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The use of reclaimed water in the local urban cycle – a case study

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ABSTRACT

The practical implementation of solutions compatible with the circular economy is crucial in Europe. The authors present a case study for a small Polish agglomeration. The local wastewater treatment plant operator took up the challenge of closing the local water cycle and limiting the use of groundwater for purposes other than households. The solution was developed based on consultations with stakeholders and research results, with particular emphasis on microbiology. Water quality was compared to the requirements of European Union law. The developed solution consists in recovering water from municipal sewage for the internal needs of wastewater treatment plant and for the needs of municipal services. Reclaimed water can be used to wash equipment, power heat pumps, irrigate green areas, and clean streets. The social and environmental benefits consist in reducing the consumption of water from the drinking water network, building the value of water services and environmental corporate responsibility.

Keywords: Water reuse; Reclaimed water; Circular economy

1. Introduction

Sustainable management of water resources requires the implementation of solutions rationalizing and optimizing the use of available resources with particular care for the environment. In many wastewater treatment plants, treated wastewater is recycled in order to use for internal technology needs (mainly washing equipment). However, in Poland, the interest in water recovery outside the wastewater treatment plant (WWTP) is still not high, but the development potential is significant. Climate change and the need to save natural water resources should favor the development of recovery systems. The experience of many cities shows that properly prepared and safe water can be very useful in developing [1,2] and developed countries [3–5]. Reclaimed water has applications across Europe and is an important part of a circular economy that avoids using resources where they can be recovered and reused [6]. Nitrogen and phosphorus, as well as micronutrients and organic matter in reclaimed water, can increase soil nutrition and fertility during irrigation and have beneficial effects on plant growth. Exall [7] emphasizes that the nutritional value of reclaimed water can be beneficial for plants, leading to savings in fertilizer costs. However, the risk of nutrient imbalance and water and soil contamination due to irrational management of reclaimed water should be considered [8].

The quality requirements depend on the needs. Southern European countries use reclaimed water mainly for agricultural purposes [9], but also for urban purposes such as washing streets, watering green areas and golf courses, etc. [10]. According to the research of the European Commission [11], watering green areas and washing streets with reclaimed water are the most frequently supported solutions.

In Spain, water reuse is of great importance, especially in areas where the scarcity of fresh water is a structural problem. According to Rodríguez-Villanueva and Sauri [10], Spain is at the forefront of water reuse in Europe. Agricultural irrigation is the destination of 41% of treated wastewater,

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followed by irrigation of golf courses and public parks (31%). Similarly, Cyprus uses water that has been reclaimed for years, but the development potential is still significant [12].

California in the US has focused on water recovery because it can improve the resource balance [13]. Melbourne, Australia, has been using reclaimed water from both wastewater and grey water since the 1970s to improve its water safety, and is currently one of the most active cities in using water recovered from treated wastewater for irrigation [14]. In Bangkok, it is planned to recover 10% of the water from wastewater for municipal purposes [15].

Green spaces are of key importance in cities. They stabilize the temperature, accumulate moisture and water, constitute recreational areas, and make life in the city possible [16]. But such areas require special care and a large amount of water, so it seems a great idea to use reclaimed water to care for urban green areas. Therefore, it is important to estimate the amount of water needed to clean streets or irrigate green areas, as well as to properly organize the cooperation of the provider of reclaimed water with municipal services [17].

In some most experienced EU countries, there are already some guidelines and legal acts enhancing the safe use of reclaimed water [18]. In addition, the ISO [19] standards provide a good knowledge base for recovery. Bearing in mind the need to ensure the safety of recovery, the EU institutions adopted Regulation 2020/741 on minimum requirements for water reuse [20]. It focuses on the use of reclaimed water for irrigation in agriculture but opens opportunities for other applications (industry, amenity-related and environmental purposes). In addition, it provides general guidance on risk assessment which, while targeting agriculture, can be useful in many other applications. Moreover, the European Commission [21] published Guidelines to support the application of Regulation 2020/741 on minimum requirements for water reuse.

Water reuse from wastewater poses a number of technical, economic, and sanitary challenges that need to be taken into account when developing local solutions.

As technology appears to be well-mastered, security and finance remain two key challenges. It is necessary to properly prepare the water so that it is safe for people and the environment. General guidelines on risk management are contained in the ISO standard [22,23] or local guidelines, such as those developed by the government of Alberta in Canada [24], the US Environmental Protection Agency [4], or the French government [25]. As part of the EU-funded Demoware project, water reuse safety plans [26] were created. Safety for people and nature focuses primarily on microbial contamination. In addition, the community must have confidence in the solutions used.

The microbiological quality of reclaimed water is very important, especially the content of fecal pathogens. When assessing microbiological risk, total coliforms, fecal coliforms, or *Escherichia coli* are the most used indicators, the latter being considered the most representative of fecal contamination [18].

Microbiology is the basic monitoring to ensure the safety of humans and animals. However, to ensure full environmental safety, wider, comprehensive monitoring is needed, including total suspended solids, turbidity, biochemical oxygen demand, chemical oxygen demand, total nitrogen, and total phosphorus. Detailed chemical requirements depending on the local situation, such as salinity, are also important. Harivandi [27] emphasizes the need to control soil salinity when reclaimed water is used to irrigate golf courses. Qian and Lin [28] point to problems with salinity and relatively high accumulation of sodium and boron in the soil.

It is still problematic to precisely define the quality of the reclaimed water. In Japan, even though water has been recovered since the 1980s, the problem with the legal ordering of quality is still valid [5].

Another important criterion for assessing water recovery solutions is cost. Spanish analyses from 2008 Moreno and Chabalina [29] indicate a higher cost of recovery due to the additional treatment. However, the price of reclaimed water should consider not only the cost of treatment but also the value of water as a resource, its environmental impact, and the benefit that comes with its use.

The cost-effectiveness of water recovery should be compared with other methods, for example, building new intakes or increasing the efficiency of existing infrastructure. US National Academies of Sciences, Engineering, and Medicine [30] emphasize the need to compare a recovery solution to the use of water from other sources. When assessing the economic viability of a project, it is important to understand the difference between economic costs and benefits, and accounting costs. The social costs may be the shortage of drinking water in the network, the benefits may be lower discharges of treated wastewater into the surface waters. The US National Academies of Sciences, Engineering, and Medicine, therefore, highlight three types of costs: financial, social, and environmental. Similarly, Molinos-Senante et al. [31] provide an example of a cost-benefit analysis for water recovery from 13 treatment plants in the Valencia region. They emphasize the need to consider external benefits, not only those determined by plant operators. Arborea et al. [32] describe the methodology used in the Italian region of Puglia, emphasizing the essence of long-term cost-benefit analysis. Often, however, the resistance of the local community does not allow finding recipients, as they prefer to use other, proven sources of water for irrigation.

The Demoware project [33] developed a manual for cost-benefit estimation. The principle of cost recovery for water services should be considered, but pricing strategies for reclaimed water should be based on a broad, beneficiary-pays approach rather than only a user-pays principle.

2. Materials and methods

Józefów is a city with a population of around 20,000, located in central Poland, adjacent to Warsaw. It is characterized by low, mostly scattered buildings, mainly residential. There are no industrial or agricultural activities here. Since 2019, a new municipal wastewater treatment plant with a capacity of 18,000 p.e. has been operating in Józefów. It serves the entire city (agglomeration) by treating wastewater in accordance with the Urban Wastewater Treatment Directive [34] and the Polish Regulation on the quality of treated wastewater discharged into waters [35]. The daily inflow of sewage is 2,200 m^3 on average, max. 3,000 m^3/d.

The wastewater treatment technology is based on flow technology with low-loaded activated sludge. Sewage from all over the city flows into the treatment plant through one main collector, then it reaches two parallel chambers with hook grates (preliminary mechanical cleaning of waste over 15 mm). Sewage is directed through an underground double pipeline to a mechanical treatment station. There are two parallel lines of mechanical pre-treatment through screens with 3 mm holes, followed by sand traps. Sand and gravel are drained and stored in a container and then collected by an external company. Then the sewage goes to two biological reactors and finally to secondary settling tanks.

The treated wastewater flows into the technological water chamber, where the pH, temperature, and flow rate are measured. The final stage of treatment is disinfection with a UV lamp. Treated wastewater is discharged into the Świder River. Fig. 1 illustrates the scheme of the treatment plant.

Disinfection with UV light is especially important as the Świder River is part of recreational areas. Although there is no official bathing area near the outlet of the WWTP, many people come to this area of the river for recreation. The Bathing Directive [36] requires intestinal enterococci to be limited to 200 cfu/100 mL and *Escherichia coli* to 500 cfu/100 mL to confirm the excellent quality of bathing water.

From the very beginning, the WWTP operator (Hydrosfera Józefów), has been striving to implement solutions that fit into the circular economy. The water supply system is based on groundwater of very good quality which motivates the operator to protect it. The wastewater treatment plant has its own needs, and due to the specificity of the city, the need for irrigation of green areas is significant. In addition, there is a golf course near the WWTP. Therefore, the possibility of obtaining water of appropriate quality from wastewater was analyzed. There is a need to look for an alternative to water intended for human consumption, in which energy, chemicals, and human labor have been invested. The WWTP operator undertook an analysis of the wastewater quality to develop an appropriate reclamation technology. The investment preparation methodology was based on the requirements of Regulation 2020/741 and ISO standards. The main goal was to ensure the microbiological safety of the reclaimed water.

The ISO standards [22,23] recommend, for urban purposes, testing of basic parameters of reclaimed water, such as pH, biological oxygen demand in 5 d (BOD_5), turbidity, and microbiological indicators such as *E. coli* and coliform bacteria. EU Regulation 2020/741 applies to agriculture but specifies a wide class of reclaimed water as it covers the irrigation of plants not intended for human and animal consumption. It recommends the control of *E. coli* (admissible content 10,000/100 mL) as well as BOD_5 and total suspended solids (TSS) in accordance with Directive 91/271/EEC [34].

Since 2019, Hydrosfera Józefów has been conducting microbiological and physicochemical analyses of raw and treated wastewater, and water from the river. The results of the analyses conducted once a month were decided to be used in assessing the potential for local use of reclaimed water. Thus, it was based on existing parameters coinciding with those indicated in Regulation 2020/741 and ISO standards. It was realized that these were only basic parameters. The test results from Directive 91/271/EEC were also considered. They follow the water permit (so the Directive) throughout the operation of the treatment plant.

3. Results

The treatment plant meets the requirements of the Regulation for agglomerations between 15,000 and 99,999 p.e. [34]. For comparison purposes, the operator also controls the water quality in Świder River. Table 1 presents the legal requirements for the treatment plant and the results obtained between September 2019 and December 2022. The analyzes were performed with the frequency resulting from the urban wastewater treatment directive, and the water permit.

Moreover, microbiological parameters are controlled: fecal enterococci, *Escherichia coli*, total coliforms, intestinal parasite eggs, and *Salmonella* spp. Microbiological samples were collected once a month. The results are presented in Table 2.

No live intestinal parasite eggs or *Salmonella* spp. were detected in the treated wastewater after the UV lamp.

In treated and disinfected wastewater, the reduction of microbiology ranges from 1 to 6 log. During the research

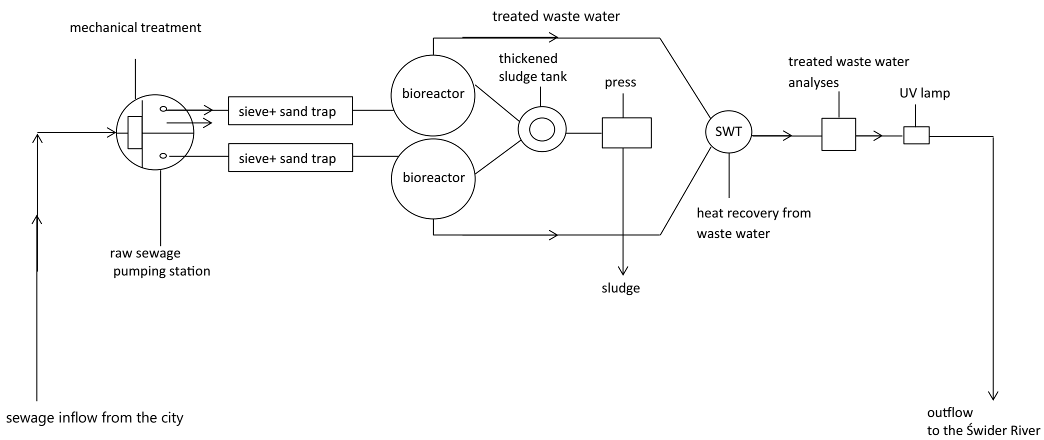

Fig. 1. Diagram of the sewage treatment process in Hydrosfera Józefów.

Table 1
Limit values for the Józefów agglomeration, resulting from the Polish law [35] and results for treated wastewater, and water in the Świder River. The analysis period lasted from September 2019 to December 2022

Parameter	Highest limit value according to the regulation (Poland 2019)	Values resulting from the water permit for the Józefów agglomeration	Values for raw wastewater	Values for treated wastewater	100 m downstream of the outlet	100 m upstream of the outlet
Biological oxygen demand BOD_5 ($mg{\cdot}O_2/L$)	15	<15	220–1,091	2–9	2–6	2–7
Chemical oxygen demand CODCr ($mg{\cdot}O_2/L$)	125	<125	378–2,021	27–82	17–54	16–45
Total suspended solids (mg/L)	35	<35	291–1,430	4–26	n/d	n/d
Total nitrogen TN (mg·N/L)	15	<10	27–136	4–13	1.9–5	1.7–6.9
Total phosphorus TPh (mg·P/L)	2	<1	9–88	0.29–1.7	0.05–0.43	0.071–0.6

Table 2
Results of analyzes of microbiological parameters in raw and treated wastewater after UV disinfection. The analysis period lasted from December 2019 to December 2022

Parameter	Raw wastewater	Treated wastewater after UV lamp
Fecal enterococci (MPN/100 mL)	106,700–23,120,000	56–5,070
Escherichia coli (MPN/100 mL)	450,000–70,225,000	56–14,140
Total coliforms (MPN/100 mL)	1,500,000–93,000,000	3–15,000
Presence and number of live intestinal parasite eggs	0	0
Presence of *Salmonella*	Present/absent	Absent

period, there were significant increases in pollutants, as shown in Fig. 2. The charts present three microbiological parameters in the wastewater flowing into the treatment plant and the same parameters for the treated wastewater flowing to the receiver (after disinfection with UV light). The first graph shows the results of quality tests for the parameter fecal enterococci, the second for *E. coli*, and the third for total coliforms. The blue bars present results for raw wastewater, and orange dots (logarithmic scale) for treated wastewater. The graphs also show the period of failure of the lamp cleaning system, which resulted in a significant decrease in disinfection efficiency.

Microbiological samples are taken monthly, starting from December 2019, when the WWTP was fully operational. The tests were performed in an accredited laboratory in accordance with PN/EN/ISO-based methodologies.

4. Discussion

Despite occasional large loads entering the WWTP, it maintains the parameters required by law and the water law permit for treated wastewater, as shown in Table 1. The exceedances for total nitrogen were noticed only at the beginning of the plant's operation. This was due to the start-up phase of the technology. Currently, the plant is working steadily. The treated wastewater does not affect the quality of water in the river, as shown in the same table. The water quality in the river is very variable. There are significant temporary pollution spikes. However, long-term trends in the impact of treated wastewater on the water quality in the river cannot be discerned. This is because above the discharge from Józefów there are outlets from other facilities. Moreover, the quality of Świder River is influenced by small settlements with disordered wastewater management. It happens that untreated sewage flows into the river.

The unevenness of a load of microbiology flowing into the wastewater treatment plant is also visible. As can be seen from the graphs in Fig. 1, a properly functioning UV lamp reduces even high microbiology reaching 6 log reductions which are effective. Rubiano et al. [37] and Muduli et al. [38] showed that a reduction at the level of 4 log can be sufficient in the normal operation of a WWTP. However, in the case of Józefów, the overriding goal of water reuse should be borne in mind. In the context of risk analysis, it is important to determine the cause of the significant increase in microbiological parameters in November 2021. This peak indicates an insufficient reduction in microbiology, implying problems with UV lamp disinfection. The lamp is cleaned

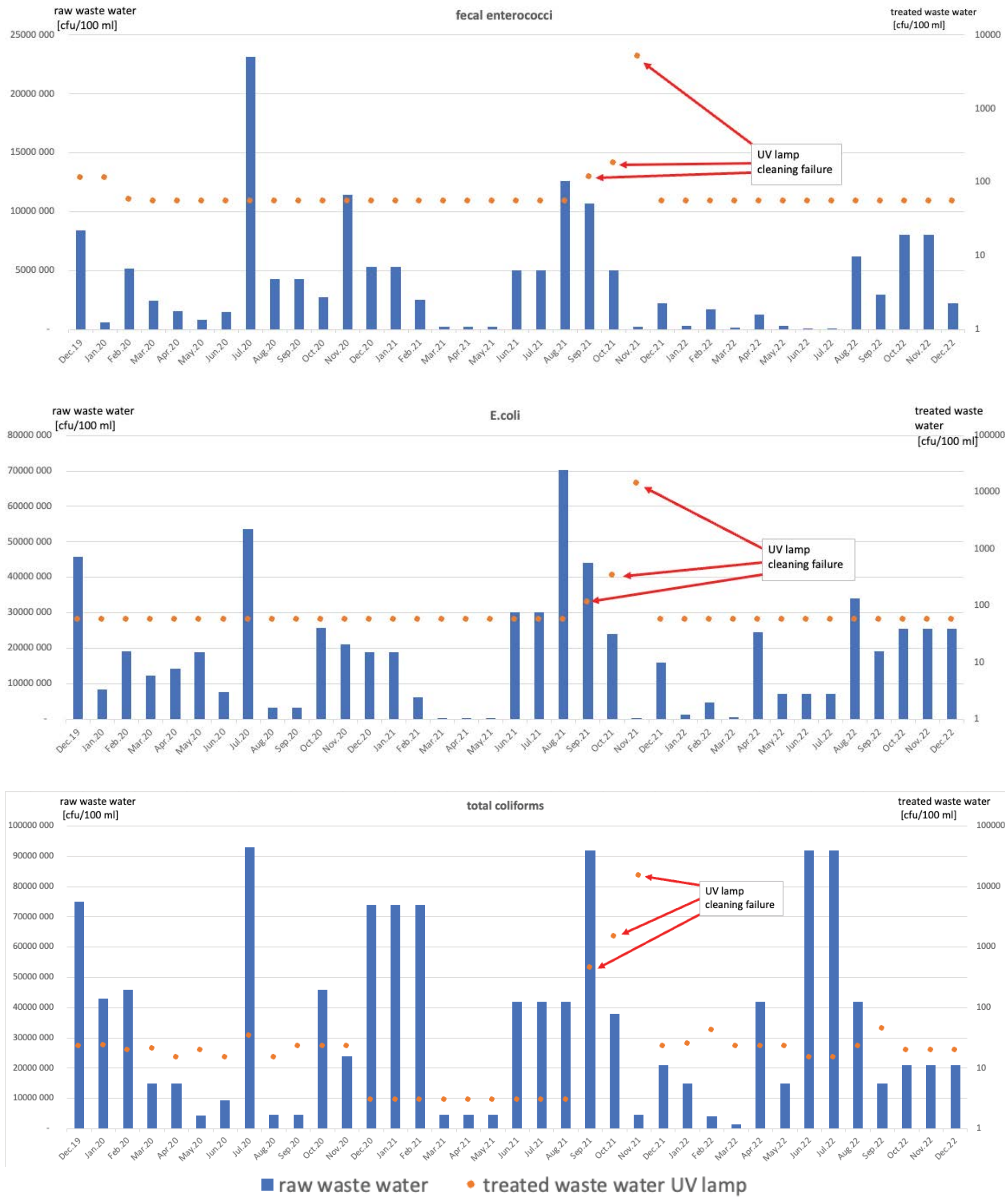

Fig. 2. Results of analyzes of microbiological parameters in raw and treated wastewater after disinfection.

automatically at certain intervals. Mechanical cleaning is carried out using special automatic brushes, and chemical cleaning is carried out based on citric acid. It turned out that the cleaning device did not work properly during the operation of the UV lamp. The problem with the cleaning efficiency can be observed as early as September 2021. However, it was not until November that the cleaning system was repaired.

Reclaimed water, that is, disinfected treated wastewater, has parameters that keep the microbiology below the requirements of the Bathing Directive [36] and the Regulation on water reuse [20], except the class A of water. However, class

A water is applicable for irrigation of food crops consumed raw, and root crops consumed raw. Such use is not planned in Józefów. Water should meet the requirements for class D, that is, for irrigation of non-food plants.

As a result of consultation with stakeholders and based on the treated wastewater quality analysis, the operator decided to use the reclaimed water in two directions: for internal purposes related to the operation of the WWTP and external – for use in the city.

Internal use includes the following directions:

- washing the press,
- supplying the upper source of the heat pump used to heat the WWTD and office space,
- use for other technological purposes,
- irrigation of green areas in the treatment plant.

This will save approximately 3,000 m^3 of drinking water per month.

External use consists in making water available for watering urban areas. The Municipal Company “Beautiful City” is responsible for the maintenance of green areas in Józefów. For this purpose, it takes water from the drinking water network. Because the reclaimed water meets the requirements set by ISO standards and the EU regulation 2020/741 for class D of water, it can be used for irrigation of green areas.

To implement the planned tasks related to the use of reclaimed water, it was necessary to build new infrastructure. Therefore, the operator decided to build two overflow tanks (Fig. 3). The first one with a capacity of 22 m^3 serves for internal use in the WWTP.

The second tank with a capacity of 14 m^3 is available to the municipal enterprise “Beautiful City”, which can take water for water carts and use it to wash streets and irrigate green areas.

The excess water can be discharged into the river as before.

Due to the use of mechanical thickening of the excess sludge, water is needed to clean the thickening belt. During the cleaning phase the demand for tap water is 8–10 m^3/h. To avoid taking water from the drinking water network, it is necessary to additionally treat, and store reclaimed water. As indicated in Table 3, the treated wastewater has too high TSS (4–26 mg/L), which makes it impossible to use for washing the press. Therefore, the operator decided to place a bucket filter behind the first retention tank, which will enable the reduction of TSS. The reclaimed water can then also be used in the biological reactor chambers to break the foam, wash the reactor walls, and clean the secondary settling tanks, which will significantly reduce water consumption from the drinking water network.

The wastewater treatment plant facilities and the water in the internal network are heated with a heat pump. The experience of using heat pumps in winter shows that at night when the sewage inflow to the WWTP is minimal, there are situations in which there is no technological water supplying the heat pump. The temperature in the return circuit drops by approx. 2°C. Efficiency can be increased when retaining treated wastewater in the reservoir.

Seasonal increases in demand for irrigation water prompt the operator to use the reclaimed water to irrigate plants at the treatment plant as well.

Hydrosfera Józefów also sees potential for the further development of a water reuse system, for example, by establishing cooperation with the operator of the golf course.

It is not possible to legally regulate all the details and rules for the safe use of circular economy solutions. Much depends on the local conditions that must be considered. Regulation 2020/741 sets out general steps to be taken by operators responsible for producing reclaimed water for agricultural purposes. They are obliged to put up barriers based mainly on additional technological processes. Considering water category D, that is, for the irrigation of industrial, energy, and seeded crops, an *E. coli* number <10,000/100 mL should be taken into account, which is easy to achieve when the UV lamp works stably. The remaining requirements are in accordance with the water permit. For this class, all irrigation methods are allowed.

Similarly, for the requirements of ISO standards [19,22,23], the limits for microbiological parameters are key, which forces the improvement of the reliability of disinfection. It is, therefore, necessary to constantly monitor the operation of the UV lamps. Other disinfection methods such as chlorination have not been accepted by stakeholders. This is due to the negative effect of residual chlorine compounds on the soil and vegetation [39–41].

The solution used in Józefów is part of the water recovery trend in Europe, although the scope of analysis was more limited than in solutions from more experienced countries, such as Spain or Portugal. However, the basis for the risk analysis is microbiological tests. Case studies described by

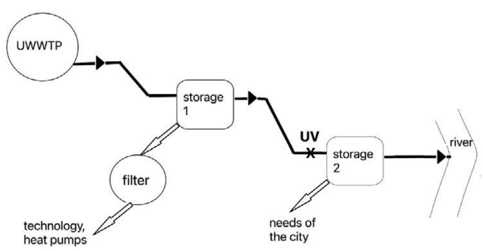

Fig. 3. Schematic diagram of the final water reclamation solution.

Table 3
Quality of reclaimed water compared to the requirement of the regulation 2020/741. Data for September, October, and November 2021 are not included

Parameter	Reclaimed water	Requirement of 2020/741			
		Water class A	Water class B	Water class C	Water class D
Escherichia coli (CFU/100 mL)	<56	≤10	≤100	≤1,000	≤10,000
BOD_5 (mg·O_2/L)	2–9	≤10	25		
TSS (mg/L)	4–26	≤10	35		

Candela et al. [42] and Molinos-Senante et al. [43] in Spain emphasize the importance of assessing the microbiological quality of reclaimed water, as it was analyzed in Józefów. It should be emphasized that the analysis performed in Józefów should be considered preliminary. It is necessary to conduct a full spectrum of risk analysis. There are already tools that can be used for such solutions, such as those described by countries with greater practice, for example, Rebelo et al. [44], Papadopoulos et al. [45].

5. Conclusions

- Implementing solutions that fit into the circular economy does not have to involve large projects. They may consist in closing small local water circuits, where no complicated and expensive infrastructure is needed. Small agglomerations where there is no risk of industrial pollution can implement local solutions such as those in Józefów. It complies with the circular economy principle, according to which the key is to avoid the use of natural resources (in this case water) and to use the same resources multiple times [6].
- Local social, environmental, and economic conditions should be considered in the cost-benefit analysis. Hydrosfera Józefów faces the challenge of assessing the value (material and immaterial) of the solutions developed. The calculation of the life-cycle assessment (LCA) should be a solution that is highly recommended in further works.
- In any solution for the recovery of water from urban wastewater, it is necessary to carry out a risk assessment for people and the environment. The first step should be to control microbiological contamination, then physicochemical, depending on the analysis of threats resulting from local conditions.
- The problem of infrastructure reliability is crucial. As more frequent microbiological monitoring can be problematic, the operator must improve the reliability of the infrastructure.

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