce are the average inflow and outflow concentrations in mg/L.

Comparison to the Lebanese standards

There are no known guidelines for wetland design and performance in Lebanon, so comparison was only possible with Lebanese standards for wastewater treatment and release. These are based on the decision issued by the Ministry of Environment: Decision 8/1 on January 30, 2001.

The wetland performance was also compared to the guidelines for wastewater reuse in agricultural irrigation as proposed by the Food and Agricultural Organization of the United Nations (FAO/UTF/LEB/019/LEB 2011).

Results and discussion

Litani river flow and wetland water budget

The flow rate measured (spring/summer 2016) at the gauging station was averaged on a monthly basis and presented in Fig. 3. The stream flow pattern typifies the Mediterranean

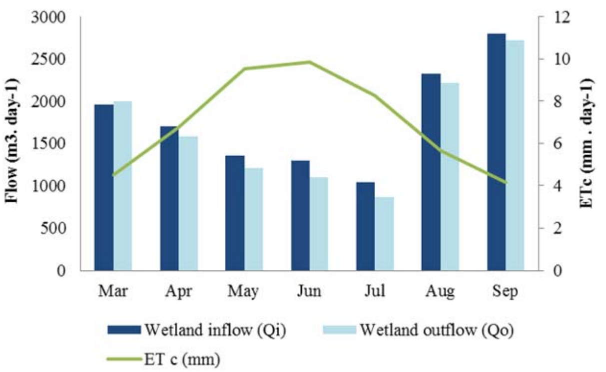

Fig. 4. Wetland inflow and outflow and plant evapotranspiration (ETc). [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

climate: higher flows were observed in the spring time, March through April (with an average discharge in March of 4.38 ± 0.23 m^3s^{-1}) while much lower flows were in May and June (0.73 ± 0.03 and 0.6 ± 0.005 m^3 s^{-1}, respectively). During the summer months (July–September) river flow was reduced below 50 L s^{-1}. On average, the Litani River provides ample flow year-round to support the constructed wetland system. However, the functioning of CW during the summer season could be questioned due to very low discharge.

In general, the wetland was able to treat 0.52, 0.89, 3.16, 5.40, 56, 64, 60, per month, respectively, from March to September of the River flow. The wetland treated on average 27.14 ± 30.86% of River flow in the dry season. This finding is in agreement with what was reported in LRBMS (2012), that the wetland is expected to treat between 20 and 100% of the Litani River flow during the dry season and approximately 1 to 2% of the flow in the wet season.

The estimated water budget, from March to September, is provided in Fig. 4 in terms of wetland inflow, outflow and vegetation evapotranspiration (ETc).

Table 1 Physico-chemical analyses of influent water (Litani River) as compared to recommended limits

Physico-chemical parameters ($mg.L^{-1}$)	Influent (Litani water)				Environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001)	Effluent specifications for wastewater reuse in irrigation based on proposed Lebanese guidelines (FAO/UTF/LEB/019/LEB 2011)		
	Min	Max	Mean	SD		Water Category I	Water Category II	Water Category III
pH	7.45	8.48	7.96	0.36	6–9	6–9	6–9	6–9
COD	15.41	75.23	50.09	19.08	125	125	250	250
BOD_5	56.00	91.00	71.00	12.14	25	25	100	100
Total Suspended Solids	11.56	198.00	69.35	69.29	60	60	200	200
chloride	27.03	87.10	58.48	20.65	250	–	–	–
Nitrates	1.70	24.10	7.26	7.68	90	30	30	30
Ammonium	0.04	7.24	3.52	3.30	10	_	_	_
Phosphates	0.31	2.43	1.25	0.63	5	_	_	_
Potassium	3.00	17.30	8.80	4.97	_	_	_	_

Table 2 Physico-chemical analyses of wetland effluent water as compared to recommended limits

Physico-chemical parameters ($mg.L^{-1}$)	Effluent				Environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001)	Effluent specifications for wastewater reuse in irrigation based on proposed Lebanese guidelines (FAO/UTF/LEB/019/LEB 2011)		
	Min	Max	Mean	SD		Water Category I	Water Category II	Water Category III
pH	7.51	8.51	7.94	0.32	6–9	6–9	6–9	6–9
COD	0.00	18.55	6.51	6.64	125	125	250	250
BOD_5	20.00	33.00	24.86	4.88	25	25	100	100
Total Suspended Solids	4.88	16.10	9.58	5.05	60	60	200	200
Chloride	30.03	57.06	47.18	10.16	250	–	–	–
Nitrates	0.70	13.00	4.13	4.09	90	30	30	30
Ammonium	0.01	6.22	2.30	2.37	10	_	_	_
Phosphates	0.07	1.80	0.56	0.58	5	_	_	_
Potassium	1.00	4.90	2.37	1.55	_	_	_	_

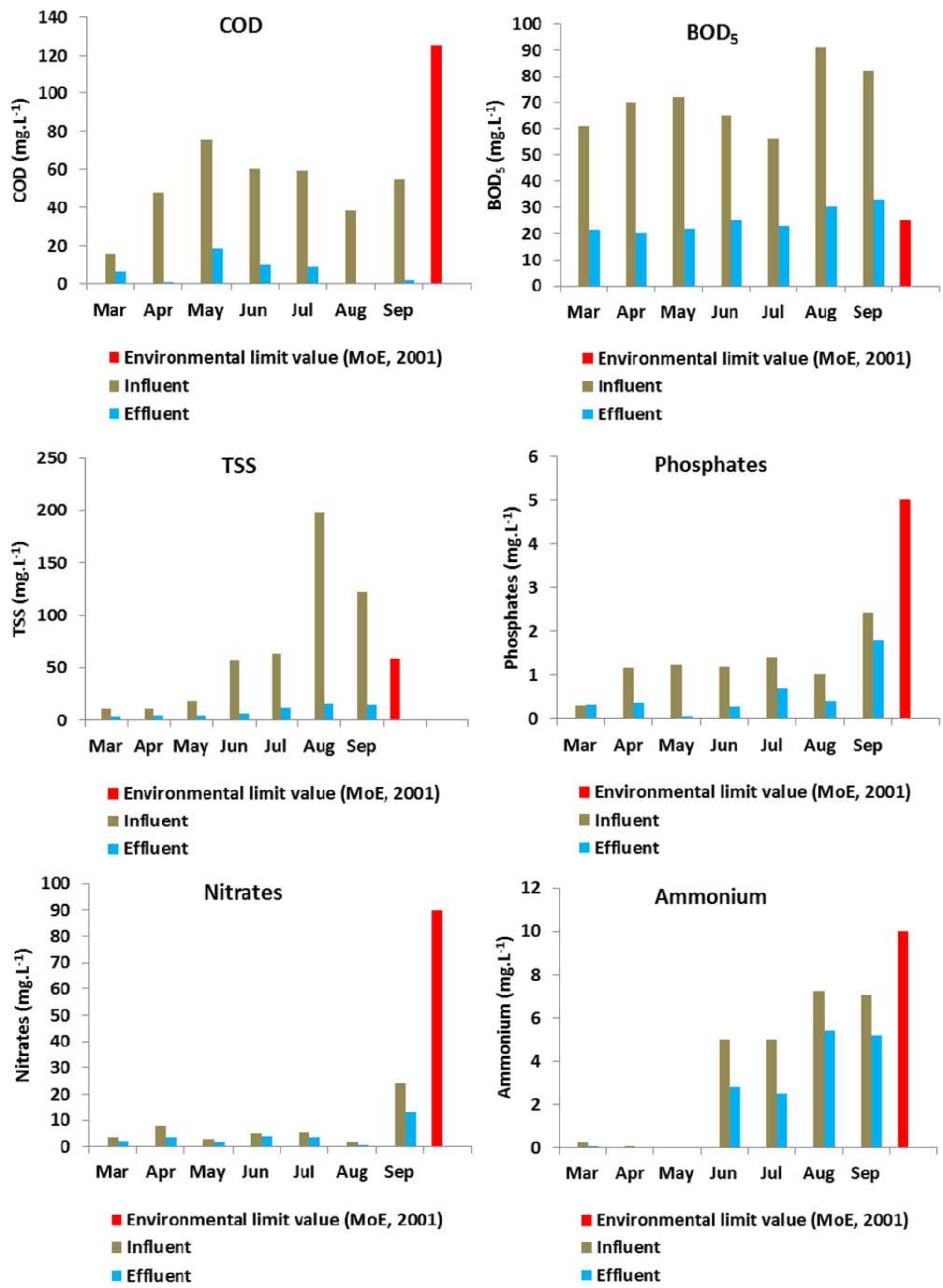

Fig. 5. Monthly analyses of wetland influent (Litani River) and effluent for COD, BOD_5, Total suspended solids (TSS), phosphates, nitrates and ammonium. [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

Physico-chemical analyses of wetland influent and effluent

The minimum, maximum, mean values and SD of pH, COD, BOD_5, total suspended solids (TSS), nitrates (NO_3—N), ammonium (NH_4—N), phosphates (PO_4—P) and potassium (K) are shown for the Litani influent water as well as for the wetland effluent in Tables 1 and 2, respectively. In addition, the monthly trends of the considered parameters are given in Fig. 5.

The influent pH, COD, NH_4—N, NO_3—N and PO_4—P concentrations (Table 1) fall within the range of the environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001). However, the influent BOD_5 and TSS concentrations were above the given national standards. In fact, the Lebanese discharge limits for surface water enforce a COD $<$ 125 mg/L, $BOD_5 <$ 25 mg/L and TSS$<$ 60 mg/L. In addition, the recommended range of effluent specifications for wastewater reuse in irrigation based on

Table 3 Wetland removal efficiency for physico-chemical parameters

	Removal efficiency (%)		
Physico-chemical parameters (mg.L^{-1})	RR-min	RR-max	RR-Mean ± SD
COD	59.77	100.00	87.01 ± 14.67
BOD_5	59.76	71.43	64.99 ± 4.85
Total Suspended Solids	57.08	91.87	86.18 ± 14.52
chloride	0.00	36.17	19.33 ± 16.04
Nitrates	22.00	58.82	43.11 ± 12.50
Ammonium	11.60	75.00	34.82 ± 20.35
Phosphates	0.00	94.35	55.07 ± 33.87
Potassium	0.00	91.07	73.05 ± 39.23

proposed Lebanese guidelines (FAO/UTF/LEB/019/LEB 2011) equally necessitates effluent concentrations of COD < 125 mg/L, BOD_5<25 mg/L and TSS < 60 mg/L for a water of Category I that is suitable for the irrigation of any kind of crops.

The effluent pH, COD, BOD_5, TSS, NH_4—N, NO_3—N and PO_4—P concentrations (Table 2) were within the range of the adopted environmental limit values. The constructed wetland treatment system achieved effluent quality that satisfies these requirements in terms of COD and TSS in all periods. The requirements were also met for BOD_5 except the summer months of August and September.

Table 6 Wetland removal efficiency for pathogens

	Removal efficiency (%)
Pathogens in water	RR-Mean
Total Coliform (CFU/100 mL)	99.98
Faecal Coliform (CFU/100 mL)	99.84
E. coli (CFU/100 mL)	96.51
Salmonella (CFU/100 mL)	100.00

The average removal efficiencies were 87.01 ± 14.67% for COD, 64.99 ± 4.85% for BOD_5, 86.18 ± 14.52% for TSS, 43.11 ± 12.50% for NO_3—N, 34.82 ± 20.35% for NH_4—N, 55.07 ± 33.85% for PO_4—P and 73.05 ± 39.23% for K (Table 3). Some of the results are different from those reported by Amacha *et al*. (2017) who worked on the same wetland for the season extending from April 2014 till July 2015;

Table 4 Pathogens analyses of influent (Litani River) water as compared to recommended limits

	Influent (Litani water)			Environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001)	Effluent specifications for wastewater reuse in irrigation based on proposed Lebanese guidelines (FAO/UTF/LEB/019/LEB 2011)		
Pathogens in water	Mean value	SD	(%) samples meeting the limit values of MoE		Water Category I	Water Category II	Water Category III
Total Coliform (CFU/100 mL)	$1.83*10^{10}$	$4.83*10^{10}$	_	_	_	_	_
Faecal Coliform (CFU/100 mL)	$1.87*10^{6}$	$3.6*10^{6}$	0	<2000	<200	<1000	_
E. coli (CFU/100 mL)	$6.19*10^{4}$	$9.6*10^{4}$	14	<2000	<200	<1000	_
Salmonella (CFU/100 mL)	Present	_	28	Absent	Absent	Absent	Absent

Table 5 Pathogens analyses of wetland effluent water as compared to recommended limits

	Effluent			Environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001)	Effluent specifications for wastewater reuse in irrigation based on proposed Lebanese guidelines (FAO/UTF/LEB/019/LEB 2011)		
Pathogens in water	Mean value	SD	(%) samples meeting the limit values of MoE		Water Category I	Water Category II	Water Category III
Total Coliform (CFU/100 mL)	$2.87*10^{6}$	$5.94*10^{6}$	_	_	_	_	_
Faecal Coliform (CFU/100 mL)	$1.92*10^{3}$	$4.88*10^{3}$	86	<2000	<200	<1000	_
E. coli (CFU/100 mL)	$1.73*10^{3}$	$4.52*10^{3}$	86	<2000	<200	<1000	_
Salmonella (CFU/100 mL)	Absent	_	100	Absent	Absent	Absent	Absent

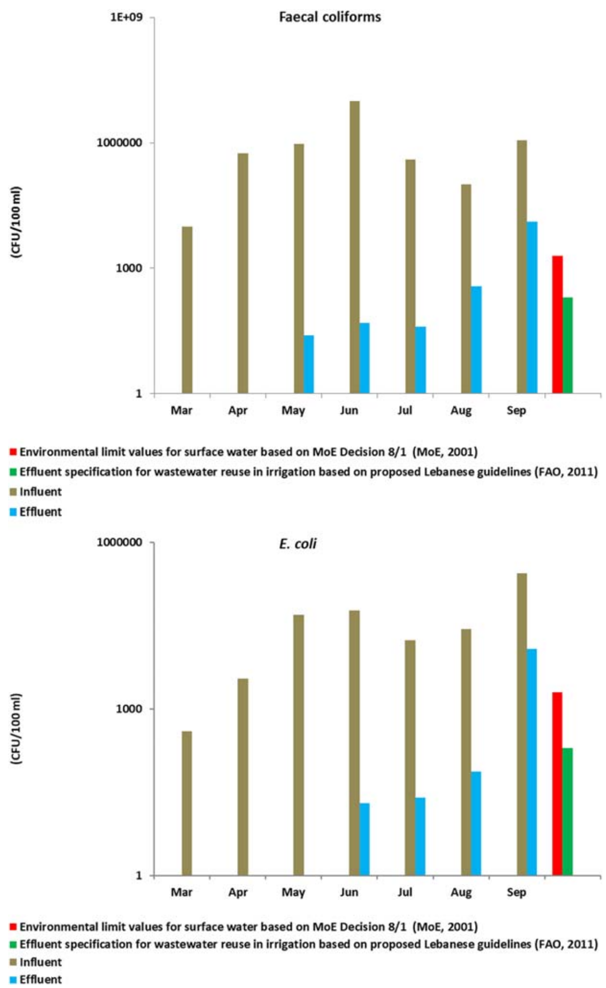

Fig. 6. Monthly analyses of wetland influent (Litani River) and effluent for faecal coliforms and *E. coli*. [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

particularly, the average removal efficiencies were 62.47% for NO_3—N, 93.3% for NH_4—N and 82.82% for PO_4—P, higher than the values obtained in the current study. They show clearly that the performance of the wetland for the removal of physic-chemical contaminants is decreasing year after year, this could be mainly attributed to a bad maintenance of wetland vegetation. Only the removal efficiency of BOD_5 (66.08%) was similar to that obtained by Amacha *et al*. (2017). The results are also in agreement with the findings of El-Sheikh *et al*. (2010) with removal rates of 52% BOD_5, 87% TSS and 52% PO_4 for a free surface constructed wetland in Egypt. The results are equally in agreement with the findings of Kadlec & Wallace (2009), who mentioned that the free water constructed wetlands are more efficient in the removal of organics and suspended solids, compared with nitrogen and phosphorus removal. Removal efficiencies above 70% can be achieved for TSS, COD and BOD_5 (Kadlec & Wallace 2009). Many authors reported in literature that CWs often show limited capacity for nutrient reduction. Among them, Anderson *et al*. (2005) and Vymazal (2007) reported removal efficiencies typically ranging from 40% to 50% for nitrogen and from 40% to 90% for phosphorous. Ghermandi *et al*. (2007) assessed the performance of 38 tertiary treatment wetlands worldwide using FWS CWs and found that on average, these CWs can efficiently remove BOD_5 (77.1%), TSS (78.1%) and COD (77.3%). The removal of NH_4—N and total phosphorous (TP) is rather variable, ranging from 28 to 96%, and 13 to 75%, respectively. In the free water surface CWs, plant uptake is considered as the primary mechanism for reducing nitrogen (Vymazal 2007). Phosphorus removal is variable and is largely dependent on both hydraulic loading rate (HLR) and size of systems (Braskerud *et al*. 2005; Tonderski *et al*. 2005). Scholz (2006) and Mustafa *et al*. (2009) equally reported that the CW systems have a high capacity to remove pollutants due to the large size of the wetland cells and the relative high mean retention time.

Pathogens analyses of wetland influent and effluent

The mean values and standard deviations of total coliforms, faecal coliforms, *E. coli* and the *Salmonella* presence are

Table 7 Trace metals analyses of influent (Litani River) as compared to recommended limits

Trace metals ($mg.L^{-1}$)	Concentration values - Influent (Litani water)				Environmental limit values for surface water ($mg.L^{-1}$) (MoE 2001)	Limit values for irrigation: long term use (mg.L-1) (US EPA 2004)	Limit values for landscape/agricultural irrigation (mg.L-1) (Salgot *et al*. 2006)
	Min	Max	Mean	SD			
Zn	<0.001	0.74	0.13	0.28	5	2.00	_
Cu	4.37	7.02	5.83	1.07	0.5	0.20	0.2-1
Pb	<0.001	0.33	0.16	0.09	0.5	5.00	0.10
Mn	0.10	0.51	0.29	0.19	1	0.20	0.20
Ni	<0.001	2.23	0.75	0.91	0.5	0.20	_
Hg	<0.001	0.0212	0.0034	0.0079	0.05	_	0.001-0.002
As	0.16	0.40	0.26	0.13	0.1	0.10	0.02-0.1
Cd	<0.001	<0.001	<0.001	_	0.2	0.01	0.005
Cr	<0.001	<0.001	<0.001	_	2	0.10	0.01-0.1

Table 8 Trace metals analyses of wetland effluent as compared to recommended limits

Trace metals ($mg.L^{-1}$)	Concentration values - Effluent				Environmental limit values for surface water ($mg.L^{-1}$) (MoE 2001)	Limit values for irrigation: long term use (mg.L-1) (US EPA 2004)	Limit values for landscape/ agricultural irrigation (mg.L-1) (Salgot et al. 2006)
	Min	Max	Mean	SD			
Zn	<0.001	0.18	0.04	0.07	5	2.00	_
Cu	2.75	5.62	4.17	1.05	0.5	0.20	0.2-1
Pb	<0.001	0.66	0.20	0.31	0.5	5.00	0.10
Mn	0.04	0.27	0.15	0.11	1	0.20	0.20
Ni	<0.001	4.69	0.81	1.73	0.5	0.20	_
Hg	<0.001	0.0094	0.0032	0.0041	0.05	_	0.001-0.002
As	<0.001	0.33	0.07	0.13	0.1	0.10	0.02-0.1
Cd	<0.001	<0.001	<0.001	_	0.2	0.01	0.005
Cr	<0.001	<0.001	<0.001	_	2	0.10	0.01-0.1

shown for the Litani influent water as well as for the wetland effluent in Tables 4 and 5, respectively.

The Litani water is highly polluted with total coliforms, faecal coliforms, *E. coli* and *Salmonella* is present in water most of the time. All pollutants do not meet the environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001). In fact, the Lebanese discharge limits for surface water enforce a limit of 2000 CFU/100 ml for faecal contamination and the absence of *Salmonella*.

The constructed wetland system effluent was shown to be effective for the removal of pathogens from Litani river water. Figure 6 shows, at a logarithmic scale, that the mean number of faecal coliforms and *E. coli* mainly ranged around 10^3 coliforms/100 mL in the effluent of the system. The number of faecal coliforms and *E. coli* even decreased to below 10^3 coliforms/100 mL in most of the monthly measurements except for September that represent the peak river pollution. The removal of faecal coliforms was around 99.84% in the constructed wetland system (Table 6). However, despite the high removal efficiencies, the effluent coliform numbers in the present study were found to fluctuate drastically from month to month (Fig. 6) and were still high particularly in August and September months. The effluent of the system was evaluated in terms of its potential for reuse in agricultural irrigation according to the criteria (Table 5) defined by the proposed Lebanese guidelines for wastewater reuse in irrigation, in which Category I involves the irrigation of any kind of crop whereas Category II involves only irrigation of fruit trees and cereal crops not even vegetables to be eaten cooked. The findings revealed that the effluent met the standards except in September in terms of faecal coliforms and *E. coli* removal. The effluent was free from *Salmonella* in all studied months.

These results are consistent with the findings for constructed wetlands in literature. Total and faecal coliform removal efficiencies achieved in the constructed wetland system was comparable to the efficiencies reported in the study of Ottová et al. (1997) ranging usually between 98.1 and 99.9%. Other studies also showed coliform removal efficiencies of 98.8% on average in CWs (Masi et al. 2008; Raboni et al. 2014).

Wetlands support a large and diverse population of bacteria which grow on the submerged roots and stems of aquatic plants and are of particular importance in the removal of microbial contaminants (El-Sheikh et al. 2010). In addition, the factors affecting bacterial elimination in CWs include vegetation, hydraulic regime and retention time, water composition, seasonal variations and pH (Davies-Colley et al. 1999). For free water surface flow CWs, sunlight intensity and exposure time are also critical influencing factors (Mayo 2004).Finally, the typical warm climate of Mediterranean areas, all year-round is suitable for using CW as wastewater treatment, since it is conducive to the plant growth and microbiological activity, which have a positive effect on treatment efficiency (Kaseva 2004; Bojcevska & Tonderski 2007; Barbagallo et al. 2012).

Trace metals analyses of wetland influent and effluent

The minimum, maximum, mean values and standard deviations of trace elements mainly Zn, Cu, Pb, Mn, Ni, Hg, As, Cd and Cr are shown for the Litani influent water as well as for the wetland effluent in Tables 7 and 8, respectively. In addition, the monthly trends of these parameters are given in Fig. 7.

Both influent and effluent Cu, Pb, As and Ni concentrations greatly exceed the range of the environmental limit values for surface water based on MoE Decision 8/1 (MoE 2001). However, the influent Zn, Mn and Hg concentrations were within the given national and international standards. Cd and Cr were less than 0.001 $mg.L^{-1}$. Such facts confirm clearly how industrial emissions in river bed violate severely the Litani water quality standards. Table 9 illustrates a summary of data concerning the removal efficiency of trace metals in constructed wetland system. On average, the constructed wetland shows moderately good removal

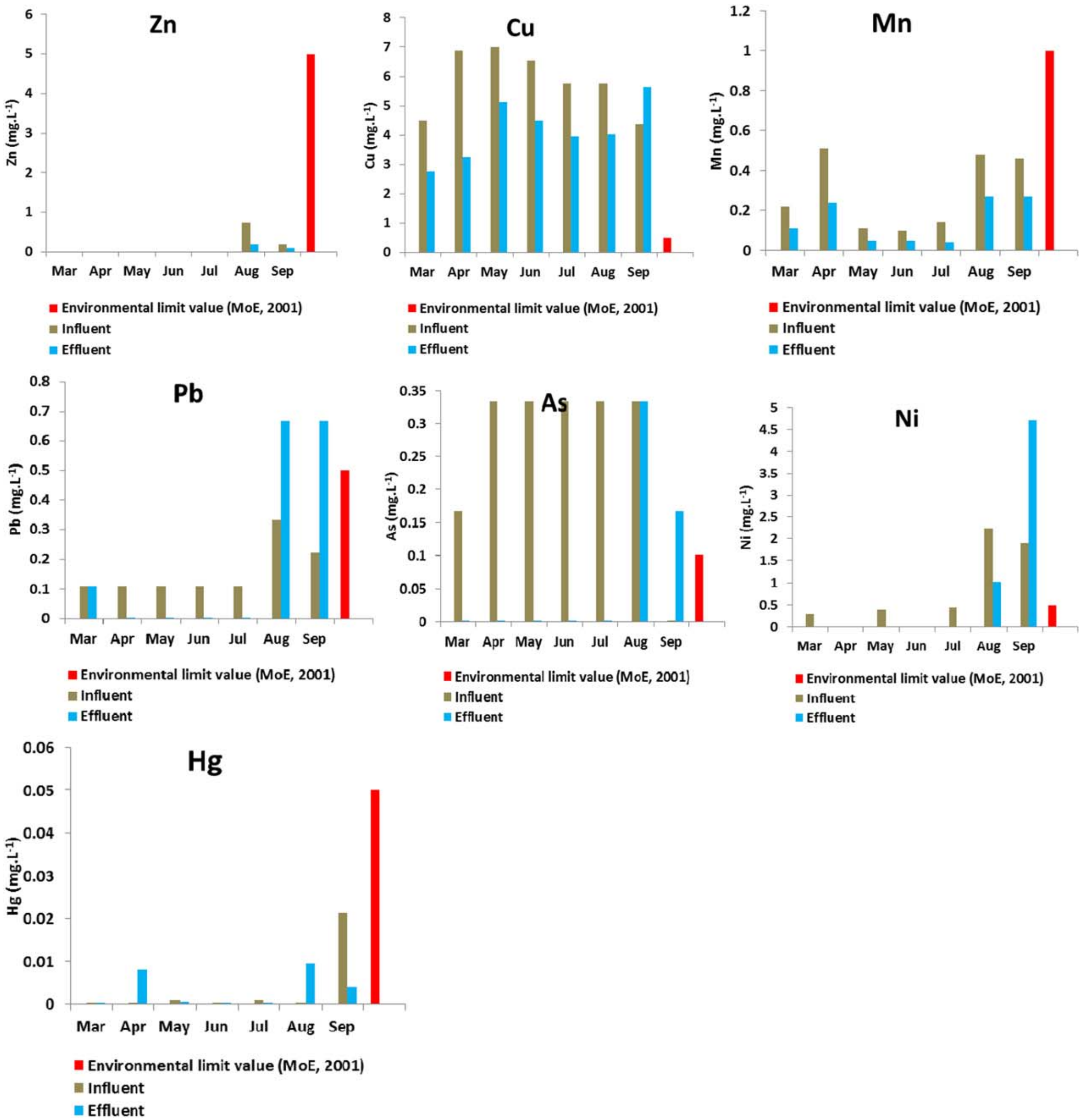

Fig. 7. Monthly analyses of wetland influent (Litani River) and effluent for trace metals. [Colour figure can be viewed at wileyonlinelibrary.com] [Colour figure can be viewed at wileyonlinelibrary.com]

efficiency for some metals (Zn, Mn, As), while other constituents are poorly removed or not removed at all. An explanation for such poor performance might be the fact that, unlike organic pollutants, metals cannot be removed from water directly by means of biological processes. Other processes occur in wetlands. These include uptake by plants, physical interactions with the substrate, formation of complexes and subsequent precipitation (Kleinmann & Girts 1987). According to El-Sheikh *et al*. (2010), important removal mechanisms for metals include cation exchange and chelation with wetland soils and sediments, binding with humic materials, precipitation as insoluble salts of sulfides, carbonates and oxyhydroxides, and uptake by plants, algae and bacteria.

We must also address the fact that non biodegradable pollutant concentration may increase in the outflow, due to the fact that large water quantities may be lost through evapotranspiration from wetland vegetation particularly during the month having peak ET (August–September) as

Table 9 Wetland removal efficiency for trace metals

Trace metals ($mg.L^{-1}$)	Removal efficiency (%)		
	RR-min	RR-max	RR-mean
Zn	42.86	74.99	58.56
Cu	0.00	52.73	28.34
Pb	0.00	100.00	0.00
Mn	41.30	71.43	49.01
Ni	0.00	100.00	0.00
Hg	0.00	88.89	6.36
As	0.00	100.00	72.73
Cd	_	_	_
Cr	_	_	_

reported by different authors (Green *et al*. 2006; El Hamouri *et al*. 2007; Headley & Tanner 2012).

Finally, other plant species, if adopted in the studied wetland, could contribute for further improvement of metal removal efficiency. Some studies showed that the aquatic macrophyte *Typha domingensis*, when compared to other species, has a great potential in constructed wetlands for phytoremediation of water contaminated with metals (Gomes *et al*. 2014).

Conclusion

The constructed wetland was able to treat more than 20% of the Litani River flow in the dry season of year 2016. In addition, results revealed that the average removal efficiencies were 64.99% for BOD_5, 86.18% for TSS, 43.11% for NO_3—N, 34.82% for NH_4—N, 55.07% for PO_4—P and 99.84% for faecal coliforms. Thus, the expected removal rates of 47% BOD_5, 81% TSS, 44% NH_4—N, 46% NO_3—N, 23% PO_4 and 99% fecal coliforms were met, as reported by LRMBS (2012).

Innovative, low-cost and natural water treatment technologies represent a valid solution to improve water quality in the Southern Mediterranean water courses. However, a deeper comprehensive performance assessment of CW system for removing various contaminants from the Litani River, over a longer time period, is needed.

The analysis of physico-chemical, pathogens and trace metal parameters revealed that river water greatly suffers from microbial and trace metals pollution. Within this context, CWs seem to be a promising green technology for the reduction of bacterial contamination and the restoration of river water bodies located downstream of polluted catchment. For this purpose, the introduction of CWs near point source microbial pollution along southern Mediterranean water courses is a promising strategy for eco-remediation.

Moreover, in such cases (as it is the Litani River), in order to limit the impact on water resources, biodiversity and human health, it is necessary to support an integrative approach for the prevention and control of industrial emissions into water, in particular when conveying metals.

Finally, adequate monitoring and policy measures should be adopted to facilitate the integration of CWs in the Southern Mediterranean environments. More research is needed to improve the selection and management of wetland plant species in order to ensure the treatment effectiveness. Further studies conducted by researchers and engineers together, to design test and improve treatment modules for different pollutants, including metals are required.

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