EFFECTIVENESS OF DOMESTIC WASTEWATER TREATMENT IN THE "GRMEČ" TEACHING CENTER USING PILOT - SCALE CONSTRUCTED WETLAND AS UNCONVENTIONAL METHOD

ORIGINAL SCIENTIFIC PAPER

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ABSTRACT: Environmental care, higher requirements for quality of effluent, high cost of conventional wastewater treatment, and increased energy costs required for their work, have led scientists to more comprehensive research on a possibility of using a constructed wetland in wastewater treatment technology. Constructed wetlands are artificially shaped swamps with the aim of creating conditions conducive to the purification of wastewaters flowing through them. They are used for treatment of municipal wastewater from small settlements and a small industrial facility, as well as other types of wastewater.

The educational pilot - scale constructed wetland on which the research was conducted is located in the area of Bihać municipality, on a plot used by the Biotechnical Faculty in Bihać. The pilot - scale constructed wetland for wastewater treatment covers an area of 20 m^2 and is dimensioned for 10 equivalents of population. In this research we have examined the effectiveness of domestic wastewater treatment in the "Grmeč" Teaching Center using pilot - scale constructed wetland.

Plants planted in the constructed wetland were *Typha latifolia and Phragmites australis*, and the substrate was made of sand and pebbles of different granulations. The recipient of purified wastewater is the Drobnica stream, which is about 10 m away from the site. The research was conducted in May, with the flow varied depending on a weekly student workload.

Efficiency of purification using constructed wetland depended on flow rate and organic wastewater load, ranging from 37.15% at a minimum flow of 9.89x10-6 m^3/s and HPK values of 35 mgO_2/L, up to 89.48% at the highest flow value of 2.51x10-5 m^3/s, and HPK values of 189 mgO_2/L. The highest concentration of ammonia in the influent was 145.62 mg N/L, and the lowest concentration of ammonia in the effluent was 6.31. mg N/L.

KEYWORDS: wastewater, constructed wetland, efficiency of purification.

INTRODUCTION

Constructed wetlands are complex biological systems, made and built to use natural processes that occur in wetland soil and plants, including microorganisms that participate in water purification. They are designed to imitate processes that happen in natural wetlands, but under controlled conditions.[1,2] These systems mostly consist of certain vegetation, substrates, soil, microorganisms and water, and they use complex procedures that include physical, chemical and biological mechanisms for removing different pollutants or for improving the quality of water.[3] Simple work, high treatment efficiency and relatively low costs of polygons construction and maintenance, in regard to conventional purification technologies – are the characteristics of a constructed wetland (CW) as acceptable quality solutions for wastewater purification. Other factors that contribute to their attractiveness are aesthetic and ecological values (biological diversity of wetland habitats). CW are used mostly for utility wastewater purification in smaller places away from the urban environment. The main role in purification process belongs to microorganisms that live on plants whose leaves, trees and roots are filled with air holes whose role is to bring the oxygen from atmosphere to the root and surrounding ground. Decomposed organic matters are built into tissue of the plants and that is how waste water is purified.[4] Plants that are mostly planted within the wetland systems for wastewater purification are cane (*Phragmites australis*), cattail (*Typha latifolia*), bur-reed (*Sparganium erectum*), common clubrush (*Scirpus lacustris*), yellow iris (*Iris pseudacorus*), sedges (*Carex sp.*) etc.[5] The main characteristics of those plants are: widely spread and adaptive to different conditions, including very low temperatures as well (below 0°C). It is recommended to choose native wetland vegetation whenever it is possible.[6] In this research paper will be present the examination results of domestic wastewater treatment efficiency (water from Teaching Centre "Grmeč"), in a month of May 2017. The pilot - scale constructed wetland was used. During this research, wastewater flow and organic loading varied on a daily basis, depending on the number of students. The plants that were used in a plant device were: cattail (*Typha latifolia*) and cane (*Phragmites australis*), and substrate consisted of sand and pebbles in various grain sizes. The aim of this research was to determine efficiency of domestic wastewater treatment with the pilot – scale constructed wetland. Efficiency of the work was confirmed by measuring the relevant standard physical-chemical and bacteriological parameters.

MATERIAL AND METHODS

The educational pilot - scale constructed wetland that was used for the research purposes is located in Bihać, on the lot that is currently used by Biotechnical Faculty. That device covers a total surface of 20 m^2, dimensioned for 10 ERU (equivalent unit), and intended for experimental purification of different kinds of wastewater for research purposes. Cattail (*Typha latifolia*) was planted in the first field of the CW, and cane (*Phragmites australis*) was planted in the second field. Domestic wastewater from Teaching Centre "Grmeč" was used for the research purposes, with the varying flow and the content of organic matter in wastewater, depending on the number of students. The research was done in a month of May, when vegetation was lush. The content of wastewater was monitored through specific parameters such as suspended solids, chemical oxygen demand (COD), biochemical oxygen demand (BOD), concentration of ammonia ion and salt, nitrate and nitrite, concentration of phosphorus etc. Determination of the physical-chemical parameters of the quality of a wastewater sample was performed according to standard APHA[7] methods and Uredba o uslovima ispuštanja otpadnih voda u okoliš i sisteme javne kanalizacije.[8] In order to measure general parameters like pH-value, temperature, electroconductivity, dissolved oxygen concentration and oxygen saturation – it used multiparameter SensoDirect 150, Lovibond, and the turbidimeter HANNA was used to measure the turbidity of water in the sample. Spectrophotometric method on Spectrophotometer photoLab® 6600 UV-VIS device was used for the determination of ammonia nitrogen, nitrite, nitrate and phosphorus, with help of Merck with special test kits from the Spectroquant®. The chemical oxygen demand was determined spectrophotometrically by the device called Spectrophotometer photoLab® 6600 UV-VIS. The method for determination of chemical oxygen demand is called a bichromatic method, and Merck tests Cod Cell Test C4/25 were used for this purpose. Microbiological analysis of the sample was determined by the membrane filtration method, and ready-made substrates for determination of total coliform bacteria and *Escherichia coli* were used for this purpose.

RESULTS AND DISCUSSION

This chapter presents the results of the physical, chemical and biological analysis of domestic wastewater at Teaching Centre "Grmeč", at the entry and exit of constructed wetland, depending on the flow rate. The research was done in a month of May 2017, and the results varied depending on the flow and workload of students.

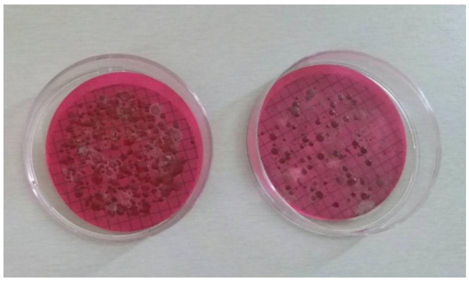

Figure 1. Total coliforms in influent and effluent at 37°C/24h (number/100 ml)

Figure 2. Colour of municipal wastewater in influent and effluent

Table 1. Physico-chemical quality indicators of municipal wastewater from Educational Centre “Grmeč” at the entry and exit of the educational pilot - scale constructed wetland

Parameter	I1	E1	I2	E2	I3	E3	Limits[8]
Flavour	Strong odour	Odourless	Strong odour	Odourless	Strong odour	Odourless	-
Colour	Light brown	Colourless	Light brown	Colourless	Yellow	Colourless	-
Fuzziness (NTU)	35.17	16.39	25.12	12.78	32.64	12.5	-
Temperature (°C)	15	14.2	13	14	14.5	15.3	30
pH	7.9	8.64	7.85	8.05	8.13	8.06	6.5-9.0
Conductivity (µS)	463	267	323	250	369	357	-
Oxygen saturation (%)	2	10.4	2.6	6.7	3.7	9.3	-
Dissolved oxygen (mg/L)	0.9	5	1.2	3.3	1.7	4.3	-
Evaporated residue (mg/L)	366	218	309	261	340	280	-
Annealed rest (mg/L)	243	115	267	188	199	165	-
Suspended solids (mg/L)	65	35	5	3	25	5	35
Ammonia (mg N/L)	48	19.04	21	6.77	42.64	6.31	10
Nitrites (mg N/L)	0.06	0.13	0.08	0.02	0.11	0.02	-
Nitrates (mg N/L)	0.7	0	0.1	0	0.05	0	10
Total nitrogen (mg N/L)	49	22.2	23.2	7.5	42.9	7.11	15
Phosphorus (mg/L)	1.73	0.66	1.52	0.64	1.57	0.62	2
Consumption of $KMnO_4$ (mg/L)	17.9	5.5	12.32	3.79	16.22	4.18	-
COD (mgO_2/L)	87	32	35	22	119	20	125
BOD (mgO_2/L)	38	14.3	15.7	10.4	44.8	17.5	25
Flow (m^3/s)	$1.54x10^{-5}$		$9.89x10^{-6}$		$1.83x10^{-5}$		
Efficiency of purification for COD (%)	63.22		37.15		83.2		

I1 – influent in the pilot - scale constructed wetland (CW) the first day; E1 – effluent from the CW, the fifth day after sampling
I2 – influent in the pilot - scale constructed wetland (CW) the second day; E2 – effluent from the CW, the fifth day after sampling
I3 – influent in the pilot - scale constructed wetland (CW) the third day; E3 - effluent from the CW, the fifth day after sampling

Table 2. Physico-chemical quality indicators of municipal wastewater from Educational Centre “Grmeč” at the entry and exit of the educational pilot - scale constructed wetland

Parameter	I4	E4	I5	E5	Limits[8]
Flavour	Strong odour	Odourless	Strong odour	Odourless	-
Colour	Yellow	Colourless	Yellow	Colourless	-
Fuzziness (NTU)	30.65	7.11	26.58	14.84	-
Temperature (°C)	14.1	15.6	14.8	16	30
Ph	8.35	8.2	8.26	8.23	6.5-9.0
Conductivity (µS)	406	348	446	334	-
Oxygen saturation (%)	5.5	12.1	2.1	7.2	-
Dissolved oxygen (mg/L)	2.5	4.7	1	3.3	-
Evaporated residue (mg/L)	260	200	360	260	-
Annealed rest (mg/L)	180	132	199	175	-
Suspended solids (mg/L)	15	10	78	25	35
Ammonia (mg N/L)	145.62	22.55	48.69	28,.3	10
Nitrites (mg N/L)	0.11	0.08	0.18	0.11	-
Nitrates (mg N/L)	0.05	0	0.09	0	10
Total nitrogen (mg N/L)	40.5	23.4	147.1	29.9	15
Phosphorus (mg/L)	1.53	0.64	1.8	0.72	2
Consumption of $KMnO_4$ (mg/L)	18.2	2.3	16.6	6.2	-
COD (mgO_2/L)	189	20	157	41	125
BOD (mgO_2/L)	88	28.6	69.8	26.6	25
Flow (m^3/s)	$2.51x10^{-5}$		$1.23x10^{-5}$		
Efficiency of purification for COD (%)	89.48		73.89		

I4 –- influent in the pilot - scale constructed wetland (CW) fourth day E4 – effluent from the CW, the fifth day after sampling
I5 - influent in the pilot - scale constructed wetland (CW) fifth day; E5 – effluent from the CW, the fifth day after sampling

Sampling of wastewaters was carried out in accordance with the wastewater sampling standards prescribed by the Pravilnik o izmjenama i dopunama pravilnika o prirodnim mineralnim i prirodnim izvorskim vodama[9], in accordance with the domestic legislation in this field. The hydraulic retention time (HRT) for plant device was 5 days. This period depends on the size of pollutant and default level of purification. The usual retention time for removing BOD is 2-5 days and 7-14 days to remove nitrogen. HRT can be calculated according to the following formula:[10]

$$HRT = V/Q = LW\,(dmn+dw)/Q = A(dmn+dw)/Q \text{ (day)} \qquad (1)$$

$$HRT = 5 \text{ DAYS}$$

V – volume of water in a plant device (m^3); Q – medium flow through a plant device (m^3/days); A – surface of a plant device (m2); L – length of a plant device (m); W – width of a plant device (m); dm - the thickness of the medium that allows water to pass through (m); dw - depth of water from media surface (m); n – porosity.

The parameters were monitored for 5 days, and the flow varied depending on the workload of students. The flow was ranging from 9.89×10^{-6} m^3/s to 2.51×10^{-5} m^3/s. The final recipient was the stream called Drobnica, which is located near the teaching centre. The pH value at the inlet and outlet samples from the device ranged from 7.85 to 8.64, which is in the line with border pH value of wastewater that can be dropped into surface water bodies, as prescribed by the Decree on the conditions of discharge of wastewater to the environment and public sewerage systems.[8] Concentration of suspended substances in influent samples varied, and it had the highest value on the first and last day of sampling, where the concentration of the suspended substances exceeded the limit values prescribed by the legislation. Nitrogen compounds in water are an indicator of current pollution. In all influent samples, concentration of ammonia and total nitrogen exceeded the maximum permissible concentration. The content of organic matter in wastewater samples (expressed as COD and BOD) varied, and the highest COD value was measured on the fourth sampling day, during the maximum flow. The COD value in the influent samples 4 and 5 exceeded the limit values prescribed by regulation. The content of organic matter expressed as COD and BOD in all wastewater samples, after passing through the constructed wetland, was below the maximum permissible concentration prescribed by regulation.[8] Efficiency of wastewater purification while using a horizontal pilot constructed wetland, expressed through COD, varied depending on the concentration of organic matter and the flow. The highest efficiency happened on the fourth day and it amounted to 89.48%, during the highest concentration of organic matter and the highest flow rate. The lowest efficiency was in the sample that went through the device on the second day - 37.15%. At that time there was also the smallest flow and the smallest content of organic matter in the input sample expressed as COD. The highest removal efficiency of ammoniacal nitrogen was in sample 4 – 84.52%, and the lowest removal efficiency of ammoniacal nitrogen was in sample 5 – 41.41%. In the wastewater samples at the entrance and exit from the constructed wetland, microbiological analysis of sample was done while using the membrane filtration method. Pre-mixed substrates for determination of total and faecal coliform bacteria were used in that process. The largest number of grown colonies was in sample 4, which had the highest content of organic substances expressed as COD. Total number of grown coliform bacteria in all samples at the entrance to the device at 37°C/24h (number/100 ml) was >1000. This number was <80 cfu/100ml in effluent. The number of *Escherichia coli* bacteria present in all influent samples exceeded the maximum number allowed in water that is released into coastal and transitional waters. In effluent samples that number is in accordance with the legal regulation.

Many researchers have dealt with this particular problem - wastewater. Merlin and associates[11] did this research on a three-phase horizontal pilot constructed wetland with subsurface flow of wastewater. This plant device was used for domestic wastewater purification and it was dimensioned for 350 population equivalent (PE). Since we are talking about a three-phase constructed wetland, there were three plant species planted: *Typha latifolia, Phragmites australis* and *Scirpus maritimus*. The hydraulic retention time of water in the device was 4-5 days. With the usage of plant equipment throughout the year, high efficiency of removal of total suspended particles was achieved, on average about 96% in the first phase already. Efficiency of the removal of organic matters expressed as COD and BOD in the first phase was on average about 60%, and on constructed wetland exit was bigger than 90%. Efficiency of nitrogen removal was on average about 57% (±21%), phosphorus 69% (±27%), respectively. Removal of total coliforms and enterococci was more or less proportional to water retention in every part of the constructed wetland. Merlin and associates[11] found that 50% of enterobacteria was removed in the first part of the constructed wetland, around 90% in second part and 99% at the plant device exit. The overall efficiency of the enterobacteria removal ranged from 90% to 99.98%. Baskar and associates[12] did the research on purification efficiency of constructed wetlands depending on the vegetation type. Two small pilot-scale constructed wetlands were used for this research. They planted *Typha latifolia* in the first device, and *Phragmites australis* in the second one. Then they let domestic wastewater to flow through those devices. The hydraulic retention time (HRT) was 2, 4, 6 and 8 days. In the constructed wetland which had *Phragmites australis* planted, with the mentioned retention time, the efficiency of organic ingredients removal expressed as COD was 39%, 44%, 64% and 69%. Efficiency of total nitrogen removal was 23%, 7%, 31% and 45%. In the plant device which had *Typha latifolia* planted, the efficiency of organic ingredients removal expressed as COD was 31%, 37%, 73% and 68%. Efficiency of total nitrogen removal was 26%, 17%, 34% and 36%. Collison and Grismer[13] did the research on a horizontal constructed wetland with subsurface flow of water which had polluted cattail (lat. *Typha latifolia*). They investigated the efficiency of nitrogen removal and organic components expressed as COD values from two types of wastewater: domestic wastewater and synthetic wastewater, starting from a month of November to a month of June. Statistical analysis of results for this time period showed that the efficiency of organic components removal expressed as COD value from domestic wastewater - was 79%, and nitrogen 94%.

Studies have shown that devices with two kinds of vegetation have better purification efficiency than devices with one kind of vegetation.[14]

CONCLUSION

This research contribute to the understanding of how horizontal pilot – scale constructed wetland with different flow functions.

- Efficiency of wastewater purification while using the horizontal pilot – scale constructed wetland, expressed through COD, varied depending on the concentration of organic matter and the flow. The highest efficiency was at $9.89x10^{-6}$ m^3/s (89.48%), with the highest concentration of organic matters. The lowest efficiency was at $2.51x10^{-5}$ m^3/s (37.15%), with the lowest concentration of organic matters in the input sample expressed as COD.
- The highest efficiency of total nitrogen removal (as indicators of current pollution) was in sample number 3 (83.43%). The lowest efficiency of total nitrogen removal was in sample number 1 (54.7%).
- Efficiency in suspended matter removal ranged from 40% to 67.95%.
- Efficiency in *E. Coli* removal during 5 days showed excellent results in this research. The number of bacteria decreased from >1000/100 ml to <20 cfu/100ml. Those results are consistent with what other investigators have reported.
- Studies have shown that devices with two kinds of vegetation have better purification efficiency than devices with one kind of vegetation.

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