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AGE OF CONSTRUCTED WETLAND AND EFFECTS OF WASTEWATER TREATMENT

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Abstract

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Constructed wetland with subsurface flow in Gložan (Vojvodina Province - Serbia) is designed to accept and treat municipal wastewater from settlement. Four-year study of removing suspended solids and BOD_5 has found that the age of the constructed wetland in the study period does not affect the concentration of suspended solids and organic compounds in the effluent. Applying Fisher F-test and Student t-test tested the homogeneity of data determined that the age of the constructed wetland is not affected, and that the removal of suspended solids is up to 96 - 93% and lowering content of organic compounds, expressed via BOD_5, is up to 84 - 79%.

Key words: wastewater, suspended solids, BOD_5, purification, mature constructed wetland

Abbreviations: CWS Gložan – constructed wetland system in Gložan, BOD_5 – five-day biochemical oxygen demand

Introduction

Sustainable wastewater treatment is associated with low energy consumption, low capital cost, and, in some situations, low mechanical technology requirements. Therefore, wetland treatment systems could be efficient alternatives to conventional treatment systems, especially for small communities, typically rural or suburban areas, due to low treatment and maintenance costs (Soukup et al., 1994; Solano et al., 2003 and Babatunde et al., 2008). Since the 1990s, wetland systems have been used for treating numerous domestic and industrial waste streams including those from tannery and textile industry, abattoirs, pulp and paper production, agriculture (animal farms and fish farm effluents), and various runoff waters (agriculture, airports, highway, and stormwater, Kadlec et al., 2000; Haberl et al., 2003; Scholz, 2006; Vymazal, 2007 and Carty et al., 2008).

The concept of constructed wetlands applied for the purification of various wastewaters has received growing interest and is gaining popularity as a cost effective wastewater management option in both developed and developing countries. Most of these systems are easy to operate, require low maintenance, and have low investment costs (Machate et al., 1997). The treatment efficiencies of constructed wetlands vary depending on the wetland design, type of wetland system, climate, vegetation, and microbial communities (Vacca et al., 2005; Ström and Hristensen, 2007; Picek et al., 2007 and Weishampel et al., 2009).

Suspened solids concentration and biochemical oxygen consumption measurements are widely used in wastewater treatment, since they illustrate water quality very well. Generally, wastewater have high suspended solids concentrations and organic compaunds, which need to be removed before releasing water into the recepient. Various types of constructed wetlands differ in their main design characteristics as well as in the processes which are responsible for pollution removal.

Constructed wetlands with free water surface are efficient in removal of organics through microbial degradation and settling of colloidal particles. Suspended solids are effectively removed via settling and filtration through the dense vegetation. Plant uptake represents only temporal storage for nitrogen and phosphor because the nutrients are released to water after the plant decay (Kadlec and Wallace, 2008).

Constructed wetlands with subsurface flow consist of gravel or rock beds sealed by an impermeable layer and planted with wetland vegetation. The wastewater is fed at the inlet and flows through the porous medium under the surface of the bed in a more or less horizontal path until it reaches the

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outlet zone, where it is collected and discharged. In the filtration beds, pollution is removed by microbial degradation and chemical and physical processes in a network of aerobic, anoxic, anaerobic zones with aerobic zones being restricted to the areas adjacent to roots where oxygen leaks to the substrate (Cooper et al., 1996 and Vymazal and Kröpfelová, 2008a).

Constructed wetland with subsurface flow in Gložan (Vojvodina Province - Serbia) is designed to accept and treatment municipal wastewater from settlement. Previous monitoring at the CWS in Gložan have confirmed that suspended solids are best removed with substrate filtration. This CWS has low water velocity and excellent filtration effect in substrate. This observation leads us to conclusion that CWS's can be used in different phases of treatment, both as primary and secondary treatment. Achieved level of suspended solids removal at 94% supports the previous statement. Average percentage of BOD_5 decrease is 81%. The system with three successive fields hosts aerobic and unaerobic microorganisms providing oxidation reactions. The most intensive oxidation is in the first field with 62.6%. In the second field, it is significantly less and ranks at 10.2%. In the third field, it is only 8.0% (Josimov-Dunđerski and Belić, 2010). This observation is in line with Reed et al. (1995) and Kadlec and Knight (1996) who state that BOD_5 reduces significantly when the concentration is high and decreases as water moves through the system and the concentration declines. The CWS Gložan uses the reed (*Phragmites australis* (Cav.) Trina. Ex Steud.) as a biofilter. Monitoring N and P that was made by Josimov-Dunđerski et al. (2011) shows that CWS Gložan retained on average 292 kg P year^{1} and 2920 kg N year^{1}. The efficiency of removal of nitrogen is 47.5% and removal phosphorus is 29.1%.

Research conducted on these systems demonstrates high removal percentages for biochemical oxygen demand, chemical oxygen demand, suspended solids, and pathogens, whereas nutrient removal percentages are usually low and variable (Kayranli et al., 2010).

Most articles have been based on pilot either plant-scale or laboratory-scale experimental systems. Very few articles have been carried out on the assessment of performance of full-scale constructed wetlands treating domestic wastewater. Constructed wetlands are often seen as complex "black box" systems, and the processes within an experimental wetland are difficult to model due to the complexity of the relationships between most water quality variables (Gernaey et al., 2004). However, it is necessary to monitor, control and predict the treatment processes to meet environmental and sustainability policies, and regulatory requirements such as secondary wastewater treatment standards (Scholz, 2004a and Scholz, 2004b).

This paper shows results of monitoring of the CWS Gložan that dominantly has cane type (*Phragmites australis*). CWS Gložan's pollutants removal was examined based on suspended solids and BOD_5 monitoring.

Materials and Methods

Research has been conducted at CWS Gložan, which lays at 45°17' N and 19°33' E. CWS in Gložan has subsurface water flow. Total area is approximately 1 ha and it lays in the area of natural bog. Substrate is made of 0.6m wide and 0.6 tall stripes with 1m wide strips of land between two substrate stripes. Covering layer is made of gravel mixed with soil and densely planted cane. Bottom layer is made of clay. Wastewater treatment is done by water flow through the substrate, with the retention time of 105 hours (4.4 days). CWS Gložan has a design capacity of 2275 population equivalent.

The investigation of the CWS operation was carried out in the 2005-2008 period. Measurements at the CWS covered both influent and effluent that was taken for analysis of suspended solids and BOD_5 in the four years period.

JUS ISO 5667-1 standard was applied for water sampling, SRPS H.Z1.160 for suspended solids determination and SRPS ISO 5815 for BOD_5. Based on the suspended solids and BOD_5 in influent and effluent chronological series of variables were formed. Series of suspended concentrations and BOD_5 in the four-year period are divided in two equal parts. The first part n_1 covers period 2005-2006, and the second n_2 2007-2008. Numerical characteristics of variables are obtained by average values, standard deviation, and variance and variation coefficient. Removal effects were calculated based on the average values.

It can be noticed that data are inhomogeneous, which is a consequence of changes that can be natural or man-made. Analysis whether the facility has reached the end of its life cycle or not was done by comparison of the differences for the suspended solids and BOD_5 in the effluent. Zero hypothesis H_0 was defined: Measured values of variables, suspended solids and BOD_5 belong to the same population. Homogeneity of n_1 and n_2 series were tested with the Student t-test. It was assumed that variances of the two samples were equal. Hypothesis that the variances are equal was checked with the Fisher F-test.

Results

Monitoring analysis of suspended solids and BOD_5 have proven the fact that mature CWS Gložan is still effective in the wastewater treatment. On the Figures 1. 2. 3. and 4. measured concentrations of suspended solids and BOD_5 for series n_1 and n_2 are shown with histograms, with the black lines showing average values.

Results of suspended solids and BOD_5 statistical analysis in the periods n_1 (2005-2006) and n_2 (2007-2008) and the efficiency of pollutants removal in the CWS Gložan are shown in Table 1.

Calculated values of statistical variables F and t for homogeneity test of suspended solids and BOD_5 in the effluent and critical values of F and t for appropriate degree of freedom and significance threshold ($\alpha = 0.05$ and $\alpha = 0.01$) are shown in Table 2.

Discussion

Influent water quality monitoring at GWS Gložan has determined that suspended solids concentration in the four year peri-

Table 1
Statistics and efficient in removing suspended solids and organic compounds (BOD_5)

Variables	CWS in Gložan n_1 (2005 - 2006)										
	Unit	*n*	**Influent**				**Effluent**				**Removal** (%)
			Mean	*S*	S^2	C_v	Mean	S	S^2	C_v	
Suspended solids	mg L^{-1}	8	304.75	135.02	18231.08	0.225	13.50	11.98	143.43	0.887	96
BOD_5	mg L^{-1}	8	379.44	140.27	19675.67	0.282	61.85	46.53	2165.04	0.582	84
Variables	CWS in Gložan n_2 (2007 - 2008)										
	Unit	*n*	**Influent**				**Effluent**				**Removal** (%)
			Mean	*S*	S^2	C_v	*Mean*	S	S^2	C_v	
Suspended solids	mg L^{-1}	8	338.13	66.78	4458.98	0.202	25.13	15.62	243.84	0.622	93
BOD_5	mg L^{-1}	8	624.48	192.74	37148.71	0.257	130.08	80.36	6457.73	0.317	79

n simple number, *S* standard deviation, S^2 variance, C_v coefficient of variation

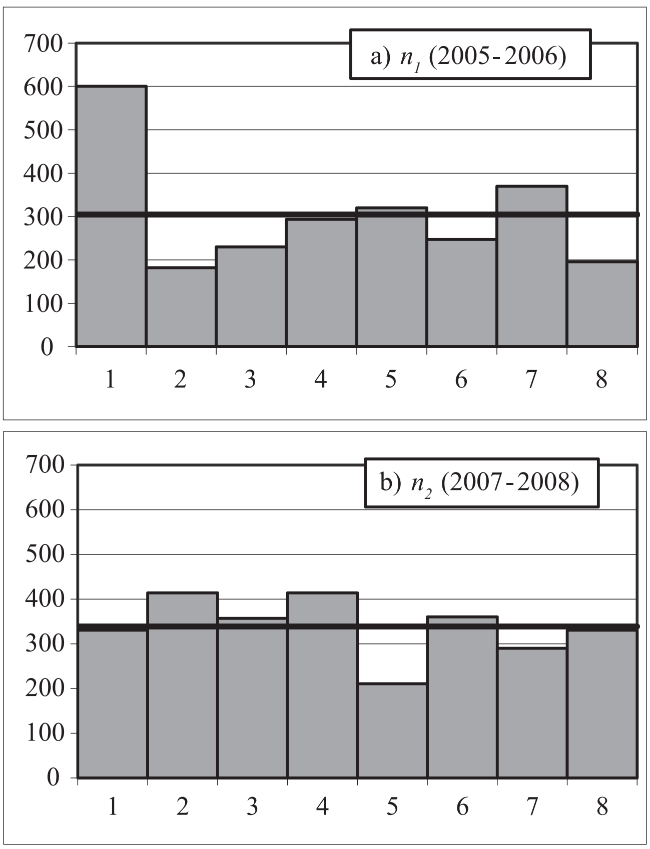

Fig. 1. Suspended solids (mg L^{-1}) in influent

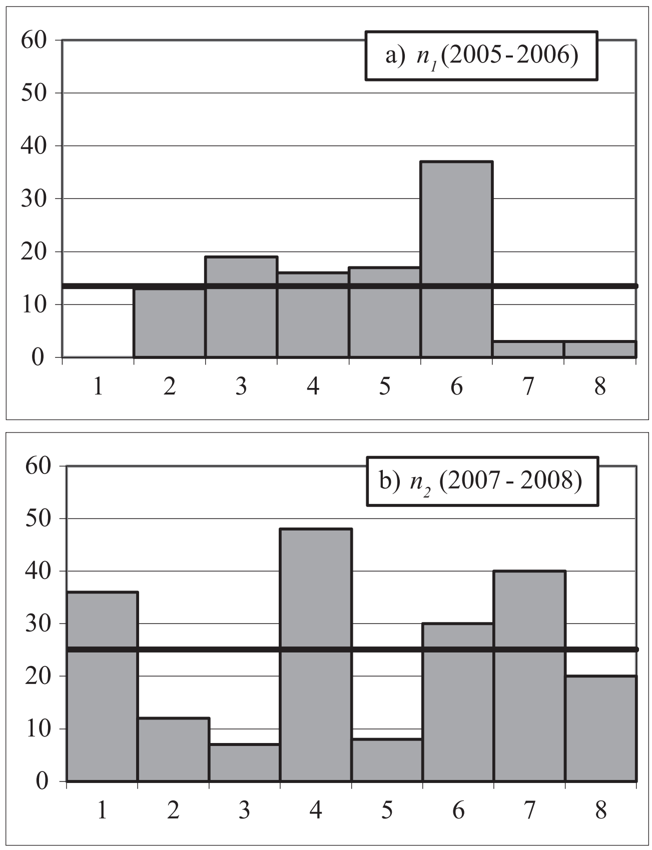

Fig. 2. Suspended solids (mg L^{-1}) in effluent

od 2005-2008 (Figure 1) and BOD_5 in the two year period (2007-2008) (Figure 3 b)) were high (Ljubisavljević et al., 2004).

Suspended solids concentrations in influent are relatively unified (Figure 1 a) b)) with average values of 304.75 mg L^{-1} n_1 (2005-2006) and 338.13 mg L^{-1} n_2 (2007-2008). Standard deviation of influent suspended solids for period n_2 has shown small variability of data when compared to period n_1. Suspended solids concentrations in effluent are < 20 mg L^{-1} for all samples but one (Figure 2 a)) in period n_1. In period n_2 concentration of 50% samples are higher than 20 mg L^{-1} and the variability of data is higher (Figure 2 b)).

CWS Gožan reduces concentrations of suspended solids. In the first two year period efficiency was 96%, and in the second 93% (Table 1). Suspended solids are retained predominantly by filtration and sedimentation and the removal efficiency is usually very high (Vymazal and Kröpfelová, 2008a).

Research done in CWS with subsurface flow in France (Molle et al., 2004), have also shown that the output can reach level of suspended solids in the range of 15 – 20 mg L^{-1}, and even for higher inputs, suspended solids removal is acceptable. The same authors stated that the age of the system does not significantly influences output suspended solids concentrations in the effluent. Up to two years old objects have shown suspended solids removal 94 ± 4%, and objects 2 – 6 years old had removal of 95 ± 2%.

Table 2
Homogeneity testing of effluent

Variables	Homogeneity testing of effluent					
	$F_{computational}$	$F_{critical}$ $(F_{0,95})$	$F_{critical}$ $(F_{0,99})$	$t_{computational}$	$t_{critical}$ $(t_{0,95})$	$t_{critical}$ $(t_{0,99})$
Suspended solids	1.70	3.79	6.99	1.56	±2.145	±2.977
BOD_5	2.98			- 0.97		

Hypothesis H_0 are accepted.

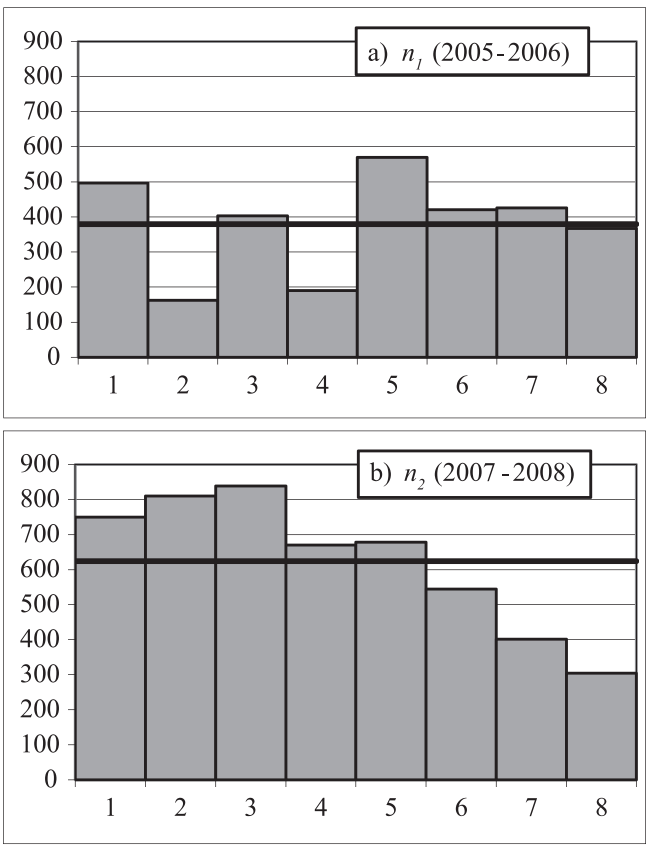

Fig. 3. BPK_5 (mg L^{-1}) in influent

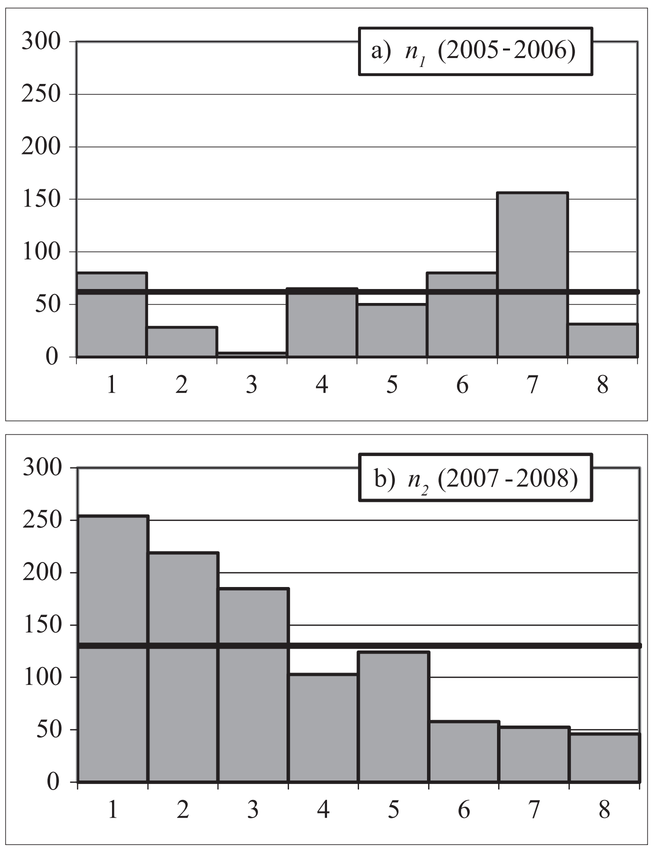

Fig. 4. BPK_5 (mg L^{-1}) in effluent

According to USEPA (2000), suspended solids removal is good for loads less than 20 g m^{-2} per day, calculated with the monthly maximum of total suspended solids. CWS Gložan has a load of 9 g m^{-2} per day at the monthly maximum, that has determined suspended solids removal efficiency of 96% and 93%.

Measured concentrations of BOD_5 in influent are in the range 162.25 mg L^{-1} to 838.40 mg L^{-1} (Figure 3 a) b)). According to Jahić (1990), BOD_5 for sanitary sewer water goes upto 400 mg L^{-1} which was also proven with the research in the period n_1 with the average value of 379.44 mg L^{-1} (Figure 3 a)). However, in the period n_2 organic pollutants had significantly higher concentrations with the average value of BOD_5 at 624.48 mg L^{-1} (Figure 3 b)). In this period, measured values in influent in all samples but one have exceeded average value for sanitary communal sewer water. High concentrations in influent have shown that not only households were discharging water to the communal sewer system. Logically, high influent concentrations of BPK_5 affected concentration in the effluent.

According to USEPA (2000), removal of organic pollutants is considered succesfull if maximum BOD_5 is less than 4.5 g m^{-2} d^{-1} for effluent with 20 mg L^{-1} and 6 g m^{-2} d^{-1} for effluent with 30 mg L^{-1}. In CWS Gložan reduction of BOD_5 in the period n_1 of 84%, and 79% in the period n_2 were achieved (Table 1). On average, in period n_1 BOD_5 was 7.4 g m^{-2} d^{-1} and in period n_2 it was 12.1 g m^{-2} d^{-1}. Results from the Czech Republic in the CWS of the same type showed an average treatment efficiency of 86.6%. The BOD_5 loading of vegetated beds varied between 2.6 and 99.6 g m^{-2} d^{-1} with an average of 33.5 g m^{-2} d^{-1} (Vymazal, 1999).

Organic compounds effectively degraded mainly by microbial degradation anoxic/anaerobic conditions, as the concentration of dissolved oxygen is very limited in constructed wetlands with subsurface flow (Vymazal and Kröpfelová, 2008b). The highest values in effluent in the period n_2 were measured during winter and spring with small hydraulic loads at the level of 1.5 L s^{-1}. The number of microorganisms is in correlation with the level of organic pollutants and ecological factors, namely temperature (Jarak and Đurić, 2006 and Jarak and Čolo, 2007). Relatively low air temperatures in the winter and spring in Gložan (average 5.9°C, minimal average -4.7°C) have slow down microbiological processes, which can be one of the causes for high BOD_5 in effluent.

Total retention time of the wastewater in the system is relatively short and is 4.4 days. In order to achieve efficient water treatment in constructed wetland system retention time has to be longer or equal to the time that is needed to achieve wanted effluent concentrations. According to Tchobanoglous and Burton (1991), retention times for constructed wetland systems with above ground or underground water flow are between 4 and 15 days, depending on the pollution type and concentration. Pollutants are reduced effectively if the hydraulic retention time is relatively high (Kadlec et al., 2000 and Carty et al., 2008). Retention time in CWS Gložan is relatively short although the influent pollution is high, especially in the period of 2007-2008. It is highly probable that hydraulic characteristics of CWS and influent pollution can affect and determine relatively high BOD_5 in effluent (Figure 4).

Statistical parameters analysis of effluent variables has unambiguously shown gentle increase of concentrations in the second two-year period. However, statistical analysis of samples have shown that CWS have not aged at the significance level of $\alpha = 0.05$ and $\alpha = 0.01$ (Table 2). Applied statistical tests have proved homogeneity of effluent at mature CWS Gložan to the level of hydro technical significance.

The new and mature constructed wetlands successfully removed traditional pollutants such as BOD from domestic wastewater. However, the biochemical oxygen demand, chemical oxygen demand, suspended solids, and ammonia-nitrogen concentrations were reduced within the mature constructed wetland system even after approximately 5 years of operation (Kayranli at al., 2010).

Conclusions

Although from the technical point of view, CWS seams like a simple structure, it is very fragile system because it has to be hydro technically effective for long time, i.e. propulse high amounts of water through itself. In the same time, it needs to allow good conditions for water treatment. At CWS Gložan suspended solids and BOD_5 homogeneity variables testing showed that there was no statistically significant changes in the pollutants removal during the research period. Mature CWS Gložan does water treatment successfully.

During the CWS design, the key action is to properly define area, considering loads and pollutants and select the biggest area analyzing all of them one by one. Looking at the variable of suspended solids in CWS Gložan, designed area was properly sized and it provided good results. Looking at the BOD_5, it can be said that the system is designed for average loads for the treated water. Measurements proved high loads for organic compounds, with relatively low retention time of 4.4 days, which is reflected in the effluent concentrations and the treatment efficiency.

Beside the designed area, retention time and substrate are also important design parameters. At CWS Gložan, cane (*Phragmites australis*) stabilizes the bottom, provides good conditions for filtration, prevents ground densifing, provides transport and release of oxygen and sufficient area for microorganisms growth. Also, the cane absorbs nutrients, and the significant amount of nutrients remains trapped in the biomass (Josimov-Dunđerski et al., 2011).

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