MIDDLE POMERANIAN SCIENTIFIC SOCIETY OF THE ENVIRONMENT PROTECTION
ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE OCHRONY ŚRODOWISKA

Annual Set The Environment Protection
Rocznik Ochrona Środowiska

Volume/Tom 19. Year/Rok 2017 ISSN 1506-218X 370-393

Analysis of the Influence of a Hybrid Constructed Wetland Wastewater Treatment Plant on the Water Quality of the Receiver

Magdalena Gizińska-Górna, Krzysztof Jóźwiakowski,
Michał Marzec, Aneta Pytka, Bożena Sosnowska,
Monika Różańska-Boczula, Agnieszka Listosz
University of Life Sciences, Lublin

1. Introduction

The continuous development of civilization leads to the growth of human impact on aquatic environments. The concentrations of contaminants washed every day into rivers, lakes and coastal waters constantly increase, which poses a huge threat to these receivers. In extreme cases, pollutants may kill all organic life forms in a body of water, depriving it of all its self-cleaning abilities (Owczarczyk 2001, Gajewska et al. 2013).

Surface water are still an important source of water for large settlements and industry. That is why high levels of pollution create not only technical problems connected with water purification for technological and food and beverage applications but also generate secondary threats associated with the growing possibility that drinking water, fish and water for industrial aims may contain many different contaminants (Owczarczyk 2001).

The discharge of industrial and domestic wastewater into surface water seriously increases the level of their pollution (Andrulewicz 1997, Chen et al. 2004, Elhatip & Güllü 2005, Kowalkowski & Buszewski 2006). The constantly growing costs connected with wastewater treatment and water purification for consumption trigger more and more interest in studies concerning the interactions between sewage and receivers (Owczarczyk 2001).

Taking effective action in the field of water protection requires, besides the understanding of the wastewater treatment process, good transport and dilution of pollutants in natural water receivers. A body of running water can only be used as a receiver of treated wastewater when sewage outflow does not interfere with the biological functioning of the ecosystem. The choice of the receiver depends on its absorbency, i.e. the ability to take in a specific volume of effluents, and the load of pollutants. The load of pollutants should not restrict the process of water self-cleaning, because the receiver is involved in further steps of wastewater treatment (Juszkiewicz et al. 2006). The speed of mixing sewage with river water depends on the quantity of sewage, the volume of water and the speed of water flow, as well as the width and depth of the water-course (Rajda & Kanownik 2007).

Numerous studies indicate that effluents from municipal wastewater treatment plants have some impact on the quality of water in sewage river-receivers, but not always so negative as to change their ecological status (Mosiej et al. 2007, Frąk 2010, Królak et al, 2011, Lewandowska-Robak et al. 2011, Wira 2011, Wiatkowski 2012, Policht-Latawiec et al. 2014). In recent years, more and more constructed wetland wastewater treatment plants have been used worldwide, often in order to protect water quality (Kivaisi 2001, Zhang et al. 2009, Gizińska et al. 2012, Avila et al. 2013, Jóźwiakowski et al. 2014, Gizińska-Górna et al. 2016). It has been found that their use complies with the principles of sustainable development (Jóźwiakowski et al. 2015). To date, however, not many studies have been devoted to the impact of wetland wastewater treatment plants on the quality of water in the receiving bodies of water. The aim of this work was to determine the impact of treated wastewater discharged from a hybrid constructed wetland wastewater treatment plant on the quality of water in the receiver (the Urzędówka River).

2. Methods

2.2. Study site

The Urzędówka River is a right tributary of the Wyżnica River, which, in turn, is a first class tributary of the Vistula River, km 318 + 500. The source of the Urzędówka River lies near Wilkołaz Village in Kraśnik county, and the estuary of the Wyżnica River is located in

Dzierzkowice Village (Wojciechowski 1972). The valley of the Urzędówka River lies in the Urzędowskie Hills, in the western part of the Lublin Upland, in South-Eastern Poland. This is an area with an extremely low density of the river network. The basin and some dry forms of erosion cut deep into the loess cover, under which lies a chalk underlay of cracked rocks (Zielinski 2011). In the 1960s, the Urzędówka River was regulated, and the grassland in the valley was reclaimed by draining (Dobrzański & Turski 1972).

The Urzędówka is one of the cleanest rivers of the region, though in the report regarding the state of plain surface water bodies issued in 2014 by Provincial Inspectorate for Environmental Protection in Lublin, the condition of its waters was assessed as bad. In terms of the biological profile, the Urzędówka was assigned to class IV (poor status), and in terms of the hydromorphological and physico-chemical profiles to class II (good status). Overall, its ecological potential was defined as weak (Provincial Inspectorate for Environmental Protection 2015). The Urzędówka belongs to rivers with a low and relatively stable water flow across the year. States of water are not read here, which is why we used data from a water gauge in Bór Village 6+100 km of the Wyżnica River, where hydrological observations had been carried out since 1996 to determine the characteristics of flow. The average flow of water in the estuary of the Urzędówka River was estimated to be about 0.625m^3/s (Zielinski 2011).

The Urzędówka River is the receiver of treated wastewater outflowing from a hybrid constructed wetland wastewater treatment plant in Skorczyce. This plant is used for the treatment of domestic wastewater from a multi-family building and has an average throughput of 2.5 m^3/d. It consists of a concrete three-chamber initial septic tank with a pumping station (with a total volume of 8.64 m^3). The main part of this system is composed of two constructed wetland beds (Fig. 1). A first bed with Vertical Subsurface Flow (VSSF type) with an area of 96 m^2 and a depth of 0.8 m has been planted with giant miscanthus (*Miscanthus × giganteus* Greef et Deu.). A second bed with Horizontal Subsurface Flow (HSSF type) with an area of 80 m^2 and a depth of 1.2 m has been planted with Jerusalem artichoke (*Helianthus tuberosus* L.) (Jóźwiakowski et al. 2011, Gizińska-Górna et al. 2016). The place where treated wastewater is discharged into the river is located at 12 + 662 km (Fig. 1).

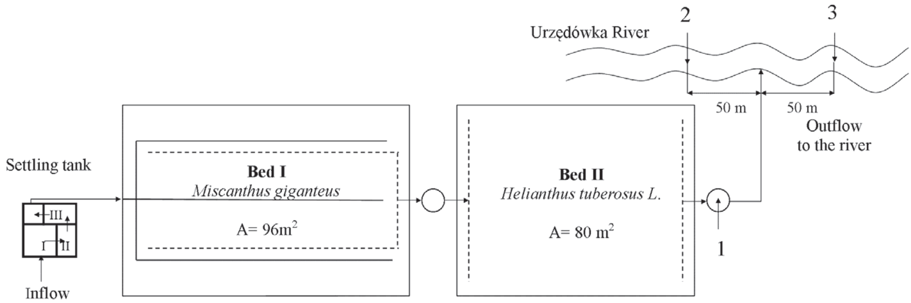

Fig. 1. Technological scheme of the hybrid constructed wetland wastewater treatment plant in Skorczyce (1, 2, 3 – sampling points of sewage to analysis) (Gizińska i in. 2012)
Rys. 1. Schemat technologiczny hybrydowej grutnowo-roślinnej oczyszczalni ścieków w Skorczycach (1, 2, 3 – punkty poboru prób do analiz)

Fot. 1. Urzędówka River – reciver of wastewater from the hybrid constructed wetland wastewater treatment plant in Skorczyce (fot. M. Gizińska)
Fot. 1. Rzeka Urzędówka – odbiornik ścieków oczyszczonych w Skorczycach (fot. M. Gizińska)

2.2. Experimental procedures

The influence of the hybrid constructed wetland wastewater treatment plant on the quality of water in the Urzędówka River was analyzed over a three-year period (2011-2013). The analyses of water and wastewater were carried out seasonally, at different times of the year: in winter (February), spring (May), summer (August), and autumn (October). Samples for analysis were taken at the outflow from the HF bed, which, together with the drain collector, is the last element of the wastewater treatment plant. Samples of water from the Urzędówka River were taken at two points: 50 m downstream and 50 m upstream of the place where treated wastewater was discharged (Fig. 1). Sampling was done in accordance with the guidelines set out in the Polish Standards (PN-74\/C-04620\/00; PN-EN 25667-2:1999). In each series of experiments, the following parameters of collected water and wastewater were determined: temperature, pH, electrolytic conductance, concentration of dissolved oxygen, total suspension, BOD_5, COD_{cr}, concentration of total nitrogen, total phosphorus, nitrate nitrogen, nitrite nitrogen, ammonium nitrogen, sulfates, and chlorides.

2.3. Analytical methods

The analysis and the physico-chemical measurements of water and wastewater were according to the table of reference methods for the analysis of wastewater samples (Dz. U. 2009, nr 27, poz. 169 [Polish Journal of Laws 2009, no. 27, item 169]) and according to the reference methods for the analysis of samples of water (Dz. U. 2011, nr 257, poz. 1550). The quality of water in the Urzędówka River was compared with the requirements set out in the regulation of the Minister of the Environment of 9 November 2011 establishing the way of classifying the state of uniform parts of surface water and environmental quality standards for priority substances (Dz. U. 2011, nr 257, poz. 1550).

In 2013, four additional series of microbiological tests of water and wastewater were performed. The samples for the microbiological assays were taken in February, May, August, and November, in accordance with PN-74/C-04620/00 and PN-EN 25667-2:1999. Bacterial counts were performed for E. coli, fecal coliform bacteria, and fecal enterococci in accordance with the current standards (PN-C-04615-05:1975P; PN-C-04615-07:1977P; PN-C-04615-25:2008P). The results of the microbiological tests were compared to the requirements set out in the regulation of the Minister of the Environment of 11 February 2004 on the classification for presenting the status of surface water and groundwater and forms and methods of monitoring and interpreting the results and presenting the status of these waters (Dz. U. 2004 nr 32, poz. 284).

On the basis of test results, characteristic values (minimum, maximum, mean and standard deviation) of the analyzed pollution indicators were determined, and a statistical analysis was carried out. The effect of the constructed wetland wastewater treatment plant on the quality of water was studied using a Shapiro-Wilk test followed by the nonparametric Wilcoxon matched-pairs signed-rank test. A dendrogram was constructed based on Euclidean distances using Ward's method, and k-means grouping was performed.

3. Results and discussion

In accordance with the regulation of the Minister of the Environment of 9 November 2011 (Dz. U. 2011, nr 258, poz. 1550), assignment of water to an appropriate class and its usefulness depend, among others, on biological and hydromorphological indicators, physico-chemical indicators, in particular salinity, acidification and nutrient conditions, and oxygen indicators. Monitoring of river waters carried out in the Lublin province in the year 2014 by the Provincial Inspectorate for Environmental Protection in Lublin, showed that the state of water in the Urzędówka River was poor. The river faced the threat of eutrophication of municipal origin and the ecological status of the river was identified as weak (Provincial Inspectorate for Environmental Protection 2015). It was supposed that one of the potential sources of these threats may be the constructed wetland wastewater treatment plant in Skorczyce.

The present study did not find any significant impact of the treated wastewater discharged from the hybrid constructed wetland wastewater treatment plant in Skorczyce on the quality of water in the Urzędówka River. This was an expected result, as the share of sewage flow in the total flow of the river was very small. The average flow of water (SSQ) at the measuring point Urzędówka – Skorczyce Bridge located at the outlet of the treated wastewater from the treatment plant, was about 0.457 m^3/s. The other characteristic flows, i.e. the medium low flow (SNQ) and the lowest flow (NNQ) were 0.242 m^3/s and 0.099 m^3/s, respectively (Structum SP. Z o.o. 2000; Zielinski, 2011). The designed wastewater treatment capacity was only 2.5 m^3/d, or about 0.00003 m^3/s, which represented 0.006% of the average flow of river water. In fact, due to the intensive transpiration from plants and beds, the volume of wastewater discharge from the treatment plant to the receiver was much smaller.

To investigate the effect of the Skorczyce treatment plant on the quality of water in the receiver, we used the nonparametric Wilcoxon matched-pairs signed-rank test, which made it possible to determine whether the examined indicators of surface water quality differed significantly at two measuring points located on the Urzędówka River: upstream and downstream of the point of discharge of treated wastewater. The Wilcoxon test was selected because most of the analyzed parameters did not have a normal distribution, as determined by the Shapiro-Wilk test (Lewandowska-Robak et al. 2011). The results of the nonparametric test, which are shown in the table below, indicate that at the level of significance $\alpha = 0.05$, there was no significant difference between the investigated quality indicators of water collected upstream and downstream of the treatment plant outlet Table 1.

Table 1. The results of sequence pairs of Wilcoxon test (T) and p-value
Tabela 1. Wyniki sekwencyjnych par testu Wilcoxona (T) i wartości p

Parameters	T	Level p-value
Temperature	12.000	0.401
pH	24.000	0.721
Conductivity	15.000	0.374
Dissolved oxygen	24.000	0.721
TSS	22.000	0.575
BOD_5	20.000	0.767
COD	7.500	0.141
Ammonium	26.500	0.918
Nitrate	26.000	0.878
Nitrite	18.500	0.635
Total nitrogen	20.500	0.475
Total phosphorus	12.000	0.401
Chlorides	12.500	0.236
Sulphates	6.000	0.051

Further analysis was conducted using averaged values of the investigated indicators for three types of sample, (1) treated wastewater, (2) water collected from the river before the discharge of wastewater, and (3) water collected from the river after wastewater discharge. After standardization, the data were processed/analyzed using Ward's method, and a dendrogram was obtained on the basis of Euclidean distances (Fig. 2).

The dendrogram (Fig. 2) clearly shows two clusters. The first type of sample formed a distinct aggregation (cluster). The grouping performed by k-means (k = 2 clusters) demonstrated why this was the case.

A table 2 shows that the greatest impact on the separation of the first type of sample from the other two was exerted by a statistically significant influence (p value < 0.05) for the following indicators: oxygen, BOD5, nitrate nitrogen, nitrite nitrogen and total phosphorus.

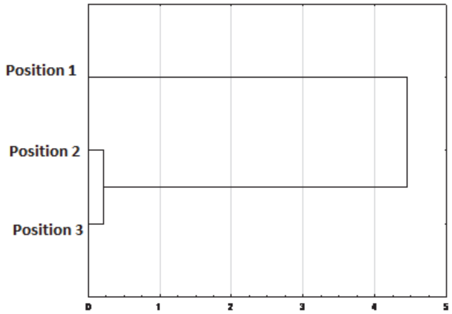

Fig. 2. Dendrogram
Rys. 2. Dendogram

Table 2. Analysis of variance (SS between – variability between clusters, df – degrees of freedom, SS variability within clusters, F – Fishera_Snedecora test)
Tabela 2. Analiza wariancji (SS pomiędzy - zmienność między klastrami, df - stopnie swobody, zmienność SS w obrębie klastrów, próba F – test Fishera_Snedecora)

Variable	SS between	df	SS within	df	F	P value
Temperature	1.237026	1	0.019795	1	62.49	0.080106
pH	0.096779	1	0.004135	1	23.41	0.129761
Dissolved oxygen	0.515685	1	0.000242	1	2128.54	0.013797
TSS	0.001840	1	0.000048	1	38.61	0.101582
BOD_5	0.000162	1	0.000000	1	18990.83	0.004620
CODcr	0.000600	1	0.000004	1	156.48	0.050784
$N\text{-}NO_2$	2.823230	1	0.000134	1	21095.28	0.004383
NO_3	1.983734	1	0.000819	1	2421.08	0.012936
N_{tot}	0.174237	1	0.000047	1	3731.85	0.010420

Both the temperature range and the average temperature of treated wastewater were very close to those of the water in the river (Table 3). Purification carried out in a ground-surface environment contributed to the cooling of treated wastewater, which was ultimately cooled down to ambient temperature when it passed through the 94 meter long outlet collector connecting the treatment plant with the receiver.

Together with the treated wastewater, about 17.4 mg/L of total suspended solids was drained to the Urzędówka River (Table 3). In the river, upstream of the discharge point, the average content of total suspended solids was 6.78 mg/L and downstream of this place we noted a slight increase in the concentration of total suspended solids to the average level of 8.58 mg/L (Table 3, Figure 3). In the case of mechanical pollutants, such as, it is difficult to talk about the impact of the hybrid constructed wetland wastewater treatment plant, because the result of the measurement may be reliant on a number of factors, e.g connected with the kinetics of water flow in the river or local eddies.

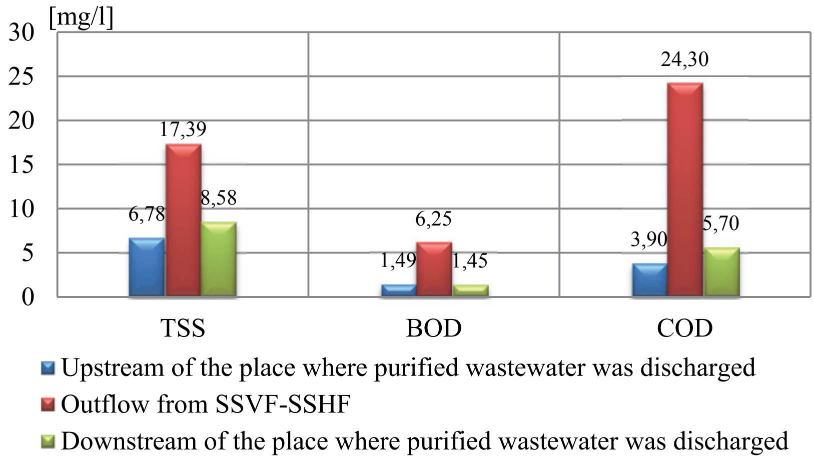

Fig. 3. Average values of pollutants in sewage discharged from the hybrid constructed wetland wastewater treatment plant and in water from Urzędówka River
Rys. 3. Średnie wartości zanieczyszczeń w ściekach odprowadzanych z hybrydowej gruntowo-roślinnej oczyszczalni ścieków komunalnych oraz w wodzie z rzeki Urzędówki

The average concentration of oxygen dissolved in treated wastewater was just over 6 mg $O_2 \cdot dm^{-3}$. The placement of the wastewater outlet high above the water surface of the receiver (Fig. 1) allowed additional oxygenation of sewage before it was mixed with river water. In the river, upstream and downstream of the discharge point, the ranges of oxygen concentration were similar at 8.98-12.80 mg O_2/L and 8.80-

12.24 mg O_2/L, respectively. The average oxygen contents at the measuring points differed only slightly (10.06 and 10.16 mg O_2/L, respectively) (Table 3) and were higher than the requirements for class I water purity (Dz. U. 2011, nr 258, poz. 1550).

The average value of BOD_5 in river water was constant over the distance between measuring points at about 1.5mg O_2/L. The concentration of BOD_5 in river water in all measuring series did not exceed the normative value specified for class I water purity (Dz. U. 2011, nr 258, poz. 1550). Treated wastewater, despite a clearly higher content of organic compounds (6.25 mg O_2/L) did not have a negative impact on the quality of water in the Urzędówka River (Table 3, Figure 3). This was due to the small participation of sewage in the total flow of the river and self-cleaning processes taking place in the surface water, especially the dilution of pollutants by the water from the receiver.

In the case of COD_{cr}, slightly larger fluctuations were observed. Upstream of the treated sewage outfall, the value of COD_{cr} was about 3.9 mg O_2/L, while downstream of this place, it was 5.7mg O_2/L (Table 3, Figure 3). Taking into consideration the fact that the average value of COD_{cr} in wastewater was 24.3 mg O_2/L, it can be stated that sewage may have had a small impact on the water in the receiver. Despite the fact that the quality of water in the Urzędówka River slightly deteriorated in terms of the concentration of organic pollutants (a 46% increase in COD_{cr}), the classification of the analyzed waters (class I) was not affected.

Indicators characterizing the salinity of water, i.e. conductivity, sulfates and chlorides, were not assayed in the treated sewage from the constructed wetland wastewater treatment plant; however, the regulation of the Minister of the Environment (Dz. U. 2011, nr 258, poz. 1550) makes it compulsory to analyze these indicators in surface water. In the investigated case, there was a slight increase in electrolytic conductivity and chlorides downstream of the outlet of the collector of the wastewater treatment plant. A study by Lewandowska-Robak et al. (2011) carried out in Kicz Creek in Tuchola shows that the changes in the concentration of chlorides may be a result of discharge of wastewater from treatment plants. The concentration of sulfates after wastewater disposal was slightly reduced. Average values of all three indicators upstream and downstream of the sewage discharge point were low compared to the values specified for high ecological status waters (class I) (Table 3).

Table 3. Selected physical and chemical indicators of purified sewage and water from Urzędówka River before and after the discharge of sewage from the hybrid constructed wetland wastewater treatment plant
Tabela 3. Skład fizyczno-chemiczny ścieków oczyszczonych oraz wód z rzeki Urzędówki przed i po dopływie ścieków z hybrydowej gruntowo-roślinnej oczyszczalni ścieków

Indicators	Purified sewage				Water from the river before discharge sewage				Water from the river after discharge sewage				The limit values*				
	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	I	II	III	IV	V
The indicators characterizing the physical condition, including thermal conditions																	
Temperature [°C]	10.60	20.80	**15.87**	**3.67**	10.70	20.40	**15.04**	**2.90**	9.60	20.70	**14.91**	**3.09**	≤22	≤24	Limits not determined		
TSS [mg·dm^{-3}]	2.04	65.10	**17.39**	**22.36**	1.20	14.20	**6.78**	**4.13**	0.70	25.00	**8.58**	**7.31**	≤25	≤50			
Indicators characterizing aerobic conditions (conditions oxygenation) and organic pollutants																	
Diss. oxygen [mg O_2·dm^{-3}]	1.27	11.42	**6.16**	**3.22**	8.98	12.80	**10.06**	**1.36**	8.81	12.24	**10.16**	**1.25**	≥7	≥5	Limits not determined		
BOD_5 [mg O_2·dm^{-3}]	0.78	36.90	**6.25**	**10.82**	0.41	2.40	**1.49**	**0.54**	0.17	2.40	**1.45**	**0.61**	≤3	≤6			
CODcr [mg O_2·dm^{-3}]	8.00	43.00	**24.30**	**11.71**	1.00	8.00	**3.90**	**2.51**	1.00	11.00	**5.70**	**4.00**	≤25	≤30			
Indicators characterizing the salinity																	
Conductivity [µS·cm^{-3}]	–	–	–	–	422.00	509.00	**469.06**	**30.74**	412.00	604.00	**491.62**	**58.92**	≤ 1000	≤ 1500	Limits not determined		
SO_4 [mg·dm^{-3}]	–	–	–	–	24.00	98.00	**60.20**	**19.62**	17.00	81	**53.30**	**18.90**	≤150	≤250			
Cl [mg·dm^{-3}]	–	–	–	–	1.90	23.1	**14.68**	**5.24**	1.50	48.40	**19.12**	**11.86**	≤200	≤300			
The indicators characterizing the acidification (as acidification)																	
pH	6.97	8.22	**–**	**0.42**	7.39	8.10	**–**	**0.24**	7.10	8.13	**–**	**0.29**	6-8.5	6-9	Limits not determined		

Table 3. cont.
Tabela 3. cd.

Indicators	Purified sewage				Water from the river before discharge sewage				Water from the river after discharge sewage				The limit values*				
	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	I	II	III	IV	V
The indicators characterizing the nutrient conditions (nutrients)																	
N-NH_4 [mg·dm^{-3}]	0.10	41.50	**15.19**	**18.02**	0.07	0.35	**0.14**	**0.08**	0.06	0.44	**0.15**	**0.11**	≤0.78	≤1.56	Limits not determined		
N-NO_3 [mg·dm^{-3}]	10.78	58.20	**32.96**	**18.60**	1.17	7.55	**4.77**	**1.85**	1.76	7.21	**4.55**	**1.85**	≤2.2	≤5			
N_{tot} [mg·dm^{-3}]	10.00	150.00	**78.80**	**49.90**	1.50	2.40	**1.87**	**0.33**	0.50	2.70	**1.87**	**0.68**	≤5	≤10			
P_{tot} [mg·dm^{-3}]	1.30	11.00	**5.85**	**3.14**	0.13	6.10	**0.99**	**1.82**	0.13	6.32	**1.08**	**1.87**	≤0.2	≤0.4			
Indicators	Purified sewage				Water from the river before discharge sewage				Water from the river after discharge sewage				The limit values**				
	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	min	max	$\bar{x}$	σ	I	II	III	IV	V
Biogenic indicator																	
NO_2 [mg·dm^{-3}]	0.03	3.62	**0.93**	**1.31**	0.02	0.13	**0.05**	**0.03**	0.03	0.22	**0.07**	**0.06**	0.03	0.1	0.5	1.0	>1.0

*The limit values of indicators of water quality appropriate for the class by the Regulation of the Minister of the Environment [2011]
** The limit values of indicators of water quality appropriate for the class by the Regulation of the Minister of the Environment [2004]

Treated sewage had a slightly alkaline pH during the entire study period. At pH values in the range of 6.97-8.22, treated wastewater had an almost identical pH range to that of river water 7.10-8.13 (Table 3), hence it is difficult to speak of any impact of sewage pH on the wastewater – receiver system. In terms of pH, the waters of the Urzędówka River were assigned to class I (Dz. U. 2011, nr 258, poz. 1550).

The analyzed constructed wetland wastewater treatment plant did not have a total nitrogen limit due to the low throughput. Nevertheless, the average concentration of total nitrogen in wastewater discharged from the treatment plant (78.8 mg/L) was relatively high, far exceeding the maximum permissible value for small purification plants (PE < 2000). This, however, did not lead to an increase in the concentration of this component in the waters of the Urzędówka River. The average content of total nitrogen in river water at both measuring points was identical at 1.87 mg/L (Table 3, Figure 4). The analyzed section of the river (100 m) seems to be too short for metabolic processes leading to permanent removal of nitrogen compounds from the incoming sewage to take place. In this situation, the tendency observed can be explained by a lower-than-average wastewater inflow rate and complete lack of inflow in some periods. When it comes to the content of total nitrogen, the water from the Urzędówka River was assigned to water purity class I (Dz. U. 2011, nr 258, poz. 1550).

An analysis of the particular mineral nitrogen forms points to similar tendencies as in the case of total nitrogen and leads to the same conclusion. The average content of ammonium nitrogen was 15.19 mg/L in treated wastewater, 0.14 mg/L in river water upstream of the sewage discharge point, and 0.15 mg/L downstream of the discharge point (Table 3, Figure 4). The contents of $N\text{-}NH_4$ in the Urzędówka River during the research period were clearly lower than the limit value for the cleanest waters. Similar results were obtained by Królak et al. (2011), whose analysis of water quality of the watercourses Zielawa and Lutnia showed that wastewater treatment plants had little impact on the concentration of ammonium ions in sewage receivers.

The average concentration of nitrate nitrogen, which is an intermediate form of nitrogen transformation, may also be used as an indicator of water pollution, both at outlets of wastewater (Królak et al. 2011) and in water bodies contaminated with untreated sewage (Wiatkowski et al. 2012). The average concentration of NO_3^- in the water from the Urzędówka River collected upstream of the sewage discharge point was 4.77 mg/L. The content of this component in the effluent disposed into the river reached an average level of 32.96 mg/L and at the measuring point located downstream of the sewage outlet, the average content of NO_3^- was slightly reduced to 4.55 mg/L (Table 3, Figure 4). The average content of NO_3^- in river water at both measuring points qualified this water for inclusion in purity class II. It is worth noting that during the research period, the content of nitrate nitrogen in river water occasionally exceeded the limit value for water purity class II (Dz. U. 2011, nr 258, poz. 1550).

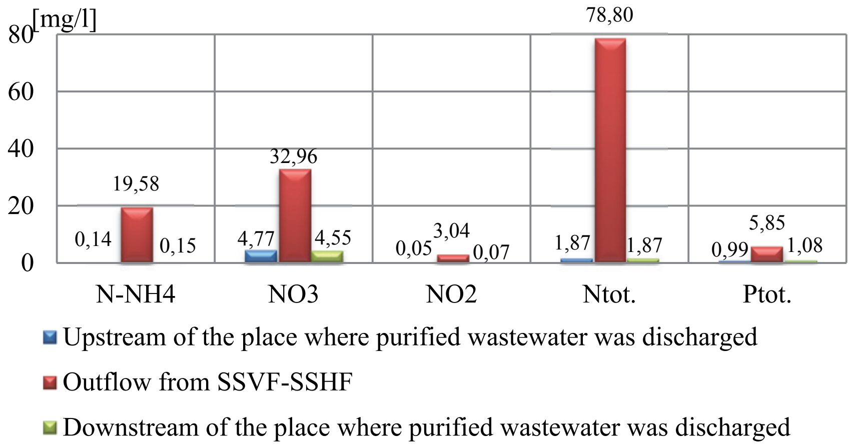

Fig. 4. Average values of nutrient compounds in sewage discharged from the hybrid constructed wetland wastewater treatment plant and in water from Urzędówka River
Rys. 4. Średnie wartości związków biogennych w ściekach odprowadzanych z hybrydowej gruntowo-roślinnej oczyszczalni ścieków komunalnych oraz w wodzie z rzeki Urzędówki

The average nitrite nitrogen content in the water collected from the river upstream of the sewage disposal point was 0.05 mg/L. Downstream of this point, there was a slight increase in the concentration of NO_2^- to 0.07 mg/L (Table 3, Figure 4). The average concentration of nitrite nitrogen in the effluent from the sewage treatment plant was

0.93 mg/L. The analyzed water could be assigned to water quality class II according to a 2004 classification of surface water (Dz. U. 2004, nr 32, poz. 284) – this parameter, however, is currently no longer used in the classification of surface water.

The average content of phosphorus in the effluent discharged from the constructed wetland wastewater treatment plant was 5.85 mg/L (range 1.3-11 mg/L) (Table 3). River water upstream of the sewage discharge point contained 0.13 to 6.10 mg/L of total phosphorus, with a mean of 0.99 mg/L. The content of this element in river water collected downstream of the discharge point was in a similar range from 0.13 to 6.32 mg/L, with a mean of 1.08 mg/L (Table 3). A comparison of the concentrations of total phosphorus (Table 3, Figure 4) for the two measuring points shows that after treated wastewater had been dropped into the river, the contents of that element in river water slightly increased, on average by 9%. The content of total phosphorus in the water from the river exceeded the standards established for water quality class II. As this situation applied to both measuring points (upstream and downstream of the place of discharge), it can be assumed that the increase was not a result of the impact of the treatment plant but of influx of phosphorus from other sources, such as agricultural land or farm buildings (Sapek & Sapek 2005).

From the data presented in Figures 5 and 6, it can be seen that water in the Urzędówka River upstream of the treatment plant already contained a certain concentration of coliform bacteria, fecal coliforms, and fecal enterococci.

The largest increases in the counts of coliform bacteria in the investigated section of the Urzędówka River were recorded in November (Table 4, Figure 5) – from $2.4 \cdot 10^3$ to $2.4 \cdot 10^4$ MPN (Maximum Possible Number) $\cdot 100$ cm^{-3}, and February – from $2.4 \cdot 10^2$ to $7 \cdot 10^2$ MPN$\cdot$100 cm^{-3}. Only in those cases, could it be concluded that the wastewater from the Skorczyce treatment plant had an impact on the counts of the tested microorganisms in the water of the Urzędówka River. In the remaining periods (May and August), the counts of bacteria at the two measuring points in the river were similar and equalled or exceeded those in the effluents from the treatment plant. These findings leads to the conclusion that the presence of coliform bacteria was the result of the impact of other sources of contamination located in the upper reaches of the river, of which the most likely were discharges of untreated domestic wastewater or organic fertilizers.

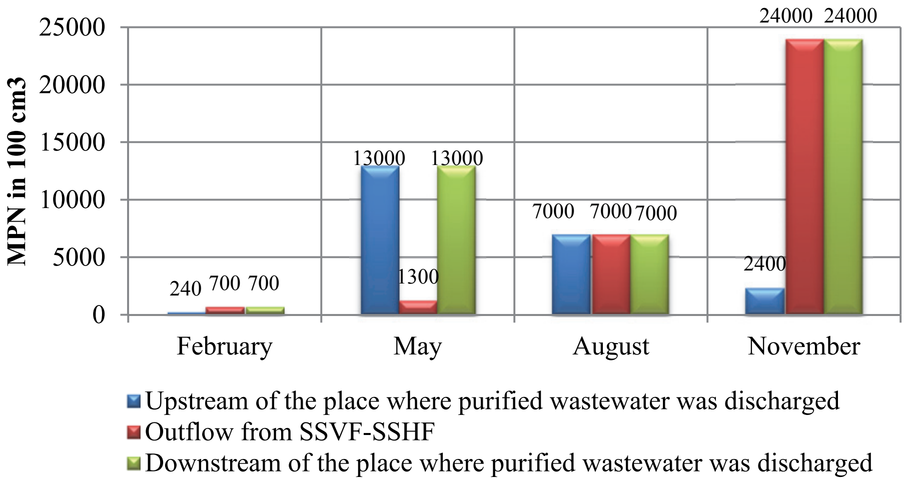

Fig. 5. Numbers of *coliform* bacteria in sewage discharged from the hybrid constructed wetland wastewater treatment plant and in water from Urzędówka River
Rys. 5. Liczebność bakterii grupy *coli* w ściekach odprowadzanych z hybrydowej gruntowo-roślinnej oczyszczalni ścieków komunalnych oraz w wodzie z rzeki Urzędówki

A similar trend could be observed in the case of fecal coliform bacteria. During spring and summer (May and August), the numbers of microorganisms upstream of the sewage discharge point were slightly higher than downstream of this point (Fig. 5, Table 4). In February and November, the number of these bacteria in the samples of water collected upstream of the wastewater outlet was low, but increased in the samples of water collected downstream of the outlet. In November, an increase in those numbers from $1.3 \cdot 10^2$ to $2.4 \cdot 10^3$ MPN·100 cm^{-3} was observed, and in February there was a much smaller increase from $2.4 \cdot 10^2$ to $7 \cdot 10^2$ MPN·100 cm^{-3}.It is not without significance that in this period treated sewage was characterized by a high concentration of fecal coliforms, which could have had a direct impact on the quality of river water (Figure 6, Table 4). A similar relationship was observed by Wira (2011) in her study of the Wełna River (a right tributary of the Warta River), which receives substantial concentrations of sewage discharged from collectors situated in surrounding towns.

Table 4. Selected indicators of microbial purified sewage and water from Urzędówka River before and after the discharge of sewage from the hybrid constructed wetland wastewater treatment plant in 2013
Tabela 4. Skład zanieczyszczeń mikrobiologicznych ścieków oczyszczonych oraz wód z rzeki Urzędówki przed i po dopływie ścieków z hybrydowej gruntowo-roślinnej oczyszczalni ścieków w 2013 roku

Indicators	Purified sewage				Water from the river before discharge sewage				Water from the river after discharge sewage				The limit values of indicators of water quality appropriate for the class by the Regulation of the Minister of the Environment [2004]				
	II	V	VIII	XI	II	V	VIII	XI	II	V	VIII	XI	I	II	III	IV	V
Numbers of *coliform* bacteria [MPN·100 cm^{-3}]	$7 \cdot 10^2$	$1,3 \cdot 10^3$	$7 \cdot 10^3$	$2,4 \cdot 10^4$	$2,4 \cdot 10^2$	$1,3 \cdot 10^4$	$7 \cdot 10^3$	$2,4 \cdot 10^3$	$7 \cdot 10^2$	$1,3 \cdot 10^4$	$7 \cdot 10^3$	$2,4 \cdot 10^4$	50	500	5000	50000	>50000
Numbers of fecal *coliform* bacteria [MPN·100 cm^{-3}]	$7 \cdot 10^2$	$7 \cdot 10^2$	$2,4 \cdot 10^3$	$2,4 \cdot 10^3$	$2,4 \cdot 10^2$	$2,4 \cdot 10^3$	$7 \cdot 10^3$	$1,3 \cdot 10^2$	$7 \cdot 10^2$	$7 \cdot 10^2$	$2,4 \cdot 10^3$	$2,4 \cdot 10^3$	20	200	2000	20000	>20000
Indicator does not mean in surface waters according to the regulations outlined																	
Numbers of fecal *enterococci* [MPN·100 cm^{-3}]	-	$1,1 \cdot 10^3$	$2,4 \cdot 10^3$	$4,6 \cdot 10^2$	-	$4,6 \cdot 10^2$	$4,6 \cdot 10^3$	$1,1 \cdot 10^4$	-	$1,1 \cdot 10^3$	$2,4 \cdot 10^3$	$4,6 \cdot 10^2$	-	-	-	-	-

According to the requirements concerning the concentration of coliform bacteria and fecal coliforms in bodies of water, set out in the Regulation of the Minister of the Environment of 2004 (Dz. U. 2004 nr 32, poz. 284), water collected from the Urzędówka River upstream of the sewage discharge point in May and August had the characteristics of class IV waters and that collected in February and November met class III water quality standards. The numbers of coliform bacteria in water collected downstream of the treatment plant in May, August and November were characteristic of class IV waters, and samples collected in February met class III standards. When described in terms of the concentration of fecal coliforms,water samples from February and May met the standards for class III waters and those from August and November met class IV water quality standards (Table 4).

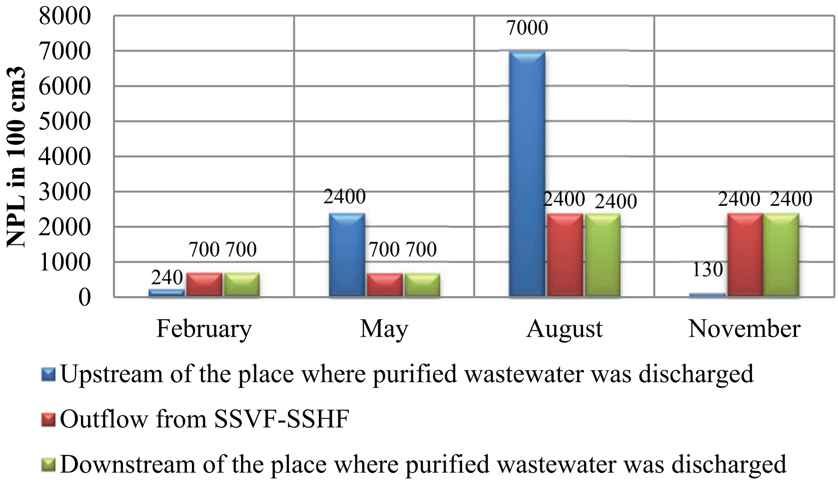

Fig. 6. Numbers of fecal coliform bacteria in sewage discharged from the hybrid constructed wetland wastewater treatment plant and in water from Urzędówka River
Rys. 6. Liczebność bakterii grupy *coli* typu kałowego w ściekach odprowadzanych z hybrydowej gruntowo-roślinnej oczyszczalni ścieków komunalnych oraz w wodzie z rzeki Urzędówki

The numbers of fecal enterococci in the effluent and in river water were analyzed three times, in May, August, and November. In those months, the largest numbers of these microorganisms were found in the water collected upstream of the sewage discharge point. Bacterial counts in the other two types of samples were much lower. Only in May, did the number of fecal enterococci in the effluent ($1.1 \cdot 10^3$ MPN$\cdot$100 cm^{-3}) exceed that found in the water collected from the Urzędówka River upstream of the discharge point ($4.6 \cdot 10^2$ MPN$\cdot$100 cm^{-3}) (Figure 7, Table 4). The presence of micro-organisms in the water which did not come into contact with sewage from the Skorczyce treatment plant shows a negative effect of some other sources of microbial contamination.

A close vicinity of rural settlements suggests that the large numbers of fecal bacteria may have been an effect of uncontrolled disposal of domestic wastewater. Similar conclusions were drawn by Frąk (2010), who examined the quality of water in the Biebrza River. In her samples, she found a large number of psychrophilic microorganisms and fecal coliform bacteria. In our study, fecal pollutants were also probably washed into the receiver from the grazing fields situated in the Valley of the Urzędówka River.

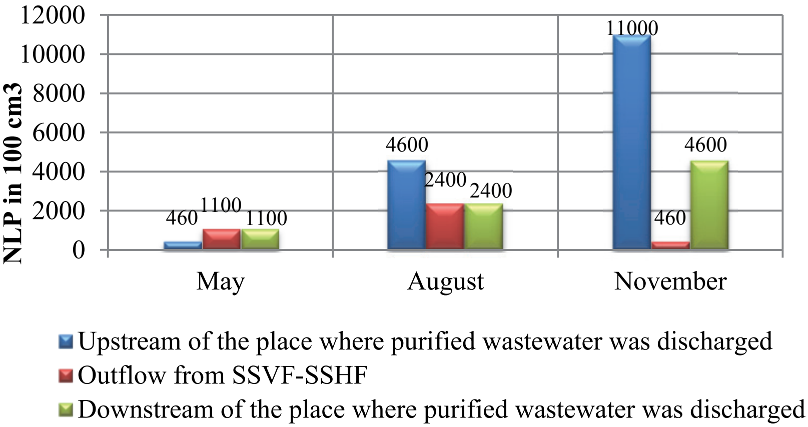

Fig. 7. Numbers of fecal enterococci in sewage discharged from the hybrid constructed wetland wastewater treatment plant and in water from Urzędówka River
Rys. 7. Liczebność bakterii enterokoków kałowych w ściekach odprowadzanych z hybrydowej gruntowo-roślinnej oczyszczalni ścieków komunalnych oraz w wodzie z rzeki Urzędówki

4. Conclusions

The wastewater treated in the investigated constructed wetland wastewater treatment plant was characterized by a small content of total suspended solids, organic matter, and other pollutants (except for nitrogen and phosphorus), and its introduction into the Urzędówka River did not have any statistically significant impact on the quality of the water in the river. The water of the Urzędówka River met water quality standards for class I waters; only the contents of phosphorus and nitrate nitrogen exceeded the limits specified for purity class II. In the autumn-winter period (February and November), a correlation was observed between the concentrations of coliform bacteria, fecal coliform bacteria and fecal enterococci found in the wastewater discharged from the constructed wetland wastewater treatment plant and those found in river water collected downstream of the sewage discharge point. In the summer months, the discharge of treated wastewater from the constructed wetland wastewater treatment plant did not increase number of microorganism in water samples from the Urzędówka River. Large numbers of fecal coliform bacteria and fecal enterococci found in the water collected from the river upstream of the place where wastewater was discharged from the treatment plant indicated the existence of other sources of microbial contamination. The impact of the investigated VF-HF treatment plant on water quality in the Urzędówka River was insignificant. This was mainly due to the high efficiency of the wastewater treatment system and the low rate of inflow of treated wastewater into the receiver relative to the flow of water in the river, which allowed self-cleaning processes to run smoothly and efficiently.

References

Andrulewicz, E. (1997). An overview on lagoons in the Polish coastal area of the Baltic Sea. *International Journal of Salt Lake Research*, *6 (2),* 121-134.

Ávila, C., Salas, J. J., Martín, I., Aragón, C., & García, J. (2013). Integrated treatment of combined sewer wastewater and stormwater in a hybrid constructed wetland system in southern Spain and its further reuse. *Ecological Engineering*, *50*, 13-20.

Chen, J., He, D., Zhang, N. & Cui, S. (2004). Characteristics of and human influences on nitrogen contamination in Yellow River system, China. *Environmental Monitoring and Assessment, 93 (1-3),* 125-138.

Dobrzański, B. & Turski, R. (1972). *Soil cover* (in Polish). [In] Spatial zoning of agricultural production in the Lublin province. Lublin, 30-36..

Elhatip, H. & Güllü, Ö. (2005). Influences of wastewater discharges on the water quality of Mamasın dam watershed in Aksaray, Central Anatolian part of Turkey. *Environmental Geology*, *48(7)*, 829-834.

Frąk, M. (2010). Bacterial pollution in the assessment of the Biebrza River water quality (in Polish). *Woda-Środowisko-Obszary Wiejskie, 10*, 73-82.

Gajewska M., Stosik M., Wojciechowska E. & Obarska-Pempkowiak H. (2013). Wpływ technologii oczyszczania ścieków na spektrum rozmiarów cząstek w odpływie. *Rocznik Ochrona Środowiska, 15*, 1191-1206.

Gizińska, M., Jóźwiakowski, K., Marzec, M. & Pytka, A. (2012). The problems of construction and commissioning of a constructed wetland wastewater treatment plant without planting of vegetation: the example of a wastewater treatment facility in Skorczyce (in Polish). *Infrastruktura i Ekologia Terenów Wiejskich, (3/I)*, 97-110.

Gizińska-Górna, M., Czekała, W., Jóźwiakowski, K., Lewicki, A., Dach, J., Marzec, M., Pytka, A., Janczak, D., Kowalczyk-Juśko, A. & Listosz, A. (2016). The possibility of using plants from a hybrid constructed wetland wastewater treatment plant for energy purposes. *Ecological Engineering, 95*, 534-541.

Jóźwiakowski, K., Marzec, M., Gizińska, M., Pytka, A. & Goral, R. (2011). An annex to the construction design of a domestic wastewater treatment plant for a residential building in the village of Skorczyce (commune of Urzędów) (in Polish). *Maszynopis Katedry Inżynierii Kształtowania Środowiska i Geodezji UP w Lublinie*, 10-20.

Jóźwiakowski, K., Marzec, M., Gizińska-Górna, M., Pytka, A., Skwarzyńska, A., Słowik, T., Kowalczyk-Juśko, A., Gajewska, M., Steszuk, A., Grabowski, T. & Szarawa, Z. (2014). The concept of construction of a hybrid constructed wetland for wastewater treatment in the Roztocze National Park. *Barometr Regionalny. Analizy i Prognozy, 12(4)*, 91-102.

Jóźwiakowski, K., Mucha, Z., Generowicz, A., Baran, S., Bielińska, J., & Wójcik, W. (2015). The use of multi-criteria analysis for selection of technology for a household WWTP compatible with sustainable development. *Archives of Environmental Protection*, *41(3)*, 76-82.

Juszkiewicz, A., Bartynowska-Meus, Z., Kawałek, M., Meus, M., & Łaptaś, A. (2006). The impact of a wastewater treatment plant on water quality in the Rudawa River basin (in Polish). *Aura, 6*, 12-13.

Kivaisi, A. K. (2001). The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological engineering, 16(4)*, 545-560.

Kowalkowski, T. & Buszewski, B. (2006). Emission of nitrogen and phosphorus in polish rivers: past, present, and future trends in the vistula river catchment. *Environmental Engineering Science*, *23(4)*, 615-622.

Królak, E., Korycinska, M., Diadik, K. & Godziuk, S. (2011). Do local sewage treatment plants influence the quality of water in sewage receiving rivers? (in Polish). *Ochrona Środowiska i Zasobów Naturalnych, 48*, 343-352.

Lewandowska-Robak, M., Górski, Ł., Kowalkowski, T., Dąbkowska-Naskręt, H. & Miesikowska, I. (2011). The influence of treated sewage discharged from a wastewater treatment plant in Tuchola on water quality of Kicz Creek (in Polish). *Inżynieria i Ochrona Środowiska*, *14*, 209-221.

Mosiej, J., Komorowski, H., Karczmarczyk, A. & Suska, A. (2007). Effect of pollutants discharged from the Łódź conurbation on the quality of water in the Ner and the Warta rivers (in Polish). *Acta Sci. Pol., Formatio Circumiectus, 6 (2)*, 19-30.

Owczarczyk, A. (2001). Radiotracer studies of natural and artificial water reservoirs (in Polish). http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/32/032/32032495.pdf (accessed on 19.05.2016)

PN-74/C-04620/00 Water and sewage. Sampling. General provisions and scope of the standard (in Polish).

PN-C-04615-05:1975P. Water and sewage. Microbiological testing. Determination of coliform bacteria by the multi-tube fermentation (in Polish).

PN-C-04615-07:1977P. Water and sewage. Microbiological testing. Determination of fecal coliform bacteria by the multi-tube fermentation (in Polish).

PN-C-04615-25:2008P. Water and sewage. Microbiological testing. Part 25. Determination of fecal enterococci by the by the multi-tube fermentation (in Polish).

PN-EN 25667-2: 1999 Water quality. Sampling. Guidelines for sampling techniques (in Polish).

Policht-Latawiec, A., Bogdał, A., Kanownik, W., Kowalik, T., Ostrowski, K., & Gryboś, P. (2014). Quality and usable values of small flysch river water (in Polish). *Rocznik Ochrona Środowiska, 16(1)*, 546-561.

Provincial Inspectorate for Environmental Protection 2015 Report on the state of the environment of the Lublin Region in 2014 (in Polish). *Biblioteka Monitoringu Środowiska Lublin*, 28-46.

Rajda, W. & Kanownik, W. (2007). Some water quality indices in small watercourses in urbanized areas. *Archives of Environmental Protection*, *33(4)*, 31-38.

Regulation of the Minister of the Environment of 11 February 2004 on the classification for the present status of surface water and groundwater and how to conduct the monitoring and interpret the results and presentation of the status of these waters. Dz. U. 2004 no. 32 pos. 284 (in Polish).

Regulation of the Minister of the Environment of 15 November 2011 on the forms and manner of monitoring of surface water bodies and groundwater. Dz. U. 2011, no. 258, pos. 1550 (in Polish).

Regulation of the Minister of the Environment of 28 January 2009 amending the regulation on the conditions to be met when discharging sewage into water or soil and on substances particularly harmful to the aquatic environment. Dz. U. 2009, no. 27, pos. 169 (in Polish).

Regulation of the Minister of the Environment of 9 November 2011 on the classification of the status of homogenous parts of surface water and environmental quality standards for priority substances. Dz. U. (Journal of Laws) no. 257, pos. 1545 (in Polish).

Sapek, A. & Sapek, B. (2005). Strategy of nitrogen and phosphorus management in agriculture for the protection of waters of the Baltic Sea (in Polish). *Zeszyty Edukacyjne. Rolnictwo Polskie i Ochrona Jakości Wody, 10*, 67-69.

Structum Sp. z o.o. (2000). Hydrological expert study for the Wyżnica River (in Polish).
Wiatkowski, M., Rosik-Dulewska, C. & Gruss, L. (2012). Profile of water quality indicators changes in Stobrawa river (in Polish). *Infrastruktura i Ekologia Terenów Wiejskich, (3/IV)*, 21-35.
Wira, J. (2011). Evaluation of the impact of selected physical and biological indices on the quality of water in the Wełna (in Polish). *Zeszyty Naukowe. Inżynieria Lądowa i Wodna w Kształtowaniu Środowiska, 3*, 71-76.
Wojciechowski, K. (1972). Hydrographic conditions and guidelines for their use (in Polish). *In: Projekt rejonizacji produkcji rolniczej w województwie lubelskim. Lublin*, 90-121.
Zhang, D., Gersberg, R. M. & Keat, T. S. (2009). Constructed wetlands in China. *Ecological Engineering, 35(10)*, 1367-1378.
Zieliński, M. (2011). *An expert study of water-related and legal aspects of discharge of treated wastewater from a domestic wastewater treatment plant into the Urzędówka River at 12+662 km* (in Polish). Biuro Projektowe „SKALA".

Analiza wpływu hybrydowej gruntowo-roślinnej oczyszczalni ścieków na jakość wód odbiornika

Abstract

This paper presents the results of research on the impact of the composition of wastewater discharged from a hybrid constructed wetland wastewater treatment plant on the quality of water in the Urzędówka River, a right tributary of the Wyżnica River. During the years 2011-2013, samples of treated wastewater and water from the river were collected (upstream and downstream of the wastewater discharge point) and subjected to physicochemical analysis and, in 2013, also to microbiological analysis. The study showed that the treated wastewater outflowing from the treatment plant did not have any negative influence on the quality of the water in the receiver. Water from the Urzędówka River met clarity standards for class I waters; only the concentrations of total phosphorus and nitrate nitrogen exceeded the limit values for water clarity class II. The studies have shown that waters from the Urzędówka River upstream of the treatment plant contained a huge concentration of E. coli bacteria, fecal coliform bacteria and fecal enterococci, which indicates the impact of other sources of microbiological pollution.

Streszczenie

W pracy przedstawiono wyniki badań dotyczące wpływu ścieków odprowadzanych z hybrydowej oczyszczalni hydrofitowej na jakość wód z rzeki Urzędówki, prawostronnego dopływu rzeki Wyżnicy. Próby ścieków oczyszczonych oraz wód z rzeki (powyżej i poniżej miejsca zrzutu ścieków) do analiz fizyczno-chemicznych pobierano w latach 2011-2013, a do analiz mikrobiologicznych w 2013 roku. Na podstawie wyników badań stwierdzono, że ścieki oczyszczone, odpływające z gruntowo-roślinnej oczyszczalni nie miały negatywnego wpływu na jakość wód odbiornika. Wody rzeki Urzędówki odpowiadały I kasy czystości, jedynie zawartość fosforu ogólnego oraz azotu azotanowego przekraczała wartości graniczne określone dla II klasy czystości. W wodzie z rzeki przed zrzutem ścieków oczyszczonych notowano wysoką liczebność bakterii grupy *coli* i *coli* typu kałowego oraz enterokoków kałowych, co wskazuje na oddziaływanie innych źródeł zanieczyszczeń mikrobiologicznych.

Słowa kluczowe:
oczyszczalnie gruntowo-roślinne, oczyszczalnie ścieków,
wody powierzchniowe, odbiornik ścieków, rzeka, jakość wód

Keywords:
constructed wetland system, wastewater treatment, surface water,
sewage receiver, river, water quality