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

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## Abstract

This research explores strategies to enhance the efficiency of secondary treatment in Vertical Flow Constructed Wetlands (CW) in Montenegro. The focus is on selecting appropriate primary treatment methods alongside three distinct substrate types to improve wastewater treatment efficacy. The study examines the combination of two primary treatments with different substrate types in constructed wetlands (CW1, CW2, and CW3). The primary treatments include the existing wastewater treatment plant (WWTP) in Podgorica, involving coarse material removal through screens, inert material separation in aerated sand traps, and sediment and suspended matter removal in primary sedimentation tanks. The Extreme Separator (ExSep) was employed to evaluate its efficacy as a primary treatment method. The research demonstrates that the efficiency of CW can be significantly enhanced by selecting suitable primary treatment methods and substrates in Podgorica's conditions. The most promising results were achieved by combining ExSep as a primary treatment with secondary treatment in CW-3. The removal efficiencies after CW3 for COD, BOD, and TSS exceeded 89%, 93%, and 91%, respectively. The outcomes underscore the significance of primary treatment in mitigating pollutant loads before discharge into the constructed wetlands, emphasizing potential areas for further optimization in wastewater treatment practices to enhance environmental sustainability and water quality management.

## Keywords

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

## 1. Introduction

A constructed wetland (CW) system is a man-made complex that mimics the structure of natural wetlands to serve as a wastewater filter [1]. It comprises four main components: water, media, microbes, and vegetation [2].

Ecoremediation achieves a high level of wastewater treatment and 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 [3]-[12].

Wetland plant wastewater treatment began in the 1950s by Dr. Käthe Seidel in Germany. The first full scale systems were put in operation during the late 1960s and since then constructed wetland systems have been spreading throughout the world [13]. Vertical flow constructed wetlands, initially designed by Seidel (1965b) as pretreatment units, evolved into independent second-generation CW systems.

The following are some advantages and disadvantages of constructed wetlands, compared to conventional facilities [14] [15] [16] [17]. Limitations of constructed wetlands (CWs) are large area requirements. However, they require large areas and may only be economical where land is available and affordable. Design criteria for different wastewater types and climates are still under development [18].

In the previous practice of CW construction, multichambered septic tanks [19]. Imhoff tanks or presetting tanks [20] were mainly used in the phase of primary treatment. Other options like newer generation extreme separators have not been thoroughly investigated for reducing space requirements in the secondary treatment phase.

Constructed wetlands come in two basic types: those with surface wastewater flow and those with subsurface flow. Regardless of type, effective preliminary treatment of raw wastewater and proper distribution within vegetated pools are crucial [20].

Directly releasing untreated wastewater into CWs leads to frequent clogging and reduced purification efficiency. Effective pretreatment is essential for optimal CW function and minimal maintenance efforts [20].

Release raw wastewater in CW, without pre-treatment, would result in frequent clogging of the filling and reduced purification efficiency [20]. Effective pretreatment of wastewater is one of the basic prerequisites for the successful functioning of CW and the achievement of a satisfactory level purification, with minimal efforts related to its maintenance (Malus 2012) [20].

The efficiency of wastewater treatment in the septic tank is different for certain indicators of water quality. With the correct design, dimensioning and construction of the septic tank, the following purification efficiency can be achieved [20]: BOD5: 25% - 50%, TSS: 50% - 70%, TN: 10%, TP: 10%.

In the previous primary settler, it is possible to remove up to 33% of BOD5 and COD, as well as 50% to 70% of suspended solids depending on the retention time [11].

The primary goal of preliminary treatment is to remove large solids and other debris typically present in raw wastewater. This stage aids in reducing the size or eliminating large suspended or floating solids. Primary treatment is designed to remove organic and inorganic solids by the physical processes of sedimentation and flotation [21].

Equipment such as coarse and fine grates, crushers, sieves, sand clarifiers, pre-aeration basins, and fat and oil separators are employed for preliminary treatment. Primary purification focuses on eliminating a significant portion of settleable and suspended solids from wastewater through sedimentation. Common facilities for sedimentation include septic tanks, Imhoff tanks, and primary settling tanks. When using chemicals, auxiliary devices are used: dispensers, mixers and flocculators [22].

According to Council Directive 91/271/EEC "Primary treatment" means treatment of urban waste water by a physical and/or chemical process involving settlement of suspended solids, or other processes in which the BOD5 of the incoming waste water is reduced by at least 20% before discharge and the total suspended solids of the incoming waste water are reduced by at least 50% [23].

Analysis of septic tank performance regarding suspended solids and organic matter removal [24] revealed that performance depends on cleanliness and retention time. When clean with a three-day retention time, SS and BOD7 removal efficiency reached 77% ± 10% and 67% ± 14% respectively. However, two months later, after desludging, SS removal efficiency decreased to 53% ± 22% and BOD7 to 32% ± 31%. Retention time also affects performance; one-day retention yielded SS and BOD7 removal efficiencies of 45% ± 40% and 33% ± 16% respectively, while three-day retention improved SS removal to 53% ± 22% but maintained BOD7 removal at 32% ± 31%.

Effluent recirculation is the transfer of part of the effluent to the inlet of the system, resulting in dilution of the influent wastewater [25], and, in VF CWs, enhancement of aerobic microbial activities, BOD removal from 50.2% (without recirculation) to 56.8%, 66.7% and 74.1% for 25%, 50% and 100% recirculation rates, respectively [26].

Research in recent years indicates that the efficiency of vertically constructed wetlands can be increased to some extent by introducing recirculation [27] [28] [29] [30] [31] [32] and aeration [33] [34].

**Wetlands implemented with a HUSB reactor accumulated ca. 30% lower sludge than a system with a conventional settler as primary treatment** [35]. The implementation of a HUSB reactor as a primary treatment for horizontal subsurface-flow treatment wetlands does not improve contaminant removal efficiency in comparison with a conventional settler in the conditions tested [36].

The UASB reactor of the system serves as an initial treatment unit. It achieved a COD removal of 53%, a BOD5 reduction of 26%, and removal rate of 82% for TSS and VFCW demonstrating excellent pollutant removal efficiencies [37].

Introduced the ExSep® (Extreme-Separator) for wastewater treatment, utilizing gravity and fluid dynamics to separate solid material from liquids with high efficiency and minimal energy and chemical usage [38]. The ExSep® is scalable, handling capacities from 0.5 to 500 $m^3/h$, significantly reducing space requirements. It complements existing wastewater treatment plants, increasing capacity without extensive modifications.

EPURATECH's patented ExSep® (Extreme-Separator) is a solid/liquid separation technology based on gravity and fluid dynamics. This innovative primary treatment system can be used for municipal and industrial wastewater treatment applications.

| Parameter | | Sewage characteristics | Reduction by ExSep® |
|---|---|---|---|
| BOD5-load | kg/d | ~125 | 40% - 50% |
| COD-load | kg/d | ~250 | 30% - 40% |
| Dry Solid Matter | kg/d | ~145 | 80% - 90% |
| TN-load | kg/d | ~23 | 10% - 15% |
| TP-load | kg/d | ~4 | 15% - 25% |

Epuramat developed its patented ExSep® (Extreme-Separator) device, a primary wastewater treatment solution that significantly reduces the load of subsequent treatment steps on a very small footprint [38].

ExSep® is a module mainly used for primary treatment of wastewater. As some of our wastewater treatment plants are reaching full capacity due to growing populations and the construction of new modern local amenities, the ExSep® was designed to help unload existing plants. For example, in Luxembourg in the 1980s a wastewater treatment plant was designed for 1.000 PE to treat wastewater from the second largest fuel and service station in Europe. Following a number of extensions, including new restaurants and toilet facilities, the gas station was soon running at 3.000 PE. The cadastral limitations onsite meant that building a new plant or extending the plant by additional sedimentation tanks was not possible. As a solution, Epuramat installed two ExSep® 500 s in a small space, immediately increasing the capacity of the wastewater treatment plant, and ensuring that the effluent was then compliant with the environmental regulations for direct discharge into open water [38].

Its ExSep (Extreme-Separator) pre-treatment solution uses fluid dynamics, with no moving parts, to separate solid matter from liquid, enabling wastewater to be more easily and more efficiently processed or recycled. Epuramat systems can be used in a variety of municipal and industrial applications, including treating wastewater from remote communities for direct discharge into open surface water;

This compact and modular solution replaces conventional sedimentation tanks as well as fat and sand traps, and allows treating up to 40 $m^3$ per hour.

Epuramat's wastewater plant, which is based on the almost complete separation of solids and liquids in the ExSep, requires much less space and minimal maintenance when compared to conventional treatment plants. Because the ExSep increases the efficiency of pre-treatment significantly, the entire plant can be constructed much more compactly.

The combination of this primary treatment (ExSep®) in combination with CW has never been investigated. Certain modifications of CW (water retention time in bathtubs and the like) should definitely be made.

### Subject and Goal of Research

The subject matter of this research is to examine the possibility of increasing the efficiency of secondary treatment in CW with vertical flow in conditions in Montenegro, through selection of adequate primary treatment in combined with three different types of substrates.

**The aim of the research increasing efficiency** waste water through use **some of the primary treatments**: 1) primary treatments of the existing WWTP in Podgorica (which serves to remove coarse material on both coarse and fine screens, remove inert material in aerated sand trap and remove sediment and suspended matter in primary sedimentation tanks) and 2) Extreme separator, **to examine the effectiveness of secondary treatment in CW with 3 different substrate types.**

Two different primary treatments were analyzed in combination with different substrate types in constructed wetlands (CW1, CW2 and CW3).

The aim of this research is to explore opportunities to increase efficiency and reduce the potential space required for CW construction (in the secondary treatment phase) through **choosing an adequate primary treatment.**

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

## 2. Materials and Method

The experiment was carried out in Podgorica of Montenegro on the banks of the Moraca River in the period from November 2020 to Oktober 2023.

### 2.1. Site Description and Existing WWTP in Podgorica

The pilot project CW was set up at the location of the area of existing WWTP in Podgorica. 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). Figure 1 **shows the location where the CW1, CW2 and CW3 troughs were installed.** There is a wastewater treatment plant (WWTP) in Podgorica, which has been in operation since 1978. It is designed for a capacity of 55.000 PE and implements a biological secondary treatment with primary sedimentation and activated sludge process. The sludge is thickened, dewatered by use of centrifuges and stored on the site of the WWTP. The initially planned sludge digestion was never put into operation.

Figure 1. Experiment Setup, location of the existing WWTP in the settlement of Krusevac-Podgorica.

Due to the limited capacity of the plant, approximately 50% of the collected wastewater is discharged into the Moraca River upstream of the plant without any treatment end from the remaining part another fraction is discharged after primary mechanical treatment only. The discharge of untreated and only partially treated effluents significantly impacts the quality of the Moraca River [39].

The analysis of 24-hour measurement campaigns at the inlet of the WWTP—during which the full wastewater flow is treated at the plant—indicates that the pollution load received at the plant is around 105.000 PE which is almost the double of the design capacity.

**The WWTP consists of the following main treatment works: Wastewater Treatment File [39]:**

- DN 1000 main collector;
- Automatic coarse screens (2 files);
- Screw pumps 2 × 180 L/s + 370 L/s (max flow capacity:
- Automatic fine screens (7 mm bar space; 2 files);
- Aerated grit and grease separator (2 files);
- Ferric chloride dosing station to improve the efficiency of the primary decantation;
- Rectangular primary sedimentation tank (1 file);
- Aeration tanks (2 files) with diffused air system;
- Rectangular secondary clarifier (2 files).

## 2.2. Experiment Setup

In November 2020, the pool was set up and a pilot project was constructed. The constructed wetland (CW) has the 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.

## 2.3. Water and Air Distribution in the CW

After the primary treatment at the WWTP in Podgorica, wastewater is pumped by the pump (Villager VSP10000) into the 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 the barrels (I, II and III) is distributed through PVC plastic pipes of 32 in diameter mm into three different vertically constructed wetlands (CW-3, CW-4 and CW-5, made of PVC with a volume of 1 $m^3$) filled with substrate 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, as follows: 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), in order to enable the CW to be evenly soaked with wastewater. Inside the constructed wetlands (CW-3, CW-4 and CW-5), at the bottom, there are drainage pipes made of PVC plastic with a diameter of DN 75 mm which are drilled (notched 1/3 of the rim) every 20 cm in order 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, 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.

## 2.4. Substrate Setting in CW and Plant Plants

**In this experiment:**

1) The CW1 vertical flow system for an area of 1 $m^2$ represents the experience of Slovenia under the conditions in Montenegro. The **substrate depth** for this system is 1.0 m. The filter medium is sand with a $d10$ between 8/16 mm, $d60$ between 0.5 and 4 mm, $d10$ between 4/8 mm, $d5$ between 8/16 mm, and $d15$ between 16/32 mm;

2) The CW2 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, $d50$ between 0 and 4 mm, $d5$-10 between 4/8 mm or 8/16, and $d20$ 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 $d20$ between 16/32 mm, $d60$ between 0.4 and 8 mm, and $d40$ 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.

In the autumn of 2020, after the construction and installation of the experiment, reed was planted in all three troughs (CW1, CW2 and CW3), being transplanted from Skadar Lake, where it grows naturally. Skadar Lake is located not far from the WWTP site in Podgorica. After the first planting, the planted reed did not take root (probably due to weather conditions), so the planting was done in the same way again in May 2021 when it was successful and most of the planted plants were rooted.

### 2.5. Primary Tretmant

In this research, in combination with the aforementioned substrate (CW1, CW2, CW3), the following types of primary treatment were tested:

**Primary treatment of the exist WWTP of Podgorica, which consists of:**

- Automatic coarse screens (2 files);
- Screw pumps 2 × 180 L/s + 370 L/s (max flow capacity;
- Automatic fine screens (7 mm bar space; 2 files);
- Aerated grit and grease separator (2 files);
- Ferric chloride dosing station to improve the efficiency of the primary decantation;
- Rectangular primary sedimentation tank (1 file);

**Extreme separator (ExSep® technology) is a solid/liquid separation technology based on gravity and fluid dynamics.**

Pre-treatment ("mechanical cleaning") in Epuramat's treatment plant begins with a rake (1) that prevents large solid materials from entering the treatment facility. The ExSep solid/ liquid separator (2) is the core of the process and replaces the grit chamber and the primary sedimentation basin that are used in conventional plants. Due to the ExSep, largely only dissolved materials go on for subsequent cleaning (3). The solids that the ExSep removes from the wastewater in the form of sludge are processed in a sludge thickener (4).

Wastewater passes through a flow tube, which has a bluff body at the end where the inflowing water is deflected and slowed down. At this stage, several hydraulic processes interact, causing the solids to sink to the cone-shaped bottom of the ExSep®, where the suspension thickens and is sucked off by a pump for subsequent sludge treatment. The performance of the ExSep® is monitored and controlled by a programmable logic control which can also be controlled remotely. All the changeable factors for treating the wastewater are programmed in an initial calibration and control session. The bluff body is adjustable, meaning the settings can be adapted onsite or remotely to meet the characteristics of the wastewater. This ability to alter the settings means the ExSep® can be used for municipal wastewater treatment plants with varying diurnal cycle lines as well as for wastewater from a variety of industrial processes, where solid material needs to be separated from a liquid medium.

### 2.6. Dosage of Waste Water after Primary Treatment

Dosing was performed in such a way that a volume of 150 liters was dosed once a day in three doses on every constructed wetland (CW1, CW2 and CW3).

### 2.7. Sample Collection and Analysis

Wastewater sampling was performed at 5 points: 1) at the inlet, 2) after primary treatment, 3) at the outlet after treatment in CW1, 4) at the outlet after treatment in CW2 and 5) at the outlet after treatment in CW3.

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) and Institute of Hydrometeorology and Seismology in the **period of August 2021 - October 2023.** The considered period was performed from more than 29 analyzed series.

## 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 dich_ romate in research standard methods for testing water quality (COD) were used, Co_ha (1990) [40].

**Determination of biochemical oxygen consumption after 5 days (BOD5)** in research standard methods for testing water quality (BOD5) were used, Coha (1990) and Lurje (1984) [40] [41].

**Procedure for determination of suspended substance (TSS)** content Standard methods for the examination of water and wastewater, 14th edition, 1975 [42] were used for determination TSS in the research.

## 4. Results

Incoming municipal wastewater exhibited varying quality. Out of 29 sampling series, TOC ranged from 130 mg/L to 564 mg/L, averaging 203 mg/L; COD ranged from 360 mg/L to 1165 mg/L, averaging 519 mg/L; and BOD ranged from 180 mg/L to 502 mg/L, averaging 313 mg/L.

**Wastewater Treatment in the Existing WWTP and Constructed Wetlands (CW1, CW2, CW3)**

Over the period from August 2021 to October 2023, 29 sampling series were conducted. The average removal rates following primary treatment were 46% for TSS, 37% for COD, and 46% for BOD.

In Table 1, average results of TSS, BOD and COD are displayed of municipal wastewater treatment post-primary treatment at the existing WWTP in Podgorica, prior to discharge into constructed wetlands (CW1, CW2, and CW3).

After primary treatment at the existing WWTP in Podgorica and secondary treatment in constructed wetlands (CW1, CW2, and CW3), the following results were observed:

**CW-1 Secondary Treatment:**

- TSS elimination averaged 75%, with concentrations averaging 45 mg/L.
- COD elimination averaged 73%, with concentrations averaging 130 mg/L.
- BOD5 elimination averaged 79%, with concentrations averaging 67 mg/L.

**CW-2 Secondary Treatment:**

- TSS elimination averaged 70%, with concentrations averaging 56 mg/L.
- COD elimination averaged 67%, with concentrations averaging 164 mg/L.
- BOD5 elimination averaged 75%, with concentrations averaging 78 mg/L.

**CW-3 Secondary Treatment:**

- TSS elimination averaged 75%, with concentrations averaging 45 mg/L.
- COD elimination averaged 81%, with concentrations averaging 99 mg/L.
- BOD5 elimination averaged 86%, with concentrations averaging 46 mg/L.

**Subsequent treatment outcomes after CW-1, CW-2, and CW-3 are detailed in tables labeled 2, 3 and 4, respectively.**

Table 2 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW1 as secondary treatment and primary treatment at WWTP Podgorica.

Table 3 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW2 as secondary treatment and primary treatment at WWTP Podgorica.

Table 4 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW3 as secondary treatment and primary treatment at WWTP Podgorica.

**Primary Treatment in ExSep and Secondary Treatment in Constructed Wetlands (CW1, CW2, CW3)**

Over 29 sampling series from August 2021 to October 2023, primary treatment achieved an average removal of 80% for TSS, 39% for COD, and 49% for BOD.

In Table 5, average results of TSS, BOD and COD are displayed of municipal wastewater treatment post-primary treatment at the ExSep, prior to discharge into constructed wetlands (CW1, CW2, and CW3).

**Table 1.** Percentage of elimination of TSS, COD, BOD5 after primary treatment (PT)-WWTP podgorica.

| Parameter | Average |
|---|---|
| TSS after PT (%) | 46 |
| COD after PT (%) | 37 |
| BOD5 after PT (%) | 46 |

**Table 2.** Percentage of elimination of TSS, COD, BOD5 after CW1-PT of WWTP at Podgorica.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 75 | 45 |
| COD | 73 | 130 |
| BOD5 | 79 | 67 |

**Table 3.** Percentage of elimination of TSS, COD, BOD5 after CW2-PT of WWTP at podgorica.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 70 | 56 |
| COD | 67 | 164 |
| BOD5 | 75 | 78 |

**Table 4.** Percentage of elimination of TSS, COD, BOD5 after CW3-PT of WWTP at podgorica.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 75 | 45 |
| COD | 81 | 99 |
| BOD5 | 86 | 46 |

**Table 5.** Percentage of elimination of TSS, COD, BOD5 after primary treatment (PT)-ExSep.

| Parameter | Average |
|---|---|
| TSS after PT (%) | 80 |
| COD after PT (%) | 39 |
| BOD5 after PT (%) | 49 |

**Subsequent treatment outcomes after CW-1, CW-2, and CW-3 are detailed in Tables 6-8.**

After primary treatment in ExSep and secondary treatment in constructed wetlands (CW1, CW2, and CW3), the following results were observed:

**CW-1 Secondary Treatment:**

- TSS elimination averaged 91%, with concentrations averaging 19 mg/L.
- COD elimination averaged 72%, with concentrations averaging 146 mg/L.
- BOD5 elimination averaged 81%, with concentrations averaging 65 mg/L.

**CW-2 Secondary Treatment:**

- TSS elimination averaged 87%, with concentrations averaging 26 mg/L.
- COD elimination averaged 66%, with concentrations averaging 163 mg/L.
- BOD5 elimination averaged 74%, with concentrations averaging 84 mg/L.

**CW-3 Secondary Treatment:**

- TSS elimination averaged 89%, with concentrations averaging 22 mg/L.
- COD elimination averaged 79%, with concentrations averaging 108 mg/L.
- BOD5 elimination averaged 82%, with concentrations averaging 52 mg/L.

Table 6 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW1 as secondary treatment and primary treatment with ExSep treatment.

Table 7 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW2 as secondary treatment and primary treatment with ExSep treatment.

Table 8 provides a concise overview of the percentage removal of TSS, COD, and BOD5 after CW2 as secondary treatment and primary treatment with ExSep treatment.

## 5. Discussion of Results

The results from municipal wastewater treatment following primary treatment at the wastewater treatment plant (WWTP) in Podgorica, before discharge into the constructed wetlands (CW1, CW2, and CW3), demonstrate significant removal efficiencies. Over the period from August 2021 to October 2023, 29 sampling series were conducted, revealing an average elimination rate of 46% for Total Suspended Solids (TSS), 37% for Chemical Oxygen Demand (COD), and 46% for Biochemical Oxygen Demand (BOD) post-primary treatment.

Comparatively, municipal wastewater purification after primary treatment in ExSep for wastewater treatment in Podgorica, prior to discharge into the constructed wetlands (CW1, CW2, and CW3), exhibits notably higher removal efficiencies. Similar to the Podgorica WWTP, the study conducted over the same timeframe encompassed 29 sampling series, indicating an average removal rate of 80% for TSS, 39% for COD, and 49% for BOD after primary treatment.

These findings underscore the effectiveness of primary treatment processes in both facilities, with ExSep showcasing superior removal efficiencies across TSS and BOD parameters compared to the WWTP in Podgorica. However, removal efficiencies for COD are comparable between the two treatment facilities. The outcomes emphasize the significance of primary treatment in mitigating pollutant loads before discharge into the constructed wetlands, highlighting potential areas for further optimization in wastewater treatment practices to enhance environmental sustainability and water quality management.

**Table 6.** Percentage of Elimination of TSS, COD, BOD5 after CW1-PT of ExSep.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 91 | 19 |
| COD | 72 | 146 |
| BOD5 | 81 | 65 |

**Table 7.** Percentage of Elimination of TSS, COD, BOD5 after CW2-PT of ExSep.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 87 | 26 |
| COD | 66 | 163 |
| BOD5 | 74 | 84 |

**Table 8.** Percentage of Elimination of TSS, COD, BOD5 after CW3-PT of ExSep.

| Parameter | % of Elimination | mg/L |
|---|---|---|
| TSS | 89 | 22 |
| COD | 79 | 89 |
| BOD5 | 82 | 52 |

Additionally, the research highlights the limitations of septic tanks in achieving adequate pollutant removal, emphasizing the importance of investing in advanced wastewater treatment infrastructure to enhance environmental sustainability and water quality management.

Chart 1 illustrates the percentage of TSS removal after primary treatment in Podgorica, ExSep, and septic tanks.

Chart 2 ilustrates the percentage of COD removal after primary treatment in Podgorica, ExSep, and septic tanks.

Chart 3 illustrates the percentage of BOD5 removal after primary treatment in Podgorica, ExSep, and septic tanks.

In Chart 4, average TSS results in effluent after CW-1, CW-2, and CW-3 as secondary treatments are presented. Chart 5 displays average results for COD in the effluent after CW-1, CW-2, and CW-3. Chart 6 shows cases the average BOD5 of wastewater from all analyzed series and the average of the top 10 series after CW1, CW2, and CW3 as secondary treatments.

In Chart 4 study, average TSS results in effluent after CW-1, CW-2, and CW-3 as secondary treatments are presented. The combination of CWs with primary treatment varies. The TSS concentration in the effluent wastewater, from the average of analyzed series CW1, CW2, and CW3 with primary treatment at the Podgorica WWTP and ExSepomo, showed no average result with deviations and concentrations greater than 60 mg/L, while concentrations lower than 35 mg/L were observed in effluent where ExSep was used as the primary treatment. The best average result was demonstrated by ExSep-CW-1 with 91% purification, while Classic-CW2 averaged 70% purification.

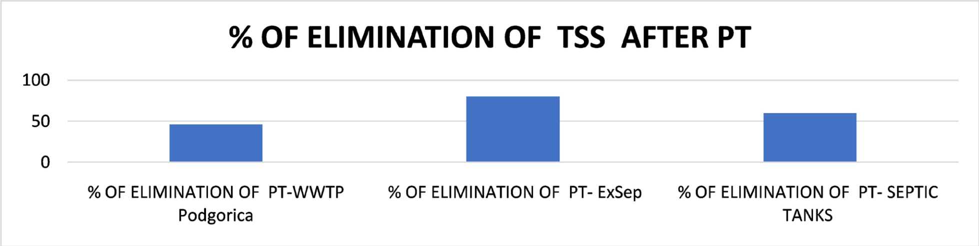


Chart 1. Percentage of TSS removal post primary treatment (PT).

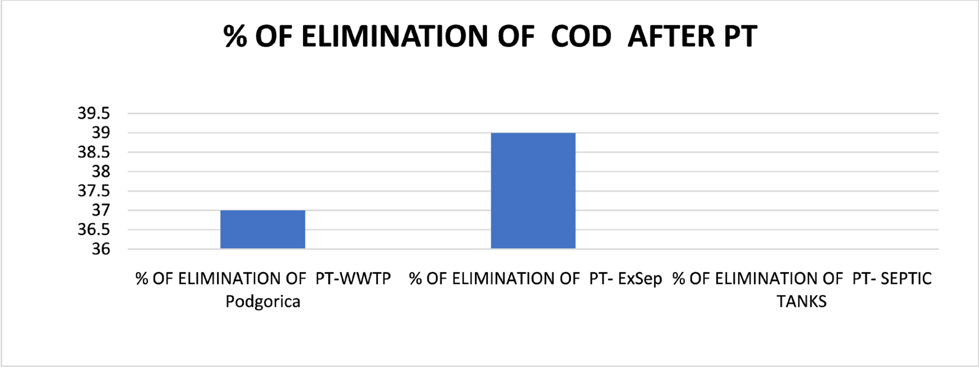


Chart 2. Percentage of COD removal post primary treatment (PT).

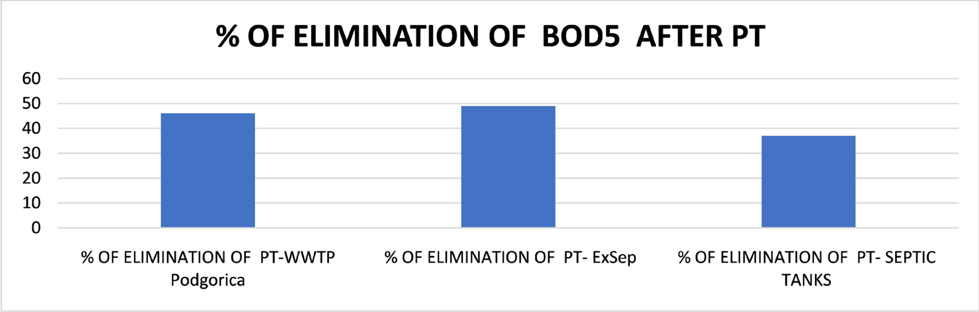


Chart 3. Percentage of BOD5 removal post primary treatment (PT).

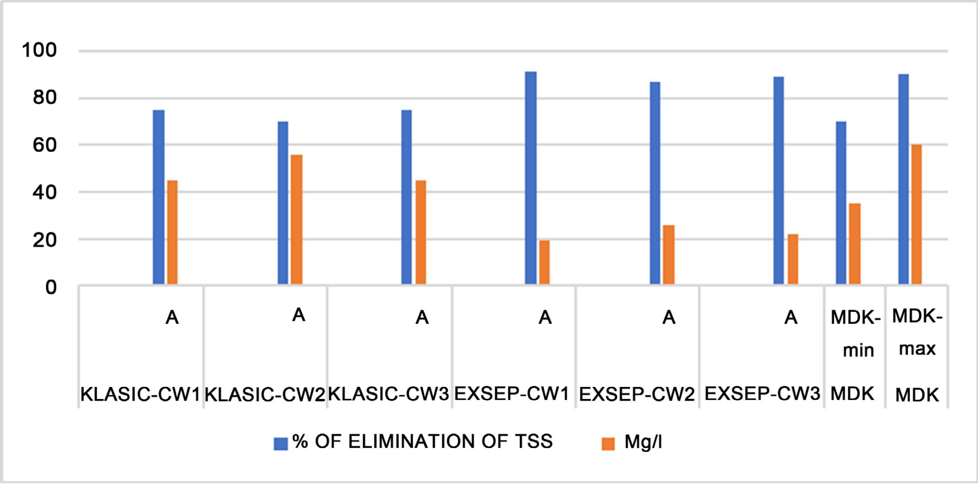


Chart 4. Percentage of TSS Removal Post CW-1, CW-2 and CW-3.

Chart 5 shows average results of all analyzed series and the average of the top 10 series for COD in the effluent after CW-1, CW-2, and CW-3 as secondary treatment are shown. The primary treatment was conventional at the Podgorica WWTP and ExSep. Deviations from the average result and concentrations greater than 125 mg/L were observed at all sites except KLASIC-CW-3 and EXSEP-CW3, which had the best results. Percentages exceeding 70% were recorded at all sites except for KLASIC-CW2 and EXSEP-CW2. The highest variation in purification recorded was 15%, with the highest purification percentage being 81% (CW3) and the lowest being 66% (EXEP-CW2).

After CW as a secondary treatment, Chart 6 shows the average BOD5 of wastewater from all analyzed series and the average of the top 10 series. Effluent from CW1, CW2, and CW3. All averages were above 25 mg/L, while all were compliant with the allowed percentage (70-90%). The highest variation in purification recorded averaged 12%, with the highest purification percentage being 86% (CLASSIC-CW3) and the lowest 74% (EXEP-CW2). The average of the top 10 samples was achieved by EXSEP-CW3 at 93% with 20 mg/L and CLASSIC-CW-3 at 92% with 23 mg/L.

Table 9 provides a summary overview of the average (A) percentage removal of TSS, COD, and BOD5 after secondary treatment in CW1, CW2, and CW3, following primary treatment with ExSep and the existing primary treatment in Podgorica (KlASIC). Additionally, the average results of the best (10-B) sampled series are shown.

## 6. Conclusions

In conclusion, the results of the municipal wastewater treatment following primary treatment at the wastewater treatment plant (WWTP) in Podgorica, along with the subsequent discharge into the constructed wetlands (CW1, CW2, and CW3), demonstrate significant removal efficiencies. Over the period from August 2021 to October 2023, 29 sampling series were conducted, revealing an average elimination rate of 46% for Total Suspended Solids (TSS), 37% for Chemical Oxygen Demand (COD), and 46% for Biochemical Oxygen Demand (BOD) post-primary treatment.

Comparatively, municipal wastewater purification after primary treatment in ExSep for wastewater treatment in Podgorica, prior to discharge into the constructed wetlands, exhibits notably higher removal efficiencies. Similar to the Podgorica WWTP, the study conducted over the same timeframe encompassed 29 sampling series, indicating an average removal rate of 80% for TSS, 39% for COD, and 49% for BOD after primary treatment.

These findings highlight the effectiveness of primary treatment processes in both facilities, with ExSep showcasing superior removal efficiencies across TSS and BOD parameters compared to the WWTP in Podgorica. However, removal efficiencies for COD are comparable between the two treatment facilities. **The outcomes underscore the significance of primary treatment in mitigating pollutant loads before discharge into the constructed wetlands, emphasizing**

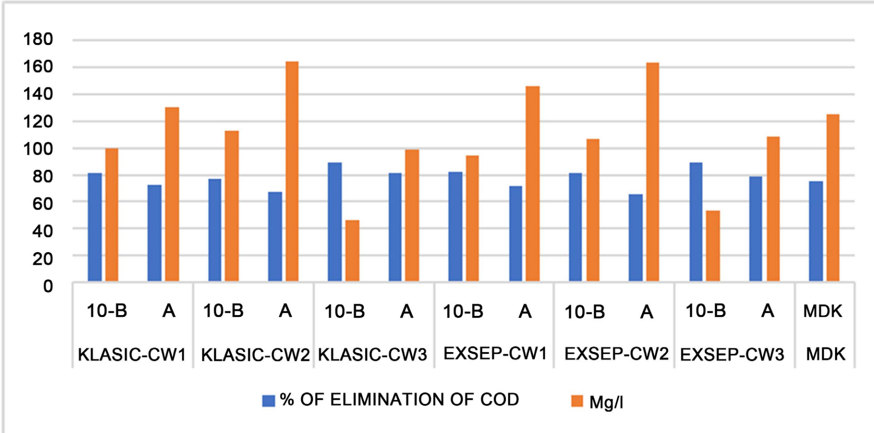


Chart 5. Percentage of COD removal post CW-1, CW-2 and CW-3.

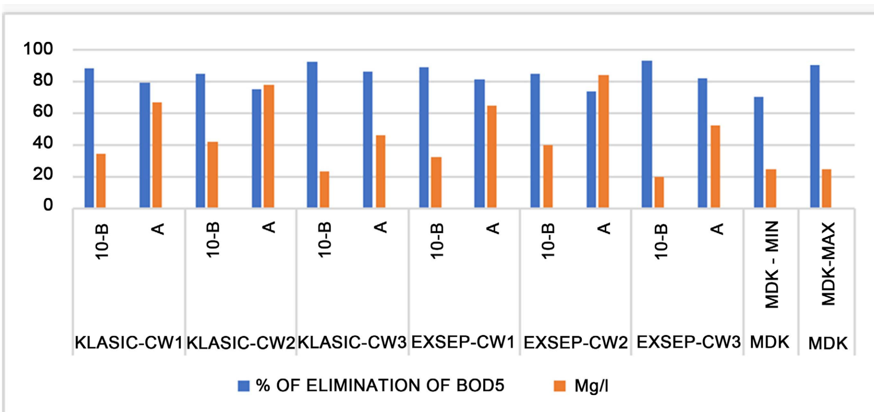


Chart 6. Percentage of BOD5 removal post CW-1, CW-2 and CW-3.

Table 9. Presents the average results for TSS, COD, and BOD5 after KLASIC-CW1, KLASIC-CW2, KLASIC-CW3, EXSEP-CW1, EXSEP-CW2 and EXSEP-CW3.

| | KLASIC-CW1 | | KLASIC-CW2 | | KLASIC-CW3 | | EXSEP-CW1 | | EXSEP-CW2 | | EXSEP-CW3 | | MDK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10-B | A | 10-B | A | 10-B | A | 10-B | A | 10-B | A | 10-B | A | |
| % OF ELIMINATION OF TSS | 77 | 75 | 73 | 70 | 76 | 75 | 94 | 91 | 90 | 87 | 91 | 89 | 70/90 |
| mg/L | 43 | 45 | 49 | 56 | 45 | 45 | 14 | 19 | 18 | 26 | 19 | 22 | 60/35 |
| % OF ELIMINATION OF COD | 81 | 73 | 77 | 67 | 89 | 81 | 82 | 72 | 81 | 66 | 89 | 79 | 75 |
| mg/L | 100 | 130 | 113 | 164 | 46 | 99 | 94 | 146 | 107 | 163 | 53 | 108 | 125 |
| % OF ELIMINATION OF $BOD_5$ | 88 | 79 | 85 | 75 | 92 | 86 | 89 | 81 | 85 | 74 | 93 | 82 | 70/90 |
| mg/L | 34 | 67 | 42 | 78 | 23 | 46 | 32 | 65 | 40 | 84 | 20 | 52 | 25 |

**potential areas for further optimization in wastewater treatment practices to enhance environmental sustainability and water quality management.**

Additionally, the research emphasizes the limitations of septic tanks in achieving adequate pollutant removal, highlighting the importance of investing in advanced wastewater treatment infrastructure to enhance environmental sustainability and water quality management.

## Conflicts of Interest

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

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