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Impact assessment of treated wastewater on water quality of the receiver using the Wilcoxon test

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Abstract. Wastewater treatment is a process which aims to reduce the concentration of pollutants in wastewater to the level allowed by current regulations. This is to protect the receivers which typically are rivers, streams, lakes. Examination of the quality of treated wastewater allows for quick elimination of possible negative effects, and the study of water receiver prevents from excessive contamination. The paper presents the results of selected physical and chemical parameters of treated wastewater from the largest on the region in north-eastern Poland city of Bialystok municipal wastewater treatment and Biała River, the receiver. The samples for research were taken 3–4 a month in 2015 from two points: before and after discharge. The impact of the wastewater treatment plant on the quality of the receiver waters was studied by using non-parametric Wilcoxon test. This test determined whether the analyzed indicators varied significantly depending on different sampling points of the river, above and below place of discharge of treated wastewater. These results prove that the treated wastewater does not affect the water quality in the Biała River.

1 Introduction

According to many researchers, sewage treatment plants have a negative impact on soil and water environment of receivers [1–4]. The most commonly used method of municipal wastewater treatment is activated sludge technology [5, 6]. This process, although gives significant environmental and economic advantages, is not without flaws. One of the main problems of biological wastewater treatment is the inability to guarantee a complete decomposition of mineral and organic substances [7]. Exploitation problems during the operation of sewage treatment plants result in a periodic worsening of the receiver due to the discharge of treated wastewater to an insufficient degree [8]. In Polish law, the quality

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requirements for purified wastewater in larger facilities are limited to monitoring of easily and hardly biodegradable compounds, total amounts of nitrogen and phosphorus, as well as suspended solids [9, 10]. In an aqueous environment, biogenic substances are important, including oxygen-derivatives of nitrogen and phosphorus, which are supplied to the environment with treated wastewater [11]. These compounds aggravate the eutrophication of surface waters, which in consequence, causes an aerobic condition [12]. The result is a clear deterioration in water quality, decrease in the utility value of the watercourse, while for a longer time, irreversible changes in the ecosystem and the decline of biodiversity [13]. Environmental protection should consist in discharging sewage into waters with pollution loads permissible from the point of view of the ability to keep their self-cleaning in environment [14, 15].

The aim of the study was to analyze the impact of treated wastewater discharged from the sewage treatment plant in Bialystok on the water quality of Biala river. The study was undertaken due to the fact that this area is one of the Polish Green Lungs. It is characterized by a low level of industrialization. It has unique natural areas and ecological systems that are some of the most valuable in Poland and Europe.

2 Materials and methods

Located in north-eastern Poland, mechanical-biological wastewater treatment plant purifies sewage from more than 300.000-inhabitants agglomeration. Its average capacity is approximately 70 000 m^3/d. The main source of contamination affecting the drains are municipal and industrial sewage from the city of Bialystok, as well as adjacent areas. The work of the plant is based on active sludge technology assuming the load of BOD_5 equal to 30 000 kg O_2/d, suspension load of 55 000 kg/d, total Kjeldahl nitrogen 6 000 kg/d and total phosphorus 850 kg/d. Organic compounds removal characterized by BOD_5 in 99%, while suspension removal in 99%, total nitrogen and phosphorus 90% [16]. After treatment, wastewater from the municipal wastewater treatment plant is discharged into the Biała river (Figure 1). The catchment of Biała river covering over 133 km^2 area is also a receiver of majority of rainfall water and surface runoff, which causes deterioration of its chemical as well as health and hygiene conditions. The purity of Biała river is very important, because it is a left-hand tributary of the Supraśl river, which in turn is a right tributary of the Narew river. Therefore, studies were undertaken upon the impact of the discharge of treated wastewater on the quality of Biała river. Samples of water above and below the discharge point (Figure 1) were taken 3–4 times a month from January to December 2015 (Figure 1) in accordance with Polish standards [17]. Physicochemical analyses included: temperature, acidity, BOD_5, COD, total Kjeldahl nitrogen (TKN), ammonia ($N\text{-}NH_4$), nitrate ($N\text{-}NO_3$), nitrite ($N\text{-}NO_2$), total nitrogen, chloride (Cl^-), total phosphorus, phosphate (PO_4), total suspended solids (TSS), and dissolved oxygen (O_2). All tests were performed in certified laboratory of Bialystok Waterworks Ltd. according to APHA [18]. The paper presents results of the monthly average for the entire study period. The applied statistical analysis takes into account the general measures of listed parameters, including: arithmetic mean, median, minimum, maximum, and standard deviation. In order to verify the impact of the sewage treatment plant on the water quality in the receiver, the nonparametric Wilcoxon test for pairs of dependent variables was performed on the basis of achieved results. The determinant for the test is the lack of normal distribution of variables taken for analysis. The variables was not characterized by normal distribution according by Kolomogorov-Smirnov test.

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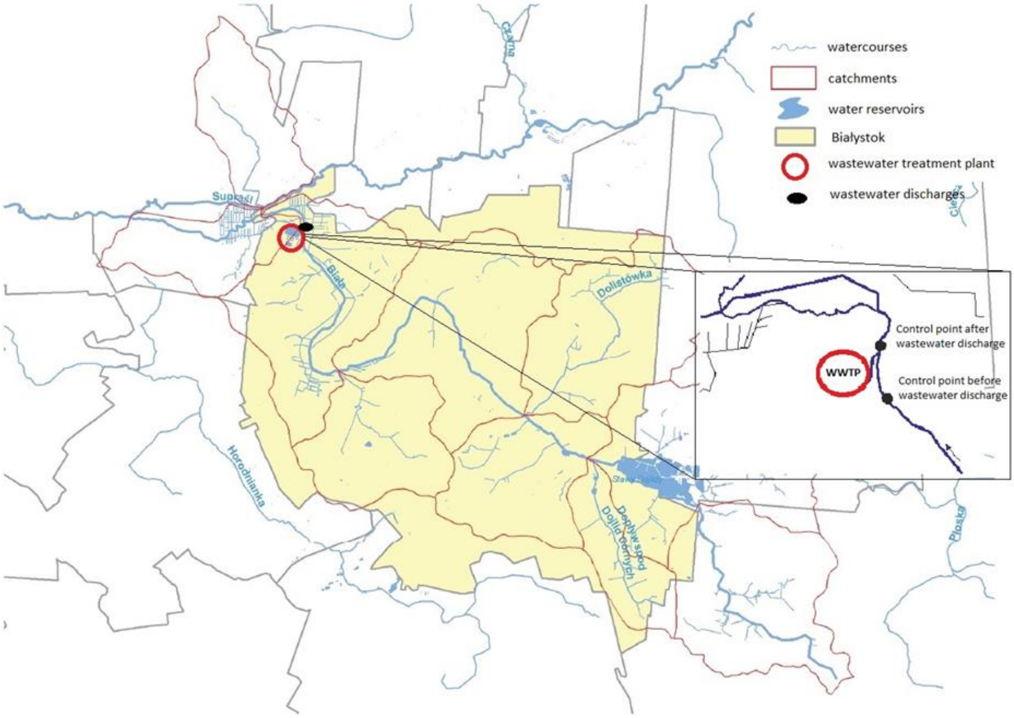

Fig. 1. Location of the research object and the arrangement of measurement and control points against the hydrographic division according to Tyszkewska and Kardel [19].

3 Results

The average temperature of water in the receiver in 2015 before discharge of treated wastewater, changed from 3.4 to 18.0°C during the study. The value of arithmetic mean (9.6°C), median (8.5°C), and standard deviation (5.2°C) indicate seasonal variations of this parameter. The temperature of water after the wastewater discharge was clearly higher as compared to the point before discharge. This parameter varied from 11.0 to 20.8°C. Values of arithmetic mean and median were similar amounting to 14.9 and 13.3°C, respectively, while standard deviation was 3.8°C. The acidity of the receiver's water before and after treated wastewater discharge point did not show remarkable changes. Minimum and maximum values recorded before and after wastewater discharge were equal and amounted to 7.7 and 8.0, respectively. A slight difference was observed only for median that before discharge point took a value equal to 7.9, whereas after discharge – 7.8. The quantity of organic compounds expressed as BOD_5 parameter before discharge of treated wastewater was slightly higher as compared to values recorded after the discharge point. Values of arithmetic means and medians for BOD_5 indicator before and after discharge amounted respectively to 3.4 and 2.8 mg $O_2 \cdot dm^{-3}$ as well as 3.1 and 2.6 mg $O_2 \cdot dm^{-3}$. The range of BOD_5 oscillations was from 1.8 to 8.2 mg $O_2 \cdot dm^{-3}$ before and from 1.6 to 4.7 mg $O_2 \cdot dm^{-3}$ after the wastewater discharge point. In the case of COD, slightly higher values of this parameter were observed after the treated wastewater discharge point. Arithmetic mean values before and after wastewater discharge were close to each other (32.8 and 35.8 mg $O_2 \cdot dm^{-3}$), medians were respectively equal to 24.0 and 33.0 before and after discharge. The COD values before wastewater discharging point varied in the range from

16.0 up to 116.0 mg $O_2 \cdot dm^{-3}$, whereas after the discharge from 22.0 to 52.0 mg $O_2 \cdot dm^{-3}$. Considering the standard deviations at both points (28.2 before and 10.2 mg $O_2 \cdot dm^{-3}$ after), it can be stated that supply of treated sewage stabilizes the naturally occurring changes in this parameter in surface waters. Water in the receiver was characterized by higher values of determined nitrogen forms after wastewater discharge point. The concentration of total nitrogen before and after discharge of wastewater was largely determined by changes in the quantity of nitrate and total Kjeldahl nitrogen (TKN). Among studied nitrogen forms, nitrate was characterized by the highest concentration and at the same time the highest variability. Arithmetic means for this parameter before and after discharge of sewage were respectively 3.8 and 4.8 mg $N \cdot dm^{-3}$, while the respective variability range was from 2.5 to 4.9 mg $N \cdot dm^{-3}$ before and from 4.9 to 9.4 mg $N \cdot dm^{-3}$ after wastewater discharge point. The second largest, in terms of concentration, form of nitrogen was the total Kjeldahl nitrogen, the mean concentrations of which before and after the discharge of wastewater were as follows 2.2 and 3.9 mg $N \cdot dm^{-3}$. Like for nitrate, range of total Kjeldahl nitrogen (TKN) variations before sewage discharge was lower and amounted from 1.7 to 3.0 mg $N \cdot dm^{-3}$, whereas after the discharge point from 2.5 to 9.7 mg $N \cdot dm^{-3}$. The slightest change concerned concentration of ammonium and nitrite. Arithmetic mean value before and after the discharge of wastewater for ammonia were equal to 1.0 and 1.8 mg $N \cdot dm^{-3}$, while for nitrite was characterized by mean value of 0.09 mg $N \cdot dm^{-3}$ before and 0.15 mg $N \cdot dm^{-3}$ after the wastewater discharging point. Average concentrations of chloride ions before and after the discharge of treated sewage were different and amounted respectively to 114.7 and 131.4 $mg \cdot dm^{-3}$. Much larger range of this parameter variability was recorded before (73.2–147.0 $mg \cdot dm^{-3}$) than after wastewater discharge point (108.0–158.0 $mg \cdot dm^{-3}$). Changes in phosphates and total phosphorus were subject to identical alterations before and after the discharge of treated sewage. Values of these parameters were similar at both points. The arithmetic means for these parameters before and after discharge of wastewater for phosphates were 0.9 and 0.9 mg $P \cdot dm^{-3}$, while for total phosphorus 0.3 and 0.3 mg $P \cdot dm^{-3}$. The value of total suspended solids after discharge of wastewater was significantly reduced in relation to that observed before discharging point. The average value of this parameter before discharge was 22.3 $mg \cdot dm^{-3}$, while after discharge 6.1 $mg \cdot dm^{-3}$. Similar differentiation characterized the variation ranges observed at both points. Before discharge of wastewater, the amount of total suspended solids (TSS) varied in the range from 3.5 to 140.0 $mg \cdot dm^{-3}$, whereas after discharge, the TSS quantity was within the range from 2.0 to 14.3 $mg \cdot dm^{-3}$. The concentration of dissolved oxygen in the waters of the receiver after discharge of wastewater underwent a slight decrease. The average concentration of this parameter before discharge of treated wastewater was 9.2, while after that point 8.8 mg $O_2 \cdot dm^{-3}$. Before discharge of treated wastewater, concentration of dissolved oxygen varied from 5.8 to 7.8 mg $O_2 \cdot dm^{-3}$. The minimum concentration of dissolved oxygen after the discharging point was slightly higher and amounted to 7.8 mg $O_2 \cdot dm^{-3}$, whereas maximum one was lower as compared to the value before discharging point, i.e. 10.3 mg $O_2 \cdot dm^{-3}$. Basic statistical measures for individual tested parameters are summarized in Table 1.

Table 1. Descriptive statistics for water quality before and after the discharge of treated wastewater.

Parameter	Unit	Average		Median		Minimum		Maximum		Standard deviation	
		B	A	B	A	B	A	B	A	B	A
Temp.	°C	9.6	14.9	8.5	13.3	3.4	11.0	18.0	20.8	5.2	3.8
pH	-	-	-	7.9	7.8	7.7	7.7	8.0	8.0	-	-
BOD_5	mg $O_2 \cdot dm^{-3}$	3.4	2.8	3.1	2.6	1.8	1.6	8.2	4.7	1.7	0.8
COD		32.8	35.8	24.0	33.0	16.0	22.0	116.0	52.0	28.2	10.2
TKN	mg $N \cdot dm^{-3}$	2.2	3.9	2.0	3.1	1.7	2.5	3.0	9.7	0.4	2.0
N-NH_4		1.0	1.8	1.0	1.2	1.0	1.0	1.0	6.8	0.0	1.7
N-NO_3		3.8	4.8	4.3	4.7	2.5	1.1	4.9	9.4	0.8	2.8
N-NO_2		0.09	0.15	0.07	0.17	0.05	0.04	0.14	0.27	0.04	0.08
TN		5.9	8.9	6.0	9.2	4.6	5.3	7.3	12.3	0.8	2.4
Cl^-	$mg \cdot dm^{-3}$	114.7	131.4	114.0	126.0	73.2	108.0	147.0	158.0	23.0	16.9
TP	mg $P \cdot dm^{-3}$	0.3	0.3	0.2	0.2	0.2	0.2	0.8	1.0	0.2	0.2
PO_4		0.9	0.9	0.6	0.6	0.6	0.6	2.6	3.0	0.6	0.7
TSS	$mg \cdot dm^{-3}$	22.3	6.1	10.0	4.5	3.5	2.0	140.0	14.3	39.6	4.0
O_2	mg $O_2 \cdot dm^{-3}$	9.2	8.8	9.1	8.6	5.8	7.8	11.7	10.3	1.7	0.9

B - before; A - after

The analysis of results applying Wilcoxon test (Table 2) showed differences between temperature of the wastewater before and after the discharge of treated sewage. Temperature changes were most evident in winter. Water temperature in the receiver during this period is usually significantly lower than the temperature of treated wastewater, which causes it to increase after the point of wastewater discharge. Another changed parameter was BOD_5. Smaller amounts of organic compounds expressed with this indicator were observed after wastewater discharge, which indicates the water dilution due to the supply of treated wastewater. In the case of total Kjeldahl nitrogen, ammonia, and nitrite, higher concentrations were recorded after the point of treated sewage discharge. The results of the test indicate a slight enrichment of water in these forms of nitrogen and, consequently, total nitrogen (TN). It has also been an increase in the concentration of chloride ions in water of the receiver after wastewater discharge point. This is due to the fact that these ions are not removed from wastewater as a result of life processes of microorganisms mostly occurring in the active sludge. The last parameter, for which statistical differences before and after discharge were observed, were total suspended solids (TSS). There was a reduction in the concentration of suspended solids, like BOD_5 value in waters after the wastewater discharging point. This indicates the dilution of water in the receiver with treated sewage. For other tested quality parameters, no significant changes were recorded after discharge of treated wastewater point.

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Table 2. Results of the Wilcoxon test for pairs of variables.

Pair of variables	T	p
°C& °C	0.00	0.00
pH & pH	3.50	0.14
BOD & BOD	6.00	0.03
COD & COD	13.00	0.08
TKN & TKN	1.00	0.00
$N\text{-}NH_4$ & $N\text{-}NH_4$	0.00	0.03
$N\text{-}NO_3$ & $N\text{-}NO_3$	23.00	0.37
$N\text{-}NO_2$ & $N\text{-}NO_2$	11.00	0.05
TN & TN	4.00	0.01
Cl^- & Cl^-	1.50	0.01
TP & TP	11.00	0.17
PO_4 & PO_4	11.00	0.17
TSS & TSS	9.00	0.03
O_2 & O_2	14.00	0.17

T – result of the Wilcoxon test; p - probability

High concentrations of biogenic substances in receivers of industrial and municipal wastewater are a worldwide problem. Tests carried out by Chen et al. [1] showed an increased content of ammonia and total nitrogen in the tributaries of the Yellow River in China. However, in Turkey in the Mamasin reservoir, high concentrations of nitrate, nitrite and ammonia were found. The source of these substances, in addition to farming operations, was municipal wastewater [2]. Increasing the concentration of chloride ions and nitrite after discharge of treated sewage was observed by Lewandowska-Robak et al. [4] during research conducted in the area of sewage treatment plants with enhanced removal of biogenic substances in Tuchola Forest. Slightly lower growth in COD value in waters of the San river after the discharge of treated sewage was indicated by Policht-Latawiec et al. [20]. Kanownik and Rajda [3] reported that the treated wastewater does not affect the pH value in Jaszczurówka stream, which is the receiver of wastewater from mechanical-biological treatment plant in Jaszczurowa.

4 Conclusions

The analyzed results related to the relationship sewage treatment plant – receiver, allow to draw the following conclusions:

1. In the analyzed period, municipal wastewater treatment plant in Bialystok provided an efficient removal of impurities in accordance with the requirements of the water permit.
2. Discharge of treated wastewater affects the values of temperature, BOD_5, total Kjeldahl nitrogen, ammonia, nitrite, total nitrogen, chloride ions, and total suspended solids in waters of the receiver, but it does not change other tested water quality parameters.
3. Water below the sewage discharge point revealed an increase in all forms of nitrogen, however not all of the observed changes were statistically significant.
4. Supply of treated wastewater reduces the amount of organic compounds (defined by BOD_5) and the concentration of total suspended solids in water of Biała river due to the dilution of the receiver's water and the water self-purification processes.
5. Taking into account results of the contents of individual indicators in Biała river before and after wastewater discharge points, no adverse effects of the sewage treatment plant

on water quality in the receiver, were recorded, despite the fact that the ratio of the amount of sewage discharged to the average flow in the river is unfavorable for the receiver.

6. The increase in the concentration of nitrogen compounds for discharge is noticeable due to the fact that the water permit is based on standards, not taking into account the size of the receiver nor his opportunities for self-cleaning.
7. Unsatisfactory status of water quality in Biała river due to its central location in 300.000-inhabitants agglomeration of Bialystok and furthermore meandering river through a large area of the city. In addition, the river is a receiver of surface runoff and rainwater from the whole catchment area, which classifies it to only good status. Therefore, to improve the quality of surface waters in urbanized catchments, integrated management and planning activities, involving the development of appropriate action programs dependent on natural conditions and needs of the economy, should be led.

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References

1. J.S. Chen, D.W. He, N. Zhang, S.B. Cui, Environmental Monitoring and Assessment, **93** (2004)
2. H. Elhatip, Ö. Güllü, Environ. Geol. **48** (2005)
3. W. Kanownik, W. Rajda, Gas, Water and Sanitary Engineering, **9** (2011)
4. M. Lewandowska-Robak, Ł. Górski, T. Kowalkowski, H. Dąbrowska-Naskręt, I. Mieszkowska, Engineering and Environmental Protection **14**, 3 (2011)
5. M. Delkash, B.E. Bakhshayesh, H. Kazemian, Micropor. Mesopor. Mat. **214** (2015)
6. S. De Gisi, G. Lofrano, M. Grassi, M. Notarnicola, Sustainable Materials and Technologies, **9** (2016)
7. I. Evan-Ezra, M. Beliavski, S. Tarre, C. Dosoretz, M. Green, Desalination **272** (2011)
8. J. Długosz, J. Gawdzik, Proceedings of ECOpole **7**, 1 (2013)
9. K. Maj, A. Masłoń, Magazine of Civil Engineering, Environment and Architecture, **62** (2015)
10. Y. Lin, M. Guo, N. Shah, D.C. Stuckey, Bioresource Technol. **215** (2016)
11. K. Pawęska, K. Kuczewski, 3rd Polish General Congress of Environmental Engineering (2009)
12. W. Miernik, D. Młyński, A. Wałęga, K. Chmielowski, R. Karwacki, Infrastructure and Ecology of Rural Areas, **1** (2016)
13. E. Neverova-Dziopak, P. Cierlikowska, Environmental Protection **2**, 36 (2014)
14. B. Kaźmierczak, Annual Set Environment Protection **15** (2013)
15. C. Przybyła, J. Bykowski, Annual Set Environment Protection, **11** (2009)
16. http://www.wobi.pl/
17. PN-ISO 5667-10:1997, Water quality - Sampling - Guidance of sampling plants in Poland
18. E.W. Rice, R.B. Baird, A.D. Eaton, L.S. Clesceri, Standard Methods for the Examination of Water and Wastewater, American Public Health Association (APHA),

American Water Works Association (AWWA), Water Environment Federation (WEF), 22 nd Edition (2012)

19. S. Tyszewska, I. Kardel, Study hydrographic valley Biała river, Białystok City Hall, (2009)
20. A. Policht-Latawiec, W. Kanownik, D. Łukasik, Infrastructure and Ecology of Rural Areas, **1** (2013)