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Treatment of campus wastewater by a pilot-scale constructed wetland utilizing *Typha latifolia, Juncus acutus* and *Iris versicolor*

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Abstract: *Constructed wetland is a popular treatment method for different sources of wastewaters, being an alternative to conventional wastewater treatment methods that have operational and financial restrictions, especially for decentralized wastewater systems. A pilot-scale, continuous flow, subsurface flow wetland was constructed at the Cukurova University in Adana, Turkey. The system works on a multi-culture planting texture employing Typha latifolia, Junkus acutus and Iris versicolor. Removal efficiency of the system was observed for approximately one year with 1.2 m^3/h steady inflow rate. Removal rates of 89.0±10.6%, 76.7±8.3% and 68.8±5.9% were achieved for TSS, COD and BOD_5, respectively. A high removal (95.4±8.3%) for fecal coliform was also observed. The obtained results imply that constructed wetlands are suitable for treatment of wastewaters originating from campuses in arid climate.*

Key words: *Constructed wetlands, Pollution control, Natural treatment system, Typha latifolia, Juncus acutus, Iris versicolor.*

Introduction

The relatively recent introduction of anthropogenic chemicals and the massive relocation of natural materials to different environmental bodies (soils, ground water, and atmosphere), has resulted in severe pressure on the self-cleansing capacity of recipient ecosystems (Susarla *et al.*, 2002). Currently, it may be accepted that the necessity to control the release of contaminants is widely recognized and conceded by many countries (Schnoor *et al.*, 1995). Aiming sustainability of the environment, many treatment techniques are being employed to accelerate the breakdown of the generated contaminants, most of which involve adsorption, air stripping or stimulation of anaerobic and aerobic microbial activities in rather small volumes. Current experiences demonstrate that all of these technologies have high costs of implementation expenditure as well as high operational costs. Constructed wetlands (CW) is a promising technology featuring both cost-effectiveness in capital and operational expenditures as well as adequate decontamination potential.

Wetlands, either natural or artificial (constructed), have a substantial capacity for wastewater treatment or renovation (Venus, 1987). It is being used in some countries that have either arid or semi-arid climates such as England, in some states in the U.S., Canada and Australia (Kadlec and Knight, 1996; Merlin *et al.*, 2002), for the removal of particular contaminants from wastewaters. CW technology is based upon the symbiotic relationship between the microorganisms and the pollutants in the wastewater (Stomp *et al.*, 1994). Thanks to this fundamental relationship, wastewater treatment occurs without any form-altered waste material, in contrast to sludge producing activated sludge or chemical precipitation methods.

In Turkey, unfortunately, the domestic waste water discharge lacks a complete monitoring and control system, mainly originating from the financial restrictions. The discharged untreated or inadequately treated domestic wastewaters impart a great stresses to the receiving water bodies as well as to the subsurface waters, with possible public health hazards. The dominant domestic wastewater treatment is done by means of conventional treatment methods like activated sludge for municipalities, and septic tanks and soak-pits for rural areas. Looking at the overall picture of natural and constructed wetlands in Turkey, reveals that the potential use of wetlands as a recipient and renovator of wastewater has not been recognized.

Wastewater treatment for small communities faces several problems, most notably high per capita cost. In small communities, wastewater collection systems are much more costly than that for large communities due to the fact that small population is usually scattered over large land areas (Al-Omari and Fayyad, 2003). Regardless of these difficulties, small communities have to meet the same discharge requirements as large communities. To overcome these challenges, small communities have to use natural systems for wastewater treatment because they are low in cost and do not require high technology to operate nor do they require highly qualified personnel (Al-Omari and Fayyad, 2003).

In the treatment of domestic wastewater, high levels of treatment, although varying according to the design, 60-88% in BOD_5 removal and 60-90% in SS removal (Karathanasis *et al.*, 2003; Reed *et al.*, 1988), can be accomplished. Besides the low construction and operation-maintenance expenditure and ease of operation, wetlands have considerable positive effects on the public with their aesthetic value. Also, it must be noted that there were no the limiting conditions in the area regarding the climate, topography and natural flora which may sometimes be faced in other locations for the decision to use wastewater treatment by constructed wetlands (Zaimoglu, 2000). This paper summarizes a study on a constructed pilot-scale wetland at

Table – 1: Ranges of the influent wastewater characteristics, based on the samples taken during the operational period.

Parameter	Unit	Range
COD	mg/l	294-734
BOD_5	mg/l	115-312
TSS	mg/l	131-285
Fecal coliform	CFU/100 ml	$8.0 \times 10^8 – 6.0 \times 10^5$

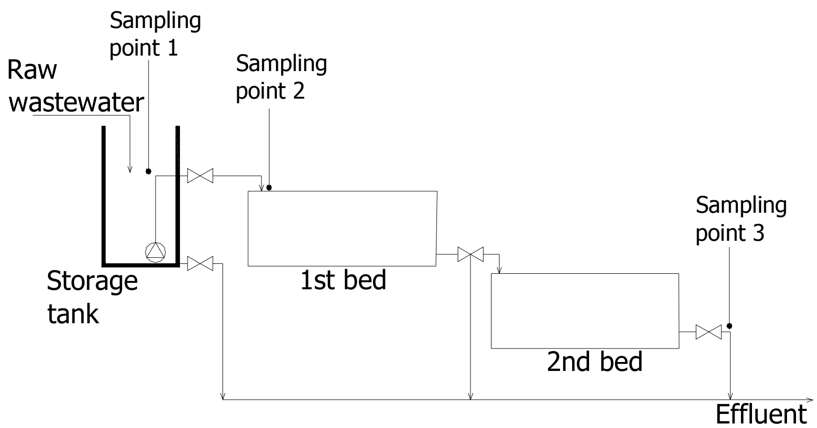

Fig. 1: The sketch of the single-family domestic wastewater treatment wetlands used in this study.

Cukurova University which examines the role of constructed wetlands in providing an efficient and economical means for treating such wastewater. In this study, the pilot-scale, sub-surface flow constructed wetland was set to treat a portion of wastewater of Cukurova University in Adana, Turkey, using three different plant species, *Typha latifolia*, *Juncus acutus* and *Iris versicolor*.

Materials and Methods

The system: The study site is located in the city of Adana, which is in the south-eastern Mediterranean region of Turkey. As a Mediterranean city, Adana has characteristics of arid climate. Cukurova University is in the northeast of the city having 1,540 teaching staff and over 20,000 students.

The wastewater was taken from one manhole that carries sewage to the municipal system, by a submersible pump, working on a timed sequence. The sequence was designed so as to ensure taken wastewater represented the overall daily characteristics. The manhole that the wastewater was taken from, receives wastewater from 7 departments, their laboratories and 2 cafeterias. Also, the wastewater flow was set to 50 l/hr, intending to represent the daily total flow rate of a single dwelling. Influent characteristics are given in Table 1.

The pilot-scaled wetland system is composed of a feed tank, two beds and relevant piping. The tank and the beds are made up of coated metal plates, where piping utilities are of PVC. The wastewater was taken to a tank where wastewater was screened and stored to supply continuous feed to the constructed wetland system. After the feed tank, wastewater entered the first planted bed with dimensions of 3 m long, 1.5 m wide and 0.5 m deep, which was connected the second bed by perforated drainage piping. Both of the beds were gravel mediated at 5-10 mm, having the same dimensions and the same planting textures. The beds had a slope of 0.5% and were placed with a 50 cm level difference, to ensure gravity flow. The gravel media was set 40 cm deep in the beds. The wastewater given to the beds was adjusted to 38±2 cm deep, ensuring the upmost level of the medium would not be exceeded. The mean detention time of the water in the system is assumed to be 24 hr, considering the calculated evapo-transpiration values for the area. This system was operated from May 2000 until April 2001. A sketch of the system is given in Fig. 1.

Plant material: The study was carried out with polyculture planting, using three plant species *Typha latifolia*, *Juncus acutus* and *Iris versicolor*, which are known to be suitable for usage in constructed wetlands (Reed *et al.,* 1988). These plants were selected according to their ability to resist wastewater, cover area and natural existence in the flora of the region. Planting texture was randomized, trying to set a uniform allocation, in the first bed and the same texture was used for the second bed.

The plants were taken from their original locations on March 3rd, 2001, one day before transplanting them to the system. The roots of the extracted plants were washed off and all the soil was removed. The spacing between the plants was set to 50-60 cm.

Sampling and analysis: The wetland system was put into operation at the time of the planting and left working for 6 months before the observational period, letting the system settles to a relatively steady-state. The observation period started in September 2001 and lasted for about 9 months,

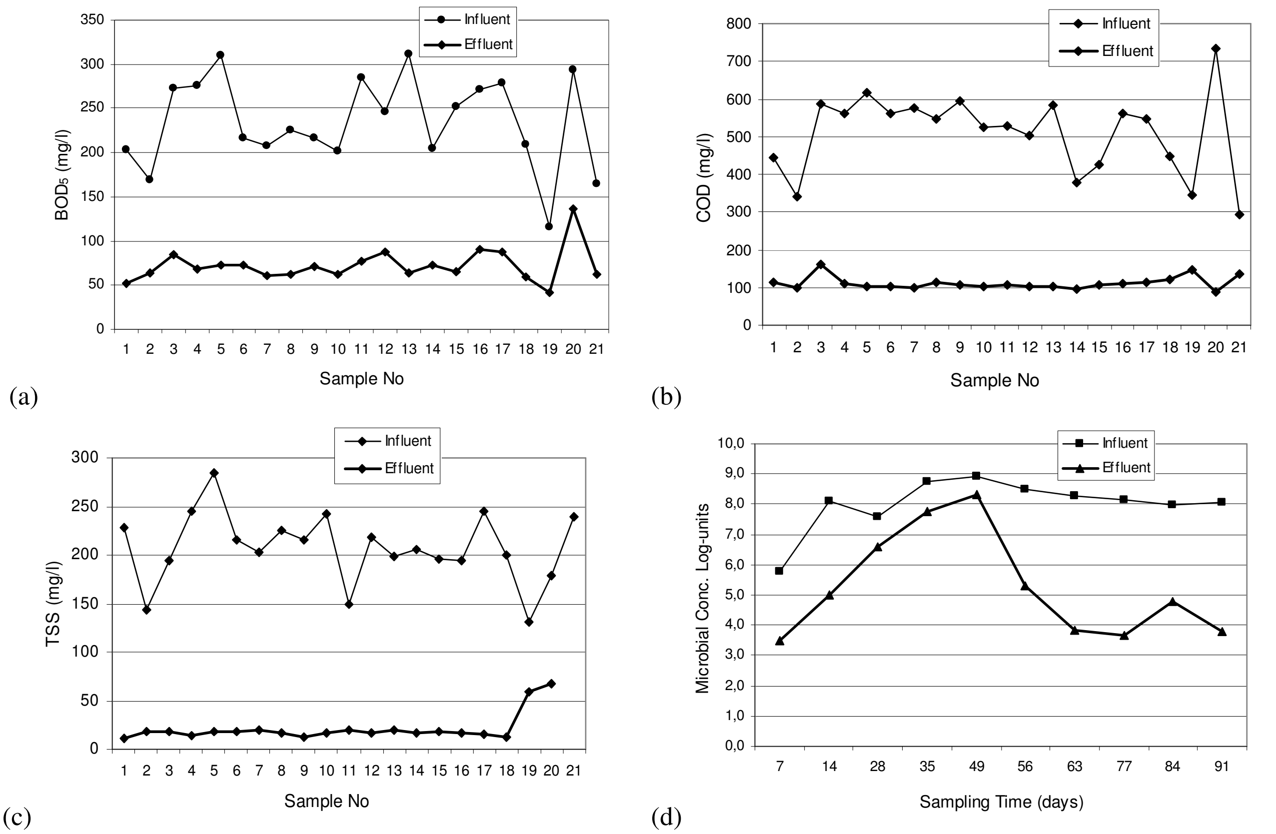

Fig. 2: Removal of the observed constituents between the influent and the effluent of the wastewater: (a) BOD_5 (mg/l), (b) COD (mg/l), (c) TSS (mg/l), (d) Total coliform (Log-Units).

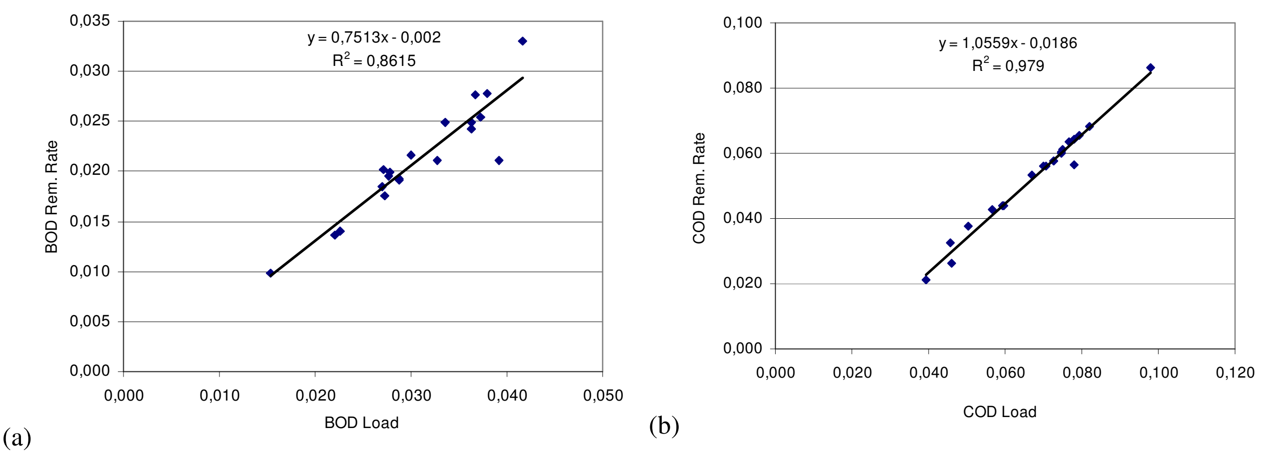

Fig. 3: BOD_5 (a) and COD (b) remaoval rates (in kg/m^{2}d) vs. organic load.

ending in May 2002. A total of 21 samples were taken between 9 and 10 a.m. during the operation period. The samples were taken from 3 locations; at the system inflow manifold, the entrance of the first bed and outflow of the system. The samples were analyzed for the following parameters; chemical oxygen demand (COD), 5-day biochemical oxygen demand (BOD_5), total suspended solids (TSS), pH and fecal coliform (FC). Test methods used for the analyses are according to standard methods for the examination of water and wastewater analysis (APHA, 1995) and all the analyses were conducted within 2 hr.

Results and Discussion

The overall system treatment performance was high and stable during the observation period. Table 2 describes the system efficiency and the observed parameters in the influent

Table – 2: Number of samples, average, and standard deviation for physical and chemical parameters at the inlet and outlet of the system, based on the samples taken during the operational period.

Month	Parameters	COD inf. (mg/l)	COD eff. (mg/l)	BOD_5 inf. (mg/l)	BOD_5 eff. (mg/l)	TSS inf. (mg/l)	TSS eff. (mg/l)	Total coliform inf. (#/100 ml)	Total coliform eff. (#/100 ml)	pH inf.	pH eff.
	Number of samples	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**2**	**2**
Sep.01	Average	457.2	125.2	215.1	66.9	188.6	16.0	$6.53x10^7$	$5.15 x10^4$	7.9	7.5
	Standard deviation	122.8	32.9	52.5	17.0	43.0	4.4	$9.15x10^7$	$6.86 x10^4$	0.3	0.1
	Number of samples	2	2	1	1	2	2	2	2	2	2
Oct.01	Average	588.0	106.3	275.2	68.2	264.9	16.0	$2.95 x10^8$	$2.95 x10^7$	8.4	7.9
	Standard deviation	38.2	3.2	-	-	28.5	2.8	$3.61 x10^8$	$3.61 x10^7$	0.1	0.3
	Number of samples	2	2	2	2	2	2	1	1	2	2
Jan.02	Average	569.0	101.5	212.0	66.6	209.0	19.0	$8.00 x10^8$	$2.00 x10^8$	8.1	7.3
	Standard deviation	8.5	3.5	5.7	7.6	8.5	1.4	-	-	0.3	0.0
	Number of Samples	4	4	4	4	4	4	2	2	4	4
Feb.02	Average	548.5	107.0	232.0	68.5	207.7	16.3	$2.45 x10^8$	$1.06 x10^5$	8.0	7.5
	Standard deviation	87.3	4.3	36.6	6.8	40.9	3.0	$9.19 x10^7$	$1.39 x10^5$	0.3	0.2
	Number of samples	5	5	5	5	5	5	1	1	5	5
Mar.02	Average	490.0	102.9	257.2	75.8	202.7	18.0	$1.40 x10^8$	$4.50 x10^3$	8.1	7.7
	Standard deviation	87.3	4.8	39.4	12.2	9.6	1.4	-	-	0.1	0.2
	Number of samples	4	4	4	4	4	4	1	1	4	4
Apr.02	Average	517.7	117.0	224.2	81.1	188.5	38.8	$9.00 x10^7$	$5.90 x10^4$	8.1	7.6
	Standard deviation	165.9	25.1	81.7	41.4	47.4	28.9	-	-	0.3	0.3
	Number of samples	1	1	1	1	1	-	1	1	1	1
May.02	Average	294.0	136.0	165.0	63.0	240.0	-	$1.20 x10^8$	$6.10 x10^3$	8.6	8.1
	Standard deviation	-	-	-	-	-	-	-	-	-	-
	Number of samples	21	21	20	20	21	20	10	10	20	20
Overall	**Average**	**509.3**	**111.3**	**234.8**	**72.2**	**207.2**	**21.4**	**$2.36 x10^8$**	**$2.59 x10^7$**	**8.1**	**7.6**
	Standard deviation	107.3	17.6	51.6	19.0	36.7	14.7	$2.53 x10^8$	$6.35 x10^7$	0.3	0.3

and effluent. It can be seen from Fig. 2 that, although the BOD_5, COD and TSS values of the influent deviate synchronized, treatment efficiencies of these parameters were observed to be different, TSS having the highest removal rate (89.0±10.6%). Organic matter content of the influent and effluent was measured as COD and BOD_5, showing removal rates of 76.7±8.3% and 68.8±5.9%, respectively. FC concentration had shown a sharp decrease of 95.4±8.3%. Effluent pH value had shown a consistent deviation with the influent values, being about 0.5 lower than the influent.

The TSS concentrations given to the wetland varied between 130.6 and 285.0 during the observation period, with effluent values of 11.0-68.0. Applying high hydraulic residence times lead high TSS removal efficiency (Fig. 2c). Although primary sedimentation was not applied to the system, the constructed wetland was able to remove up to 95.2% TSS removal, thanks to the wetland being subsurface-flow and utilizing planting with hairy roots.

The organic matter given to the wetland was observed to be in the ranges 294-734 mg/l of COD or 115-312 mg/l of BOD_5. The values of these parameters are given in Table 2, by means of monthly deviations. As it can be seen from Table 2 and Fig. 2a and 2b removal of the organic matter fluctuates in connection with the influent with relatively stable removal efficiency in terms of both COD and BOD_5. The highest COD removal efficiency achieved was 88.1%, where the least was observed as 53.7%, with 76.7% mean. The highest and the lowest BOD_5 removal rates of this study were 79.4% and 53.7%, respectively, with 68.8% mean. On the contrary to the study done using duckweed (Ran *et al.*, 2004), the BOD_5 removal efficiency was under the efficiency of the COD removal. This may be resulted from the influent wastewater characteristics, which show higher COD/BOD_5 values in this study. Also implementing primary sedimentation may result in this differentiation. But, removal efficiencies of these two parameters are close to the current literature (Ran *et al.*, 2004; Mashauri *et al.*, 2000; Ayaz and Akca, 2000; Kern and Idler, 1999).

Relating the BOD loading vs. BOD removal rate and COD loading vs. COD removal rate (Fig. 3a and 3b), a linear relationship with R^2 values 0.86 and 0.98, respectively, was found. Organic removal rates and efficiencies were also investigated to find relationship with water and environment temperatures. Although, a relationship is set between nitrogen removal process and climatic temperature values in the study accomplished by Kuschk *et al.* (2003), any meaningful relation between organic removal rate and temperature can not be achieved, in this study. It is thought to be resulting from relatively stable and warm Mediterranean climate of this study location.

The effluent values for TSS, COD and BOD_5 obtained were, with very few exceptions during observational period, convenient with current Turkish regulations for domestic wastewater discharge, implicating that constructed wetland technology is suitable for decentralized domestic wastewater treatment alone.

Even though 95.2% medial removal of fecal coliform was achieved during the operation period (Figure 2d), because the wastewater has medium to strong characteristic by means of total coliform ($6x10^5$-$8x10^8$ CFU/100 ml), the effluent was observed to contain $3x10^3$ to $2x10^8$ #/100 ml total coliform concentration. This result implies that the removal efficiency of a constructed wetland treating domestic wastewater is comparable to a conventional activated sludge (Veschetti, 2003).

The pilot-scale subsurface flow wetland constructed at the University of Cukurova was observed to decrease all the observed water quality parameters of the campus wastewater, resulting in increasing water quality.

TSS, COD and BOD_5 values achieved were meeting the current Turkish regulations. In other words, this system is suitable as stand-alone treatment method for treating low-middle strength wastewaters that show high variations in characteristics, especially originating from campuses.

High microbial removal values of FC were observed. The achieved removal rate is comparable to conventional treatment methods, like activated sludge. But, the system needs to be supported by an additional disinfection unit following the wetland beds, in order to reuse the treated water, due to remaining microbial content.

An additional primary sedimentation unit installed before the wetlands and hydraulic residence time of the wetland beds can be decreased to achieve higher capacities at lower area requirements, giving an acceptable quality of discharge.

Because the plants used for this study are members of the natural flora of the study area, these plants are suitable for treatment with constructed wetlands in arid climate, especially the Mediterranean zone.

Applying the wastewater treatment system on-campus will support to enhance the environmental consciousness of the campus residents besides being readily functional on educational purposes.

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