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Significance of Substrate Selection in the Efficiency of Wastewater Treatment in Constructed Wetlands (CWs)

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Abstract

Constructed wetlands (CWs) can achieve a high-quality wastewater treatment and a quality that meets the prescribed standard, defined by legislation on wastewater discharge. A limitation in the application of constructed wetlands (CWs) is the large area requirement, which limits their application. The subject matter of this research is to check the possibility of improving the efficiency of wastewater treatment and reducing the required area for constructed wetlands (CWs) by using an adequate substrate under the conditions found in Montenegro. In the described experiment, the constructed wetlands (CW) have a vertical flow system and play the role of a secondary wastewater treatment, receiving water from the existing WWTP in Podgorica after the primary treatment. These vertical flow systems reflect experience with the use of similar systems in Slovenija, Austria and Italy. Measurements to date show that the substrate plays an important role and that wastewater treatment efficacy varies significantly with respect to the type of substrate when used under the conditions available in Montenegro.

Keywords

Constructed Wetlands (CW), Reduced Area of Wetlands, Substrates for Wetlands, Vertical Flow System, Primary Treatment, Treatment Efficacy

1. Introduction

Nature-derived solutions are both natural and constructed systems that utilize and reinforce physical, chemical and microbiological treatment processes (Sean O'Hogain, 2018) [1]. These processes form the scientific and engineering principles for water/wastewater treatment and hydraulic infrastructure. Nature-based solutions may be low cost, require low energy for operation and maintenance, generate low environmental impacts and provide added value through the benefits that accrue to humanity (ecosystem services). Ecoremediation achieves a high level of wastewater treatment and a water quality that meets the prescribed standard defined by legislation on wastewater discharge in Montenegro, as well as the standard defined by EU Directive 91/271/EEC (Didanovic, S., Sekulic, G., 2011, 2012) [2]-[11].

The implementation of projects from the Ecoremediation Strategy in Montenegro has enabled a significant reduction in the costs of individual projects in relation to sector studies. Given the challenges of Montenegro in the field of wastewater, it can be concluded that ecoremediation in integrated form with existing strategies can successfully contribute to increasing environmental quality and reducing costs in the implementation of Council Directive 91/271/EEC of 21 May 1991 concerning urban wastewater treatment, which is planned in full by 2035, as well as significantly reducing the WWTP construction and maintenance costs [12].

The following are some advantages and disadvantages of constructed wetlands, compared to conventional facilities (EPA 2003, Vrhovšek 2017, Malus 2012, Tushar, 2009, Vidali, 2001) [13] [14] [15]. Advantages of constructed wetlands (CW) are that they can be less expensive to build than other treatment options and that they utilize natural processes. They can be set up by simple construction (can be constructed with local materials), they necessitate simple operation and maintenance. In addition, they lead to cost-effectiveness (low construction and operation costs), and process stability. Limitations of constructed wetlands (CWs) are large area requirements. Also, wetland treatment may be economical relative to other options only where land is available and affordable. In addition, design criteria have yet to be developed for different types of wastewater and climates (UN-HABITAT, *et al.* 2008) [16].

There are two basic types of constructed wetlands (Malus 2012, Tushar *et al.* 2009) [17], which differ in the type of wastewater flow through them: constructed wetlands with surface wastewater flow and constructed wetlands with subsurface wastewater flow. In both types, it is extremely important to ensure the preliminary treatment of raw wastewater and the method of discharging wastewater and distribution in pools with vegetation (Malus 2012, Tushar 2009) [18].

Constructed wetlands (CWs) consist of pools that are lined on one side with impermeable foil or clay, on which the substrate is placed (usually a mixture of sand and gravel, the ratio of which depends on the permeability of the substrate) in which selected plants are planted (Phragmites australis, Botur, Typha, Carex).

The use of CW often depends on the availability of the required construction area. The possibility of reducing the space required for constructed wetland (CW) has not yet been sufficiently explored. The impact of substrates on the efficacy of treatments is insufficiently examined, as is the impact on the required surface for CW area.

1.1. Constructed Wetland (CW) Sizing

There are many different guidelines for CW sizing summarized in a number of papers: Cooper (2005), Vymazal *et al.* (2008), Kadlec and Wallace (2009) *et al.* [19] [20] [21]. In determining the required area for CW, Brix and Johansen (2004) [22] define a simple rule according to which the constructed wetland A area (m2) is calculated as a triple multiple of the population equivalent with the sole aim of achieving 95% removal of BOD5 when using vertical subsurface flow constructed wetlands in a temperate climate zone. According to German guidelines (DWA, 2006) [23], the required area of vertical subsurface flow constructed wetlands is calculated from the following formula: A (m^2) = 4·PE (population equivalent), regardless of the influencing factors.

Danish guidelines Hans Brix, Carlos A. Arias (2005) [24], the use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: The necessary surface area of the filter bed is 3.2 m^2/person equivalent and the effective filter depth is 1.0 m. The filter medium must be filter sand with a $d10$ between 0.25 and 1.2 mm, a $d60$ between 1 and 4 mm, and a uniformity coefficient ($U = d60/d10$) less than 3.5.

The vertical flow **CW area** varies, and the experiences of countries are different (Hrast T. 2012) [25], so that an area of 1.53 m^2 is required for the construction of these systems per PE in Italy, 5 m^2 in Austria, 4.6 m^2 in Denmark, and 2.3 m^2 in Slovenia. The hydraulic load also varies, so it is 180 l/day PE in Italy, 150 l/day PE in Austria, 146 l/day PE in Denmark, and 145 l/day PE in Slovenia. The water retention time in these systems also varies.

For the sizing of wastewater treatment plants (Sekulić, 2015) [26], it is important to keep in mind the following:

1) Population (expressed in PE)

2) Specific water consumption (usually calculated at 150 l/day per capita)

3) Daily amount of wastewater (Qd = Number of PE × 0.150 × 0.8)

The **substrate depth** for these systems also varies, so it is 1.1 m in Italy, 0.83 m in Austria, 1.1 m in Denmark, and 0.66 m in Slovenia. The slope of the bottom is 1.5% in Italy, 1.03% in Austria, 1.1% in Denmark and 1% in Slovenia.

The possibility of reducing the space required for constructed wetland (CW) construction has not yet been sufficiently explored. The impact of substrates on the efficacy of treatments is insufficiently examined, as is the impact on the required surface for CW area. In the previous practice of CW construction, multichambered septic tanks, Imhoff tanks or presetting tanks (Malus 2012, Tushar 2009) were mainly used in the phase of primary treatment, while other possibilities available on the market, such as newer generation extreme separators, use of efficient microorganisms, etc., have never been sufficiently investigated with the aim of reducing the potential space required for CW construction (in the secondary treatment phase).

1.2. Subject and Goal of Research

The subject matter of this research is to check the possibility of reducing the required area for CW construction (secondary treatment) by using an adequate substrate under the conditions in Montenegro.

The aim of this research is to examine the efficiency of municipal wastewater treatment under the conditions in Montenegro through the treatment in a CW vertical flow system on 3 different types of substrates used in Italy, Austria and Slovenia and thus the possibility of reducing the area required for CW construction, depending on the choice of substrate. Additionally, the aim of the research is to use the primary treatment of the existing WWTP in Podgorica to examine the effectiveness of secondary treatment in CW with 3 different substrate types.

The defined goals will be accompanied by setting up an experiment and applying methods for the analysis of physico-chemical parameters: t˚C, pH, TSS, COD and BOD_5.

2. Materials and Method

2.1. Site Description

The pilot project CW was set up in the area of an existing WWTP in Podgorica (**Figure 1**). The existing WWTP in Podgorica is located in the settlement Krusevac, in the city centre, on the right bank of the Moraca River (Winsoft D.O.O. 2015) [27]. There is a wastewater treatment plant (WWTP) in Podgorica, which has been in operation since 1978. The site is within the existing WWTP in Podgorica in the city district of Krusevac.

WWTP is designed for a capacity of 55.000 PE and implements a biological secondary treatment with primary sedimentation and activated sludge process (DHV, December 2007) [28].

2.2. Experimental Setup

In November 2020, the pool was set up, and a pilot project was constructed. The basic elements of the CW used in this experiment are shown in **Figure 1**. The constructed wetland (CW) has a vertical flow system and the role of secondary wastewater treatment in this experiment, receiving water from the existing WWTP in Podgorica after the primary treatment. The primary treatment at the existing WWTP is done for the purpose of removal of coarse material on coarse and fine screens, removal of inert material in aerated sand traps, and removal of sediment and suspended matter in primary sedimentation tanks. According to 2019 data obtained by municipal wastewater treatment plant management, regarding the incoming water or the influent, the percentage of COD and BOD_5 of treated wastewater was reduced by approximately 31% after mechanical treatment (Source: archive of Podgorica Water and Sewage Corporation).

Scheme 1 shows the experimental setup in the settlement Krusevac-Podgorica city.

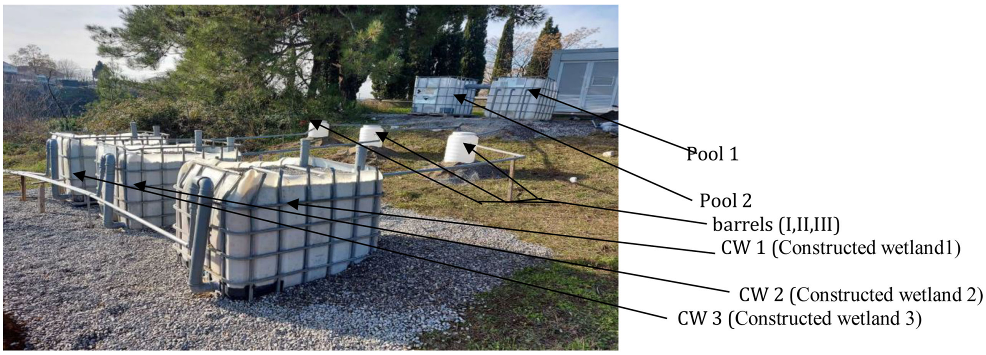
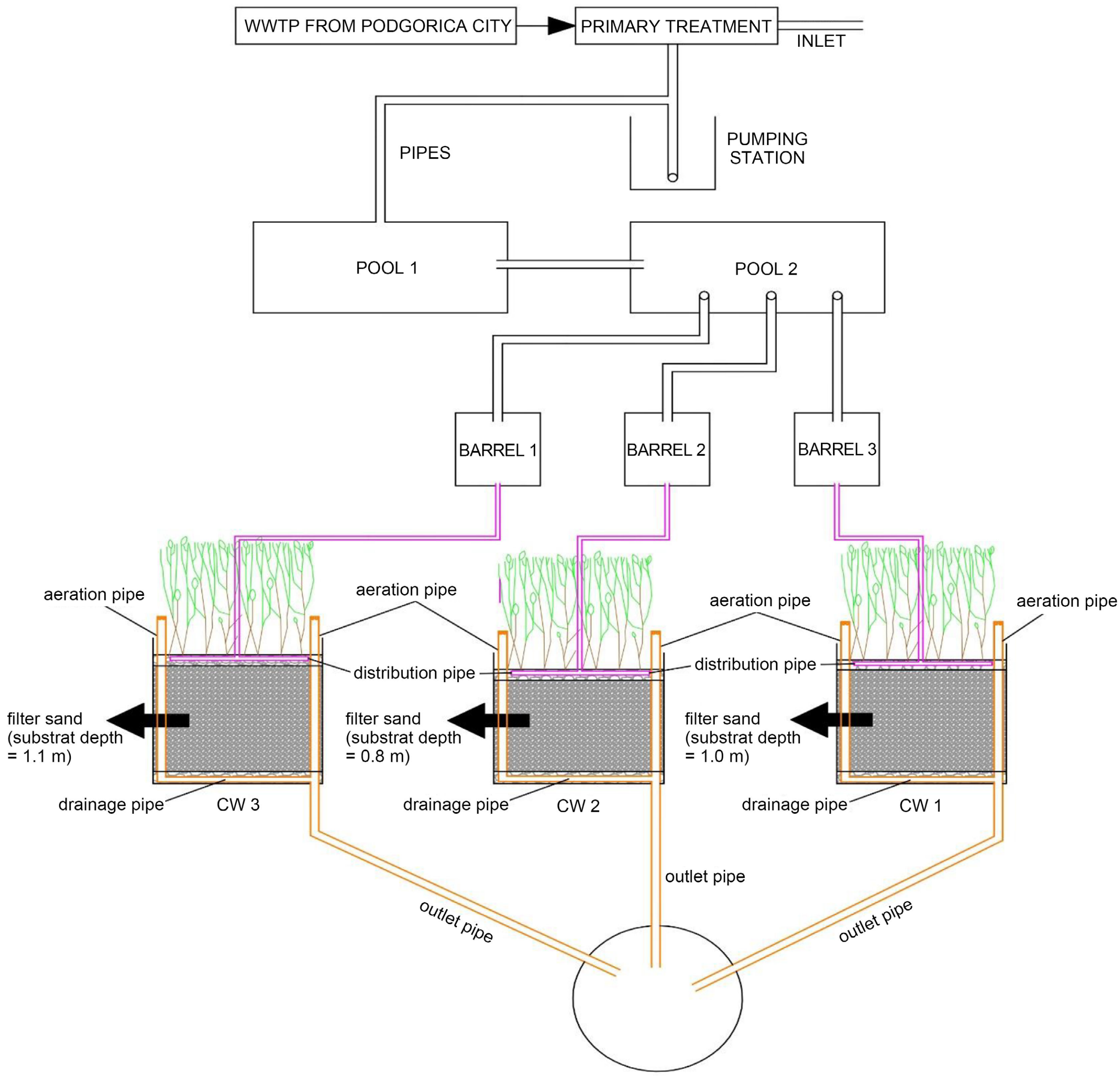


Figure 1. Experimental setup, location of the existing WWTP in the settlement of Krusevac-Podgorica.



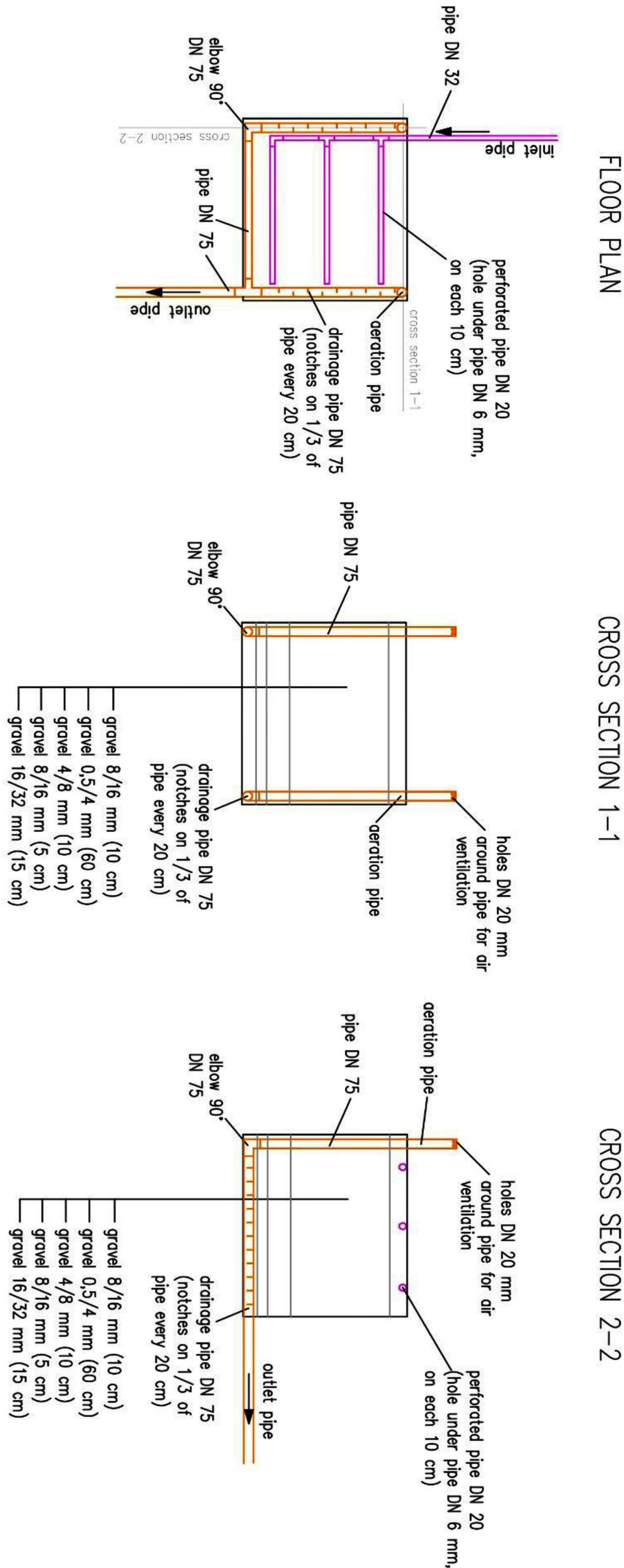
Scheme 1. Layout of a vertical flow constructed wetland system (CW 1, CW 2 and CW 3) in the settlement Krusevac-Podgorica city.

2.3. Water and Air Distribution in the CW

After the primary treatment at the WWTP in Podgorica (**Figure 2**), wastewater is pumped by the pump (Villager VSP10000) into Pool 1 using a 1 m^3 PVC water hose, and then through a PVC plastic pipe of DN 125 mm in diameter, it is pumped to the adjacent Pool 2 made of PVC with a volume of 1 m^3, on which valves for water distribution are installed using PVC plastic pipes of DN 32 mm in diameter, and through plastic barrels with a volume of 60 liters, which have the role of water retention and additional sedimentation. Water from barrels I, II and III is distributed through PVC plastic pipes 32 mm in diameter into three different vertically constructed wetlands (CW-1, CW-2 and CW-3, made of PVC with a volume of 1 m^3) filled with substrates of different granulation and water and air distribution pipes. These vertical CW fields represent the experiences of different countries in the application of secondary wastewater treatment using plants, such as Italy, Austria and Slovenia. In the CW surface zone, perforated pipes made of PVC plastic with a diameter of DN 32 mm are placed every 40 cm along its width, in addition to a side pipe through which water flows into the CW fields. These pipes (except the side one) are drilled every 10 cm (holes with a diameter of 6 mm) to enable the CW to be evenly soaked with wastewater. Inside the constructed wetlands (CW-1, CW-2 and CW-3), at the bottom, there are drainage pipes made of PVC plastic with a diameter of DN 75 mm that are drilled (notched 1/3 of the rim) every 20 cm to enable the reception of water passing through the substrate, and then the water is taken using a full pipe from the CW into the joint pipe (in the joint, this pipe is of DN 75 mm diameter) whose height later regulates the water level in the CW itself (**Figure 1**), and from there, after treatment, water is drained using PVC plastic pipes of DN 32 mm in diameter into a manhole located in the immediate vicinity.

Scheme 2 shows the cross section through constructed wetland (CW 1). The directions, diameters and types of the installed pipes are shown. The granulation, depth and structure of the substrate are also shown.

Figure 2. Wastewater after primary treatment (PT).



Scheme 2. Cross section through CW 1.

2.4. Substrate Setting in CW and Plant Plants

In this experiment:

1) CW 1 vertical flow system for an area of 1 m^2 represents the experience of Slovenia under the conditions in Montenegro (Scheme 2). The **substrate depth** for this system is 1.0 m. The filter medium is sand with a *d*10 between 8/16 mm, *d*60 between 0.5 and 4 mm, *d*10 between 4/8 mm, *d*5 between 8/16 mm, and *d*15 between 16/32 mm;

2) The CW 2 vertical flow system for an area of 1 m^2 represents the experience of Austria under the conditions in Montenegro. The **substrate depth** for this system is 0.83 m. The filter medium is sand with a *d5*-10 between 8/16 mm, *d*50 between 0 and 4 mm, *d5*-10 between 4/8 mm or 8/16, and *d*20 between 8/16 mm or 16/32 mm.

3) The CW3 vertical flow system for an area of 1 m^2 represents the experience of Italy under the conditions in Montenegro. The **substrate depth** for this system is 1.1 m. The filter medium is sand with a *d*20 between 16/32 mm, *d*60 between 0.4 and 8 mm, and *d*40 between 16/32 mm.In May 2021, after the construction and installation of the experiment, reeds were planted in all three troughs (CW1, CW2 and CW3) and transplanted from Skadar Lake, where they grow naturally.

2.5. Sample Collection and Analysis

Substrate efficiency analyses in the CW-1, CW-2 and CW-3 troughs were performed in the period of March-August 2021. Since the reed was rooted late, the efficacy of the substrate and the plants together will be examined in the following period because the plants need a certain period to develop a root system.

Analyzed parameters: biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids, temperature and pH. The analyses were performed in the laboratory located within the WWTP (Podgorica Water and Sewerage Corporation) at least twice a month in the **period of March-August 2021.** Wastewater sampling was performed at 6 points: 1) at the inlet, 2) after mechanical treatment, 3) from the pool to which water is pumped and where it is retained, 4) at the outlet after treatment in CW1, 5) at the outlet after treatment in CW2, and 6) at the outlet after treatment in CW3.

Wastewater dosing in the considered period was performed in several ways from 14 analyzed series, dosing was performed in such a way that a volume of 120 liters was dosed three times per day in each CW in three and four doses, a volume of 60 liters was dosed two times per day in one and three doses, a volume of 200 liters was dosed once a day in three doses, and a volume of 100 - 150 liters was dosed seven times per day in such a way that dosing was performed once, twice and three times per day.

3. Methods and Sampling Used

Sampling

Sampling is performed using an aluminum grip with a telescopic handle. The container on the gripper in which the sample is taken is plastic and has a volume of 1 l. Sampling was performed at 6 points: inlet water, water after primary treatment, pool, effluent after CW1, CW2 and CW3.

Temperature and pH

A mercury thermometer (PRECISION) with a scale division of 1/10˚C. is used to measure the temperature. The temperature was measured in a sample bottle with a volume of 1 L. The bottle must not be exposed to thermal or direct sunlight. The measurement is performed by placing the thermometer directly in the sample bottle, and the temperature is read only after a time period that provides constant values. Recording is performed at the nearest division of 0.5˚C. pH was measured with a pH meter WTW 315 (Gmbh D-82362 Weilheim).

Determination of chemical oxygen demand (COD) with potassium dichromate

In research standard methods for testing water quality (COD) were used, Coha (1990) [29].

Determination of biochemical oxygen consumption after 5 days (BOD_5)

In research standard methods for testing water quality (BOD_5) were used, Coha (1990) and Lurje (1984) [29] [30].

Procedure for determination of suspended substance (TSS) content

Standard methods for the examination of water and wastewater, 14th edition, 1975 [31] were used for determination TSS in the research.

4. Results

Table 1 shows the results of the analyzed samples in the period of March-August 2021. Wastewater analysis was performed at 6 points: at the inlet to the WWTP, after primary treatment, in Pool 1 (to which water is pumped after primary treatment), at the outlet (effluent) from CW 1 (substrate-experience of Slovenia), at the outlet (effluent) from CW 2 (substrate-experience of Austria), and at the outlet (effluent) from CW 3 (substrate-experience of Italy). There were 13 series of performed sample analyses, including 6 previously mentioned points, in total. The analyzed parameters were t (temperature), pH, suspended solids, chemical oxygen demand (COD), and biological oxygen demand (BOD_5). Considering that the plants were rooted later (in the second half of June), as well as that they needed time to develop the root system, as concerns the incoming water, it can be concluded that the previous analyses mainly examined the substrate efficiency under weather conditions in Podgorica, Montenegro. Table 2 shows the percentage of SM, COD and BOD_5 elimination after primary treatment for the incoming water, while Table 3 shows the percentage of SM, COD and BOD_5 elimination after discharge from CW 1, CW 2, CW 3, with respect to the respective values for Pool 1 and the outgoing water.

Wastewater dosing in the considered period was performed in several ways; from 14 analyzed series, dosing was performed in such a way that a volume of

120 liters was dosed three times per day in each CW in three and four doses, a volume of 60 liters was dosed two times per day in one and three doses, a volume of 200 liters was dosed once a day in three doses, and a volume of 100 - 150 liters was dosed seven times per day in such a way that dosing was performed once, twice and three times per day.

Table 1. Results of analyzed samples in the period march to august 2021.

Dosing: poured 120 liters per day (60 liters at 9, 60 liters at 3 p.m.)											
DATE/SAMPLING POINT	**t (temperature)**	**pH**	**TSS**			**COD**			**BOD_5**		
	˚C		**mg/l**	**%**	**%**	**mg/l**	**%**	**%**	**mg/l**	**%**	
01.03.2021 (INLET)	**16**	**7.8**	**234**			**592**			**380**		
Sampling point after primary treatment	**16**	**7.5**	**120**			**500**			**170**		
03.03.2021											
POOL 2	**16**	7.8	132		**44**	452		**24**	174		**54**
EFFLUENT-ITALY	**16**	7.4	90	**32**	**62**	368	**19**	**38**	82	**53**	**78**
EFFLUENT-AUSTRIA	**16**	7.5	76	**42**	**67**	292	**35**	**51**	80	**54**	**79**
EFFLUENT-SLOVENIA	**16**	7.5	98	**26**	**58**	360	**20**	**39**	83	**52**	**78**
Dosing: poured 60 liters per day (in a single dose)											
	t (temperature)	**pH**	**TSS**			**COD**			**BOD_5**		
	˚C		**mg/l**	**%**		**mg/l**	**%**		**mg/l**	**%**	
16.03.2021 (INLET)	**17**	**7.9**	**168**			**416**			**230**		
Sampling point after primary treatment	**16.5**	**7.6**	**154**			**304**			**174**		
17.03.2021											
POOL 2	16	7.8	128		**24**	512			335		
EFFLUENT-ITALY	16.5	7.6	40	**69**	**76**	140	**73**		104	**69**	
EFFLUENT-AUSTRIA	16.5	7.4	36	**72**	**79**	68	**87**		66	**80**	
EFFLUENT-SLOVENIA	16.5	7.8	78	**39**	**54**	108	**79**		76	**77**	
Dosing: poured 120 liters per day in three doses (for 8 hours)											
19.03.21	**t (temperature)**	**pH**	**TSS**			**COD**			**BOD_5**		
INLET	**16.5**	**8.1**	**200**			**348**			**325**		
Sampling point after primary treatment	**16**	**7.8**	**162**			**304**			**172**		
24.03.2021	**˚C**	**pH**	**mg/l**	**%**		**mg/l**	**%**		**mg/l**	**%**	
POOL 2	16	7.7	316			388			335		
EFFLUENT-ITALY	16	7.7	48	**85**		188	**51.5**		118	**65**	
EFLUENT-AUSTRIA	16	7.5	44	**86**		136	**65**		96	**71**	
EFLUENT-SLOVENIA	16	7.8	46	**85.5**		180	**54**		138	**58**	
26.03.2021	16	8.2	284			384			310		

Continued

Dosing: poured 120 liters per day in four doses											
31.03.2021	**t (temperature)**	**pH**	**TSS**			**COD**			**BOD_5**		
POOL 2	22	7.6	220			312			210		
EFFLUENT-ITALY	21.5	7.7	40	**82**		228	**27**		120	43	
EFFLUENT-AUSTRIA	21.5	7.4	48	**78**		148	**53**		90	57	
EFFLUENT-SLOVENIA	22	7.7	90	**59**		184	**41**		118	44	
07.04.2021											
INLET	17	8.2	146			324			185		
Sampling point after primary treatment	16.5	7.7	122			208			144		
Dosing: poured 60 liters per day in three doses											
08.04.2021											
POOL 2	18	7.9	118		**20**	240		**26**	150		
EFFLUENT-ITALY	18	7.8	86	**27**	**41**	132	**45**	**59.3**	80	47	57
EFFLUENT-AUSTRIA	18	7.5	70	**41**	**52**	128	**47**	**60.5**	72	52	61
EFFLUENT-SLOVENIA	19	7.9	88	**25**	**40**	136	**43**	**58**	60	60	68
14.04.2021											
INLET	16	8.1	188			340			220		
Sampling point after primary treatment	16	7.7	122			248			152		
Dosing: poured 150 liters per day in three doses (3 · 50 liters)											
15.04.2021											
POOL 2	12	7.8	160			252			160		
EFLUENT-ITALY	13	7.8	86	**46**	**54**	120	**52**	**65**	72	55	**67**
EFLUENT-AUSTRIA	13	7.6	52	**67**	**72**	104	**59**	**69**	56	65	**74**
EFLUENT-SLOVENIA	12	7.8	80	**50**	**57**	136	**46**	**60**	70	56	**68**
23.04.2021											
INLET	16	8.2	114			320			165		
Sampling point after primary treatment	16	7.7	66			180			120		
Dosing: poured 100 liters per day in two doses (2 · 50 liters)											
29.04.2021											
POOL 2	20	7.6	110			340			200		
EFLUENT-ITALY	23.5	7.8	76	**31**	**x**	148	**56**	**X**	90	**55**	
EFLUENT-AUSTRIA	23	7.7	50	**55**	**x**	180	**47**	**X**	104	**48**	
EFLUENT-SLOVENIA	23	7.8	70	**36**	**x**	160	**53**	**x**	100	**50**	
11.05.2021											
INLET	19	8.2	212			460			268		

Continued

Sampling point after primary treatment	19		7.7	110			340			178		
12.05.2021												
Sampling point after primary treatment	21		7.7	122			300			150		
POOL 2												
EFLUENT-ITALY	21		7.8	84	**31**	**60**	112	**63**	**76**	50	67	**81**
EFLUENT-AUSTRIA	20		7.4	58	**52**	**73**	160	**47**	**65**	78	48	**71**
EFLUENT-SLOVENIA	21		7.6	78	**36**	**63**	140	**53**	**70**	82	45	**69.4**
25.05.2021												
INLET	19		8	152			380			240		
Sampling point after primary treatment	19		7.7	118			216			145		
27.05.2021												
Dosing: (poured 100 - 150 L)												
POOL 2	23		6.9	130			300			140		
EFLUENT-ITALY	24		6.9	104	**20**	**32**	100	**67**	**74**	52	63	**78**
EFLUENT-AUSTRIA	24		6.9	38	**71**	**75**	60	**80**	**84**	34	76	**86**
EFLUENT-SLOVENIA	24.5		6.9	24	**82**	**84**	120	**60**	**68**	54	61	**77.5**
10.06.2021												
INLET	22		8.3	174			560			260		
Sampling point after primary treatment	22		8	98			464			164		
11.06.2021												
Dosing: (poured 150 L)												
POOL 2	25.5		7.9	76			372			200		
EFLUENT-ITALY	26		8.2	68	**10**	**61**	60	**84**	**89**	34	83	**87**
EFLUENT-AUSTRIA	26		8.0	40	**47**	**77**	40	**89**	**93**	38	81	**85**
EFLUENT-SLOVENIA	26		7.9	10	**87**	**94**	112	**70**	**80**	92	54	**65**
22.06.2021												
INLET	21		8	158			340			222		
Sampling point after primary treatment	21		7.8	100			220			144		
23.06.2021												
Dosing: poured 200 l per day in three doses												
POOL 2	26		7.9	92			280			195		
EFLUENT-ITALY	26.5		8.3	52	**43**	**67**	148	**47**	**56**	56	71	**75**
EFLUENT-AUSTRIA	27		8.0	36	**61**	**77**	120	**57**	**65**	36	82	**84**
EFLUENT-SLOVENIA	27		7.9	18	**80**	**89**	180	**36**	**47**	94	52	**58**
15.07.2021												

Continued

INLET	22	8.1	220			300			215		
Sampling point after primary treatment	22.5	7.8	150			160			132		
16.07.2021											
Dosing: (poured 100 - 150 L)											
POOL 2	26	8.1	106			160			100		
EFLUENT-ITALY	27	8.0	74	**30**	**66**	60	**63**	**80**	44	56	**80**
EFLUENT-AUSTRIA	27	7.9	94	**11**	**57**	140	**12**	**53**	86	14	**60**
EFLUENT-SLOVENIA	28	7.9	36	**66**	**84**	40	**75**	**87**	32	68	**85**
27.07.2021											
INLET	22	7.9	146			360			**230**		
Sampling point after primary treatment	22	7.7	92			260			142		
Dosing: (poured 100 - 150 L)											
28.07.2021											
POOL 2	24	8.0	130			216			185		
EFLUENT-ITALY	24	8.2	118	**9.3**	**19.2**	60	**72**	**83**	44	76	**81**
EFLUENT-AUSTRIA	24.5	8.1	90	**31**	**38**	180	**17**	**50**	170	8	**26**
EFLUENT-SLOVENIA	24.5	7.9	42	**68**	**71**	140	**35**	**61**	132	29	**43**
11.08.2021											
INLET	22.5	7.2	104			356			260		
Sampling point after primary treatment	22.5	7.8	70			236			156		
Dosing: (poured 100 - 150 L)											
12.08.2021											
POOL 2	22.5	7.3	44			168			135		
EFLUENT-ITALY	22.5	7.8	30	**32**	**71**	96	**43**	**73**	76	44	**71**
EFLUENT-AUSTRIA	23	7.7	146	**/**	**/**	172	**/**	**52**	160	/	**39**
EFLUENT-SLOVENIA	22.5	7.7	78	**/**	**25**	140	**17**	**61**	130	4	**50**

Table 2. Percentage of elimination of TSS, COD, BOD5 after Primary Treatment (PT).

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	AVERAGE
% OF ELIMINATION OF TSS AFTER PT	49	9	19	25	16	35	42	48	22	44	37	25	37	33	30%
% OF ELIMINATION OF COD AFTER PT	15	27	13	19	36	27	54	26	43	17	35	47	28	34	30%
% OF ELIMINATION OF BOD_5 AFTER PT	55	24	47	32	22	31	27	34	40	37	35	39	38	40	36%

Table 3. Percentage of elimination of TSS, COD, BOD5 after CW1, CW2, CW3.

PERCENTAGE OF ELIMINATION OF TSS AFTER CW1, CW2 I CW1 (EFLUENT)														AVERAGE	% ELIMINATION OF TSS
EFLUENT CW1	26	39	85	59	25	50	36	36	82	87	80	66	68	**57%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW1	58	54	/		40	57		63	84	94	89	84	71	**69%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW2	42	72	86	78	41	67	55	52	71	47	61	11	31	**55%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW2	67	79	/	/	52	72	/	73	75	77	77	57	38	**67%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW3	32	69	85	82	27	46	31	31	20	10	43	30	9	**40%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW3	62	76	/	/	41	54	/	60	32	61	67	66	19	54%	% ELIMINATION IN RELATION TO INLET WATER
PERCENTAGE OF ELIMINATION OF COD AFTER CW1, CW2 I CW1 (EFLUENT)														**AVERAGE**	**% ELIMINATION OF COD**
EFLUENT CW1	20	79	54	41	43	46	53	53	60	70	36	75	35	**51%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW1	39	/	/	/	58	60	/	70	68	80	47	87	61	**63%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW2	35	87	65	53	47	59	47	47	80	89	57	12	17	**54%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW2	51	/	/	/	61	69	/	65	84	93	65	53	50	**66%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW3	19	73	52	27	45	52	56	63	67	84	47	75	72	**56%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW3	38	/	/	/	59	65	/	76	74	89	56	87	83	70%	% ELIMINATION IN RELATION TO INLET WATER
PERCENTAGE OF ELIMINATION OF BOD_5 AFTER CW1, CW2 I CW1 (EFLUENT)														**AVERAGE**	**% ELIMINATION BOD_5**
EFLUENT CW1	52	77	58	44	60	56	50	45	61	54	52	68	29	**54%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW1	78	/	/	/	68	68	/	69	78	65	58	85	43	**68%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW2	54	80	71	57	52	65	48	48	76	81	82	14	8	**57%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW2	79	/	/	/	61	74	/	71	86	85	84	60	26	**70%**	% ELIMINATION IN RELATION TO INLET WATER
EFLUENT CW3	53	69	65	43	47	55	55	67	63	83	71	56	76	**62%**	% ELIMINATION IN RELATION TO POOL 1
EFLUENT CW3	78	/	/	/	57	67	/	81	78	87	75	80	81	**78%**	% ELIMINATION IN RELATION TO INLET WATER

Treatment is intended to remove pollutants from wastewater to a certain extent (Sekulić, 2015) [26]. The level of wastewater treatment is defined by the formula (1):

$$RE = \left(1 - C_{inf} / C_{efl}\right)100\% \quad (1)$$

RE—the percentage of removal of a particular substance from wastewater (%);
C_{inf}—concentration of a substance before treatment;
C_{eff}—concentration of a substance after treatment.

5. Discussion Results

The results indicate that the percentage of suspended matter (SM) elimination is as follows:

- in the CW1 effluent (experience of Slovenia), for the Pool and the influent, it averaged 57% and 69%, respectively;

- in the CW2 effluent (experience of Austria), for the Pool and the influent, it averaged 55% and 67%, respectively;

- in the CW3 effluent (experience of Italy), for Pool 1 and influent, it averaged 40% and 54%, respectively;

The results indicate that the percentage of COD elimination (Chemical Oxygen Demand) is as follows:

- in the CW1 effluent (experience of Slovenia), for Pool 1 and the influent, it averaged 51% and 63%, respectively;

- in the CW2 effluent (experience of Austria), for Pool 1 and the influent, it averaged 54% and 66%, respectively;

- in the CW3 effluent (experience of Italy), for Pool 1 and the influent, it averaged 56% and 70%, respectively;

The results indicate that the percentage of BOD_5 elimination (Biochemical Oxygen Demand) is as follows:

- in the CW1 effluent (experience of Slovenia), for Pool 1 and the influent, it averaged 54% and 68%, respectively;

- in the CW2 effluent (experience of Austria), for Pool 1 and the influent, it averaged 57% and 70%, respectively;

- in the CW3 effluent (experience of Italy), for Pool 1 and the influent, it averaged 62% and 78%, respectively;

The results also indicate that the substrate efficiency in the CW2 trough (experience of Austria) in the first 11 series (before clogging) recorded the best results, where the percentage of SM elimination in the effluent for Pool 1 and the influent averaged 61% and 72%, respectively. The percentage of COB elimination in the CW2 effluent (experience of Austria) for Pool 1 and the influent averaged 61% and 70%, respectively, while the percentage of BOD_5 elimination in the CW2 effluent (experience of Austria) for Pool 1 and the influent averaged 65% and 77%, respectively. The average results of the overall analyses indicate that in regard to the percentage of SM elimination, the best result was recorded in the CW1 effluent (for the Pool and the influent, 57% and 69%, respectively); it was approximate in CW 2 (for the Pool and the influent, 55% and 67%, respectively), while in CW 3, the percentage of SM elimination was significantly lower (for the Pool and the influent, 40% and 54%, respectively). The average results of the overall analyses indicate that in regard to the percentage of COD elimination, the best result was recorded in the CW3 effluent (for the Pool and the influent, 56% and 70%, respectively); it was approximate in CW 2 (for the Pool and the influent, 54% and 66%, respectively), while in CW 1, the percentage of HPK elimination was lower (for the Pool and the influent, 51% and 63%, respectively). The average results of the overall analyses indicate that in regard to the percentage of BOD_5 elimination, the best result was in the CW3 effluent (for the Pool and the influent, 62% and 78%, respectively); it was approximate in CW 2 (for the Pool and the influent, 57% and 70%, respectively), while in CW 1, the percentage of SM elimination was lower (for the Pool and the influent, 54% and 68%, respectively).

The above indicates that depending on the choice of substrate, the efficiency of wastewater treatment can vary significantly, even in some cases by approximately 20%. Additionally, there is an evident influence of the quality of the effluent discharged after the secondary treatment in CW1, CW2, and CW3, depending on the efficiency of the treatment achieved in the primary treatment.

In the forthcoming period, it is expected that the impact of plants on CW1, CW2 and CW3 will be pronounced because plants have developed their root system, which will significantly affect the efficiency of wastewater treatment. Statistical significance analysis showed that there was no significant difference in performance between *Phragmites australis* and *Scirpus* regarding the removal of organic matter for a given organic load mass. The average removal efficiencies ranged between 62% (unplanted bed) and 70% (*Scirpus*) (Joana *et al.*, 2010) [32].

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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