JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(8), 57–66
https://doi.org/10.12911/22998993/22998993/203662
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Received: 2025.03.20
Accepted: 2025.05.26
Published: 2025.06.10

Preliminary studies on the possibility of recovering water from wastewater using constructed wetlands

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ABSTRACT

Due to climate change, among other factors, many countries are experiencing problems with water resources consumed by population, industry and agriculture. In addition to the implementation of water conservation, it may be necessary to use the process of water recovery from treated wastewater discharged to receivers. One of the factors facilitating the reuse of treated wastewater is the use of increasingly efficient municipal and industrial wastewater treatment systems. The authors' used constructed wetland (CW) beds for wastewater treatment, as a simple, inexpensive and effective way to carry out the project of water recovery. The scientific objective of the study was to determine the treatment efficiency of organic matter, nutrients and microbial during CW treatment of sewage discharged from municipal and dairy WWTPs. The analysis concerned the basic parameters of wastewater after treatment in municipal and dairy wastewater treatment plants (WWTPs), namely the content of organic matter and biogenic compounds. Microbiological tests included determination of the total coliform (TC) and *Esherichia Coli* (EC) index. The treatment efficiency in relation to the unit area of the CW beds was determined. Dairy sewage used in the study was characterized by significantly lower microbial contamination in comparison with municipal sewage, which predisposes them to be used in the process of water recovery. The conducted research indicates a high potential of CW for water recovery from wastewater, providing an alternative to conventional technologies.

Keywords: constructed wetlands, municipal and industrial treated wastewater, water recovery.

INTRODUCTION

Around the world, many countries are experiencing problems with water resources consumed by population, industry and agriculture. One solution to this problem may be the use of treated wastewater, most of which is discharged to receiving bodies in the form of surface water. Modern multi-stage systems (mechanical-biological-chemical) provide very high treatment efficiency which predisposes them to become a source of reusable treated wastewater. Treatment plants are able to remove microbiological contaminants by using disinfection with UV lamps. The agricultural sector can use treated wastewater for crop irrigation, while service sectors and households can reuse water for urban cleanliness or firefighting. In selected industries, water can be used, for example, for plant cooling purposes. Such solutions can bring environmental and financial benefits due to the reduced lack of need to draw water from surface and underground intakes (Ramm and Smol, 2023; Smith et al., 2018; Voulvoulis, 2018). An interesting proposal, for example, is the use of treated wastewater for beer production (Clark, 2023). Water recovery is also part of circular economy (Czerwionka et al., 2025).

Although Europe is facing a growing water scarcity problem, it still lags behind Asia and North America in the implementation of treated wastewater reuse solutions (Tzanakakis et al., 2023). Water scarcity in Europe was assessed using the water stress index (the ratio of annual water withdrawals from groundwater and surface water to total renewable freshwater resources). At the time, it was estimated that 10% of the area and 14% of the population were affected by water scarcity (Bixio et al., 2006). European Union (EU) member states were ranked and divided into four categories (Figure 1) according to their water stress index. Cyprus, Bulgaria, Malta and Belgium have the highest percentage of water deficit index (40–80%). Countries located in warm climate zones with a high percentage of drought are the most advanced in the search for innovative water recovery technologies (Bixio et al., 2006; Ungureanu et al., 2020). The topic of water recovery has grown significantly in the EU, and is one of the most popular research areas in Europe. Belgium, Denmark, France, Germany, Greece, Italy, Netherlands, Poland, Portugal and Spain are the 10 EU countries with the highest number of publications on water recovery (Koseoglu-Imer et al., 2023).

The reuse of wastewater is subject to regulations and legal standards for safe use and human protection. Guidelines depend on the region and country. Examples are the WHO guidelines for the use of wastewater in aquaculture and agriculture and the reuse of drinking water (WHO, 2006) and the EU Regulation on requirements for water reuse (EU 2020/741). Water reuse projects are more numerous in Southern European countries (Cyprus, Malta, France, Greece, Spain and Portugal). Several projects have also been implemented in northern and central countries (Belgium, UK, Sweden) (Helmecke et al., 2020; Saurí and Arahuetes, 2019).

In order for the reuse of water from wastewater to be safe (e.g., not to pose a risk to human health, increase salinity in soils), advanced treatment technologies are needed, and these are still being researched and developed by scientists (Mishra et al., 2023; Shakir et al., 2017). More and more municipal treatment plants are using tertiary and quaternary wastewater treatment with a disinfection process. The choice of technology for water recovery is based on the quality and quantity of wastewater. A number of physicochemical processes, biological processes, membrane technologies (reverse osmosis, ultrafiltration) and disinfection technologies (UV radiation etc.) can be used to recover water from wastewater. CW technologies can also be applied (Florides et al., 2024; Kehrein et al., 2021; Roccaro, 2018).

CW beds have recently become a popular method of sewage treatment around the world. They are an efficient, low-cost methods (Lavrnić et al., 2020; Nan et al., 2020). They are also characterized by simple construction, easy operation and do not generate waste. The technology is very effective in eliminating conventional pollutants (TSS, COD, BOD_5, nutrients). Heavy metals or microbial contaminants are also effectively removed, which predisposes CWs to be used in the recovery of water from treated wastewater (Almuktar et al., 2018; Hdidou et al., 2022; Nan et al., 2020).

The scientific objective of the study was to determine the treatment efficiency for organic matter, nutrients and microbial during CW treatment of sewage discharged from municipal and dairy WWTPs. The practical aim was parameter evaluation for water recovery with CW technology. The research was conducted as part of a project on recovering water from treated wastewater for reuse. The research is part of a closed-loop economy, and is intended to be the basis for developing a simple system for recovering water from wastewater using the CW method.

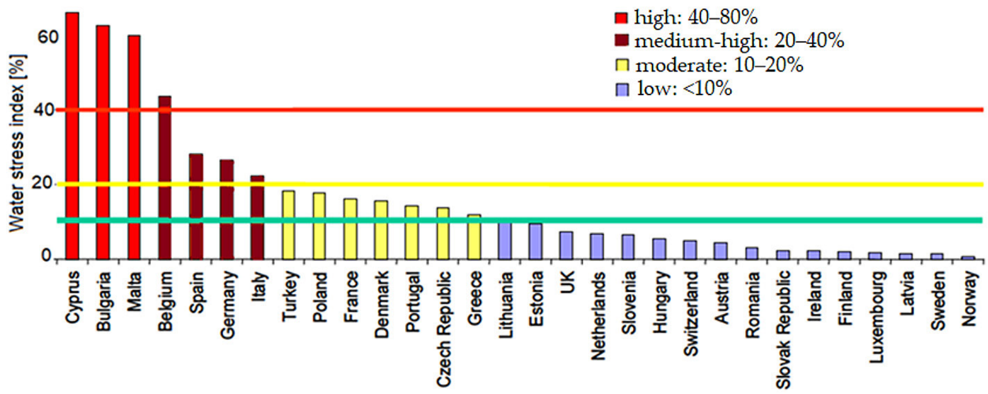

Figure 1. European Union member states ranked by water stress index (Ungureanu et al., 2020)

MATERIALS AND METHODS

Research installation

The research installation used in this study was designed in the Department of Technology in Environmental Engineering of Bialystok University of Technology (BUT). It was designed to treat different kinds of sewage: domestic, industrial, reject water etc. (Dąbrowski et al., 2019). The main elements of the installation presented in Figure 3 were two VF-CWs filled typically with gravel and sand. A cross section of CW beds is presented in Figure 2. The total height of the CW beds was 0.8 m with three layers.

Both beds were supplied from two retention tanks (one with treated municipal sewage from Bialystok WWTP and the other with treated dairy sewage from Mlekovita WWTP) with a hydraulic load of 0.4 m d^{-1}. This value of hydraulic load is higher in comparison with a typical value for domestic wastewater treatment systems due to low contamination of sewage used in the experiment (Brix and Arias, 2005). Typical hydraulic load for raw domestic sewage is 0.05–0.20 m d^{-1}. The beds were planted with *Phragmites australis*. Figure 3 presents beds during vegetation period and a scheme of the research installation with sampling points (treated municipal sewage - I, after treatment with CW - II, treated dairy sewage - III and after treatment with CW - IV).

Sampling and analytical procedures

To obtain the data for evaluation of treatment efficiency, ten series were performed during the vegetation period (May–June 2024). Research period was chosen due to fact, that water recovery is usually performed from spring to autumn (vegetation period). Each series consisted of a treated municipal (I) and dairy sewage sample (III) and two samples of sewage after treatment with CWs (II, IV). The scope of the physical and chemical tests included: organic matter (BOD_5,

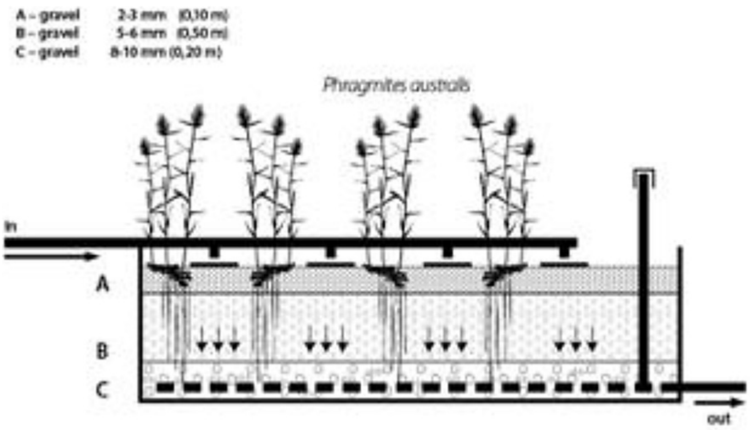

Figure 2. Cross section of VF CWs scheme of research installation

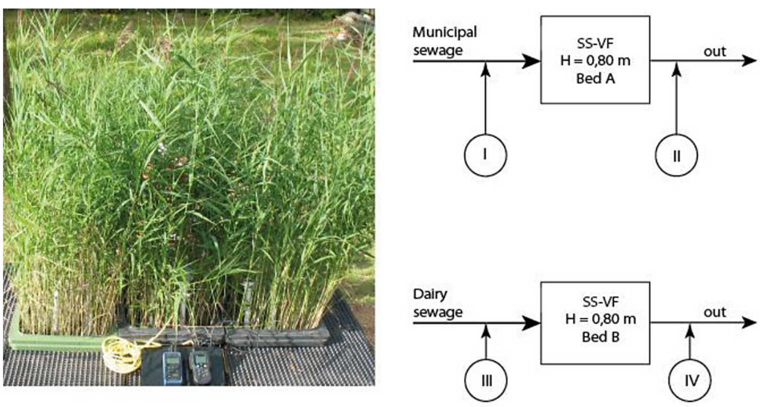

Figure 3. Research installation during vegetation (June) and scheme of research installation with sampling points (I-IV)

COD), total nitrogen (TN), ammonia nitrogen ($N\text{-}NH_4$), total phosphorus (TP) and turbidity (TB). The tests recommended by Merck were performed in the Department of Environmental Engineering and Natural Sciences laboratory at BUT. Wastewater testing was conducted following the requirements of the American Public Health Association (APHA, 2005) and Regulation of the Minister of Maritime and Inland Waterway Economy (Journal of Laws, 2019 item 1311). Microbiological tests included determination of the TC and EC index (PN-EN ISO 9308-2:2014-06 NPL). Determination of the TC and EC indexes was performed following the fermentation-tube method. Spectrophotometer Spectroquant Pharo 200 was used. BOD_5 was determined using OXI-TOP®. In addition, measurements of air temperature and dissolved oxygen concentration were taken.

Data analysis methodology

Removed loads (per unit surface and time) were calculated using effluent and influent concentrations along with the hydraulic load:

$$L_{rem} = l\left(C_{inf} - C_{eff}\right) \qquad [l] = \frac{m^3}{m^2 d} = \frac{m}{d} \tag{1}$$

where: C_{eff}, C_{inf} – effluent and influent concentrations; l – hydraulic load; L_{rem} – removed load.

For BOD_5 and COD the units of removed loads are:

$$[L_{rem}] = \frac{gO_2}{m^2 d} \tag{2}$$

For nitrogen and phosphorus the removed loads were reported in the units of:

$$[L_{rem}] = \frac{g}{m^2 d} \tag{3}$$

Concentrations of organic matter, nitrogen and phosphorus compounds varied in the analyzed sewage. To compare them, treatment efficiencies η were calculated (Kadlec and Wallace, 2008):

$$\eta = 1 - \frac{C_{eff}}{C_{inf}} \tag{4}$$

By replacing the concentrations with turbidity in Equation 4, a similar formula gives turbidity removal efficiency (η_{TB}). TC and EC were compared on a relative logarithmic scale by using removal factors *f*, defined by:

$$f = -\ln\left(\frac{value_{eff}}{value_{inf}}\right) \tag{5}$$

where: f – removal factor, $ln(\cdot)$ – natural logarithm.

Higher value of *f* means more microorganism removed from the sewage.

Distributions of the obtained removal factors, removed loads and treatment efficiencies were presented using the following values:

$$mean \pm sd\left(median \pm mad\right) \tag{6}$$

where: *mean* – the mean; *sd* – standard deviation; *median* – the median; *mad* – scaled absolute deviation.

The scale for median absolute deviation was chosen so that it approaches asymptotically the standard deviation for data following natural distribution. Box plots were further used to present treatment efficiencies and removal factors. Each such box plot consists of a box (marking quartile 1 and 3 along with median in the middle) and whiskers extending by a distance proportional to the interquartile range, but not further than the minimum or maximum of the data (Chambers et al., 1983).

Plotting and data analysis were performed in R statistical environment version 4.4.0 "Puppy Cup" (CRAN R). Function boxplot available in the graphics package was used to generate the box plots. Packages stats and base provided functions for calculating aggregate statistical measures like mean, median, standard deviation and scaled median absolute deviation. Those packages are by default shipped with the R environment.

RESULTS AND DISCUSSION

Table 1 shows the basic parameters of the municipal and dairy WWTPs. The treated wastewater was used for further treatment to recover water. Both facilities have similar personal equivalent (PE) values. The municipal wastewater treatment plant handles a much higher daily flow than the dairy wastewater treatment plant, but the dairy wastewater is more concentrated in terms of organic pollutants. Table 2 presents input parameters of sewage used in the experiment (Figure 3 point

Table 1. Basic parameters of the municipal and dairy WWTPs (data obtained from exploiters in 2023)

Parameter	Unit	Value
Municipal sewage (PE)	-	515 804
Raw municipal sewage flow (2023)	$m^3\ d^{-1}$	58 951
Dairy sewage PE	-	520 000
Raw dairy sewage flow (2023)	$m^3\ d^{-1}$	8 800

I and III). In general, dairy wastewater is characterized by a high organic content, which translates into high BOD_5 and COD loads. Compared to municipal wastewater, their values are higher by up to 6–8 times. This includes crystallized and dissolved fats (triglycerides, glycerol), proteins (casein) and sugars (lactose) (Slavov, 2017; Struk-Sokolowska, 2018). Municipal wastewater tends to have lower organic matter values, but is more diverse in composition (e.g., detergents, microorganisms, heavy metals, microplastics) (Aziz and Ali, 2017). In the conducted experiment, organic matter content, measured as COD, is similar for both sources of sewage. Municipal sewage contains less of easily biodegradable content than the dairy one (higher content of inorganic impurities). Nitrogen in dairy sewage occurs in the form of organic nitrogen (nucleic acids, urea, proteins) and NH_4, NO_3 and NO_2 ions. Total nitrogen content is also very similar, but again, municipal sewage contains less ammonia nitrogen. Total phosphorus is also less concentrated. The presence of phosphorus in dairy wastewater may be related to the use of cleaning agents containing phosphates (Reder et al., 2018). It is worth noting that the content of nitrogen and phosphorus in dairy wastewater varies depending on the type of processed dairy products and the technological processes used (Slavov, 2017). Municipal sewage parameters are also less dispersed, as both standard deviations and scaled median absolute deviations are smaller. Those differences can be explained by treatment mechanisms applied and original WWTP input concentrations. The greatest difference is in the microbial content. Municipal sewage contains two to three orders of magnitude greater concentrations of TC and EC than the dairy one. Municipal wastewater is characterized by a greater microbiological diversity, including containing a large number of pathogens (e.g. *Salmonella*, *Clostridium*). Therefore, they pose a greater threat to public health. Dairy wastewater mainly contains microorganisms associated with milk processing (e.g. *Lactobacilli*, *Streptococcus*, yeasts and molds) (Shah and Patel, 2013; Ungureanu et al., 2018). Table 3 shows the treatment efficiencies and removal factors obtained in the experiment.

Relative effect of treatment is presented also in Figure 4 and Figure 5. Treatment efficiencies are very similar for BOD_5, COD, and TP. Slightly higher results were achieved for dairy wastewater due to the higher amount of readily biodegradable organics. Studies indicate that these systems can achieve organic compound reductions of 60–90% (Dabrowski et al., 2019; Stefanakis et al., 2014) and TP of about 50% (Dabrowski et al., 2021). TN and TB removal efficiencies show greater differences, but still the median efficiency obtained on municipal sewage falls within the range of the dairy one. A study of brewery wastewater treatment showed 54.6% TN reduction (Dabrowski et al., 2021). Ammonia nitrogen removal is clearly different for both sewage sources. High efficiency of ammonia nitrogen removal is possible due to nitrification processes, supported by oxygen

Table 2. Input parameters of municipal and dairy sewage used in the experiment. BOD_5, COD, $N\text{-}NH_4$, TN and TP in mg l^{-1}, TC and number of EC-CFUs in 100 ml^{-1}

Influent parameters and units	Dairy	Municipal
C_{inf,BOD_5}	6.3 ± 2.0 (6.5 ± 3.0)	4.25 ± 0.87 (4.00 ± 0.74)
$C_{inf,COD}$	40.7 ± 7.7 (41.0 ± 9.6)	38.1 ± 5.2 (40.0 ± 3.0)
$C_{inf,N-NH_4}$	6.3 ± 2.3 (6.0 ± 2.8)	1.58 ± 0.45 (1.50 ± 0.67)
$C_{inf,TN}$	9.2 ± 3.5 (7.7 ± 2.3)	9.26 ± 0.61 (9.40 ± 0.59)
$C_{inf,TP}$	1.03 ± 0.29 (1.00 ± 0.22)	0.308 ± 0.076 (0.300 ± 0.111)
$C_{inf,TC}$	$3\,230 \pm 960$ $(3\,220 \pm 990)$	$113\,000 \pm 10\,000$ $(111\,000 \pm 12\,000)$
$C_{inf,EC}$	39 ± 12 (39 ± 11)	$25\,800 \pm 8\,100$ $(27\,100 \pm 7\,600)$

Table 3. Treatment efficiencies and removal factors obtained on sewage used in the experiment

Treatment efficiency/Removal factor	Dairy	Municipal
η_{BOD_5}	0.634 ± 0.096 (0.646 ± 0.134)	0.61 ± 0.13 (0.60 ± 0.15)
η_{COD}	0.729 ± 0.039 (0.735 ± 0.031)	0.693 ± 0.069 (0.733 ± 0.034)
η_{N-NH_4}	0.959 ± 0.013 (0.955 ± 0.016)	0.830 ± 0.079 (0.834 ± 0.104)
η_{TN}	0.37 ± 0.13 (0.35 ± 0.13)	0.314 ± 0.067 (0.310 ± 0.099)
η_{TP}	0.32 ± 0.18 (0.26 ± 0.12)	0.318 ± 0.122 (0.292 ± 0.099)
η_{TB}	0.866 ± 0.048 (0.871 ± 0.039)	0.832 ± 0.060 (0.839 ± 0.066)
f_{TC}	2.42 ± 0.32 (2.51 ± 0.22)	3.70 ± 0.16 (3.74 ± 0.11)
f_{EC}	1.54 ± 0.53 (1.58 ± 0.34)	3.55 ± 0.24 (3.57 ± 0.25)

access and appropriate environmental conditions (Tan et al., 2017).

Besides TP, removal efficiency is generally higher for dairy sewage. Removal factors obtained on sewage from both sources differ significantly. Treatment of municipal wastewater with VF-CW yields favorable results in the removal of microbial contaminants. There are many other studies confirming the effectiveness of SS-VF CWs in reducing pollutants in both dairy (Minakshi et al., 2021; Yazdani et al., 2023) and municipal wastewater (Abou-Elela et al. 2013). In a study conducted by Garcia-Avila (2020), the removal efficiency of TC and fecal coliforms (FC) was 96.02 and 93.74% respectively. A study in Oman showed that the VF-CW system achieved an average removal efficiency of up to 99.9% for TC and 99.8% for FC (Kamal, 2023). Table 4 presents removed loads, measured in $g \cdot m^{-2} d^{-1}$. This is a universal indicator used to evaluate the effectiveness of CW (Mæhlum and Stålnacke, 1999; Obarska-Pempkowiak et al., 2015).

Similar results were achieved for the removal of organic compound loads measured by BOD_5 and COD values. A slightly better effect was observed for dairy wastewater. The removed pollutant loads were significantly lower than in the case of municipal wastewater treatment despite the use of high hydraulic loading (Kadlec and Wallace, 2008). This was due to the fact that the experiment used treated dairy and municipal wastewater characterized by low concentrations of BOD_5

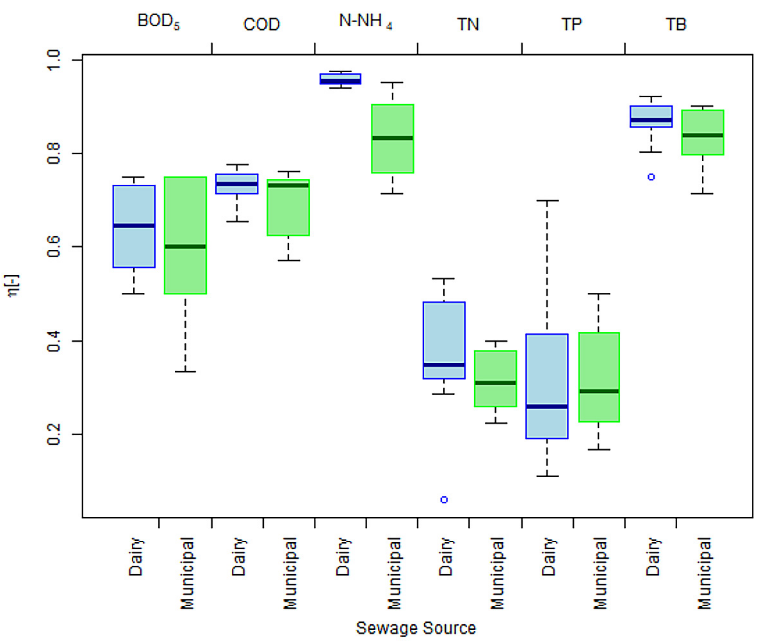

Figure 4. Treatment efficiencies obtained during the process

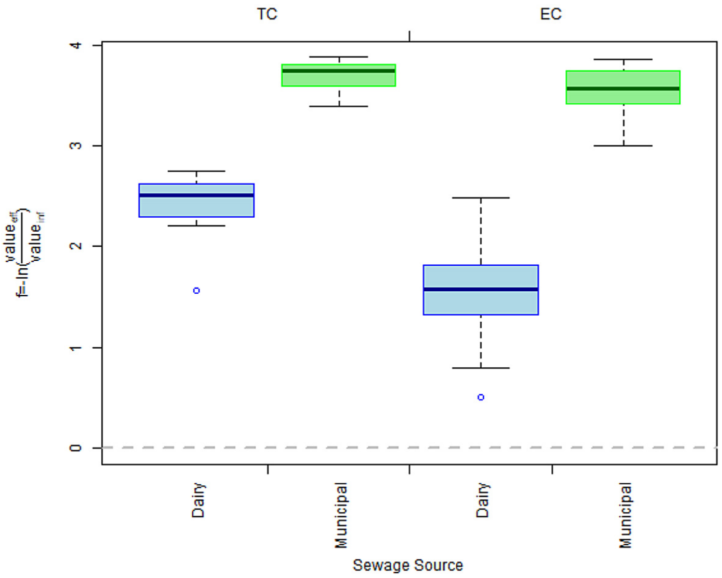

Figure 5. Removal factors obtained during the process

Table 4. Loads removed during the experiment

Load removed	Dairy	Municipal
L_{rem,BOD_5}	1.57 ± 0.40 (1.60 ± 0.59)	1.03 ± 0.27 (1.20 ± 0.00)
$L_{rem,COD}$	11.9 ± 2.4 (12.4 ± 2.4)	10.6 ± 1.8 (10.8 ± 1.8)
$L_{rem,N-NH_4}$	2.40 ± 0.89 (2.32 ± 1.13)	0.53 ± 0.19 (0.46 ± 0.21)
$L_{rem,TN}$	1.33 ± 0.57 (1.34 ± 0.65)	1.18 ± 0.31 (1.14 ± 0.47)
$L_{rem,TP}$	0.127 ± 0.070 (0.100 ± 0.030)	0.038 ± 0.016 (0.040 ± 0.000)

and COD. The same was true for ammonium and total nitrogen. The results achieved were much lower than, for example, in the case of treatment of domestic wastewater or from septic tanks (Karolinczak and Dabrowski, 2017). The difference in ammonia nitrogen removed loads is related to both treatment efficiencies and input concentrations. Nitrification and denitrification processes are crucial in filtration layers to enable efficient conversion of ammonia to nitrate. In contrast, to remove TN, anaerobic zones or hybrid systems are needed to reduce nitrates to gaseous nitrogen (Vymazal, 2013). The slightly better phosphorus removal results from dairy wastewater were due, as with the other indicators, to the higher concentrations observed in the experiment.

CONCLUSIONS

The CW systems used in the experiment were designed to clean the wastewater discharged from the treatment plants (municipal and dairy) for reuse-recovery of water.

During the experiment, a much higher hydraulic load, than for domestic wastewater treatment, was applied. A high organic matter and nitrogen removal effect was achieved. It was slightly higher for dairy wastewater, which had a higher pollutant concentrations, compared to municipal wastewater. The pollutant removal effect, measured as the BOD_5 load removed by unit area of the bed, was higher for dairy wastewater (1.57 g · m^{-2} d^{-1}), than for municipal wastewater (1.032 g · m^{-2} d^{-1}). For ammonium nitrogen it was 2.40 and 0.53 g · m^{-2} d^{-1} , and for phosphorus it was 0.127 and 0.038 g · m^{-2} d^{-1} , respectively.

The biggest difference between the input parameters of municipal and dairy wastewater was observed in the microbiological parameters. Higher TC and EC removal rates/factors were obtained for the municipal wastewater. Dairy wastewater after the treatment process in industrial

WWTPs is characterized by significantly lower microbiological parameters compared to the tested municipal wastewater. The TC parameter in the dairy wastewater used in the VF-CW bed treatment experiment averaged 3230, while for municipal wastewater it was 113,000 and the EC was 39 and 25800, which clearly predisposes dairy wastewater for reuse.

CW systems are a promising technology for recovering water from wastewater, playing an important role in realizing the goals of a closed-loop economy. With their efficiency, low cost and labor, they can contribute to reducing water shortages in an environmentally friendly way.

Acknowledgments

The work was carried out as part of a team project no. WZ/WB-IIŚ/5/2020 and financed by the Polish Ministry of Science and Higher Education.

The authors would like to thank Bialystok Waterworks Ltd. and Mlekovita company for their cooperation and assistance in carrying out the research.

REFERENCES

1. Abou-Elela, S., Golinielli, G., Aboutaleb, E., and Hellal, M. (2013). Municipal wastewater treatment in horizontal and vertical flows constructed wetlands. *Ecological Engineering, 61*, 460–468. https://doi.org/10.1016/j.ecoleng.2013.10.010
2. Almuktar, S. A., Abed, S. N., and Scholz, M. (2018). Wetlands for wastewater treatment and subsequent recycling of treated effluent: a review. *Environmental Science and Pollution Research, 25*, 23595–23623. https://doi.org/10.1007/s11356-018-2629-3
3. American Public Health Association (APHA). (2005). *Standard Methods for Examination of Water and Wastewater* (Version 21st edition), Washington, DC.
4. Aziz, S. Q., and Ali, S. M. (2017). Characterization of municipal and dairy wastewaters with 30 quality parameters and potential wastewater treatment by biological trickling filters. *International Journal of Green Energy, 14*(13), 1156–1162. https://doi.org/10.1080/15435075.2017.1370594
5. Bixio, D., Thoeye, C., Koning, J., Joksimovic, D., Savic, D., Wintgens, T., and Melin, T. (2006). Wastewater reuse in Europe. *Desalination, 187*, 89–101. https://doi.org/10.1016/j.desal.2005.04.070
6. Brix, H., and Arias, C. A. (2005). The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines. *Ecological Engineering, 25*(5), 491–500. https://doi.org/10.1016/j.ecoleng.2005.07.009
7. Chambers, J. M., Cleveland, W. S., Kleiner, B. and Tukey, P. A. (1983). *Graphical Methods for Data Analysis.* Wadsworth & Brooks/Cole.
8. Clark, W. (2023). *Gilbert-based brewery to use recycled wastewater in its beer.* Retrieved 8 February 2025, from https://www.azfamily.com/2023/05/10/gilbert-based-brewery-use-recycled-wastewater-its-beer/
9. CRAN R; R Core Team (2024). A language and environment for statistical computing. *R Foundation for Statistical Computing*, Vienna, Austria. https://www.R-project.org/
10. Czerwionka, K., Kołecka, K., Kasprzyk, M., Fitobór, K., Wilińska-Lisowska, A., and Gajewska, M. (2025). Circular economy in Poland: Good practices and recommendations – case study. *Journal of Ecological Engineering, 26*, 166–176. https://doi.org/10.12911/22998993/199698
11. Dąbrowski, W., Karolinczak, B., Malinowski, P., and Boruszko, D. (2019). Modeling of pollutants removal in subsurface vertical flow and horizontal flow constructed wetlands. *Water, 11*(1),. https://doi.org/10.3390/w11010180
12. Dąbrowski, W., Karolinczak, B., Malinowski, P., and Magrel, L. (2021). Treatment of craft brewery sewage with SS VF and FWS constructed wetland – Lab scale experiment. *Rocznik Ochrona Środowiska, 23*, 290–300. https://doi.org/10.54740/ros.2021.019
13. EU 2020/741; *The European Parliament and the Council Regulation EU 2020/741, Minimum Requirements for Water Reuse*. European Commission: Brussels, Belgium, 2020.
14. Florides, F., Giannakoudi, M., Ioannou, G., Lazaridou, D., Lamprinidou, E., Loukoutos, N., Spyridou, M., Tosounidis, E., Xanthopoulou, M., and Katsoyiannis, I. A. (2024). Water reuse: A comprehensive review. *Environments, 11*(4), 81. https://doi.org/10.3390/environments11040081
15. García-Ávila, F. (2020). Treatment of municipal wastewater by vertical subsurface flow constructed wetland: Data collection on removal efficiency using Phragmites Australis and Cyperus Papyrus. *Data in Brief*. https://doi.org/10.1016/j.dib.2020.105584
16. Hdidou, M., Necibi, M. C., Labille, J., El Hajjaji, S., Dhiba, D., Chehbouni, A., and Roche, N. (2022). Potential use of constructed wetland systems for rural sanitation and wastewater reuse in agriculture in the Moroccan Context. *Energies, 15*(1), Article 1. https://doi.org/10.3390/en15010156
17. Helmecke, M., Fries, E., and Schulte, C. (2020). Regulating water reuse for agricultural irrigation: Risks related to organic micro-contaminants. *Environmental Sciences Europe, 32*(1), 4. https://doi.

org/10.1186/s12302-019-0283-0

18. Kadlec, R. H., Wallace, S. D. (2008). *Treatment Wetlands*, 2nd ed.; CRC Press: Boca Raton, FL, USA. https://doi.org/10.1201/9781420012514
19. Kamal M. A. (2023). Performance evaluation of subsurface vertical flow constructed wetlands to treat and reuse institutional wastewater in arid regions (KSA). *Journal of Environmental Engineering and Its Scope, 6*(3). https://doi.org/10.5281/ZENODO.10052416
20. Karolinczak, B. and Dąbrowski, W. (2017). Effectiveness of septage pre-treatment in vertical flow constructed wetlands. *Water Sci. Technol, 76*(9), 2544–2553. https://doi.org/10.2166/wst.2017.398
21. Kehrein, P., Jafari, M., Slagt, M., Cornelissen, E., Osseweijer, P., Posada, J., and Loosdrecht, M. (2021). A techno-economic analysis of membrane-based advanced treatment processes for the reuse of municipal wastewater. *Journal of Water Reuse and Desalination, 11*. https://doi.org/10.2166/wrd.2021.016
22. Koseoglu-Imer, D. Y., Oral, H. V., Coutinho Calheiros, C. S., Krzeminski, P., Güçlü, S., Pereira, S. A., Surmacz-Górska, J., Plaza, E., Samaras, P., Binder, P. M., van Hullebusch, E. D., and Devolli, A. (2023). Current challenges and future perspectives for the full circular economy of water in European countries. *Journal of Environmental Management, 345*, 118627. https://doi.org/10.1016/j.jenvman.2023.118627
23. Lavrnić, S., Nan, X., Blasioli, S., Braschi, I., Anconelli, S., and Toscano, A. (2020). Performance of a full scale constructed wetland as ecological practice for agricultural drainage water treatment in Northern Italy. *Ecological Engineering, 154*, 105927. https://doi.org/10.1016/j.ecoleng.2020.105927
24. Mæhlum, T., and Stålnacke, P. (1999). Removal efficiency of three cold-climate constructed wetlands treating domestic wastewater: Effects of temperature, seasons, loading rates and input concentrations. *Water Science and Technology, 40*(3), 273–281. https://doi.org/10.1016/S0273-1223(99)00441-2
25. Minakshi, D., Sharma, P., and Rani, A. (2021). Effect of filter media and hydraulic retention time on the performance of vertical constructed wetland system treating dairy farm wastewater. *Environmental Engineering Research, 27*. https://doi.org/10.4491/eer.2020.436
26. Mishra, S., Kumar, R., and Kumar, M. (2023). Use of treated sewage or wastewater as an irrigation water for agricultural purposes- Environmental, health, and economic impacts. *Total Environment Research Themes, 6*, 100051. https://doi.org/10.1016/j.totert.2023.100051
27. Nan, X., Lavrnić, S., and Toscano, A. (2020). Potential of constructed wetland treatment systems for agricultural wastewater reuse under the EU framework. *Journal of Environmental Management, 275*, 111219. https://doi.org/10.1016/j.jenvman.2020.111219
28. Obarska-Pempkowiak, H., Gajewska, M., Wojciechowska, E., and Kołecka, K. (2015). Sewage gardens – constructed wetlands for single family households. *Environment Protection Engineering, 41*(4). https://doi.org/10.37190/epe150406
29. PN-EN ISO 9308-2:2014-06 (Version Oznaczanie ilościowe Escherichia coli i bakterii grupy coli. Metoda najbardziej prawdopodobnej liczby).
30. Ramm, K., and Smol, M. (2023). Water reuse-analysis of the possibility of using reclaimed water depending on the quality class in the European Countries. *Sustainability, 15*, 12781. https://doi.org/10.3390/su151712781
31. Reder, P., Kruszelnicka, I., and Ginter-Kramarczyk, D. (2018). Oczyszczanie ścieków w zakładach mleczarskich. *Przemysł Spożywczy, T. 72*(10). https://doi.org/10.15199/65.2018.10.5
32. Regulation of the Minister of Maritime and Inland Waterway Economy from 12th July 2019 on substances that are particularly harmful to the aquatic environment and the conditions to be met for the introduction of sewage into water or soil and for the discharge of rainwater or snowmelt into water or into water facilities. Journal of Laws 2019 item 1311 (in Polish).
33. Roccaro, P. (2018). Treatment processes for municipal wastewater reclamation: The challenges of emerging contaminants and direct potable reuse. *Current Opinion in Environmental Science & Health, 2*. https://doi.org/10.1016/j.coesh.2018.02.003
34. Saurí, D., and Arahuetes, A. (2019). Water reuse: A review of recent international contributions and an agenda for future research. *Documents d'Anàlisi Geogràfica, 65*, 399. https://doi.org/10.5565/rev/dag.534
35. Shah, N., and Patel, A. (2013). Lactic acid bacteria in the treatment of dairy waste and formation of by-products-a promising approach. *Indian Food Industry Mag., 32*, 45–49.
36. Shakir, E., Zahraw, Z., and Al-Obaidy, A. H. M. J. (2017). Environmental and health risks associated with reuse of wastewater for irrigation. *Egyptian Journal of Petroleum, 26*(1), 95–102. https://doi.org/10.1016/j.ejpe.2016.01.003
37. Slavov, A. (2017). Dairy wastewaters – General characteristics and treatment possibilities – A review. *Food Technology and Biotechnology, 55*. https://doi.org/10.17113/ftb.55.01.17.4520
38. Smith, H. M., Brouwer, S., Jeffrey, P., and Frijns, J. (2018). Public responses to water reuse—Understanding the evidence. *Journal of Environmental Management, 207*, 43–50. https://doi.org/10.1016/j.jenvman.2017.11.021

39. Stefanakis, Alexandros I., Akratos, Christos S., and Tsihrintzis, Vassilios. A. (2014). Vertical Flow Constructed Wetlands: Eco-engineering Systems for Wastewater and Sludge Treatment. *Newnes*.
40. Struk-Sokolowska, J. (2018). Variability of dairy wastewater characteristics in Piatnica – one of the largest and most advanced milk processing plants in Poland. *E3S Web of Conferences, 44*, 00169. https://doi.org/10.1051/e3sconf/20184400169
41. Tan, Y., Tang, F., Ho, C., and Jong, V. (2017). Dewatering and treatment of septage using vertical flow constructed wetlands. *Technologies, 5*(4), 70. https://doi.org/10.3390/technologies5040070
42. Tzanakakis, V. A., Capodaglio, A. G., and Angelakis, A. N. (2023). Insights into global water reuse opportunities. *Sustainability, 15*(17), Article 17. https://doi.org/10.3390/su151713007
43. Ungureanu, N., Vladut, V., and Voicu, G. (2020). Water Scarcity and wastewater reuse in crop irrigation. *Sustainability, 12*, 9055. https://doi.org/10.3390/su12219055
44. Ungureanu, N., Vlăduţ, V., Ferdeş, M., Dincă, M., Zăbavă, B. Ş., and Voicea, I. (2018). *Microbiological analysis of raw wastewater from a dairy farm.*
45. Voulvoulis, N. (2018). Water reuse from a circular economy perspective and potential risks from an unregulated approach. *Current Opinion in Environmental Science & Health, 2*, 32–45. https://doi.org/10.1016/j.coesh.2018.01.005
46. Vymazal, J. (2013). The use of hybrid constructed wetlands for wastewater treatment with special attention to nitrogen removal: A review of a recent development. *Water Research, 47*(14), 4795–4811. https://doi.org/10.1016/j.watres.2013.05.029
47. WHO. (2006). *Guidelines for the safe use of wastewater, excreta and greywater.* World Health Organization, Geneva
48. Yazdani, V., Golestani, H., and Golestani, H. (2023). Advanced treatment of dairy industrial wastewater using vertical flow constructed wetlands. *Desalination and Water Treatment, 162*, 149–155. https://doi.org/10.5004/dwt.2019.24335