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The effect of a Sewage Treatment Plant modernization on changes in the microbiological and physicochemical quality of water in the receiver

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Abstract: Due to insufficient operation efficiency, the studied treatment plant has undergone modernization. The aim of this study was to assess whether this modernization improved quality of the STP effluent and water quality in the receiver. The research period of fifty months covered time before and after the modernization. Samples were collected in four sites – upstream and downstream of the STP and by the sewage discharge. Electrolytic conductivity, water temperature and pH were measured onsite. Chemical analyzes were based on ion chromatography and determined the concentration of NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, TDS. Microbiological analysis comprised serial dilutions to assess the number of mesophilic and psychrophilic bacteria and membrane filtration to enumerate *E. faecalis*, total and fecal coliforms as well as total and fecal *E. coli.* Values of most analyzed parameters did not improve after the modernization, or improved for a very short period of time (NH_4^+), while some of them even increased, such as PO_4^{3-}, total and thermotolerant coliforms and *E. coli*. The maximum value of thermotolerant *E. coli* reached nearly 7 million CFU/100 ml and was observed after modernization. Also at the sites situated downstream of the STP some of analyzed parameters increased. The conducted modernization did not improve the quality of treated sewage and even a further deterioration was observed. It could have been a result of rapidly growing number of tourists visiting the studied area, thus generating large amounts of sewage causing STP overload coupled with poor water and wastewater management. Significant percentage of unregistered tourists hinders proper assessment of the STP target efficiency.

Introduction

Poland's integration with the European Union caused the necessity to adjust a number of national laws to meet the EU regulations. One of them is the Water Framework Directive, according to which the member states are required to prevent the deterioration of surface waters quality (Directive 2000/60/EC, Godela et al. 2017). Water quality in rivers can be affected by many factors of both, anthropogenic and natural origin. These factors can further be divided into point and diffuse sources of pollution (Dambeniece-Migliniece and Lagzdiņš 2017). Point sources are generally easy to identify and locate, as in most cases they include inflow of household sewage, discharge from municipal sewage treatment plants, or industrial wastewater (Vega et al. 1998). Deterioration of water quality in receivers caused by inflow of purified sewage is still a worldwide problem (Kanownik et al. 2016). Municipal sewage is a very complex mixture, consisting of a high number of substances. Sewage discharge from small treatment plants, below 2,000 PE may negatively affect surface water management and protection. In order to meet the new regulations, different activities have been carried out to improve the quality of water in long-term. These activities include, among others, construction of new and modernization of the existing – sometimes underestimated – sewage treatment plants, which is a basic activity aimed at reducing the amount of anthropogenic pollutants of surface waters (Godela et al. 2017). The construction of new sewer systems and modernization of the operating STPs are concentrated mainly in rural areas (Wałęga et al. 2009). Among the main tasks of sewage treatment plants is the removal of all substances considered as pollutants and stabilization of their composition so that they do not disturb the balance of the receiver, which is most often river water (Kanownik and Rajda 2011). The use of surface water as sewage receiver is possible only if the sewage discharge does not disturb the biological functions of the ecosystem. Also, the selection of the receiver should be dictated by its capacity, i.e. capability of receiving a certain volume of sewage and pollutant load. Another important aspect to consider when designing a sewage treatment plant is that the pollutant load does not disturb the self-purification process of the receiver, which is another stage of the sewage purification process (Holguin-Gonzalez et al. 2013).

There have been multiple studies carried out in Poland on the effect of sewage discharge on the quality of water in receivers. Most of those studies indicate that discharge of sewage deteriorates the quality of surface water, sometimes severely (Godela et al. 2017, Kanownik et al. 2017, Skorbiłowicz et al. 2016). Some studies indicate, however, that if the STP undergoes modernization, its effectiveness increases and it effectively protects the quality of water in the receiver (Jaromin-Gleń et al. 2015, Miernik et al. 2016) and that the modernization process allows to obtain the required values of all basic pollution indicators in treated sewage (Neverova-Dziopak and Cierlikowska 2014). However, what needs to be mentioned is that all studies, which conclude that after STP modernization the sewage discharge does not cause deterioration of the quality of water in the receiver, focus mainly on physicochemical parameters of water and wastewater. For instance, Olańczuk-Neyman et al. (2001) emphasize that the effluent from the municipal sewage treatment plant, even after its modernization and with the use of highly effective biological processes, is heavily microbiologically polluted. Also Godela et al. (2017) conclude that even after modernization of the STP, which was studied in their research, the discharged sewage still contains significant numbers of bacterial contaminants, thus deteriorating the quality of river water. This might be due to the fact that the modernization process focuses mainly on the removal of physicochemical contaminants, including nutrients, but still does not ensure proper removal of bacteria (Godela et. al. 2017).

Lenart-Boroń et al. (2016b) in their study conducted at the Białka river catchment observed that the municipal sewage treatment plant is the major point source of pollution of the analyzed river. It supplies both enormous amount of bacterial contaminants and nutrients, thus contributing to a significant deterioration of the river water quality. The considered STP in the period of the mentioned analyzes operated inefficiently, since it was not adjusted to purify large amount of sewage produced during increased tourist traffic in winter and summer. Information obtained from the management of the STP indicates that the studied treatment plant encountered enormous hydraulic difficulties, i.e. during the increased tourist traffic the volume of sewage supplied to the STP exceeded its maximum capacity by several times, however the STP was obliged to receive the transports of sewage, even if this meant that the retention time would be significantly decreased. In further more detailed studies, Lenart-Boroń et al. (2016a) observed a significant diurnal variation in the concentration of microbial indicators of water quality as well as physicochemical characteristics of water, as a result of the operation of the studied STP. The stream being the receiver of sewage was severely contaminated and the contamination of the Białka river was significant even a few kilometers downstream of the sewage discharge.

The treatment plant in the analyzed area has undergone modernization and therefore the aim of this study was to examine whether the conducted modernization resulted in increased microbiological and physicochemical quality of water in stream being the receiver of sewage and in the Białka river, downstream of the STP.

Study area

The study area includes the Białka river, which is a mountain river, with a natural unregulated riverbed. The studied fragment of the Białka valley is located in the Bukowina Tatrzańska municipality. The Białka river valley in the studied section is protected within the Natura 2000 network, as having valuable riverside habitats. At the same time, this area is one of the most attractive tourist destinations in Poland and tourism and recreation are widely recognized environmental hazards in the area (Management strategy for the Natura area 2000 „Dolina Białki"). Białka in the Trybsz water gauge section is a mountain river with an area of 202.9 km^2, its mean slope is 17.4° and the forest ratio 20.1% (Rutkowska et al. 2017). Its upper section drains the highest part of the Polish and Slovak Tatra mountains and belongs to the Tatra Hydrographic Region, while its middle and northern part in the research area – Flysh Hydrographic regions (Żelazny et al. 2015)

The area is characterized by a well-developed tourist infrastructure, particularly ski-related and accommodation base. There are eight ski resorts in the considered region. Unfortunately, only a part of the area is connected to the sewerage system and only about half of the population (54.3%) uses sewerage system (CSO 2016). Particularly in the winter season the number of people staying in the considered area exceeds the number of citizens by multiple times, resulting in the sewage treatment plant overload and reduced efficiency of pollutant removal (Lenart-Boroń et al. 2016a). In the area of the Bukowina Tatrzańska municipality there are also numerous points of illegal discharge of untreated sewage which enters the streams and rivers.

The study area is served only by one municipal sewage treatment plant. In August 2014 its expansion and modernization was started in the aspect of mechanical and biological treatment. The investment included the improvement of the mechanical treatment process (introduction of two gratings) and the dewatering of sewage sludge has been changed from the DRAIMAD bags system into the press usage. The construction changes were only minor, i.e. a new reactor and a new sewage collector were built, enabling the increase in the STP capacity from 735 m^3/day to 1,690 m^3/day. The modernized sewage treatment plant was put into operation on July 31st, 2015.

Methods

Field methods

The studies were conducted from January 2013 to March 2017 in four sampling sites. Three of them were located on the Białka river and one by the discharge of sewage from the treatment plant (STP). The site before STP is situated c.a. 100 meters upstream of the sewage discharge from the STP. The site intake is located a few kilometers downstream of the sewage discharge, where water is drawn for the production of artificial snow at slopes of one of the largest ski stations in Poland. The Trybsz site is situated downstream of the ski station. The precise location of the sampling sites is shown in Fig. 1.

Water temperature (T), electrical conductivity referred to the water temperature of 25°C ($EC_{25°C}$) and reaction (pH) were measured onsite. The measurements were conducted using

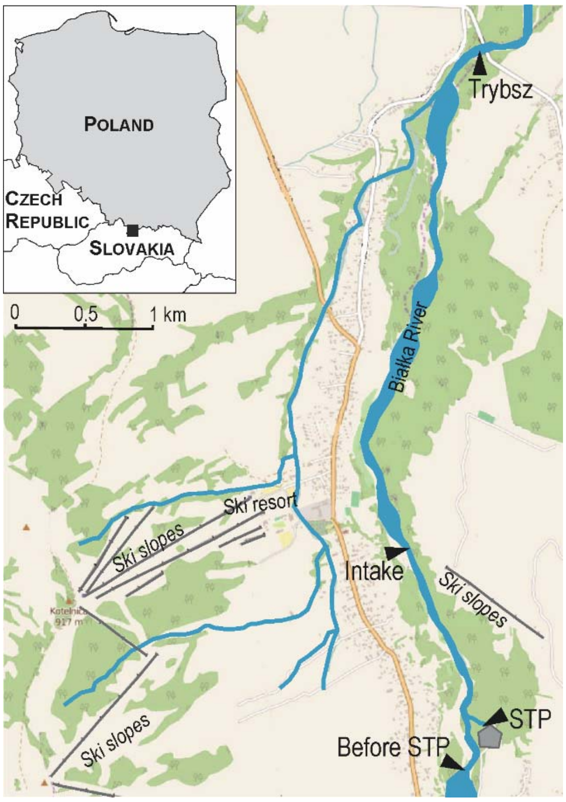

Fig. 1. Study area

a WTW Multi 350i meter with a combined glass electrode POLYPLAST PRO (Hamilton) and a conductometric sensor LR-325/01 (WTW) with a constant k=0.1 and a built-in temperature sensor. Water samples for microbiological analyzes were collected in a volume of 1,000 ml into sterile polypropylene bottles, while for the determination of chemical composition samples of 500 ml were collected into disposable polyethylene bottles. The samples were collected over a period of more than four years (50 months), during which the sampling was conducted at intervals of approximately a month, resulting in a collection of 45 samples per each study site, which allowed not only to determine the changes in the quality of water over the four examined study periods, but also to assess the impact of changing seasons of the year on the effectiveness of sewage treatment in the examined STP.

Laboratory methods

The chemical composition of water was determined in a laboratory of the Institute of Geography and Spatial Management of the Jagiellonian University in Cracow. The concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, Cl^-, NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, Li^+, Br^-, F^- in water were determined by ion chromatography using two DIONEX ICS-2000 chromatographs and an autosampler AS-4. Water mineralization (TDS) was calculated as a sum of the determined ions. The following parameters were used for statistical analyzes: T, EC, pH, TDS as well as nitrogen and phosphorus compounds (NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}). In the case of microbiological analyzes, the number of bacterial indicators of water quality was assessed using membrane filtration (*Enterococcus faecalis*, total and thermotolerant coliforms, *Escherichia coli*) and serial dilutions method (mesophilic and psychrophilic bacteria) using proper general culture or selective media as described by Lenart-Boroń et al. (2016b).

Statistical analysis

In order to verify whether there are statistically significant differences in microbiological indicators of water quality and physicochemical properties of the sewage discharged into the river and water in the sampling sites located on the Białka river between the periods before, during modernization and after launching the modernized STP, analysis of variance ANOVA was performed along with the post-hoc Least Significant Difference (LSD) test for p at 0.05. The analysis of variance was also used to determine the significance of differences upstream and downstream of the sewage discharge from the treatment plant.

Results

General characteristics of bacteriological indicators and physicochemical parameters of water quality in the examined sites

Tab. 1 presents the bacteriological and physicochemical parameters of sewage discharged from the sewage treatment plant (STP) and water of the Białka river upstream of the sewage discharge (Before STP) as well as downstream (Intake, Trybsz). Treated sewage discharged from the sewage treatment plant is characterized by very high mean values of bacteria, amounting to even several hundred thousand, particularly in the case of coliforms and fecal coliforms. At the same time it should be emphasized that the variability in the number of bacteria, expressed as the coefficient of variation (CV), is also very high and reaches from 198.2 to 324.9%. Treated sewage is also characterized by high values of temperature (T), conductivity (EC) and mineralization (TDS). Among nitrogen and phosphorus compounds, the highest mean concentrations were observed for NO_3^- ions. The mean values of NH_4^+ and PO_4^{3-} were also quite high, while the values of NO_2^- concentrations were clearly lower. However, as in the case of bacteriological parameters, also the concentrations of nutrients are characterized by high variability (CV>100%).

Waters of the Białka river, in each of the sampling sites are characterized by multiple times lower values of bacteriological indicators of water quality as compared to the values recorded at sewage discharge from the treatment plant (STP) – Tab. 1. However, during the research period, the variability of these parameters was also very high and the CV exceeded usually 200%. The increase in the mean number of bacteria along the course of the river was also evident. In comparison to the sewage discharge from the treatment plant, waters of the Białka river are also characterized by significantly lower values of physicochemical parameters. Water temperature is approx. 5.5°C, pH – 7.9 and these values do not change along the course of the river. Mean values of the remaining parameters increase along the course of the river. The mean concentrations of nitrogen and phosphorus compounds are very low, only NO_3^- exceeds 2.5 mg/l.

Changes of bacteriological and physicochemical parameters as a result of the STP modernization

As a result of the conducted modernization of the sewage treatment plant, in terms of bacteriological indicators of water quality, treated sewage discharged to the nearby stream did

Table 1. Characteristics of microbiological indicators of water quality and physicochemical parameters in the sampling sites

Parameter	Unit	Before STP				STP			
		Mean	Min	Max	CV [%]	Mean	Min	Max	CV [%]
Sum of bacteria	CFU/100ml	12 106	21	177 872	226.0	4 754 831	7 064	47 403 638	198.4
Total coliforms	CFU/100ml	4 262	0	95 000	338.3	1 744 214	140	24 860 000	227.3
Total *E. coli*	CFU/100ml	1 990	0	80 000	585.6	823 976	0	6 300 000	198.2
Fecal coliforms	CFU/100ml	1 303	0	22 000	282.3	1 266 057	17	20 380 000	265.2
Fecal *E. coli*	CFU/100ml	485	0	7 000	286.6	664 750	0	6 950 000	244.1
Mesoph. bact.	CFU/ml	518	0	3 620	158.8	120 139	342	2 470 000	324.9
Psychr. bact.	CFU/ml	3 483	0	44 800	242.7	132 005	0	1 750 000	235.2
E. fecalis		22	0	470	321.3	1 841	0	58 760	464.2
T	°C	5.5	-0.1	14.7	84.4	10.7	4.5	18.4	31.3
pH		7.9	6.9	8.3	4.5	7.2	6.3	8.8	6.8
EC	μS/cm	217.8	126.6	300.0	19.1	1 222.8	427.0	1 729.5	26.5
TDS	mg/l	176.4	96.0	235.6	17.7	875.4	345.8	1 295.8	25.1
NH_4^+	mg/l	0.017	0.000	0.071	114.9	20.049	0.000	73.351	118.0
NO_3^-	mg/l	2.661	1.512	5.488	31.8	25.152	0.001	90.912	113.3
NO_2^-	mg/l	0.015	0.000	0.551	545.2	1.676	0.000	18.741	217.6
PO_4^{3-}	mg/l	0.014	0.000	0.192	268.6	13.174	0.125	134.847	153.2
Parameter	Unit	Intake				Trybsz			
		Mean	Min	Max	CV [%]	Mean	Min	Max	CV [%]
Sum of bacteria	CFU/100ml	20 478	250	163 973	174.2	33 319	341	351 077	179.2
Total coliforms	CFU/100ml	8 482	0	112 000	241.1	12 021	0	110 000	198.5
Total *E. coli*	CFU/100ml	2 395	0	44 600	298.5	4 014	0	39 100	212.9
Fecal coliforms	CFU/100ml	2 440	0	30 100	243.7	3 721	0	37 200	213.8
Fecal *E. coli*	CFU/100ml	1 609	0	25 390	298.2	1 335	0	24 000	274.5
Mesoph. bact.	CFU/ml	1 649	10	14 510	177.3	2 467	15	27 500	221.9
Psychr. bact.	CFU/ml	3 790	0	42 600	204.7	9 483	0	312 000	477.4
E. fecalis		38	0	452	243.7	72	0	790	237.2
T	°C	5.3	-0.1	15.0	84.6	5.6	0.0	16.0	86.4
pH		7.9	7.0	8.5	4.5	7.9	6.7	9.2	5.6
EC	μS/cm	224.3	133.7	306.0	20.2	240.9	142.3	322.7	19.5
TDS	mg/l	180.9	100.9	241.6	17.9	191.0	108.2	251.2	17.6
NH_4^+	mg/l	0.061	0.000	0.422	162.2	0.080	0.000	0.585	170.4
NO_3^-	mg/l	2.887	1.508	5.014	31.0	3.188	1.284	6.394	37.4
NO_2^-	mg/l	0.030	0.000	0.683	364.2	0.041	0.000	0.598	247.1
PO_4^{3-}	mg/l	0.063	0.000	0.490	161.8	0.060	0.000	0.490	188.2

not show any significant improvement or change. On the other hand, mean values of physicochemical characteristics (pH, NH_4^+, NO_3^- and NO_2^-) showed significant differences. The pH reaction during the STP start-up and after the modernization was significantly lower than before the modernization works. The concentrations of NH_4^+ and NO_2^- during the start-up period were significantly lower than before the modernization, while the concentrations of NO_3^- – significantly higher. In the case of other physicochemical parameters there were no significant changes found (Fig. 2).

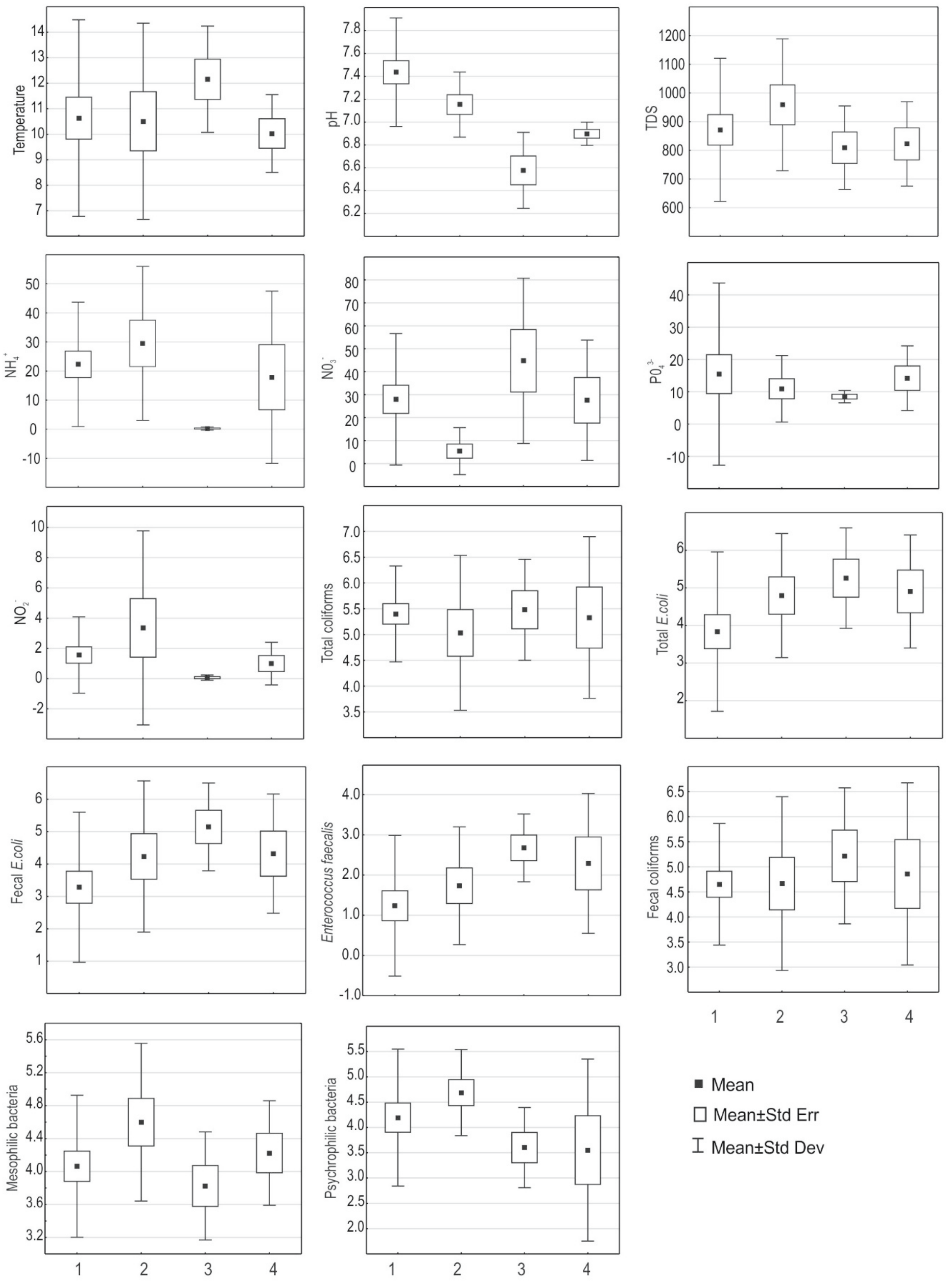

Fig. 2. Values of temperature [°C], pH, TDS [mg/l] and ion concentrations [mg/l] along with the number of bacteria [logCFU/100ml and logCFU/ml] in treated sewage: before modernization (1), during the modernization works (2) during the start-up period (3) and after launching of the modernized STP (4)

Tab. 2 presents the significance of differences in the examined physicochemical and bacteriological parameters of water collected by the discharge from the STP and at two sampling sites located along the Białka river (Intake and Trybsz) between the four considered periods, i.e. before modernization, during the modernization works, during the start-up period and after launching the modernized STP. The *p*-value shows the probability that the observed phenomenon could have been the result of a coincidence, i.e. as a result of the random variation. In Tab. 2 the values of parameters, whose differences between the examined periods were considered significant, are shown in boldface. And so, at the discharge from the STP, there were no significant differences between the examined periods in the case of bacteriological parameters. Significant differences were observed in the case of water pH, NH_4^+, NO_3^- and NO_2^-. Water pH was the highest before the modernization (mean value of c.a. 7.4, Fig. 2), then it decreased during the modernization works to reach lower values during the start-up period (pH 6.6), after which it increased to c.a. pH 6.9. The values of NH_4^+ and NO_2^- showed similar patterns of fluctuation (Fig. 1) – in the period during the modernization works, they were higher than before the modernization, then dropped significantly during the start--up period, to slightly increase afterwards. In the case of NO_3^-, its concentration was much smaller during the modernization, it increased significantly during the start-up and then after launching the modernized treatment plant dropped to the values similar to the one observed before the modernization. At the site Intake, the following parameters of water of the Białka river showed significant differences at individual stages of the STP modernization: total coliforms, total *E. coli*, fecal *E. coli*, mesophilic bacteria, pH, NH_4^+ and PO_4^{3-} (Tab. 2). The values of the mentioned bacteriological parameters were lower before the STP modernization and they increased significantly after the modernization. For instance, the number of total *E. coli* increased from 625 CFU/100 ml before the modernization to 6,994 CFU/100 ml afterwards. The number of fecal *E. coli* increased from 508 before to 5,432 CFU/100 ml in the period during the modernization. Water pH fluctuated – its values were higher in the period before the modernization (pH=8.05), then were lower during the modernization and in the start-up period (pH=7.68), to increase after the modernized STP was launched (pH=7.96). The concentrations of NH_4^+ were high before the modernization (0.09 mg/L) and decreased significantly during the start-up period (below 0.001 mg/L) and after the new STP was launched. On the other hand, the PO_4^{3-} concentrations were the lowest during the STP start-up (0.016 mg/L) but after launching the modernized treatment plant they increased to the highest values (0.13 mg/L). At the site Trybsz, the sum of bacteria, total coliforms, mesophilic bacteria, pH, NH_4^+ and PO_4^{3-} varied significantly between the examined periods. The mean numbers of total coliforms were the highest after the modernized STP was launched, the numbers of mesophilic bacteria were the lowest before the modernization and they increased during the modernization, and never dropped (Fig. 3). The pH values were the highest (c.a. 8.1) before the modernization, then they dropped to c.a. pH 7.5 during the start-up period and increased to c.a. pH 7.9 after the modernized STP was launched. The lowest values of NH_4^+ were observed during the start-up period, while in the case of PO_4^{3-} their lowest values were observed during the modernization and the start-up period (Fig. 3).

Impact of sewage discharge from the treatment plant and the functioning of the ski resort on the quality of water in the Białka river

The observed deterioration in the quality of water in the Białka river after the discharge of sewage from the STP and as a result

Table 2. Results of the ANOVA analysis showing the differences in physicochemical and bacteriological parameters of water from the STP discharge site and at the sampling sites situated on the Białka river, before modernization, during the modernization works, during the start-up period and after launching the modernized STP

Parameter	STP		Intake		Trybsz	
	*F**	*p***	*F**	*p***	*F**	*p***
Sum of bacteria	0.190	0.902	2.248	0.096	**4.079**	**0.012**
Total coliforms	0.183	0.907	**3.027**	**0.040**	**5.976**	**0.002**
Total *E. coli*	1.495	0.229	**3.443**	**0.025**	2.180	0.104
Fecal coliforms	0.343	0.794	0.932	0.433	1.102	0.359
Fecal *E. coli*	1.826	0.157	**3.871**	**0.015**	0.496	0.687
Mesoph. bact.	1.447	0.242	**2.839**	**0.049**	**4.511**	**0.008**
Psychr. bact.	1.875	0.148	0.142	0.934	0.310	0.818
E. faecalis	1.890	0.146	1.794	0.163	0.723	0.544
T	0.580	0.631	1.966	0.133	2.175	0.105
pH	**15.165**	**0.000**	**9.922**	**0.000**	**6.988**	**0.001**
EC	0.797	0.502	0.716	0.548	1.335	0.275
TDS	0.970	0.416	0.470	0.705	1.344	0.273
NH_4^+	**10.827**	**0.000**	**13.030**	**0.000**	**7.310**	**0.000**
NO_3^-	**3.373**	**0.027**	0.533	0.662	1.062	0.375
NO_2^-	**3.762**	**0.017**	0.761	0.522	0.656	0.583
PO_4^{3-}	0.387	0.763	**7.417**	**0.000**	**3.259**	**0.031**

* – the critical value of Fisher-Snedecor test (ANOVA); ** – probability value; Values at which differences are considered significant are set in boldface.

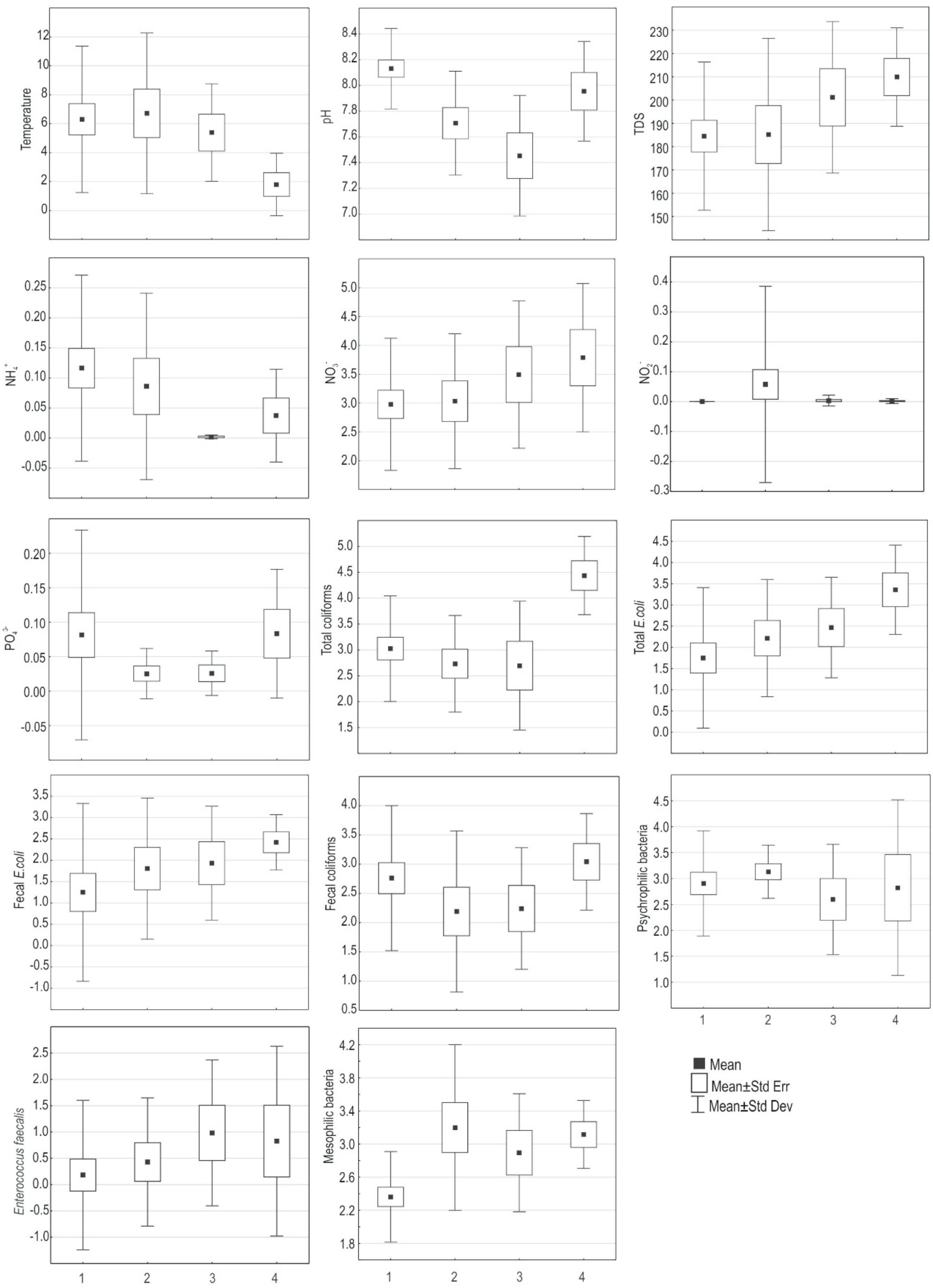

Fig. 3. Values of temperature [°C], pH, TDS [mg/l] and ion concentrations [mg/l] along with the number of bacteria [logCFU/100ml and logCFU/ml] in water at the Trybsz site: before modernization (1), during the modernization works (2) during the start-up period (3) and after launching of the modernized STP (4)

of the supply of untreated sewage from numerous households in the close vicinity of the ski resort was statistically significant. Tab. 3 presents the significance of differences in the examined physicochemical and bacteriological parameters of water collected upstream of the sewage discharge and the samples collected downstream of the discharge from the sewage treatment plant. The values, whose concentrations differed significantly between the site upstream and those downstream of the STP, are set in boldface. The results presented in Tab. 3 show that the quality of water in Białka deteriorated mainly due to the increase in the number of total coliforms, total *E. coli*, fecal coliforms, fecal *E. coli* and mesophilic bacteria. The values of psychrophilic bacteria and *Enterococcus faecalis* did not differ significantly between the examined sites. In terms of physicochemical parameters a significant increase in the water conductivity and in the concentrations of NO_2^- and PO_4^{3-} ions was observed.

The conducted study also allowed to assess whether the concentration of the examined parameters in effluent from the STP changed throughout the year. Fig. 4 shows that the number of total and fecal *E. coli* (bacterial indicators presented as log values) shows similar trends, with the highest values observed in winter and spring months and visibly lowest value in October. The number of *E. faecalis* was also the lowest in October, but it increased significantly in November and its values remained high. On the other hand, the concentration of NO_3^- was the highest in October and the lowest values were observed in August. The NH_4^+ concentrations were higher in winter months, while NO_2^- did not change significantly throughout the year, but – similarly as NO_3^- – its highest value was observed in October.

Table 3. Results of the ANOVA analysis showing the differences in the values of physicochemical and microbiological parameters of water quality for the Białka river upstream and downstream of the sewage discharge from the treatment plant and the ski resort

Parameter	*F**	*p***
Sum of bacteria	**4.783**	**0.0098**
Total coliforms	**8.422**	**0.0004**
Total *E. coli*	**7.159**	**0.0011**
Fecal coliforms	**6.395**	**0.0022**
Fecal *E. coli*	**3.552**	**0.0313**
Mesophilic bacteria	**9.822**	**0.0001**
Psychrophilic bacteria	0.699	0.4989
E. faecalis	1.114	0.3312
Temperature	0.011	0.9895
pH	0.388	0.6792
EC	**3.542**	**0.0316**
TDS	2.771	0.0661
NH_4^+	0.602	0.5490
NO_3^-	2.386	0.0958
NO_2^-	**4.611**	**0.0115**
PO_4^{3-}	**11.060**	**0.0000**

* – the critical value of Fisher-Snedecor test (ANOVA); ** – probability value; Values at which differences are considered significant are set in boldface.

Discussion

Poland is among countries with significant water deficit and is one of the last European countries in terms of the amount of water per capita (Gutry-Korycka et al. 2014), therefore the attention to the quality of water, including microbiological quality, is particularly important for Poland's water resources (Chmiel et al. 2016).

The values of bacterial indicators of poor water quality detected in treated sewage discharged from the municipal sewage treatment plant in the examined region were extremely high. The mean value of fecal *E. coli* was more than 660,000 CFU/100 ml, while the maximum value recorded in this study reached almost 7 million CFU/100 ml. These values are generally higher than the ones observed by other authors, as e.g. Sanders et al. (2013) report that the mean values of *E. coli* in the effluents of STPs analyzed in their study ranged from 231 to 330 CFU/100 ml while the maximum values ranged from 1,600 to 2,400 CFU/100 ml of water. Among Polish studies, Budzińska et al. (2011) report that the treated sewage discharged into the Drwęca river from the STP contain on average $1.9 \cdot 10^2$ CFU/100 ml. The presence of bacterial indicators of poor water quality, such as fecal coliforms or *E. coli*, especially in such high numbers, is a disturbing observation. This is because the presence of *E. coli* in samples of water is still widely recognized as an indication of a heightened risk of the presence of other fecal-borne bacteria and viruses, many of which, such as *Salmonella* or hepatitis A virus, are pathogenic (Brüssow et al. 2004). This is why *E. coli* is commonly used as an indicator organism for water samples that may contain unacceptable levels of fecal contamination (Atlas and Bartha 1993). Another interesting observation in this study is the very high variability of the numbers of bacteria (CV ranging from 198.2 to 324.9%) in the treated sewage discharged to the receiving waters. This is due to the fact that the contamination of water in all examined sites is subjected to considerable fluctuations during the year as a result of the fluctuation of the amount of sewage generated by the tourist traffic of varying intensity in the considered region of the Bukowina Tatrzańska municipality (Lenart-Boroń et al. 2016b). Another reason for such high variability of the results is that there is a significant diurnal variation in the contamination of the stream receiving the effluent from the STP, as well as in waters of the Białka river nearby the discharge point from the STP (Lenart-Boroń et al. 2016a).

The effluent from the sewage treatment plant is characterized by high mean concentrations of nitrogen and phosphorus compounds. And although nutrients are necessary for the growth of all organisms, their excessive concentration in the aquatic environment, for example through their supply from poorly treated sewage, may have adverse effects on human health and may worsen the functioning and ecological conditions of aquatic ecosystems, e.g. through algal blooms or decreasing the dissolved oxygen content. It can be disturbing that the concentration of $N\text{-}NH_4$ has the highest share among all nitrogen compounds. This could indicate an improperly operating treatment plant, in which NH_4^+ should be converted to NO_3^- as a result of the biological treatment process. However, in the effluent from the treatment plant the concentration of $N\text{-}NH_4$ is three times higher than the concentration of $N\text{-}NO_3$. Studies conducted in other treatment plants (Gizińska-Górna et al. 2017, Wąsik et al. 2017) show that the concentrations of ammonium ions are lower and the proportions of $N\text{-}NH_4$ and $N\text{-}NO_3$ are reverse with the concentrations of $N\text{-}NO_3$ significantly exceeding $N\text{-}NH_4$. The mentioned Authors also found that the inflow of treated sewage did not cause significant deterioration of the quality of water in the receiver. On the other hand, Kanownik et al. (2016) found the concentrations

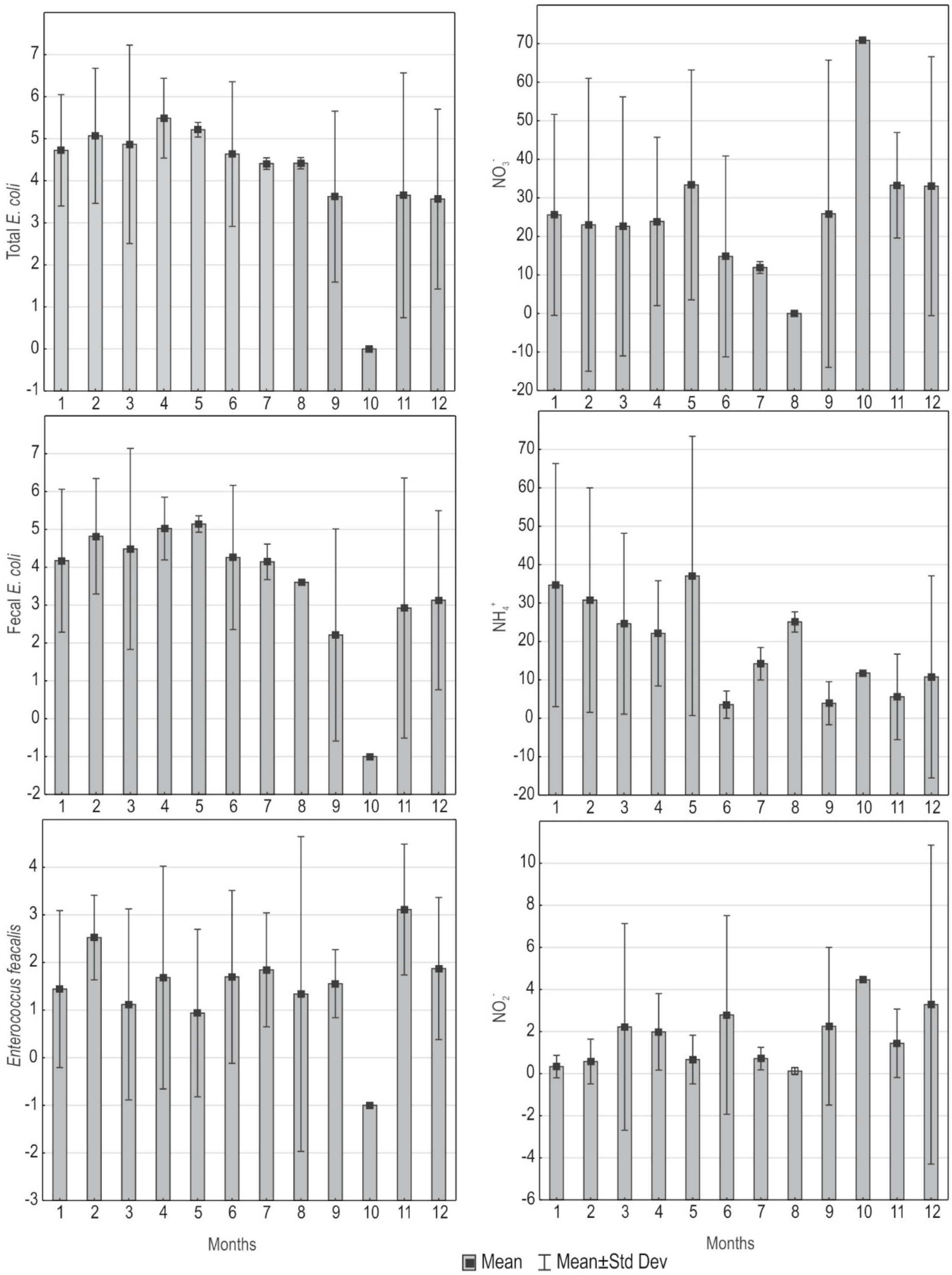

Fig. 4. Values of temperature [°C], pH, TDS [mg/l] and ion concentrations [mg/l] along with the number of bacteria [logCFU/100ml and logCFU/ml] in water at the Trybsz site: before modernization (1), during the modernization works (2) during the start-up period (3) and after launching of the modernized STP (4)

of N-NH_4 in treated sewage exceeding the concentrations of N-NO_3 by multiple times, significantly deteriorating the quality of water in the receiver. Similarly as in the case of bacteriological parameters, also the concentrations of nitrogen and phosphorus compounds are highly variable (CV range from 113.3 to 217.6%). This is related to the varied amount of sewage inflow, resulting mainly from seasonal changes in the number of people served by the treatment plant. The largest load of the treatment plant occurs in the period of the winter tourist season, when the number of tourists exceeds the number of permanent residents by multiple times. Then, the concentrations of nutrients in treated sewage are very high. Also the variability in the nutrient concentration in treated sewage can be affected by the confirmed diurnal fluctuation of the municipal water and therefore sewage discharge (Lenart--Boroń et al. 2016a).

The significantly lower concentrations of pollutants in the sampling sites located downstream of the sewage discharge, even at points located at approximately 3 km downstream of the STP, might indicate a good waste assimilation capacity of the Białka river, i.e. the capability of the receiver to adopt and process a certain amount of sewage and pollutant load (Design considerations for sewage treatment plants 2016, Kanownik and Rajda 2011).

Surface water is used for a wide range of purposes, it is a source of drinking water, it is used for field irrigation or for recreation but in the case of all these purposes bacteriological contamination may cause a health hazard. Microbiological contamination is therefore one of the most important parameters affecting water quality (Chmiel et al. 2016). Our study showed that the modernization of the municipal sewage treatment plant did not result in improved quality of sewage discharged into the receiving stream. This is evident particularly in the case of bacteriological indicators of fecal contamination of water – total and fecal coliforms, as well as total and fecal *E. coli*, whose concentrations even increased both in the effluent from the STP and in the sites downstream. Similarly, Olańczuk-Neyman et al. (2001) observed that the modernization of STP analyzed in their study did not show any significant improvement in microbiological quality of the effluent, even after using highly effective biological processes of sewage treatment. The upgrade of techniques as well as the machinery and equipment of sewage treatment plants allows for highly efficient treatment of sewage in terms of the amount of phosphorus and nitrogen compounds, but it does not ensure proper removal of bacteria (Godela et al. 2017).

Another aspect to consider in terms of the reason for the observed lack of improvement, or even further deterioration in microbiological quality of water after the modernization of the STP, is the constant development of tourist infrastructure in the considered region (Hełdak 2016). The citizens of the studied region are very enterprising. The existing ski resorts are developing constantly – new ski slopes and cross-country skiing routes are prepared, coupled with the development of aprés-ski activities, e.g. spa and wellness (Hełdak 2016). All this might result in further increase in the number of tourists visiting the Bukowina Tatrzańska municipality. The number of citizens of largest ski resort in the municipality, Białka Tatrzańska, is approx. 2,200 while according to Krzesiwo (2016) the number of tourists visiting only the Kotelnica Białczańska ski station in the winter season 2014/2015 reached 318,000 – 342,000 people. Even if the lower number was taken into the calculations, this number is 144 times higher than the number of Białka Tatrzańska inhabitants. Moreover, even though possibly the most accurate estimation of the number of tourists is crucial for the sustainable development of tourist towns, it is an extremely difficult issue (Krzesiwo 2016). The most frequently used method for assessing the number of people visiting Polish tourist destinations was the one based on the registration of persons using collective accommodation facilities. The obtained information is published annually by the Central Statistical Office. Unfortunately, this method does not provide complete data on the size of the tourist traffic and is burdened with a number of disadvantages (Mika and Pitrus 2007). One of the most important ones is that it does not allow for the registration of people visiting the place for one day only, who however also contribute to the amount of produced sewage. In addition, many facilities providing accommodation services in the considered region do not register visitors or the registration is random. The officially registered reception capacity of the accommodation base in Białka Tatrzańska was approx. eight thousand places in 2014. In the winter season this was not sufficient, therefore tourists were forced to stay in neighboring towns (Krzesiwo and Mika 2011). All this suggests that it is also extremely difficult to properly assess the number of population equivalent (PE) for which the newly built or modernized sewage treatment plant should be designed. The most possible explanation for the observed results is that when the modernization was planned the estimated number of tourists visiting the area was much smaller than the actual one that can be observed currently.

Also the observed increase in the values of bacteriological indicators in the sites located downstream of the STP in the period after the modernization could be the result of constantly increasing tourist traffic, coupled with increasing number of accommodation places. This, on the other hand, is not coupled with the development of sewerage system, as still just over half of the households in the municipality is connected to the sewerage system (CSO 2016), for which reason some households and guesthouses illegally discharge untreated sewage directly into the river, for economic reasons.

Before the STP modernization, nutrient removal process was insufficient, as evidenced by high concentrations of ammonium and phosphate ions in the effluent from the treatment plant. The disturbances of the effective operation of the treatment plant in the removal of nitrogen and phosphorus compounds can be influenced by, among others, fluctuations in the temperature, pH and oxygen concentration, the amount and quality of sewage, as well as the problems with activated sludge (Przywara 2017, Sadecka and Mazurkiewicz 2011). The conducted modernization resulted in a clear improvement in the removal of nitrogen compounds from sewage. The concentrations of NH_4^+ in treated sewage decreased, with increased concentrations of NO_3^-. It is disturbing, however, that the phosphorus concentrations, after decreasing in the period of the STP startup, returned to the level observed before the modernization. A general reduction in the effectiveness of biogenic compounds removal from sewage is observed in autumn and winter seasons (Jakubaszek and Płuciennik-Koropczuk 2012). It should also be noted that the winter season is the one when the largest number of people stay in the studied area, producing increased amounts of sewage. This is why an overload of the sewage treatment plant may occur and the ability to remove nitrogen and phosphorus compounds can deteriorate.

The quality of water, particularly the concentration of nitrogen and phosphorus compounds, at the sites situated downstream of the discharge of sewage (Intake, Trybsz) confirms the significant impact of the treatment plant on the deterioration of water quality in the considered area. When the concentrations of NH_4^+ and PO_4^{3-} decreased in treated sewage after the modernization of the STP, i.e. during the startup period, a significant decrease in the concentration of these ions in water of the Białka river was also observed. On the other hand, when the concentrations of PO_4^{3-} in treated sewage increased, there was also an increase in the concentration of these ions in waters of the receiver.

This study showed that the discharge of sewage, as well as the presence of multiple points of untreated sewage inflow into the Białka river, significantly deteriorates its quality. Similarly, as in the case of the analysis of the impact of STP modernization on the quality of water, this was particularly evident in terms of bacteriological indicators. Chmiel et al. (2016) in their study conducted on six major and minor rivers in the Małopolska Voivodeship also observed a significant deterioration of water quality as a result of sewage inflow. Such effect is widely observed, not only in densely populated areas, but also in protected areas which are expected to be least anthropogenically transformed. Both Lewandowska-Robak et al. (2011) in their study conducted in Tuchola, and Frąk (2010) in the study on the quality of water in the Biebrza river valley, which is an extremely valuable natural area covered by many special protection programs, observed deterioration of water quality caused by, among others, uncontrolled discharge of sewage from households.

Conclusions

The results of our study show that the conducted modernization did not improve the microbiological quality of treated sewage discharged into the Białka river. Even though some new solutions were applied, a further deterioration could rather be observed, as evidenced particularly by extremely high concentrations of bacteriological indicators of poor sanitary quality, i.e. coliforms and *E. coli*. The values of physicochemical parameters observed in the treated sewage discharged into the receiving stream were still high, but the modernization process allowed to decrease the values of at least some of them (e.g. temperature, pH, TDS or NH_4^+). The concentrations of phosphorus compounds remained at very high levels. However, the values of the examined contaminants decrease in the site Intake, located a few kilometers downstream of the discharge from the STP, indicating a probable good waste assimilation capacity of the river. The increase in the concentrations of most parameters along the course of the river is also evident, pointing to the presence of multiple sources of sewage discharge from individual households. A statistically significant negative impact of the studied sewage treatment plant on the quality of water in the Białka river was demonstrated in the case of most bacteriological parameters and – in terms of physicochemical ones – for $EC_{25°C}$, NO_2^- and PO_4^{3-}. We also observed that the values of most parameters in the effluent from the STP varied significantly throughout the year, with the lowest levels observed mostly in autumn and the highest in winter and spring.

The observed lack of improvement of the operation effectiveness of the STP could be the result of constantly increasing popularity of the studied region, resulting in rapidly growing number of tourists visiting the area and generating large amounts of sewage causing STP overload. The factor that makes it difficult to properly assess the target efficiency of the modernized STP is the fact that a large number of accommodation places in the considered area are not officially registered, as there are numerous private guesthouses. Another aspect to consider is that even though the municipal sewage treatment plant was modernized, the percentage of households connected to the sewer system increased only slightly, which indicates very poor water and wastewater management and environmental awareness in the studied area.

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Wpływ modernizacji oczyszczalni ścieków na zmiany jakości mikrobiologicznej i fizykochemicznej wody w odbiorniku

Streszczenie: Z powodu niewystarczającej efektywności, badana oczyszczalnia ścieków została poddana modernizacji, a celem badań była ocena czy modernizacja ta poprawiła jakość ścieków wypływających z oczyszczalni i jakość wody w odbiorniku. Okres badań (50 miesięcy) objął czas przed i po modernizacji. Próbki pobrano w czterech punktach – przed i za oczyszczalnią oraz przy zrzucie ścieków. Przewodnictwo elektrolityczne, temperaturę i pH wody mierzono na miejscu. Analizy chemiczne oparto na chromatografii jonowej i oznaczono stężenia NH_4^+, NO_3^-, NO_2^-, PO_4^{3-}, TDS. Analizy mikrobiologiczne obejmowały oznaczenie liczby bakterii mezofilnych i psychrofilnych techniką seryjnych rozcieńczeń oraz filtrację membranową w celu oznaczenia liczebności *E. faecalis*, bakterii grupy coli i *E. coli* całkowitych i kałowych. Wartości większości badanych parametrów nie uległy

poprawie po modernizacji lub poprawiły się na bardzo krótki okres (NH_4^+), natomiast wartości niektórych wzrosły, np. PO_4^{3-}, bakterii grupy coli i *E. coli*. Maksymalną liczebność termotolerancyjnych *E. coli* – niemal 7 milionów jtk/100 ml – stwierdzono w okresie po modernizacji. Również w punktach położonych za oczyszczalnią nastąpił wzrost niektórych analizowanych parametrów. Przeprowadzona modernizacja nie poprawiła jakości mikrobiologicznej oczyszczanych ścieków, a nawet stwierdzono dalsze jej pogorszenie. Może być to wynikiem gwałtownie rosnącej liczby turystów odwiedzających badany region, generujących ogromne ilości ścieków powodujących przeciążenie oczyszczalni, a także może być spowodowane słabą gospodarką wodno-ściekową. Znaczny odsetek turystów, których pobyt nie jest rejestrowany, utrudnia właściwe zaprojektowanie docelowej skuteczności oczyszczalni ścieków.