Wastewater treatment of combined system of biofilter and constructed wetland in arid region (Touggourt-Algeria)

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Abstract: *The design of wastewater treatment system is an important challenge facing the arid areas. In this paper, an integrated system is presented and tested in situ with a vertical up-flow biofilter followed by a three separated horizontal constructed wetland. This research aims to assess the water quality parameters resulting on up flow biofilter combined, with constructed wetland planted with local plant species for the removal of organic matter and nutrients pollutants from water in arid regions. The present experiment demonstrated that the wetlands planted with P. australis and T. latifolia showed the highest removal. T. latifolia performed better than P. australis for mostly parameters, while, the wetland efficiency indicated that P. australis contributed greatly to the removal of TP.*
The methodology is based on a statistical analysis of the collected data.

Key-Words: Wastewater, Biofilter, Constructed wetland, Engineering, arid areas

I. INTRODUCTION

The degradation of water resources are a worldwide issue especially in arid regions [1]. It is strongly increased by industrialization and urban growth as well as changing climate conditions [8]. The use of treated wastewaters is an alternative for conventional water in arid regions [2]. The use of natural treatment approaches such as biopurification systems and constructed wetlands may provide additional alternative means for pollution elimination in an ecofriendly manner. The biofilter process has gradually been adopted in the small communities, since it is simple to manage and able to remove organic materials and suspended solids simultaneously [4]. Constructed wetlands can effectively remove suspended solids, organic pollutants and nutrients from wastewater [9]. These technologies can offer lower costs of construction, maintenance requirements, and lower energy consumption. This work aims to determine at the pilot scale the efficiency of an integrated wastewater treatment system made of vertical up-flow biofilter combined with three horizontal flow constructed wetlands during seven months operating in arid region through weekly physico-chemical analysis for the removal of organic matter and nutrients pollutants from water.

II. MATERIAL AND METHODS

II.1. Pilot experimental

The pilot experimental shown in Figure. 1 was carried out in the scientific and technical research center on the arid regions of Touggourt, (Algeria) for the treatment of domestic wastewaters. The area is characterized by an arid climate with a very high summer temperatures exceeding 40 °C in July and August, and winter temperatures of around 5 °C in December and January, and characterized by annual precipitation of 80mm.

The system was combined with cylindrical vertical up-flow biofilter and constructed wetlands. The biofilter had a diameter of 400mm and depth of 800mm. it was filled with three superimposed layers. The lower layer was composed of 150mm in depth of coarse gravel (Ø = 20mm), the medium layer of 400mm in depth of the fine gravel (Ø = 10mm) and the upper layer of 100mm in depth of sand (Ø = 0.2mm), the biofilter then was feeding three constructed wetland; with a height of 250mm and an area of $0.28m^2$each, these constructed wetlands were filled with the same substrate as the biofilter, in the inlet and outlet was filled with coarse gravel, the rest by two superimposed layers of fine gravel and fine sand. The constructed wetland were planted individually with young plants., the first was planted with *T. latifolia*, the second with *P. australis*, and the third was without plantation to monitor the efficiency of the planted filters.

Biofilter and constructed wetlands were fed periodically once a week by 20 liters of polluted water from storage tank ($1.20m^3$) which considered as a decanting and feeding tank of the integrated system.

II.2. Methodology of sampling and analysis

Water samples were taken by opaque glass bottle (1L) after a 3 days retention time in the filters every week under normal conditions to monitor water quality, from January to July 2017 at around 9:00 am at the influent (Rw), outlet biofilter (Bf), and the outlet of each constructed wetland (Phr, Ty, Np), equal volume (1L) were collected from all sampling ports were directly transported to the CRSTRA laboratory for immediate physicochemical and biological analysis. For the determination of the BOD_5, membrane manometers (Oxitop Box WTW) were used. COD was measured according to the standard methods using the closed reflux dichromate colorimetry (AQUA Lytic Al 200, AL 120). The SS was determined using weight method (Centrifuge. ROTOFIX 32 A. Hettich), TP was determined using persulfate digestion followed by the ascorbic acid spectrophotometric method, while PO_4-P was measured using the ascorbic acid spectrophotometric method (Spectrophotometer UV Visible, JENWAY 6310, wavelength 880 nm). TKN was determined using the Kjeldahl method, NH_4-N was determined according to the titrimetric method. All samples were manually collected, handled and analyzed following Rodier [11] approved standard methods.

Figure1. Schematic representation of the integrated system with biofilter and a constructed wetlands

III. RESULTS AND DISCUSSION

III.1. Performance and removal efficiencies

- *Suspended solid SS***:** The highest values for SS was noted for raw wastewater varying between 20 and 1261.3 mg l^{-1} and with an average concentration 423.33 ± 281 mg l^{-1}. The removal of SS was very efficient and consistent within the biofilter ranged between 74.03 and 94.43% for Bf (Figure 2). This emphasizes the importance of the primary treatment on SS removal, crucial for avoiding clogging of the bed media in wetlands [1].

- *Chemical oxygen demand COD***:** The concentrations of COD in the raw wastewater influent (Rw) were extremely high which ranged between 350-1365 mg l^{-1} during the entire experimental period. The average removal efficiencies of COD were 57%, which ranges between 28 and 80% for Bf. It is possible that the biofilter is responsible for the removal of most part of the organic matter, however the treated effluents showed a reduction values across the treatment system, the overall average COD removal values obtained were 91.07% for Phr, 90.07% for Ty and 88.52% for Np. As the water passed through the wetland, the reduction of organic matter due to decomposition was achieved by biological communities comprising aerobic, anaerobic and facultative bacteria attached to the filter medium [12].

- *Biochemical oxygen demand BOD*: During the study period, the influent (Rw) BOD_5 concentrations were varying between 60 and 490 mg l^{-1}(324.65 ± 96 mg l^{-1}). it was observed that the greatest portion of the BOD_5 was removed in the biofiltre, from 54.6 % to 83.8%, while the average removal efficiency in CWs was lower than biofilter where the complete treatment systems reached a BOD_5 average removal of 89.3%, 88.1% and 86.2% for the Ty, Phr and Np. This could be because the majority of the easily biodegradable BOD_5 is removed in the biofilter [6]. In the unplanted filter, the BOD_5 effluent concentrations showed a decrease of the removal efficiencies all along the treatment time. The lack of plant in the unplanted filter is responsible of SS, COD and BOD_5 concentration evolutions ways. So gravel can only hold back a part of polluted matters. Planted filter efficiency is in fact due to the combination of gravel and plant actions. The organic matter, expressed as BOD_5 is decomposed by aerobic and anaerobic microbial processes and also by physical processes, such as sedimentation and filtration [6]-[10].

- *Ammonia nitrogen NH_4-N*: NH_4-N concentrations in the raw wastewater (RW) and biofilter (Bf) were in average 111,5 ± 42 and 96.93 ± 39 respectively, with the removal efficiencies of 13.8% for Bf. Subsequently, the final average ammonia nitrogen concentrations in the effluent of planted CWs were measured to be 54.1 ± 42.9 and 37.33 ± 17.5 mg l^{-1} with contaminant average removal efficiency of 55.53% and 65.25% for Phr and Ty respectively . While, in the unplanted CWs (Np) the average concentrations values increased than planted CWs with 64.42 ± 29.13 with average removal efficiency of 40.94% (Figure 2). The removal efficiency in the planted CWs being significantly higher than unplanted CWs, which is similar to what it has been observed in the literature [10]. In this study, the best NH_4-N removals were observed in planted CWs which could be mainly attributed to the presence of aerobic zones on the roots and rhizomes of the vegetation providing suitable nitrification sites and to a lower extent to NH_4-N plant uptake [3].

- *Total Kjeldahl nitrogen (TKN)*: The influent TKN concentrations fluctuated between 96.6 and 295.4 mg l^{-1} with an average of 172.2±39mg l^{-1} during a continuous operation of 29 weeks (Table 1). TKN average removal efficiencies in the biofilter were 21.3, this may be due to the low nitrification ,whereas in the CWs; TKN average removal efficiencies increased to be 70.65% (Ty), 62.98% (Phr) and 56.6 % (Np), this can be concluded that the organic nitrogen and ammonia-nitrogen were the main species contributing to the effluent total Kjeldahl nitrogen concentration, and according to the results of several studies comparing unplanted and planted wetlands showed that plants only marginally increased the removal rate of organic matter but clearly increased the removal rate of ammonium [13].

- *Phosphate phosphorous PO_4^{3}-P*: Over the monitoring period, the average values of the PO_4-P concentrations in the influent was equal to 5.56 ± 1.70 mg l^{-1} which ranged from 1.23 to 7.99 mg l^{-1} (Table1). The average concentrations of *PO_4^{3}-P* was 1.88 ± 0.81 mg l^{-1} which means a removal efficiency of over 66% in

Bf (Figure 2). In the CWs , a low PO_4-P concentrations in the effluents than in the biofilter were observed. The average removal rate of PO_4-P ranged from 95 % to 98 % (Figure 2). This may be explained by the mechanisms responsible of phosphorus removal which are the substrate adsorption and precipitation at high pH of 9 -11[7]. However, as pH was not high enough in this study to trigger precipitation, and the uptake of phosphate by *P. australis* and *T. latifolia* was low and contributes less to phosphorus removal comparing with CWs without plants (Np) as shown in table1, thus, the bacteria activity was may be only mechanism for phosphorous removal in this trial.

- *Total phosphorus TP***:** During the study period, the concentration of total phosphorus in wastewater ranged from 2.82 to 21.12 mg l^{-1}(a mean of 7.29 ± 3.34 mg l^{-1}) (Table 1). The average TP concentrations of Bf was 3.94 ± 2.53, which accounts for almost half of phosphorus removal efficiencies with 46 %. A similar tendency was observed in CWs for the concentration of TP aver time. CWs showed a reduction of TP concentration in all effluents, and the average overall TP removal efficiencies were 87.72%, 69.88% and 81.94% for Phr, Ty and Np respectively. In this integrated system, the particulate phosphorus was intercepted by the filter material in the biofilter. Phosphorous removal is governed mainly by sorption processes on the media that is used, and phosphorus can be stored in the accumulated sediments. In the constructed wetland, phosphorus removal was mainly accomplished in two ways: the interception (including the functions of adsorption and precipitation) and the uptake by the aquatic plants [5].

Table 1. Average concentration of the influent and effluents water quality parameters (n=29). (**a**: Mean ± standard deviation, **b**: Min-Max).

Parameters	Rw	Bf	Ty	Phr	Np
T (°C)	25.11 ± 6.80[a]	24.29 ± 6.74	23.01 ± 6.49	22.78 ± 6.55	22.55± 6.38
	(16.2-37)[b]	(15.5-36.1)	(12 .8-34.1)	(12.4-34)	(12.20-31.40)
pH	7.6 ± 0.25	7.71 ± 0.29	7.25 ± 0.22	7.33 ± 0.16	7.6 ± 0.21
	(7.15-8.1)	(6.95-8.14)	(6.90-7.88)	(6.85-7.66)	(7.14-7.95)
EC (ms cm^{-1})	7.83 ± 1.07	7.84 ± 0.86	17.96 ± 6.92	22.77 ± 11.16	14.41 ± 5.75
	(6.93-12.12)	(4.37-9.69)	(8.66-27.7)	(8.64-40.2)	(6.45-22 .50)
DO (mg l^{-1})	0.09 ± 0.10	0.32 ± 0.87	0.36 ± 0.74	0.32 ± 0.56	0.14 ± 0.13
	(0- 0.26)	(0- 4.75)	(0.02-3.84)	(0.02-2.69)	(0-0.41)
SS (mg l^{-1})	423.33 ± 281	56.03 ± 47.78	60.69 ± 28	93.17 ± 52.23	49.39 ± 17.10
	(20- 1261.25)	(3.75- 250)	(10-123.7)	(29-222.5)	(14-87.50)
BOD_5 (mg l^{-1})	324.65 ± 96	86 ± 41.70	34.23 ± 19	36.92 ± 42.03	43.85 ± 22.64
	(60-490)	(30-220)	(10-90)	(10-230)	(10-110)
COD (mg l^{-1})	820.44 ± 308	388.13 ± 246	75.89 ± 34	65.72 ± 33.50	87.48 ± 32.15
	(350-1365)	(86- 998)	(19-130)	(20-133)	(16-144)
NH_4^+-N (mg l^{-1})	111.5 ± 42	96.93 ± 39	37.33 ± 17.5	54.1 ± 42.95	64.42 ± 29.13
	(54 - 192.4)	(48.4-168)	(11.2-85.4)	(11.2-162.4)	(19.6-128.8)
TKN (mg l^{-1})	172.15 ± 39	137.46 ± 38	53.21 ± 33.1	64.83 ± 49.25	75.2 ± 32.48
	(96.6-295.4)	(71.4-222.6)	(4.2- 169.4)	(2.80-168)	(22.40-140)
PO_4-P (mg l^{-1})	5.56 ± 1.70	1.88 ± 0.81	0.09 ± 0.11	0.19 ± 0.27	0.21 ± 0.13
	(1.23- 7.99)	(0.34-3.2)	(0-0.46)	(0.01-0.92)	(0.05-0.49)
TP (mg l^{-1})	7.29 ± 3.34	3.94 ± 2.53	2.13 ± 2.32	0.83 ± 1.47	1.24 ± 1.87
	(2.82-21.12)	(0.85-13.19)	(0.01-7.80)	(0.02-7.97)	(0.14-9.08)

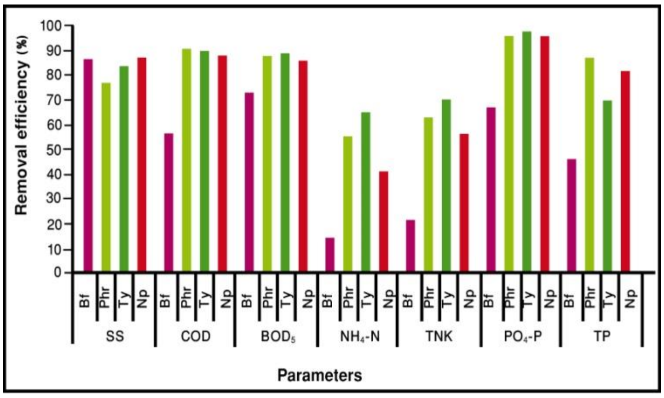

Figure 2. Total and biofilter removal efficiencies

IV. CONCLUSION

Our research aimed to design a natural integrated wastewater treatment system in arid areas by the assessment of biofilter and CWs agronomic species performance based on water quality values. The experiment demonstrated that CWs planted with *P. australis* and *T. latifolia* provide the highest removal. In this last case, the *T. latifolia* performed better than *P. australis* for most of the tested parameters. The wetland efficiency indicated that *P. australis* contributed greatly to the removal of TP. In this integrated system, Organic matter, and PO_4-P removal mainly happened in the biofilter, whereas NH_4-N, TKN and TP were mostly removed in the CWs. In the future, the management of water quality in arid areas needs more practical researches to face the wastewater treatment issue. First, experiment trials should be tested including microbiological water quality parameters to evaluate the system performance. Second, the system working with CWs planted with *P. australis* and *T. latifolia* in association.

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