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Article

Study of the Applicability of the Root Wastewater Treatment Plants with the Possibility of the Water Recirculation in Terms of the Surfactant Content

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Abstract: Anthropogenic activities cause the accumulation of pollutants in the aquatic environment. Conventional wastewater treatment plants do not completely remove emergent pollutants, including personal care products, in which the surfactants are an essential ingredient. The results of our study confirm the presence of the surfactants in the aquatic environment, which represents an ecological and environmental risk. It was confirmed by ecotoxicological tests (test with using *Daphnia magna* and *Lemna minor*) and the specified content of the surfactants in the samples. The content of the surfactants in personal care products is significant and their impact on the aquatic environment is not sufficiently monitored. Root wastewater treatment plants, as innovative cleaning methods, represent effective cleaning methods, which can be used as a separate object or as an object for further cleaning already cleaned water from conventional wastewater treatment plants. Purified water from these devices can be recycled and used again as utility water (according to the model presented in the article). A significant benefit from the point of view of global warming and the effect of anthropogenic activity is the saving of drinking water as a natural resource. Root wastewater treatment plants ensure the required quality of discharged water in the aquatic environment.

Keywords: emergent pollutants; personal care products; surfactants; ecotoxicity; root wastewater treatment plant; aquatic environment

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1. Introduction

Waste waters represent a mixture of pollutants from various anthropogenic activities. Purified water at a wastewater treatment plant (WWTP) can still contain a complex mixture of the toxic pollutants as emergent pollutants, including pharmaceutical and personal care products (PPCPs). There are specific substances that have been entering the environment for the past decades from the anthropogenic activities, e.g., agriculture, industrial activity, activities in households, etc. Their properties and impact on the environment remain insufficiently explored. [1,2]. In most cases, conventional WWTPs only partially reduce the content of the specific pollutants from waste water.

The wastewater treatment process is an important social problem, which is closely related to an environmental protection. The conventional wastewater treatment process consists of a set of physical, chemical, and biological methods. Their main role is the achievement of the required quality of the waste water discharged into the recipient based on legislative requirements (Regulation of the Government of the Slovak Republic No. 269/2010 Coll., which sets requirements for achieving good water status; BOD_5, COD_{Cr}, insoluble substances, nitrogen, phosphorus), but not for the removal of the specific substances, whose content has been constantly increasing in recent times. The waste waters concentrate various toxicants which are contained in cleaning agents, disinfectants, and cosmetics. These products contain toxicants, such as surfactants, alcohols, acids and bases, oxides, and sodium salts, among various additives which endanger aquatic environment. The main components of these products are surfactants [1,3]. Conventional methods cannot remove all toxicants from wastewater, because these methods have the short retention time. For this reason, toxicants do not have time to completely mineralize, their degradation products reach to the recipient and act toxic. They are part of the sewage sludge which application to the soil and seepage into the groundwater leads intoxication of the food and entry into the human body [4,5]. Activated sludge, as a mixture of various microorganisms, breaks down present organic pollution. Specific emergent pollutants are not sufficiently removed and thus the efficiency of the treatment process is reduced. [6]. The presence of these substances in purified waters represents an ecological and environmental risk, which can be eliminated by using modern wastewater treatment methods. Their essence is to ensure the harmlessness of purified waters, or their purification to such a level that it will also allow the repeated use of purified water (utility water, technological water in industrial production, water for irrigation, etc.) in view of global climate problems everywhere, but especially in locations with lack of water from natural sources [7].

Innovative methods of the water purification (not only root waste water treatment plant, which we deal, but also methods such as membrane processes, advanced oxidation processes and others) can be applied as a further purification stage of already conventionally purified water before it is discharged into the recipient. Another option is to replace conventional water purification with a root technological unit—a root treatment plant, which realizes naturally occurring self-cleaning processes in aquatic environment. The use of the appropriate vegetation ensures the creation of a specific filter of microorganisms to remove pollutants from aquatic environment [8,9]. These are phytoremediation procedures, where it is possible to degrade organic substances with the help of bacterial communities located on root systems [10]. The root WWTP consists of primary—mechanical wastewater treatment process (retention of floating and settling insoluble substances), which limit the clogging of the root system of the plants. For this purpose, for example, a septic tank or sedimentation tank is used. Behind the mechanical treatment process, there is a filter area with vegetation, where organic and ammonia pollution, phosphorus, sulfur, heavy metals, but also organic substances from the group of the emergent pollutants are removed. In practice, filter cartridges are used, which are divided according to the flow of the waste water, in a vertical, horizontal, or radial direction. Various types of the vegetation are used: vegetation similar in composition to natural swamps, rooted aquatic, or free-floating aquatic. After the filter part, a stabilization tank in the form a wetland or a pond can also be included. Another possibility of the using purified water is its application for irrigation, or its release into a recipient [9,11–14].

The advantages of the root WWTP are their esthetic impact on society, improvement of the microclimate of the environment in which are built, low operating and investment costs, including electricity consumption, which is practically not used here, minimal maintenance, etc. The disadvantage of the root WWTP is its purchase price, but its activity and duration of the operation will return the investment. During operation, root WWTP do not represent high energy and economic costs. The root WWTP is still being built on a small scale in the Slovak Republic. In our country, there is still no such awareness about the possibility of cleaning methods when it comes to waste water. Root WWTPs are considered new facilities that need to be made more widely known to society [15].

The article is focused on the assessment of the efficiency of the wastewater treatment process in root WWTPs. The monitored indicators were changes of content of the surfactants (as the main component of PPCP's) in the water from the purification process and the ecotoxicity of the discharged purified water from the WWTP.

The aim of the study was to demonstrate the need for a more intensive and innovative method of the wastewater treatment process in the Slovak Republic, which will ensure the required quality of the discharged water not only in terms of mandatory monitored indicators, but also in terms of the content of emergent pollutants. In our country, conventional wastewater treatment process represents the highest share of the cleaning method. The root WWTP, which represent a higher level and quality of wastewater treatment process (as evidenced by the results of the article), are being built on a smaller scale. The article is also focused on the reuse of purified wastewater in the facility, which simultaneously saves the resource of drinking water. For this reason, we consider the construction of large-scale root WWTPs to be highly important and positive for the environment.

2. Materials and Methods

The experiment was carried out in water samples from root WWTPs for accommodation facilities: type ECOver, ECOkocka, ECOair, and their combinations with the possibility of the water recirculation. These types of the root waste water treatment plants were designed and are actually operated in the Banská Bystrica Self-Governing Region, Slovak Republic by ECOPLANET SLOVAKIA, s. r. o. All root WWTPs are built in accordance with the current legislation of the Slovak Republic and are approved by the relevant district authorities focused on the field of the environmental protection. WWTPs built by ECOPLANET SLOVAKIA s.r.o. have their own designation, as follows:

(1) ECOver—root waste water treatment plant with vertical filter, with an area of 3–4 m^2/person, with the possibility of expansion if the number of people increases,
(2) ECOkocka—small compact root WWTP with EU certificate, area: <1 m^2/person,
(3) ECOair—root WWTP for a larger number of people, larger buildings, area: <1 m^2/person.

More information about ECOPLANET SLOVAKIA s.r.o. products is available: https://www.ekocisticky.sk/ (3 September 2022). Wastewater samples from the WWTPs were taken over a period of one month. It was a month when the selected WWTPs had the greatest load (objects during full operation, during the main accommodation season). The collection was carried out in accordance with STN EN ISO 5667-1—Water quality—Sampling - Part 1: Guidance on the design of sampling programmes and sampling techniques (ISO 5667-1:2020). Sampling was performed twice a week for one month; it was always a one-time point sampling. The results presented in the tables present average values from all measurements.

The monitored parameters were: The content of the surfactants and ecotoxicity (ecotoxicological tests: Determination of the inhibition of the mobility of *Daphnia magna* and Determination of the toxic effect of water and waste water components on *Lemna minor*). These parameters were selected to assess the efficiency of the cleaning process.

Description of analysed root WWTPs:

- isolated fields (excavated pits) lined with sand, with the walls insulated with PVC film and geotextile; fields are filled with aggregate in several layers (with different fractions according to the requirements and needs arising from the project documentation),
- suitable plant communities are planted in the aggregate, water flows through the root system (the exact composition of the plant community is the know-how of the company, it is made up of species: *Phragmites australis (Cav.) Trin*, *Typha latifolia* L., *Caltha palustris* L., *Lythrum salicaria* L., *Iris pseudacorus* L., *Iris sibirica* L., *Hippuris vulgaris* L., etc. in different numbers),
- built on a natural basis, without the need to add bacteria,
- no electricity is needed during operation (only in the case of the aerated WWTP), the treatment process is noiseless and odourless.

Input raw material: Waste water supplied from the sedimentation tanks or septic tanks.

Output from the WWTP: purified water can be piped into the public sewerage, into a recipient, or used as utility water in an ornamental pond, accumulation tank, or fire tank.

2.1. Determination of the Surfactant Content

Surfactants are not a standard indicator, which is determined (based on the valid legislation and the waste water discharge permits, which individual producers have, the monitored parameters are primarily BOD_5 and insoluble substances). The maximum permissible concentrations of anionic surfactants in water are surface water = 1.0 mg/L and water intended for irrigation = 2.0 mg/L (Regulation of the Government of the Slovak Republic No. 269/2010 Coll.).

The determination of surfactant content is based on the reaction of a water sample with methylene blue. Anionic surfactants in alkaline media form colored ionic associates with methylene blue, which are extracted with chloroform. The absorbance of the samples at 650 nm is evaluated. The WTW CINTRA 20 spectrophotometer (GBS Scientific Equipment Pty. Ltd., Australia) was used [16].

2.2. Ecotoxicological Assessment of Purified Water—Ecotoxicological Tests

Acute toxicity test on *Daphnia magna*: The principle of this test is an assessment of the percentage of immobilized individuals after 48 h from the beginning of exposure of a tested sample to test organisms of *Daphnia magna* [17,18]. Conditions of the preliminary test, including control of meeting test conditions with a reference substance, are shown in Table 1.

Table 1. The test conditions for *Daphnia magna* [17–19].

Test organism	*Daphnia magna* Straus, individuals younger than 24 h
Biotest conditions	21 °C ± 2 °C; 7.8 ± 0.2; laboratory conditions
Control sample	diluting water prepared from the solutions of $CaCl_2.2H_2O$ (1), p.a., $MgSO_4.7H_2O$ (2), p.a., $NaHCO_3$ (3), p.a., KCl (4), p.a.; by the addition of solutions (1)–(4) per 10 mL and adding demineralized water into a volume of 1 L
Reference substance	$K_2Cr_2O_7$, EC_{50} = 0.82 mg/L (limit 0.3–1.5 mg/L)
Test duration	48 h
Preliminary test	20 daphnia/sample (10 mL), same conditions for a control
Validity of the test	immobilization $\leq$ 10%, change of concentration of dissolved oxygen $O_2 \leq 2$ mg/L
Monitored response	% of immobilized individuals

Growth inhibition test with *Lemna minor*: The test organism *Lemna minor* is relatively easy to cultivate in laboratory conditions and has a short reproduction period. The test evaluated the effect of the samples on the vegetative growth of the plant compared to the control. The testing conditions are listed in Table 2.

Table 2. The test conditions for *Lemna minor* [19–21].

Test organism	*Lemna minor*
Biotest conditions	25 °C ± 2 °C, day and night simulation; continuous lighting with min. intensity 6500 lux, thermostat ST FOT (Eko Pol Poland)
Control sample	Z-medium (nutrient solution prepared according to the instructions of the supplier CCALA, Třeboň, Czech Republic)
Reference substance	3,5-dichlórfenosl, EC_{50} = 2.9 mg/L (limit 2.2–3.8 mg/L)
Test duration	7 days
Preliminary test	15 leaf/sample
Validity of the test	mean number of leaflets in the control after the end of the test > than eight times at the beginning of the test, pH at the end of the test < than 1.5 compared to the input pH
Monitored response	growth rate (inhibition)

3. Results

The removal of the pollution in waste water through root systems is a suitable alternative to conventional WWTP, especially for larger buildings or smaller municipalities which do not have them built. They have the potential to make the landscape more aesthetically pleasing and create space for biodiversity. We tested three types of root WWTPs (ECOver, ECOkocka and ECOair; facilities under management ECOPLANET SLOVAKIA s.r.o.), including their combination with the possibility of the water recirculation.

3.1. ECOver

It is a root WWTP with the number of p. e. (population equivalents) = 75, with hourly water flow = 0.82 L/sec and annual water flow = 4100 m^3/year. It is operated to clean waste water from the buildings of the national cultural monument, in which the museum is located, and also provides spaces for social events (celebrations, weddings, etc.). The scheme of the WWTP is shown in Figure 1.

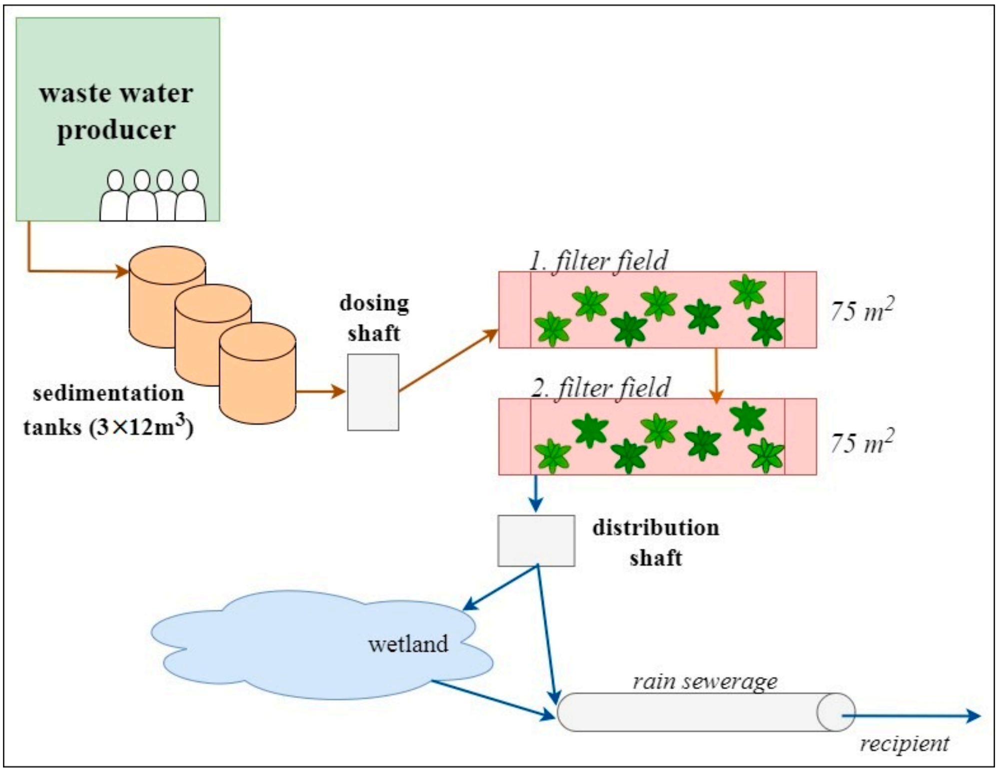

Figure 1. Scheme of a root WWTP type ECOver (according to the project documentation of ECOPLANET SLOVAKIA, s.r.o.; [19]).

Purified water from the 2nd filter field flows into the distribution shaft. From there, it can be discharged (according to the current need and the load of the root WWTP) into a constructed wetland or directly into the rain sewerage which flows into the recipient.

From the project documentation follows that the mandatory monitored limits for BOD_5 and insoluble substances are met behind the 2nd filter field. The data in Table 3, show that the concentration of the surfactants decreased by 86.70% after the pre-treatment of the waste water in the 1st filter field, by 86.46% after the 2nd filter field, and the total content of the surfactants decreased by 98.20%. The concentration of the surfactants in the sample already after the 1st filter field meets the limit value for the content of the surfactants in surface waters resulting from Regulation of the Government of the Slovak Republic No. 269/2010 Coll. By purifying the water through the 2nd filter field and through the wetland, the content of the surfactants is completely minimized. Purified water is discharged into the recipient.

Table 3. Average concentration of the surfactants (mg/L) with standard deviation (SD) in the waste water samples from the WWTP ECOver.

Sedimentation Tank	SD	N	After 1. Filter Field	SD	N	After 2. Filter Field	SD	N	After the Wetland	SD	N
7.22	0.04	8	0.96	0.08	8	0.13	0.01	8	<0.10	0.01	8

Note(s): SD—standard deviation, N—number of the experimental samples.

3.2. ECOkocka

It is a domestic root WWTP with aeration. A total of 3 households are connected, from which waste water is pumped into a common septic tank. The scheme is shown in Figure 2.

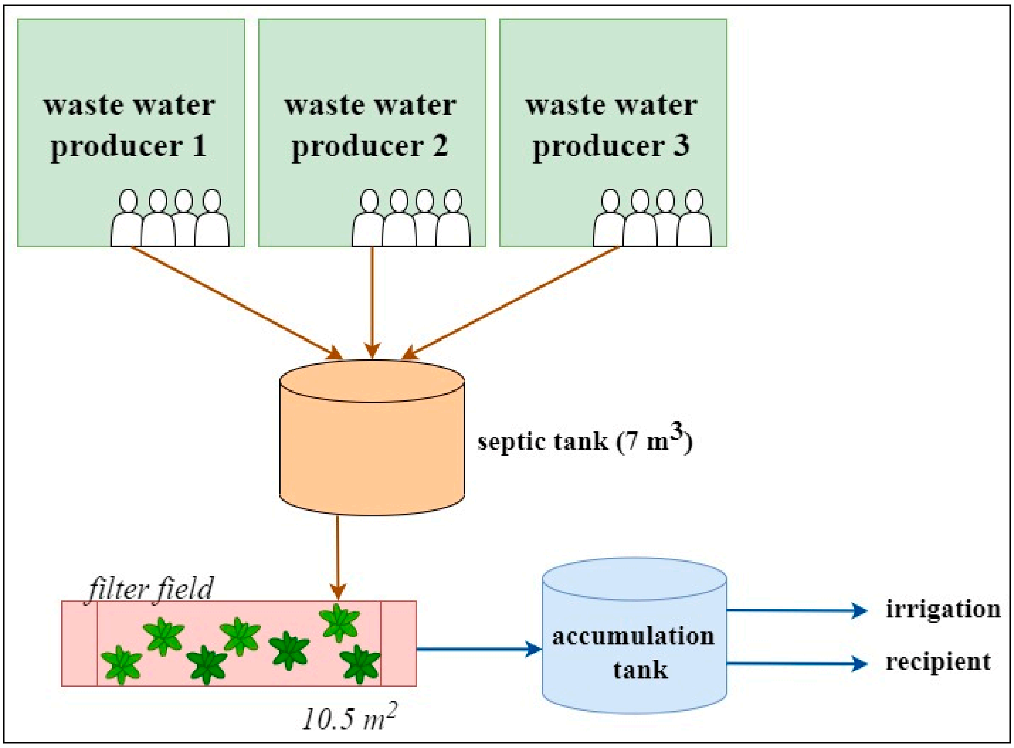

Figure 2. The scheme root WWTP type ECOkocka [19].

Analyses of purified waste water from the root WWTP meet the required quality parameters (BOD_5, insoluble substances). The efficiency of the root WWTP in terms of reducing the concentration of the surfactants is shown in Table 4. The data show that the efficiency of the biodegradation process is 99.62%. Purified water meets the limit value for the content of the surfactants (Regulation of the Government of the Slovak Republic No. 269/2010 Coll.). The content of the surfactants after water purification is minimal. Purified water is collected in an accumulation tank. As needed, it is used as utility water, e.g., for irrigation, or in the case of an excess, it is discharged into the recipient.

Table 4. Average concentration of surfactants (mg/L) with standard deviation (SD) in the waste water samples from the WWTP ECOkocka.

Septic Tank	SD	N	After Filter	SD	N
26.30	0.62	8	<0.10	0.02	8

Note(s): SD—standard deviation, N—number of the experimental samples.

3.3. ECOair

It is an aerated root WWTP, which is suitable for larger buildings (e.g., accommodation facilities: hotels, guesthouses, cottages, camps and others). The efficiency was assessed for purified waste water. The originator is a recreational facility with a root WWTP with parameters: number of p. e. = 50; with hourly water flow = 0.27 L/sec and annual water flow = 2400 m^3/year. The ECOair scheme is shown in Figure 3.

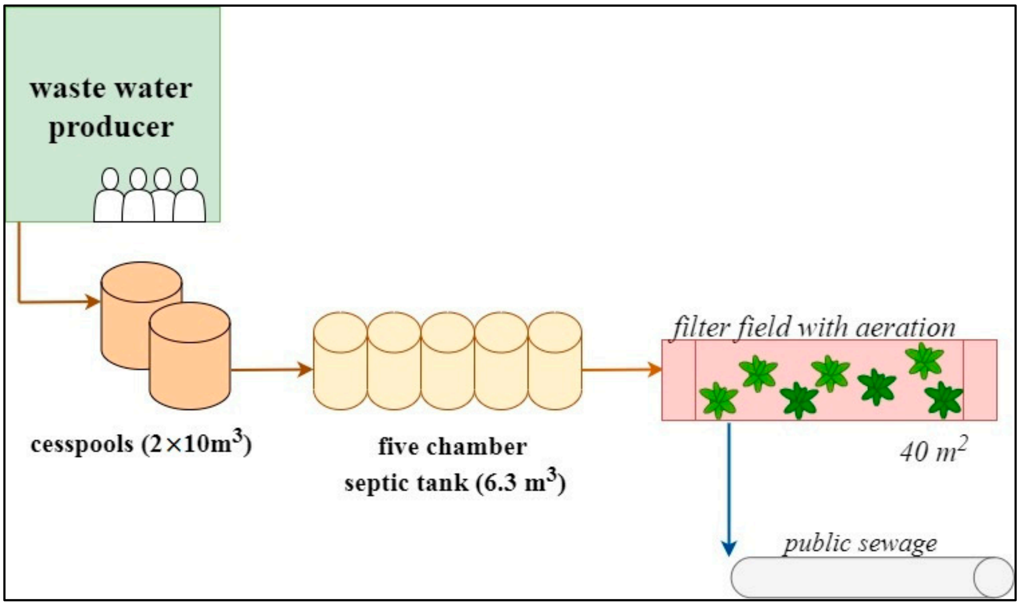

Figure 3. The scheme root WWTP type ECOair (according to the project documentation of ECOPLANET SLOVAKIA, s.r.o.; [19]).

The aeration is ensured by the aeration hoses (artificial aeration root beds), which are placed directly in the filter and at regular intervals. The aeration increases cleaning efficiency by up to 10 times and reduces the surface area requirements by 4–6 times.

From the project documentation, it follows that aerated root fields achieve the desired cleaning effect in terms of monitored indicators (BOD_5, insoluble substances). The effectiveness of the root WWTP in terms of the surfactant content is shown in Table 5. Purified water meets the limit value for the content of the surfactants resulting from Regulation of the Government of the Slovak Republic No. 269/2010 Coll. The content of the surfactants after purification was reduced by >99.10%. Purified water can be discharged directly into a surface water source. In this case, it is led into the public sewerage, where it does not contribute to increasing pollution at the WWTP.

Table 5. Average concentration of surfactants (mg/L) with standard deviation (SD) in the waste water samples from the WWTP ECOair.

Septic Tank	SD	N	After Filter	SD	N
11.23	0.18	8	<0.10	0.01	8

Note(s): SD—standard deviation, N—number of the experimental samples.

3.4. Realization of the Recirculation of the Water from Surface Runoff and the Waste Water Using the Root WWTP

The project of the company ECOPLANET SLOVAKIA, s.r.o. solves complex water management for the conference/congress center. The scheme of this object is shown in Figure 4. This root WWTP is designed for number p. e. = 75 and annual water flow = 4900 m^3 of waste water.

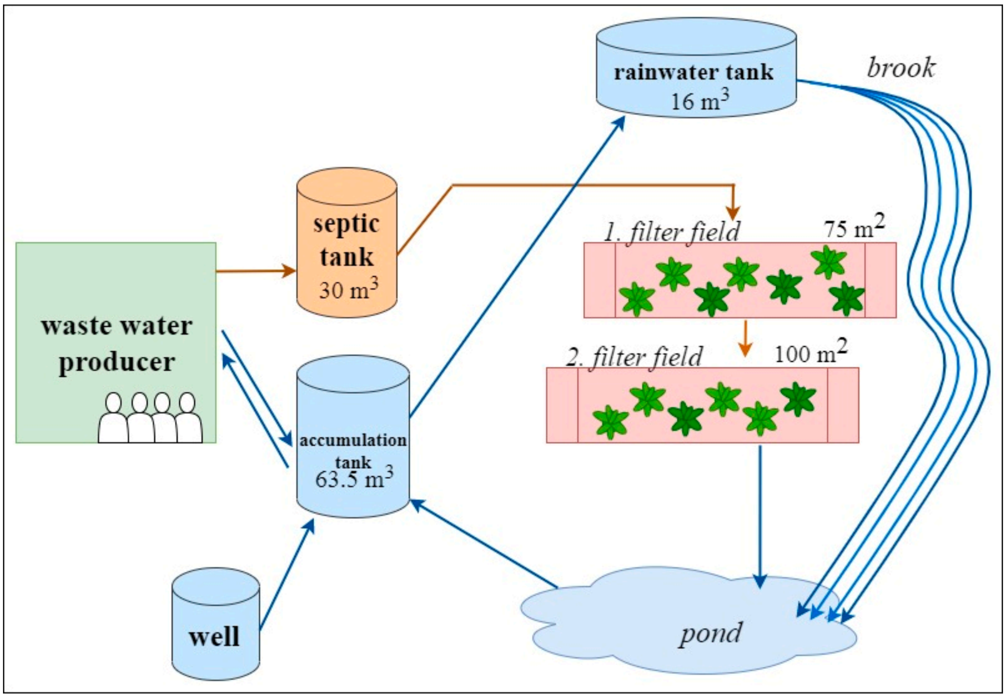

Figure 4. The circulation of the water from surface runoff and waste water in the facility (according to the project documentation of ECOPLANET SLOVAKIA, s.r.o.; [19]).

Description of the technical solution:

Water from surface runoff—water from the roofs and reinforced surfaces of the building is raised to the accumulation tank. The tank is used to supply the building with utility water for flushing toilets and urinals, watering lawns and filling the rainwater tank. In the event of a shortage of water in the accumulation tank, the tank is supplemented with water from the well. At the same time, the accumulation tank is also used for fire water needs. The rain tank supplies water to the stream, which complements the esthetic element in the garden.

Sewage waste water: Water is fed into the septic tank and following through the root sewage treatment plant system. After cleaning, the water flows into an artificial pond. Surplus water from the pond is raised through an overflow into the accumulation tank, which closes the recirculation circuit.

The project of the complete water management of the building, including the use of the root WWTP, meets the required mandatorily monitored parameters (BOD_5 and insoluble substances) in accordance with the current Slovak legislation. The degradation of PPCP´s in terms of the surfactant content is shown in Table 6. The waste water already meets the limit value for the surfactants in the sample after the 1st cleaning filter (Regulation of the Government of the Slovak Republic No. 269/2010 Coll). The efficiency of the surfactant degradation is 95.73%.

Table 6. Average concentration of surfactants (mg/L) with standard deviation (SD) in waste water samples from the root WWTP built in a closed recirculation circuit.

Septic Tank	SD	N	After 1. Filter Field	SD	N	After 2. Filter Field	SD	N
5.86	0.48	8	0.74	0.05	8	0.25	0.04	8

Note(s): SD—standard deviation, N—number of the experimental samples.

3.5. Ecotoxicological Assessment

The samples of the waste water from cleaning processes at the root WWTPs were used to assess the ecotoxicity of the waters from these objects in terms of their impact on aquatic environment. Bioassays with aquatic test organisms were used in all analyzed samples (Table 7). Preliminary tests were carried out at two trophic levels: with consumers *Daphnia magna* and producers *Lemna minor*. The ecotoxicity of purified water was negative (according to [17,18,20,21]. It was not necessary to perform a basic test.

Table 7. Ecotoxicological assessment of the quality of treated waste water from selected root WWTPs and the water recirculation project.

	Sample	Test with *Daphnia magna*	Test with *Lemna minor*
		ECOver	
1.	Sedimentation tank	+	+
	After 1. filter field	−	−
	After 2. filter field	−	−
	After the wetland	−	−
		ECOkocka	
2.	Septic tank	+	+
	After filter	−	−
		ECOair	
3.	Septic tank	+	+
	After filter	−	−
	Project circulation of water from surface runoff and waste water in the facility		
4.	Septic tank	+	+
	After 1. Filter	−	−
	After 2. Filter	−	−

Note(s): (+) positive preliminary test, (−) negative preliminary test according to [17,18,20,21].

From the data in Table 7, it follows that waste water cleaned by root WWTPs does not pose an ecological and environmental risk. It is also possible to use in the recirculation process as irrigation water, utility water, but also as water in an ornamental pond. A big advantage of this method of the water purification is the recovery of the used water. At the same time, it can be supposed that the implementation of the ecotoxicological tests is a one of the appropriate methods of biomonitoring of the purified water. Test organisms appear to be suitable bioindicators of the quality of discharged water and realistically present the impact of these waters on ecosystems.

To compare the results of the water samples from root WWTPs, we also tested samples of treated waste water from conventional WWTPs. Table 8 shows the results of a preliminary ecotoxicological test with the using test organism *Daphnia magna* and *Lemna minor* and the content of the surfactants in waste water. From Table 8, it follows that the concentration of the surfactants >1 mg/L is in samples of the purified waste water mainly from smaller WWTPs. We note that the higher content of the surfactants in the water from smaller WWTPs is caused by the discharge of the waste water from households with various levels of the pollution. In total, 50% of the tested WWTPs had positive water samples for the presence of the surfactants. This fact indicates the need to expand conventionally used separation methods in wastewater treatment with innovative methods. Based on our experience, we recommend, in addition to the use of root WWTPs for separate objects or groups of the objects, the extension of conventional WWTPs with root purification systems for purified water before it flows into the recipient [19,22].

Table 8. Evaluation of the surfactant content (mg/L) in water samples from conventional WWTP, including ecotoxicological evaluation.

WWTP	Number of Projected e. p.	Effluent from the WWTP		
		Surfactant Content (mg/L)	Test with *Daphnia magna* *	Test with *Lemna minor* *
A	100	3.62	+	+
B	16,500	0.66	−	−
C	250	2.74	+	+
D	1000	0.51	−	−
E	1500	0.79	−	−
F	3000	0.83	−	−
G	750	2.17	+	+
H	12,500	0.47	−	−

Note(s): * (−) negative preliminary test; (+) positive preliminary test [17,18,20,21].

4. Conclusions

Conventional WWTPs ensure water purification in terms of the mandatorily monitored indicators, which do not include the surfactants as one of the important indicators of the presence of the emergent pollutants, i.e., PPCPs, in water. Based on the results of the study, in which we focused on the use of root WWTPs from ECOPLANET SLOVAKIA, s.r.o., we recommend that the construction of root WWTPs be applied as a suitable wastewater treatment method for various social facilities (hotels, dormitories, schools...), or households, as it removes emergent pollutants contained in discharged waste water directly at the producers. Another example is the use of the purified waste water from root WWTPs as irrigation water, or the potential to complement the environment in the form of the ornamental ponds, wetlands, etc. Purified waste water from these treatment plants is used as utility water. The water meets the quality criteria in accordance with the current Slovak legislation. At the same time, the operator (ECOPLANET SLOVAKIA, s.r.o.) regularly provides water analyzes for clients who have their own wastewater treatment plant in terms of all mandatory monitored indicators. The water is therefore safe for health.

Water is an exhaustible resource. In the article, our knowledge points to the possibilities of the recirculation and thus repeated use of the purified water, which ensures water savings. This is a very significant idea in relation to the global problems of the Earth, such as global warming. Another possibility of using root WWTPs is also supplementing conventional WWTPs with root systems, where they would fulfill the function of the purifying waste water before discharging it into the recipient.

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