# Removal of organic pollutants from municipal wastewater by a horizontal pilot scale constructed wetland utilizing *Phragmites australis* and *Typha latifolia* -Effectiveness monitoring per season

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#### Keywords:

constructed wetland, organic matter, purification efficiency, wetland plants. Constructed wetlands, as an alternative to conventional methods, are systems designed on the basis of the application of natural purification processes that take place in watery and swampy overgrown habitats, with certain microbiological groups. In the wastewater treatment process various types of constructed wetlands can be combined to achieve a higher efficiency of the purification.

In this study, the removal effectiveness of the organic substances from municipal wastewater was monitored, using a horizontal pilot - scale constructed wetland utilizing *Typha latifolia* and *Phragmites australis*. In addition to the measurement of organic substances content through COD, BOD and KMnO<sub>4</sub> consumption, and total dissolved substances (TDS) in influent and effluent, microbiological sample analysis was performed, monitored by total number of coliform bacteria.

The aim of this study was to calculate the effectiveness of removing organic substances from municipal wastewater, depending on the season, as well as the effectiveness of eliminating total coliform bacteria.

The results of one-year research have shown that the removal effectiveness of the organic substances from municipal wastewater, expressed as the chemical oxygen demand (COD), was the highest in summer -  $87.82\% \pm 2.83\%$ , and the lowest in the winter -  $64.51\% \pm 5.89\%$ . During the study, effectiveness of elimination of total coliform bacteria was 97.88  $\pm$  0.80% and total dissolved substances 71.27%.

#### INTRODUCTION

Constructed wetlands are artificial swamps primarily constructed to improve water quality, made and built to use natural processes that occur in wetland soil and plants, but have flexibility in making process since they can be built in places where they are needed. Just as in natural wetlands, undersurface constructed wetlands consist of four basic components: water, soil, plants and microorganisms (Kadlec et al., 2000). Constructed wetlands implementation technology is based on the mutual relations between microorganisms and pollutants present in wastewater (Stomp et al., 1994). Different substrates and plant species can be used in wetlands (Haberl et al., 2003). The specificity of constructed wetlands is that there is no universal solution for their construction and maintenance. Every place where they are being built has different geomorphological, hydrological, climatic and biological characteristics, and the wastewater that is supposed to be cleaned does not have the same composition (Tušar, 2009). Plants can be included, directly or indirectly, during the removal of almost all typical pollutants present in municipal wastewaters. The commonly accepted fact is that plants increase the amount of oxygen that is absorbed from the atmosphere into the water. Plants can be an important factor for the constructed wetland efficiency. Although there have been numerous researches about this topic (Akratos & Tsihrintzis, 2007; Calheiros et al., 2007; Taylor et al., 2011), the role and significance of a particular plant species in relation to the other is still being conducted.

Organic substances present in wastewater are being removed via aerobic and anaerobic processes using bacteria found on the underground part of the plant (root and rhizome). Many studies have shown that the cane oxygen transport capacity is insufficient to ensure aerobic degradation in the rhizosphere and that the anoxic and anaerobic degradation have an important role in horizontal constructed wetlands (Vymazal & Kröpfelova, 2006).

During the research, depending on the season, the effectiveness of organic matter removal and total coliform bacteria removal from municipal wastewater while using the horizontal pilot – scale constructed wetland was monitored. *Typha latifolia* (Bulrush) and *Phragmites australis* (Common Reed) were used in wetland. The research was one year long.

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## MATERIAL AND METHODS

Constructed wetlands (CW) for wastewater treatment are used for municipal wastewater in small villages and small industrial areas, for isolated households, as decentralized wastewater treatment in tourist resorts, as well as other types of wastewater with toxic substances present as the third level of wastewater treatment.

This municipal wastewater treatment research used the horizontal pilot – scale constructed wetland located at the Biotechnical Faculty, and is dimensioned for 8-10 PE (population equivalent). Primary wastewater cleaning is carried out in the precipitation device. Due to proper particle precipitation, it is necessary to provide enough time in the precipitation device, that will enable 70% reduction in the TSS parameter (total suspended solids). In addition to that, in the precipitation device there is also a degradation of organic matter, so the reduction of the parameters COD (Chemical Oxygen Demand) and BOD<sub>5</sub> (Biochemical Oxygen Demand) by 30% is going on. The constructed wetland is composed of two fields:

- Filtering Fields (FF),
- Cleaning Fields (CF).

The Filtering Field (FF) is the first CW field and it means it is most loaded. Its function is to retain (filter) suspended and other substances, which will not be previously retained in the precipitation device. Intensive waste degradation is performed in the Cleaning field. Cleaning field functions include retention, accumulation and later incorporation of nutrients into plant and microbial biomass.

In the first field of the constructed wetland *Typha latifolia* was used, and in the second *Phragmites australis*. Sampling was done for all working days during the week (Monday to Friday), in three repetitions, for all seasons. The results show average and standard deviation of the measurement.

The research lasted for a year, and the efficiency of removing organic substances from municipal wastewater depending on the season was researched. The degradation of organic matter was monitored through chemical oxygen demand, biochemical oxygen demand and KMnO<sub>4</sub> consumption. The effectiveness of eliminating total coliform bacteria was monitored as well.

Determination of the physical-chemical parameters of the quality of the wastewater sample was done according to the standard APHA methods (APHA, 1998) and the Decree on the conditions of wastewater discharge into the environment and public sewerage systems (Službene novine Federacije BiH, No.101/15).

Chemical oxygen demand was determined spectrophotometrically using the photoLab<sup>®</sup> 6600 UV-

VIS Spectrophotometer. The method for determining the chemical oxygen demand is called a bichromatic method, and for this purpose Merck tests were used, Cod Cell Test C4/ 25.

The microbiological analysis of the sample was determined by the Membrane filter technique, and for this purpose, ready-to-use substrates for determination of total coliform bacteria were used.

#### **RESULTS AND DISCUSSION**

The results of the research are presented in tabular and graphical form, representing the average of the measurements made for each season.

Constructed wetlands are primarily intended for the purification of municipal wastewater, but can also be used for agricultural and industrial wastewater (Kadlec & Wallace, 2008).

Pilot – scale constructed wetland on which research has been done showed stability during one year long research. Tables 1 and 2 are showing the mean value and standard deviation of the physical-chemical parameters of municipal wastewater from the campus of the Biotechnical Faculty.

In the purification of municipal wastewater, depending on the construction of the constructed wetland itself, high efficiency can be achieved - ranging from 60 to 88% for the removal of organic substances expressed through  $BOD_5$  and 60 to 90% for removing total dissolved substances (TDS) (Karathanasis et al.; Reed et al., 1988).

The most common plants used in the constructed wetlands are *Phragmites australis*, *Typha latifolia* and *Juncus effuses*. These plant species are used because of their high tolerance to contaminants, salinity and toxic compounds (Vymazal & Kröpfelová, 2008). Although many studies have researched the efficiency of wastewater treatment using constructed wetlands during different seasons (Hijosa-Valsero et al., 2010; Reyes-Contreras et al., 2012), insufficient attention has been devoted to variations related to the physiological status of plants during the year. Instead, change of seasons throughout the year served as an explanation for low wastewater treatment efficiency during the winter and high efficiency during the summer.

By measuring the content of organic matter in municipal wastewater, it was found that the removal of organic matter efficiency expressed through COD was highest in the summer period - 87.82%. Good external factors and growing vegetation caused the highest efficiency during the summer period, while the lowest efficiency was 64.51% in the winter period. The average COD value in the influent was ranged from 129 mg/L to 186 mg/L, while at the effluent this value ranged from

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Season	Parameters	COD inf. (mg/L)	COD eff. (mg/L)	BOD₅ inf. (mg/L)	BOD <sub>5</sub> eff. (mg/L)	KMnO <sub>4</sub> cons. inf. (mg/L)	KMnO4 cons. eff. (mg/L)	pH inf.	pH eff.
Spring	Average	175,53	34,12	71,69	19,94	17,63	5,85	8,13	8,11
	Standard deviation	31,15	4,77	15,64	3,67	1,98	0,79	0,12	0,22
Summer	Average	186	22,66	75,48	9,57	15,68	5,9	7,94	7,81
	Standard deviation	56,30	3,97	22,20	3,37	4,36	2,89	0,25	0,14
Autumn	Average	163,50	22,41	69,46	8,27	13,08	6,68	7,31	7,38
	Standard deviation	27,44	1,71	11,21	1,40	2,49	1,54	0,59	0,37
Winter	Average	129,3	45,89	55,71	20,43	16,11	11,16	8,02	7,56
	Standard deviation	20,04	9,65	8,57	6,32	3,67	2,31	0,91	0,22

Table 1. Average and standard deviation for physical – chemical parameters in influent and effluent of the system, based on the samples taken during the seasons

influent – municipal wastewater after leaving the sewerage system, before entering the precipitation device and constructed wetland effluent - cleaned municipal wastewater after leaving the constructed wetland

22.41 mg/L to 45.89 mg/L. In the research conducted by Winthrop et al. (2002), the efficiency of the removal of organic matter expressed through COD was 93% to 96% in an average temperature of about 24°C, while at 4°C the efficiency was 77%.

Haberl et al. (2003) investigated the efficiency of municipal wastewater treatment using constructed wetland for six years. The results have shown that the average efficiency of removing organic matter during this period, expressed through COD was 91%, and  $BOD_5$  97%.

Efficiency of organic matter removal expressed through COD was followed by degradation of organic matter expressed through  $BOD_5$ . Related to this, efficiency of organic matter removal expressed through  $BOD_5$  was also the highest in the summer period, when it was 87.33%, and the lowest during the winter time -63.33%. Average values of biochemical oxygen demand during 5 days ranged from 55.71 mg/L to 75.48 mg/L in the influent, while at the effluent values ranged from 8.27 mg/L to 20.43 mg/l. Efficiency of organic matter removal expressed through the use of KMnO<sub>4</sub> was somewhat smaller and ranged from 30.73% to 66.82%.

Season	Parameters	TDS inf. (mg/L)	TDS eff. (mg/L)	Total coliform inf. (CFU/100ml)	Total coliform eff. (CFU/100ml)
Carring	Average	74,72	22,66	1,41x10 <sup>6</sup>	1,10x10 <sup>3</sup>
Spring	Standard deviation	11,95	7,38	2,82x10 <sup>6</sup>	1,19x10 <sup>3</sup>
Cumono ou	Average	163,1	29,64	2,81x10 <sup>6</sup>	9,54x10⁴
Summer	Standard deviation	160,65	15,28	3,30x10 <sup>6</sup>	1,77x10⁵
Autumn	Average	90,91	17,86	3,50x10⁵	2,82x10 <sup>3</sup>
Autumn	Standard deviation	38,45	2,03	2,89x10⁵	3,52x10 <sup>2</sup>
\\ <i>\\</i> ;	Average	165,4	77,4	1,61x10 <sup>6</sup>	6,23x10 <sup>3</sup>
vvinter	Standard deviation	72,58	37,73	2,90x10 <sup>6</sup>	7,76x10 <sup>3</sup>

Table 2. Average and standard deviation for TDS and total coliform in influent and effluent of the system, based on the samples taken during the seasons



Figure 1. The removal effectiveness of the organic substances from municipal wastewater during the seasons, expressed as COD



Figure 3. The removal effectiveness of the organic substances from municipal wastewater during the seasons, expressed as KMnO4 consumption



Figure 5. The removal effectiveness of the total coliform from municipal wastewater during the seasons

Constructed wetlands proved to be very effective in removing the total dissolved solids from the wastewater. The existence of the primary precipitation device has contributed to the high efficiency of removing TDS. The long enough water retention time in the precipitation device allows reduction of the parameters of the suspended solids, but in the



Figure 2. The removal effectiveness of the organic substances from municipal wastewater during the seasons, expressed as BOD<sub>5</sub>



Figure 4. The removal effectiveness of the total total dissolved substances during the seasons (TDS)

precipitation device there is also the degradation of organic matter going on, which is reducing the value of COD and  $BOD_5$  parameters by 30%. In the results of the research, tabular and graphical, overall efficiency of the removal of specific parameters using this constructed wetland was presented.

The undersurface device system and the use of hairy root plants have also contributed to the high efficiency of removing the suspended solids. The highest efficiency of TDS removal was in the summer period - 81.83%, and the lowest in winter time - 53.21%.

Merlin et al. (2002) did their research with municipal wastewater on a horizontal pilot – scale constructed wetland with underwater wastewater. The conclusion regarding the efficiency of this device came after six years of work. Three types of plants were planted in this CW: Typha latifolia, Phragmites australis and Scirpus maritimus. While using this, high efficiency of removing total suspended matter throughout the year was achieved: 95.6% (± 3.6%) on average, in the first stage already. Physical processes (decanting, filtration) associated with biological oxidation were key factors for removing total suspended matter. Efficiency of

organic matter removal expressed as COD and  $BOD_5$ in the first stage was about 60% on average, and at the constructed wetland exit higher than 90%.

Microbiological analysis of wastewater was made at the entry and exit of the constructed wetland. Using the Membrane Filter Technique in the samples, a total number of coliform bacteria was determined. The total number of coliform bacteria in the influent ranged from  $3.50 \times 10^5$  to  $2.82 \times 10^6$  and in the effluent  $1.10 \times 10^3$  to  $9.54 \times 10^4$ . The average colifomorous bacteria efficiency elimination from municipal wastewater during one year long research was  $97.88 \pm 0.80\%$ .

Zaimoglu (2006) also investigated the efficacy of removing total coliform bacteria from municipal wastewater as part of his research on a pilot - scale constructed wetland located in Adana, Republic of Turkey. Although the efficacy of eliminating total coliforms up to 95.2% was achieved during the CW usage and research period, the total number of coliforms in efluent ranged from 3x10<sup>3</sup> to 2x10<sup>8</sup> CFU/100 ml. Merlin et al. (2002) found that 50% of enterobacteria was removed in the first part of constructed wetland, about 90% in the second part, and 98% to 99.98% at the constructed wetland exit. The overall efficiency of the removal of enterobacteria ranged from 90% to 99.98%. Horizontal constructed wetland proved to be very effective in reducing the number of coliforms (2.3 to 2.6 log units) (Le et al., 2013).

## CONCLUSION

Prior to the construction of constructed wetland, it is recommended to build a pilot version first, and that version should have been used at least for a year in order to determine the optimum operating conditions of the pond.

Wetland plants used in constructed wetland should come from a natural local area, so plants can adapt as quick as possible. It is also recommended to use at least two plant species in the constructed wetland to achieve better purification efficiency. This is the reason why the first CW field had *Typha latifolia*, and in the other had *Phragmites australis*.

Efficiency of organic matter removal from municipal wastewater was the highest in the summer period. Good weather conditions and the growth of vegetation have contributed to 87.82% of the efficiency of organic matter removal through the chemical oxygen demand (COD), and to 87.33% of biochemical oxygen demand during 5 days (BOD<sub>5</sub>). The lowest efficiency was in the winter period - COD it was 64.51% and BOD<sub>5</sub> was 63.33%.

Removing the content of organic substances from municipal wastewater caused the decrease in total

dissolved solids. Efficiency of removing TDS from wastewater was also the highest in the summer period - 81.83%.

Constructed wetland proved to be very effective regarding the bacterial water status. The average efficacy of eliminating total coliform bacteria throughout the year was 97.88%.

The existence of this pilot constructed wetland contributed to the research field and also to the improvement of environmental awareness of the users themselves.

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