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Wastewater Treatment by Floating Macrophytes (*Salvinia Natans*) Under Algerian Semi-Arid Climate

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Abstract

Macrophyte pond has developed strongly in the field of wastewater treatment for irrigation in rural areas and small communities. Their association allows, in some cases, to increase the hydraulic capacity while maintaining the highest level of quality.

The present work is devoted to the treatment of domestic wastewater under climatic conditions of Algeria (semi-arid) through a system using two tanks planted with *Salvinia natans*.

The performance study and treatment efficiency of the system overall shows that the latter provides a significant removal of nitrogen pollution: total Kjeldahl nitrogen NTK (85.2%), Ammonium NH_4^+-N (79%), Nitrite NO_2^--N (40%) also, a major meaningful reduction of biochemical oxygen demand BOD_5 was observed at the output of the system (96.9 %). As BOD_5, the chemical oxygen demand (COD) removal was higher than 95 % at the exit of the two tanks. A moderately low yield of phosphate-phosphorus (PO_4^{3-}-P) was achieved with values not exceeding 37 %. In general, the quality of treated effluent meets the Algerian standard of discharge and which allows us to select a suitable species in constructed wetland treatment systems under semi-arid climate.

Key words

Nutrient removal, Salvinia natans, semi-arid climate, Wastewater treatment

INTRODUCTION

In most countries of the world, there has been growing and irreversible interest of the public for the protection of the environment. In Algeria, for instance, the water pollution problem is quite serious and therefore, purification techniques including constructed wetlands (CWs) using macrophytes are currently widely used for treatment of wastewater. CWs become an interesting alternative for the treatment of wastewater, seen the great benefits that they exhibit, they are less expensive to build and operate, are constructed directly on the wastewater discharge site, require little mechanized equipment and ultimately are less sensitive to changes in pollutant loads [1].

The main functions of CWs include surface water storage, holding and recycling nutrients, providing wildlife habitats, stabilizing shorelines, controlling and buffering storm related flooding, recharging groundwater, providing treatment for pollutants in water [2]. Furthermore, CWs can effectively remove organic matter, suspended solids, metals, and excess nutrients (such as nitrogen, phosphorus, etc.) through various processes including filtration, sedimentation, biological and microbiological adsorption, and assimilation [3].

Macrophyte-based wetland systems (MBWS) are reported to be effective for the treatment of primary, secondary and tertiary urban wastewater, domestic, stormwater, agricultural and industrial wastewater [4, 2, 5], however, the challenge is to maximize efficiency the lowest possible cost [6]. The choice of plants is an important issue in the filters planted with macrophytes because they have to survive the potential toxic effects of sewage and their variability. The use of local plants with economic and environmental interests in the sewage systemmakes them more exciting.

Aquatic plants, emergent or free floating, acquire more and more importance in the world especially in countries with hot climates where the photosynthetic efficiency is important. The produced biomass is valued using biomethanation or by incorporation in animal nutrition [7]. Floating or emergent aquatic plants, such as water hyacinth (*Eichhornia crassipes* (Mart) Solms), water lettuce (*Pistia stratiotes L.*), *Salvinia natans* (L.), cattail (*Typha latifolia L.*), bulrush (*Scirpus validu .L.*), are able to treat wastewater with high purification yields [8, 9, 10].

2. MATERIALS AND METHODS

2.1. Experimental device and methods

The experiment was carried out under semi-arid conditions at the town of Merouana (35°37’43’’N, 05°54’42’E) located 500 km East of Algiers (Fig. 1), which has a semi-arid to arid Mediterranean climate with an average rainfall of about 240mm per year and an average temperature of about 5 to 38°C. The experimental device used for the present study depicted in Figure 2. Thre biofiltration unit, comprised two tanks of 75 liters capacity (50 cm(L) x 50 cm(W) x 60 cm(H)). The tanks are filled to 5 cm in depth and 30 cm with respectively gravel (5-10mm) and soil with silty clay-sandy texture (31% clay, 20% silt and 49% sand). The tanks were planted with *S. natans* (36.5 g per tank).

The systems supplied by raw domestic wastewater (25 liters/day) acquired from Merouana municipal sewage treatment works, and Table 1 summarizes its physicochemical characteristics. Tanks inclined at 10° to the surface such that water can be directly downstream, and fitted with a drain at the bottom for percolating water collection (effluent). Wastewater passes from a tank to another through a 4-cm (outside diameter) perforated PVC pipe. The experiment lasted eight months from April to November 2015.

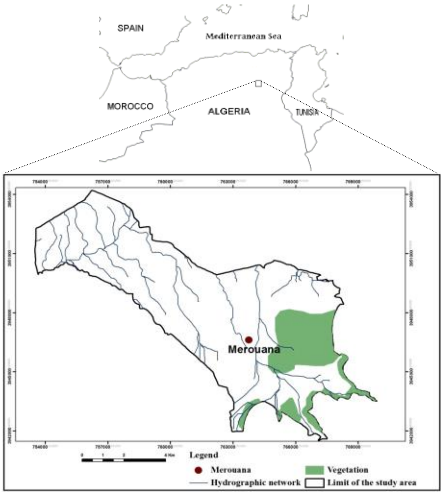

Figure 1. Location map of analyzed area.

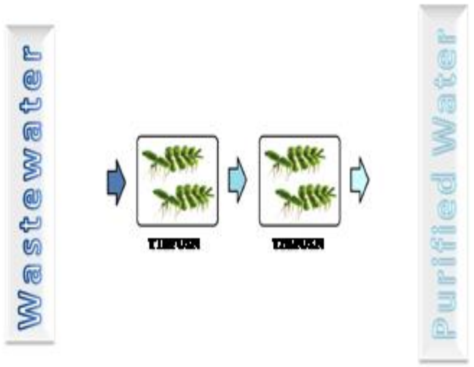

Figure 2. Macrophyte-biofiltration system used for wastewater treatment. T1 BFUSN, T2 BFUSN(Tanks 1 and 2 of second biofiltration unit planted with Salvinia natans).

.2.2. Wastewater quality monitoring and statistical analyses

The CWs placed in operation in April 2015. Their removal efficiency and treatment performance evaluated in eight sampling campaigns, which took place in the eight-month period from April to November 2014.

Wastewater samples (influent and effluent) were collected and stored in glass bottles, transported to the laboratory and analyzed immediately for biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), nitrate-nitrogen (NO_3-N), nitrite-nitrogen (NO_2-N), ammonium-nitrogen (NH_4-N) and phosphate–phosphorus (PO_4-P) according to French standard methods [11]. In addition, measurement of temperature (T) and pH had done using a portable instrument (ProfiLine pH 3110, WTW). We used at least five repetitions of each sample to achieve sufficient accuracy.

Treatment efficiency of chemical parameters was calculated as the percentage of removal for N and P as follows:

Removal efficiency (%) = $\left(\frac{Ci-Ce}{Ci} \right) x\ 100$, where Ci and Ce are the influent and effluent concentrations in mg/L.

Data analyzed using one-way ANOVA and least significant difference tests (LSD at alpha = 0.05) to find differences among means of the different physicochemical parameters of wastewater before and after treatment. Statistical analyses carried out using STATGRAPHICS Centurion XV (Manugistics, Rockville, MD, USA)

3. RESULTS AND DISCUSSION

Constructed wetlands (CWs) using macrophytes are currently widely used for treatment of wastewater. In order to investigate whether the CWs using emergent macrophyes (EM) and floating macrophytes (FM) were effective for the treatment of domestic wastewater, we carried out the present study the aquatic plant species, namely *S. natans* an FM

Overall, our results indicate that the biofiltration system (FM) is highly effective in the treatment of domestic wastewater (Tables 1, 2 and Fig. 3a-i).

3.1. Mean physicochemical parameter variation

Table 1 summarizes results of the measured physicochemical proprieties of wastewater before and after biofiltration treatment. Figure 3, however, displays the seasonal variation of all these parameters throughout the eight-month period of experience. In contrast to the mean values of the wastewater temperature, which showed only slight spatial variations along the biofiltration unit and generally ranged from 18.2 to 24.6ºC depending on the season (Fig. 3a), all the studied parameters were showed a significant variation after wastewater biofiltration (Table 1).

As revealed by Figure 3b, the mean pH value of input water used in this study was 7.2 and ranged from 7 to 7.5. However, at the outlet of biofiltration units, the pH values were ranging from 7.1 to 8.3. This decrease in pH values was statistically significant ($P<0.01$).

In contrast to the slight decrease observed in the mean values of wastewater temperature at the outlet the biofiltration unit, can be explained by the fact that water surface was fully hedged by *S.natans* (Fig. 3a and Table 1), the mean values of pH were significantly increased (Table 1). Similar results observed in previous studies [12- 13]. Both decrease in temperature and increase in pH can be explained by the algal growth observed at the surface of each tank since foliar cover may preserves the tank surface against summer drying and offer shade to bacteria and the fact that algae can absorb CO_2 faster than it can be replaced by bacterial respiration [12].

3.2. Pollutant removal efficiency

Table 2 presents the variation of mean removal efficiency along the various biofiltration unit for all the pollutants. Overall, we calculate the removal for each constituent based on its concentrations at the inlet and outlet of the biofiltration unit. As displayed by Table 2, with the exception of nitrate (NO_3-N), the biofiltration system exhibited high percentages of removal efficiency of nitrogen from wastewater namely in term of NH_4-N, and TKN.

Regarding nitrogen pollution, our results indicate high average removal efficiencies of the biofiltration system, particularly for ammonium (NH_4-N) and TKN. Consistent with this, in aquatic ecosystems, the decrease in NH_4-N content was usually explained by the transformation of NH_4-N into NO_3-N (the so-called nitrification), which is favored by aerobic conditions, plus a subsequent denitrification [14]. Another possible way is volatilization as NH_3, which is inducible by the increase of pH [15]. Under natural growth conditions, NH_4-N is probably the main N source preferred for most aquatic macrophytes as revealed by results of numerous studies [16-17].

Table 1. *Physicochemical parameter and pollutant concentration statistics*

		INLET	**OUTLET**	**F**	**LSD5%**
			BFUSN		
pH	Mean	7.18 $^{(c)}$	7.41 $^{(bc)}$	5.50**	0.29
	SD	0.17	0.23		
	Min	7.0	7.1		
	Max	7.5	7.75		
T °C	Mean	21.13 $^{(a)}$	19.94 $^{(ab)}$	1.63 $^{n.s}$	n.s
	SD	2.25	2.10		
	Min	18.2	17.3		
	Max	24.6	23.3		
NH_4-N	Mean	64.36 $^{(a)}$	13.38 $^{(bc)}$	264.3***	5.51
	SD	8.46	2.29		
	Min	51.84	10.42		
	Max	76.18	16.46		
NO_3-N	Mean	2.43 $^{(b)}$	3.61 $^{(b)}$	25.77***	10.11
	SD	0.93	2.32		
	Min	1.4	1.0		
	Max	3.9	6.9		
NO_2-N	Mean	0.128 $^{(a)}$	0.083 $^{(ab)}$	3.73*	0.056
	SD	0.05	0.06		
	Min	0.08	0.02		
	Max	0.20	0.22		
TKN	Mean	102.4 $^{(a)}$	15.84 $^{(b)}$	97.43***	86.52
	SD	22.81	11.01		
	Min	69.6	6.40		
	Max	131.3	40.1		
PO_4-P	Mean	10.95 $^{(a)}$	6.86 $^{(b)}$	10.66***	3.85
	SD	1.47	1.90		
	Min	8.9	5.1		
	Max	13.2	11.1		
BOD_5	Mean	311.3 $^{(a)}$	8.31 $^{(b)}$	43.7***	302.07
	SD	129.7	3.65		
	Min	112.4	4.2		
	Max	466.1	15.5		
COD	Mean	981.7 $^{(a)}$	40.56 $^{(b)}$	209.08 ***	935.64
	SD	171.4	4.47		
	Min	683.5	33.2		
	Max	1230.1	47.1		

Table 2. Removal efficiency (%) of different nutriments for the three units

		BFUSN	**F**	**LSD5%**
NH_4-N	Mean	79.0 $^{(a)}$	18.18***	3.45
NO_3-N	Mean	17.1 $^{(a)}$	n.s	n.s
NO_2-N	Mean	40.0 $^{(a)}$	n.s	n.s
TKN	Mean	85.2 $^{(a)}$	4.32*	7.75
PO_4-N	Mean	36.9 $^{(a)}$	n.s	n.s
BOD_5	Mean	96.9 $^{(a)}$	n.s	n.s
COD	Mean	95.7 $^{(a)}$	5.04*	1.25

*, **, *** indicate significant differences at $P<0.05$, 0.01 and 0.001 respectively. n.s, not significant. Different small letters mean significant differences ($P < 0.05$) among treatments.

The lower removal of NO_3-N in the outlet water compared to wastewater, on some individual occasions, bear witness to the great nitrifying activity. In agreement, aquatic macrophytes have well-developed internal air spaces (aerenchyma) throughout the plant tissues that ensures the transfer of oxygen to the roots and rhizomes [18]. The oxygen that diffuses through the roots stimulates growth of nitrifying bacteria in the rhizosphere [19]. In general, the positive removal efficiencies of BFUSN can probably due to macrophytes uptake [20] and/or the process of denitrification [21].

Nitrite concentrations of the inflow and the outflow are of secondary importance for the evaluation of the overall annual nitrogen removal of the wetland [22]. In general, the low outflow concentrations (< 1mg/L) been brought about by nitrification of NH_4-N to NO_3-N and NO_2-N at aerobic plant roots, with subsequent rapid denitrification to the atmosphere in the anaerobic parts of the substrate or is immobilized by plant uptake, adsorption, and precipitation [23].

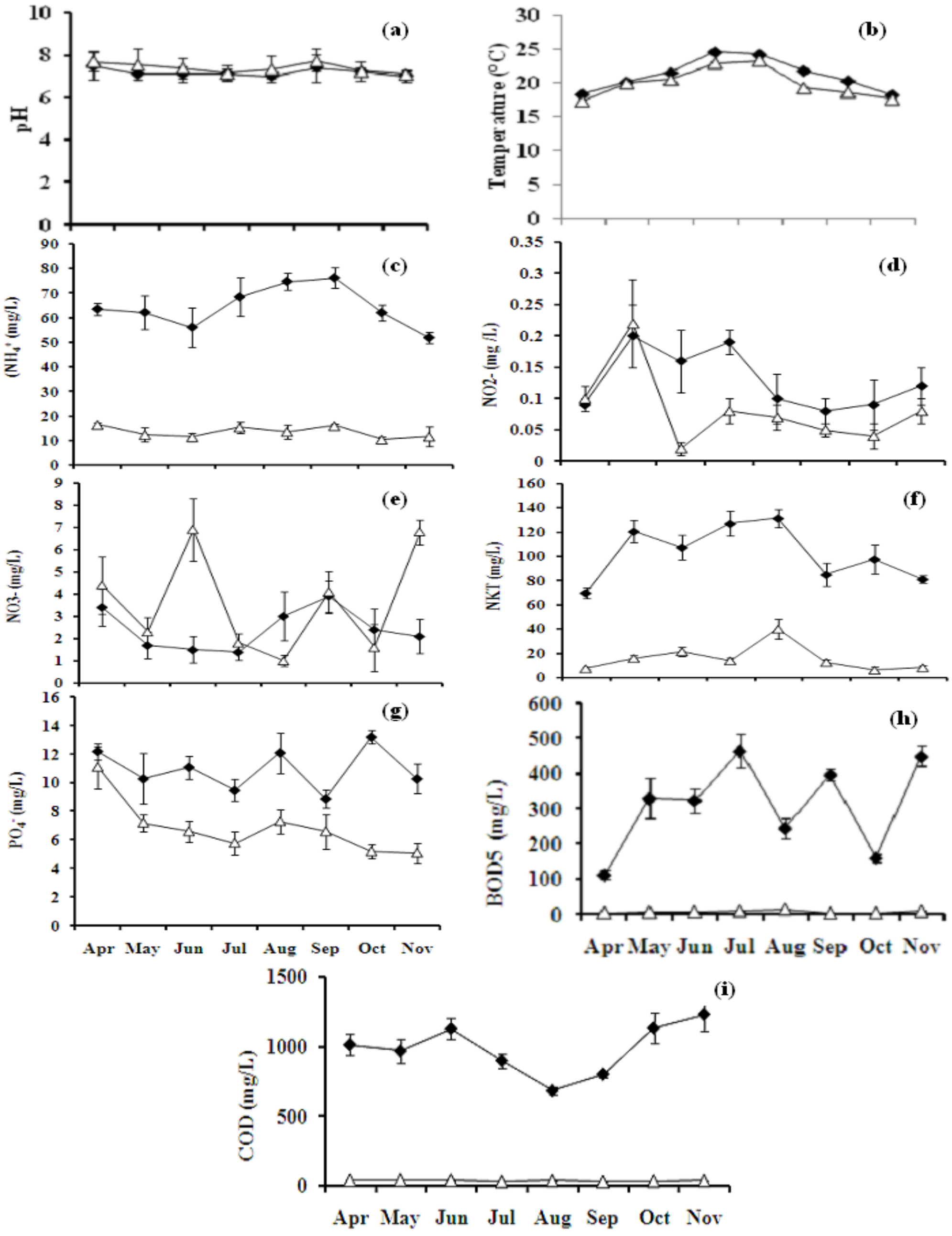

Figure 3. Time-course of change in Temperature (a), pH (b), NH_4-N (c), NO_2-N (d), NO_3-N (e), TKN (f), PO_4-P (g), BOD_5 (h), COD (i) throughout the period of study (Mean ± SD).

The high levels of TKN removal efficiencies in all the treatments are probably due to macrophytes that play a major role in eliminating TKN through nitrification, metabolism, and storage processes [24, 25, 26]. TKN removal efficiency increases with increase in pH [27-28].

In addition, it appears from the same figure that the concentration of the main forms of nitrogen (NH_4-N, NO_3-N and TKN) and PO_4-P as well as BOD_5 and COD in wastewater showed highly significant decreases ($P<0.001$) after biofiltration (Table 1 and Fig. 3).

Table 2 also showed the variation in removal of orthophosphate from the wastewater in the various experimental devices. Overall, there is no significant difference in the removal efficiency of PO_4-P among the biofiltration unit. The efficiencies of removal in BFUSN increase by 09-60.6% with an overall average of 36.9%. It is worth noting that even though PO_4-P concentrations increased in the outlet waters on some individual occasions.

The moderately high level of phosphorus monitored as orthophosphate (PO_4-P) could be due to direct use of PO_4-P by plants [29] or attributed to adsorption on the soil particles and precipitation reactions [30]. However, it also added that release of orthophosphate and clogging of the system could explain this low average reduction.

The average concentrations and overall efficiency elimination of BOD_5 in the influent and effluent throughout the study period displayed in Figure 3h and Table 2 respectively. The removal of BOD_5 found higher (96.9 %).

Otherwise, the higher reduction of BOD_5 can be attributed to several mechanisms (physical and biological processes) including sedimentation and filtration associated with settleable solids or filterable material, in addition to oxidation mainly by aerobic bacteria (protozoa, rotifers, etc.) attached to plant roots [31].

The load of domestic wastewater chemical oxygen demand (COD) fluctuates greatly between 683.5 mg/L and 1230.1 mg/L with a mean value of 981.7 mg/L. Thus, at the outlet of the three units follows fluctuations in domestic wastewater with significant picks (Fig. 3i). Overall, compared to domestic wastewater, the treated wastewater quality is significantly better. The removal rates of COD (95.7 %).

Like BOD_5, COD reduction is almost entirely due to physical processes such as filtration and adsorption rather than biological processes associated with the microbial community or with the plants [32]. These findings are in agreement with some studies reported in the literature, which found better COD removal whether using floating macrophytes [33-28].

4. Conclusion

This work provides an opportunity to highlight the potential of floating plants (*S. natans*) to treat the domestic wastewater under semi-arid conditions. Overall, our result indicates that the bioinfiltration unit provide a significant removal of the organic (BOD_5, COD) and inorganic (TKN, NH_4-N and PO_4-P) pollutants from domestic wastewater. The effluent quality was lower than the Algerian standards related to effluent quality for agricultural reuse purposes, therefore, it is possible to reuse the treated wastewater for restricted irrigation and can be environmentally friendly. The good results given by *S. natans* (rare plant) involve its use in wastewater treatment in order to preserve this kind of plants. Finally, the use of this kind of biofiltration system for the treatment of other types of water pollution (e.g. microorganisms and heavy-metal pollution) is required.

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