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Changes in the quality of a small lowland river in Poland under the influence of pollution and a dam reservoir located in its course

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Abstract: The study on a small lowland river was conducted in order to determine changes in water quality under external loading (inflow of treated wastewater, runoff from agricultural areas) and the location of a dam reservoir in its course. The 21 km long River Pogona (Greater Poland, Poland) is a small tributary of the Obra Canal in Kościan. In 2004, in its valley, the Jeżewo Reservoir, with an area of 78 ha, was utilized to supply the flow in the Obra Canal during the dry season and to irrigate agricultural areas. The river is also a receiver of treated sewage from the sewage treatment plant in Karolewo. The research, carried out in 2017 at six sampling stations in its course, showed that the discharge of treated wastewater resulted in an increase in conductivity, concentration of ammonium nitrogen, nitrites and total nitrogen in the waters of the River Pogona. On the other hand, the location of the Jeżewo Reservoir in its course contributed to an increase in water temperature, pH, dissolved oxygen, chlorophyll-a and nitrite concentration in the outflowing river. The results showed that the inflow of treated wastewater from the sewage treatment plant, surface runoff from the catchment area and the Jeżewo Reservoir formed in its course, influenced seasonal and spatial changes in the water quality of the River Pogona.

Key words: river, dam reservoir, nutrients, treatment plant, pollution

Introduction

Water pollution, in addition to flooding and drought, is the most critical problem of water management and environmental protection in Poland, despite the fact that the quality of water in Poland has been systematically improving over the last few years. After 1990, new wastewater treatment plants were built or modernized as a result of which the trend of increasing pollution of the main Polish rivers was halted (Kundzewicz 2010).

Rural areas, especially agricultural districts, are seen as one of the primary sources of pollution and water eutrophication (Sapek 1996). The fertilization of arable land mainly leads to an increase in the nitrogen load flowing out of the fields, as the phosphorus in the soil is relatively low mobile. Heavy rains flush out nitrogen from the surface layer of the soil which flows into river channels and water bodies, contributing to an increase of their productivity (Lampert and Sommer 1996).

Another source of pollution is wastewater from treatment plants, which is discharged to a receiver. These receivers can be surface water or soil. Most often, they are rivers, streams or lakes. Surface waters as sewage receivers, especially in rural areas, may receive a load of pollutants not only from the sewage treatment plant outflow but also from farmland, in the case of agricultural use of sewage (Pawęska and Kuczewski 2009).

Preliminary lowland dam reservoirs, both those overgrown by macrophytes and those dominated by phytoplankton, can be particularly useful in protecting waters from spatial pollution from agricultural areas. However, it is most effective to locate them in areas near agricultural fields as the concentrations of biogenic compounds are the highest there (Ilnicki 1992). Dam reservoirs possess

indirect characteristics between rivers and stagnant waters and their quality depends on the river basin morphology, hydrological conditions, water chemistry, plant and animal worlds and the watercourses supplying the reservoir (Grodzińska-Kujawa and Wrocławska 2004). Lowland dam reservoirs contribute to the reduction of biogenic compounds in the flowing water and can be used for water protection, especially in areas with a large amount of spatial pollution originating from farmland (Gołdyn 2000).

The aim of the study was to determine changes in water quality in a small lowland river under the influence of spatial and point pollution and as a result of its flow through a dam reservoir.

Study area and methods

The River Pogona is a left-hand tributary of the Obra Canal in Kościan, into which it flows at km 82.9. It flows at a prevailing length to the north. The total area of the river basin is 132.5 km^2, the average slope – 1.8 ‰ and the total length – 21 km. It drains areas with very intensive farming and a low degree of forestation. The main tributary of the river is a stream from Gorecznik with a catchment area of 36.4 km^2 (Stachowiak 2003).

In the valley of the River Pogona in the village of Skokówko (near the town of Borek Wielkopolski), the Jeżewo Reservoir is located. It has an area of 78 ha and its volume is 1.6 hm^3. The average depth of the reservoir is 2.3 m and the maximum depth (by the dam) – 7.0 m. The construction of the Jeżewo Reservoir was a continuation of the reconstruction of the water system of the Obra Canal in Kościan valley, completed in 2001. The system enables more effective protection against flooding of agricultural land with an area of 10,000 ha along the Obra Canal in Kościan along a 45 km section, and the water accumulated in the reservoir is used to supply the flow in the Obra channel during the dry season and to irrigate agricultural land. The reservoir was first used in 2003, when its filling began, being completed in spring 2004 (Pelczar 2009).

The functions of the Jeżewo Reservoir are: reduction of the flood risk in the valley of the Obra Canal in Kościan below the estuary of the River Pogona, conducting fishery management, increasing biodiversity in the areas neighboring the reservoir, increasing the level of groundwater on the borders of the reservoir, increasing groundwater retention, increasing the supply of groundwater, fire protection of the adjacent forest areas and reducing the erosion of the River Pogona below the reservoir by leveling the flows (Pelczar 2009). In the area of the Borek Wielkopolski commune there are sewage treatment plants which have an impact on the quality of the River Pogona, supplying the Jeżewo Reservoir. The river receives directly treated wastewater from the treatment plants in Karolewo and smaller ones in Zimnowoda and Wycisłowo. The Karolewo wastewater treatment plant was built in 1997 and then modernized in 2004. As a result of the modernization its capacity increased from 300 to 1026 m^3 d^{-1}. The sewage treatment plant receives sewage from the Meat Processing Plant Mróz, Karolew and Borek Wielkopolski. In turn, the Social Welfare House Zimnowoda sewage treatment plant from 1991 was modernized in 2002. It is a modified SEBIOFIKON treatment plant with an aerated biological bed with a capacity of 8 m^3 d^{-1}, actual 6 m^3 d^{-1}. Another one is the sewage treatment plant at the Primary School in Zimnowoda, constructed in 2000. Its maximum capacity is 10.7 m^3 d^{-1}, the actual capacity is 15.7 m^3 d^{-1}. The last one is the treatment plant for the Wycisłowo Primary School with a capacity of 4 m^3 d^{-1} and an actual capacity of 3 m^3 d^{-1}. It was built in 2003 and is based on mechanical, biological and chemical processes (Anon. 2005).

The study of water quality of the River Pogona and the surface layer of the Jeżewo Reservoir was conducted in 2017. Surface water sampling was conducted once a month in the period from January to December on six sampling stations (Fig. 1). Station 1 was located on the River Pogona 100 m before the outflow of treated wastewater from the treatment plant in Karolewo. Station 2 was located just by their outflow while station 3 was located 100 m behind the treatment plant. Station 4 was located on the River Pogona in Skokówko, ahead of the mouth of the river to the Jeżewo Reservoir. Station 5 was the Jeżewo Reservoir and station 6 was the River Pogona flowing out of the reservoir.

At all sampling stations water temperature and conductivity were measured with a Hanna Combo meter directly in the field. The value of pH, water oxygen saturation and dissolved oxygen concentration in water was measured with WTW Multi 350i.

In the water samples collected from the River

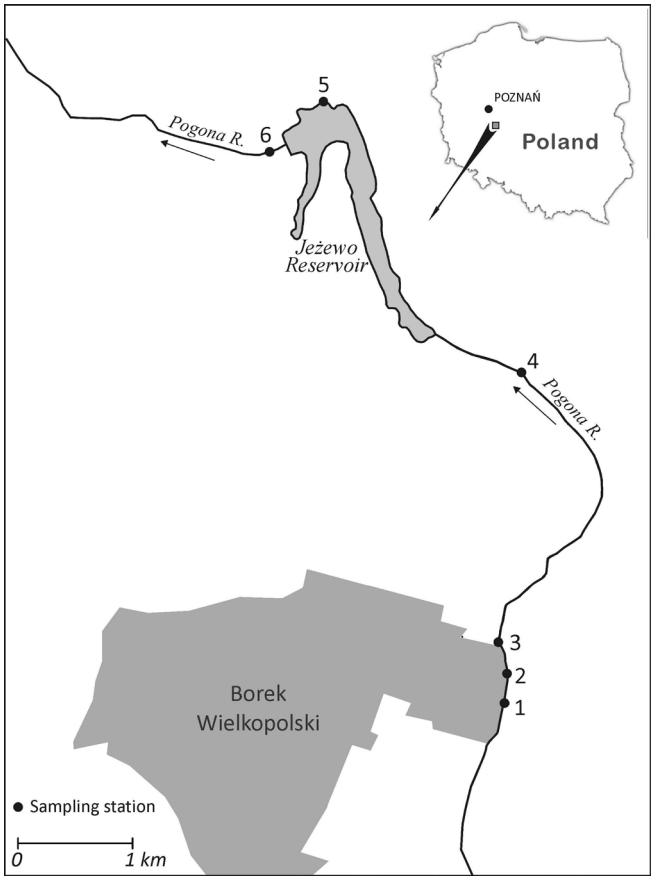

Fig. 1. Location of sampling stations

Pogona and the Jeżewo Reservoir, the concentrations of phosphorus (orthophosphates and total phosphorus), nitrogen (ammonium, nitrite, nitrate, organic and total nitrogen), chlorophyll-a concentration, total suspended soils and biochemical oxygen demand (BOD_5) were determined. The analyses were done in accordance with Polish Standards (Elbanowska et al. 1999).

The assessment of the ecological state of the River Pogona and the Jeżewo Reservoir was carried out on the basis of the Regulation of the Minister of Environment on the classification of the state of surface water bodies and environmental quality standards for priority substances (MŚ RP 2016).

Results

During the study, the water temperature at the analyzed stations ranged from 0.9°C (January, st. 1) to 25.4°C (July, st. 5) (Fig. 2A). Comparing the average temperature values of the River Pogona and the surface layer of the Jeżewo Reservoir, it was found that the highest temperature occurred at station 2 – at the outflow of treated wastewater from the treatment plant in Karolewo (15.24 ±5.07°C) and the lowest at station 1 (10.91 ±6.86°C). As a result of the flow of the River Pogona through the Jeżewo Reservoir and the inflow of treated wastewater, the temperature of water in the river increased (Fig. 3A). However, no statistically significant differences in temperature between individual stations were found (Kruskal-Wallis test $p > 0.05$).

The pH value at the analyzed stations varied between 7.0 and 8.4. The highest value was recorded in December at stations 5 and 6 and the lowest in May at station 1 (Fig. 2B). In the river course, similar pH values were observed at stations 1-4. An increase of pH was observed in the surface waters of the Jeżewo Reservoir. However, the differences between individual stations were not statistically significant (Kruskal-Wallis test $p > 0.05$) (Fig. 3D).

The highest value of electrolytic conductivity was observed in January at station 2 – 3350 µS cm^{-1}. Values above 1800 µS cm^{-1} were found at this station throughout the whole study period. The minimum was recorded in February at station 5-283 µS cm^{-1} (Fig. 2C). With the course of the river, electrolytic conductivity increased significantly at the station at the outlet of treated wastewater, where the highest mean value was recorded (2817 ±500 µS cm^{-1}), which then decreased. The lowest mean value was recorded in the surface waters of the Jeżewo Reservoir (856.2 ±261 µS cm^{-1}). The differences between the analyzed stations were statistically significant (Kruskal-Wallis test $p < 0.05$). As a result of the flow of the River Pogona through the Jeżewo Reservoir, a decrease in this parameter was observed at the outflow, and the inflow of treated wastewater led to its increase (Fig. 3B).

The concentration of dissolved oxygen in the River Pogona and on the surface of the Jeżewo Reservoir ranged from 6.8 (July, st. 1) to 13.92 mg O_2 dm^{-3} (January, station 6). The highest concentrations of this indicator were observed in the autumn-winter period and lower in the summer (Fig. 2d). The analysis of mean values at individual stations showed that in the place of sewage outlet the amount of oxygen was slightly decreased (9.53 ±1.2 mg O_2 dm^{-3}) and as a result of river flow through the reservoir, it increased (10.63 ±1.67 mg O_2 dm^{-3}) (Fig. 3C). The differences between individual sampling stations were not statistically significant (Kruskal-

Wallis test $p > 0.05$).

The highest concentration of ammonium nitrogen was observed in January at station 2, when it was 14.21 mg $N\text{-}NH_4$ dm^{-3} and the lowest concentration was noted in December at station 4 – 0.26 mg $N\text{-}NH_4$ dm^{-3} (Fig. 4A). Comparing the mean levels of this form of nitrogen it was found that the highest values were characteristic of the waters of the River Pogona at the inflow of treated wastewater (station 2 – 3.0±3.93 mg $N\text{-}NH_4$ dm^{-3}) and the lowest in the surface waters of the Jeżewo Reservoir (station 5 – 0.56 ±0.19 mg $N\text{-}NH_4$ dm^{-3}). As a result of the flow of the River Pogona through the Jeżewo Reservoir a decrease of ammonium nitrogen concentration was observed and the supply of sewage from the treatment plant caused its increase (Fig. 6A). The differences between the studied sampling stations were statistically significant (Kruskal-Wallis test $p < 0.05$).

The concentration of nitrite nitrogen at individual sampling stations during the period of the study showed quite a distinct variability. The maximum was noted in July at station 3 – 0.153 mg $N\text{-}NO_2$ dm^{-3}, the minimum in August at station 5 – 0.002 mg $N\text{-}NO_2$ dm^{-3}. Higher concentrations of nitrites were found at most of the sampling stations in the summer (Fig. 4B). The highest mean value of this form of nitrogen was observed at station 3 (0.060 ±0.041 mg $N\text{-}NO_2$ dm^{-3}) and the lowest at station 4 (0.019 ±0.017 mg $N\text{-}NO_2$ dm^{-3}), located in the River Pogona behind the outlet of treated wastewater and at the inflow to the Jeżewo Reservoir (Fig. 6B). Both the sewage inflow and the location of the dam reservoir in its course contributed to an increase in concentrations of this form of nitrogen in the waters of the River Pogona and the differences between the analyzed stations were statistically significant (Kruskal-Wallis test $p < 0.05$).

During the study period, higher nitrate concentrations were characterized by colder seasons of the year and lower during the summer months. The maximum concentration was noted in December at station 3 – as much as 40.81 mg $N\text{-}NO_3$ dm^{-3} and the minimum in September at station 5 amounting 0.17 mg $N\text{-}NO_3$ dm^{-3} (Fig. 4C). Comparing the mean values at sampling stations it was found that the minimum was observed at the outlet of treated wastewater (station 2 – 8.31 ±4.21 mg $N\text{-}NO_3$ dm^{-3}) and the maximum at the next sampling station (station 3 – 16.8 ±12.1 mg $N\text{-}NO_3$ dm^{-3}). As a result

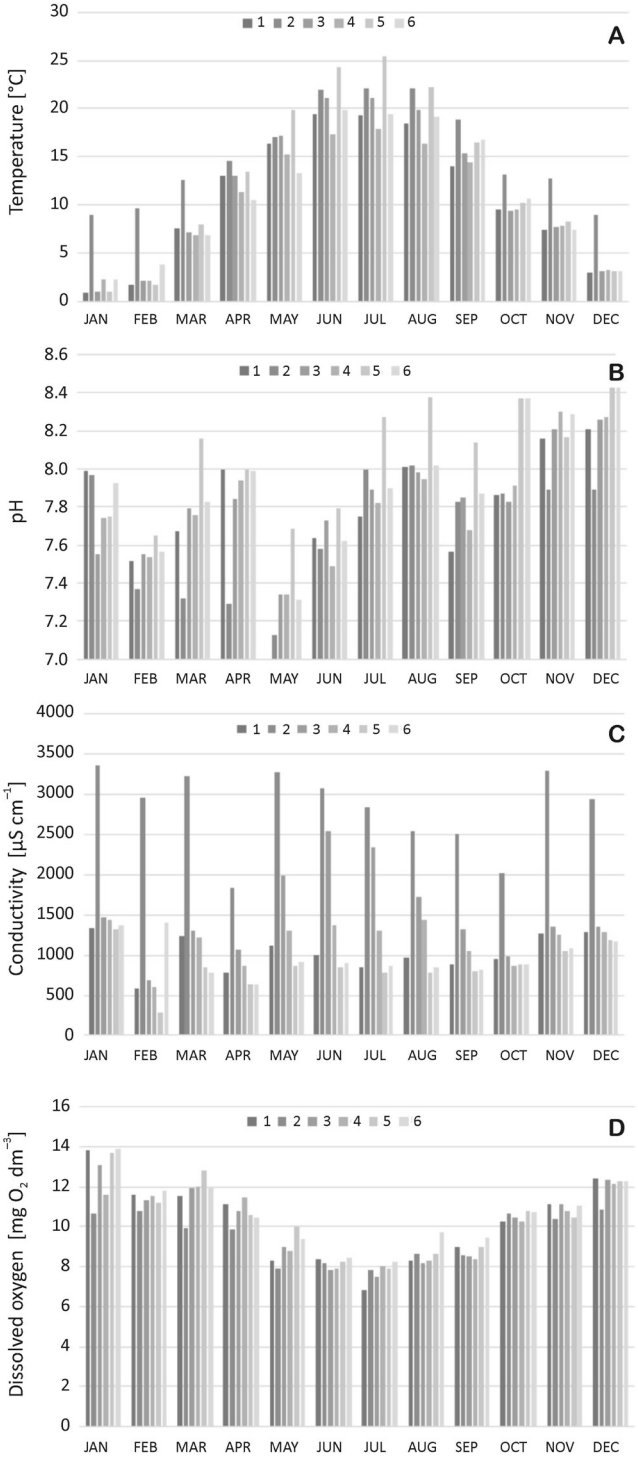

Fig. 2. Changes in the temperature (A), pH (B), conductivity (C) and dissolved oxygen concentration (D) of the River Pogona and surface layer of the Jeżewo Reservoir during the study at individual sampling stations

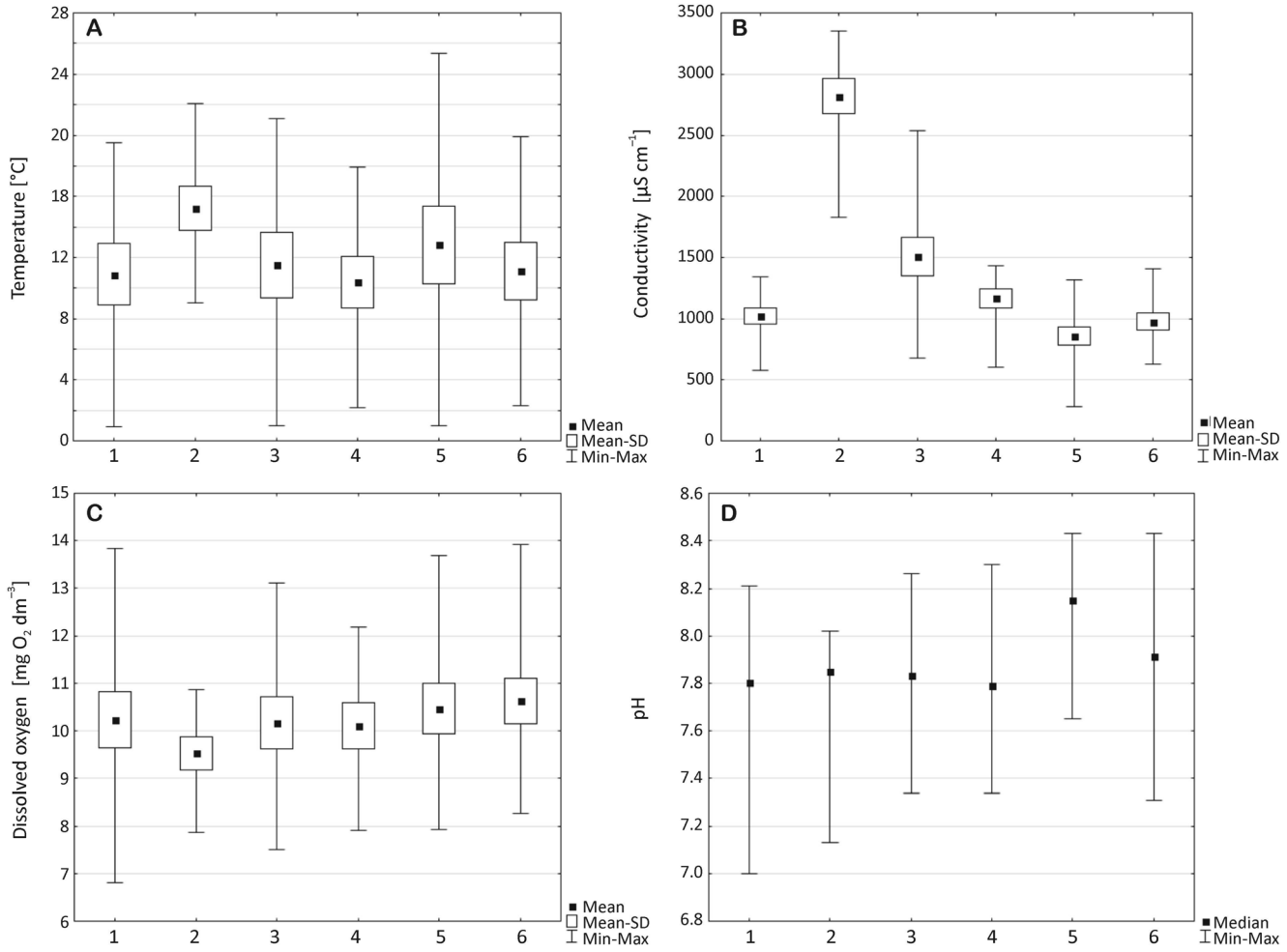

Fig. 3. Minimum, maximum and mean values of water temperature (A), conductivity (B), dissolved oxygen (C) and pH (median) (D) at individual sampling stations during the study period

of the flow of the River Pogona through the Jeżewo Reservoir the concentration of this form of nitrogen decreased (Fig. 6C). Moreover, no statistically significant differences between the analyzed stations were found (Kruskal-Wallis test $p > 0.05$).

In the waters of the River Pogona and the Jeżewo Reservoir the concentrations of organic nitrogen were significantly higher between June and October. An exception was station 2 in January (outflow from the sewage treatment plant), when a maximum of 9.08 mg N dm^{-3} was recorded. In the remaining seasons the concentrations of organic nitrogen did not exceed 4.2 mg N dm^{-3} (Fig. 4D). When analyzing the mean concentrations of this form of nitrogen at individual stations the highest levels were found at station 2 (sewage outlet from the treatment plant) amounting 3.04 ±2.2 mg N dm^{-3} and the lowest at the outflow from the Jeżewo Reservoir (1.63 ±0.7 mg N dm^{-3}) (Fig. 6D).

The content of mineral nitrogen in the period of the study showed seasonal variability. Significantly lower concentrations of this form of nitrogen were observed in summer (VI-IX) and were higher in colder seasons. Nitrates were the dominant form in all months. The concentration of mineral nitrogen varied from 0.66 (September, station 6) to 41.25 mg N dm^{-3} (December, station 3) (Fig. 5A). The minimum mean concentration of this mineral form was recorded at station 2, at the outlet of treated wastewater (11.4 ±4.22 mg N dm^{-3}) and the maximum at the next station (18.7 ±11.8 mg N dm^{-3}) (Fig. 6E). At all sampling stations the dominant form was nitrate nitrogen (about 90%) and the share of the ammonium form did not exceed 10%, except for station 2, where it reached 25% (Fig. 5B).

Total nitrogen concentrations ranged widely

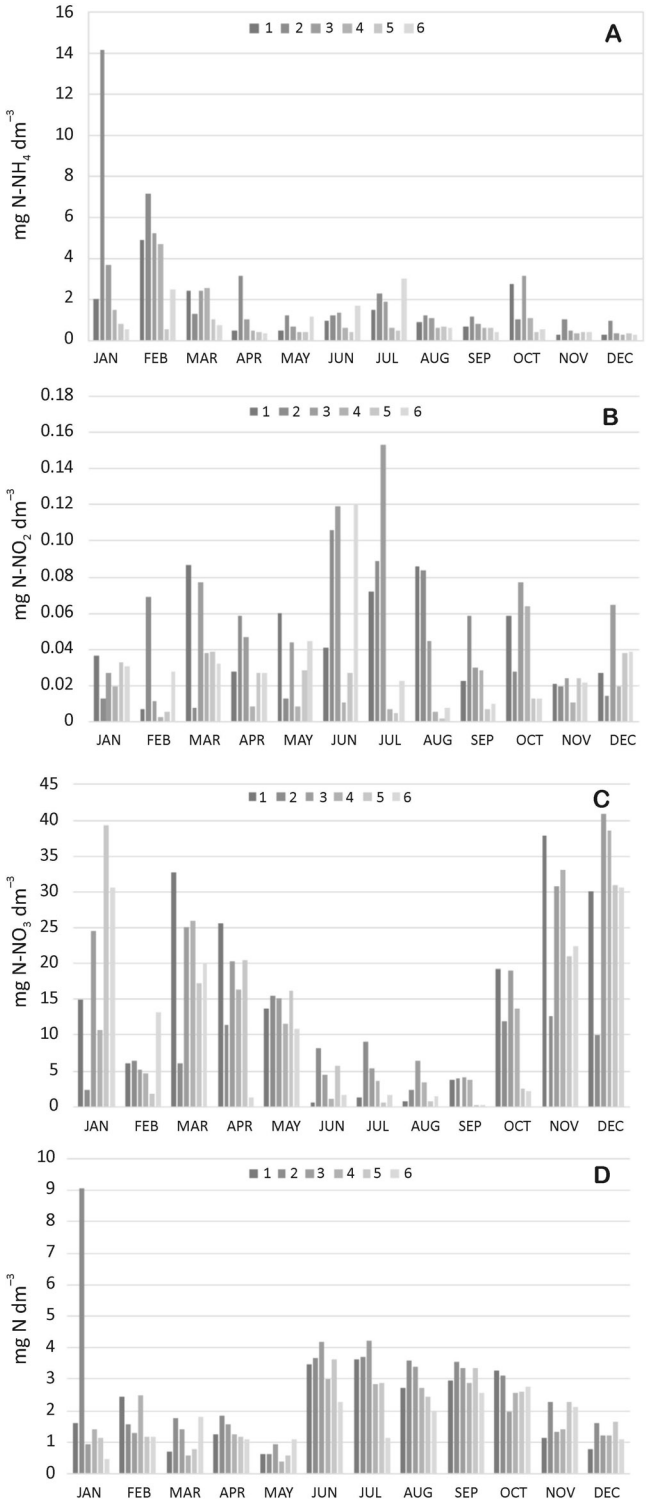

Fig. 4. The concentration of ammonium nitrogen (A), nitrite nitrogen (B), nitrate nitrogen (C) and organic nitrogen (D) during the study at the analyzed sampling stations

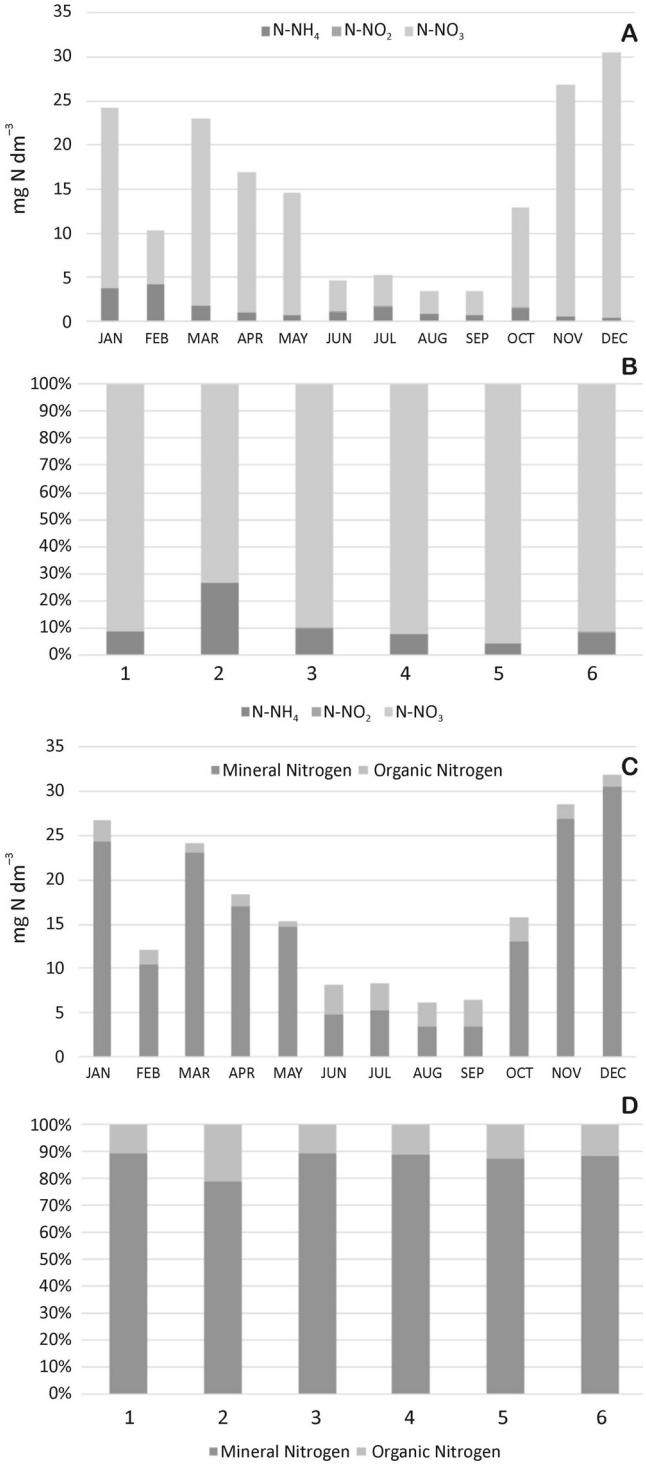

Fig. 5. Changes of the concentration of mineral nitrogen (A) and total nitrogen (C) during the study period and the mean share of their individual forms at the analyzed sampling stations (B, D)

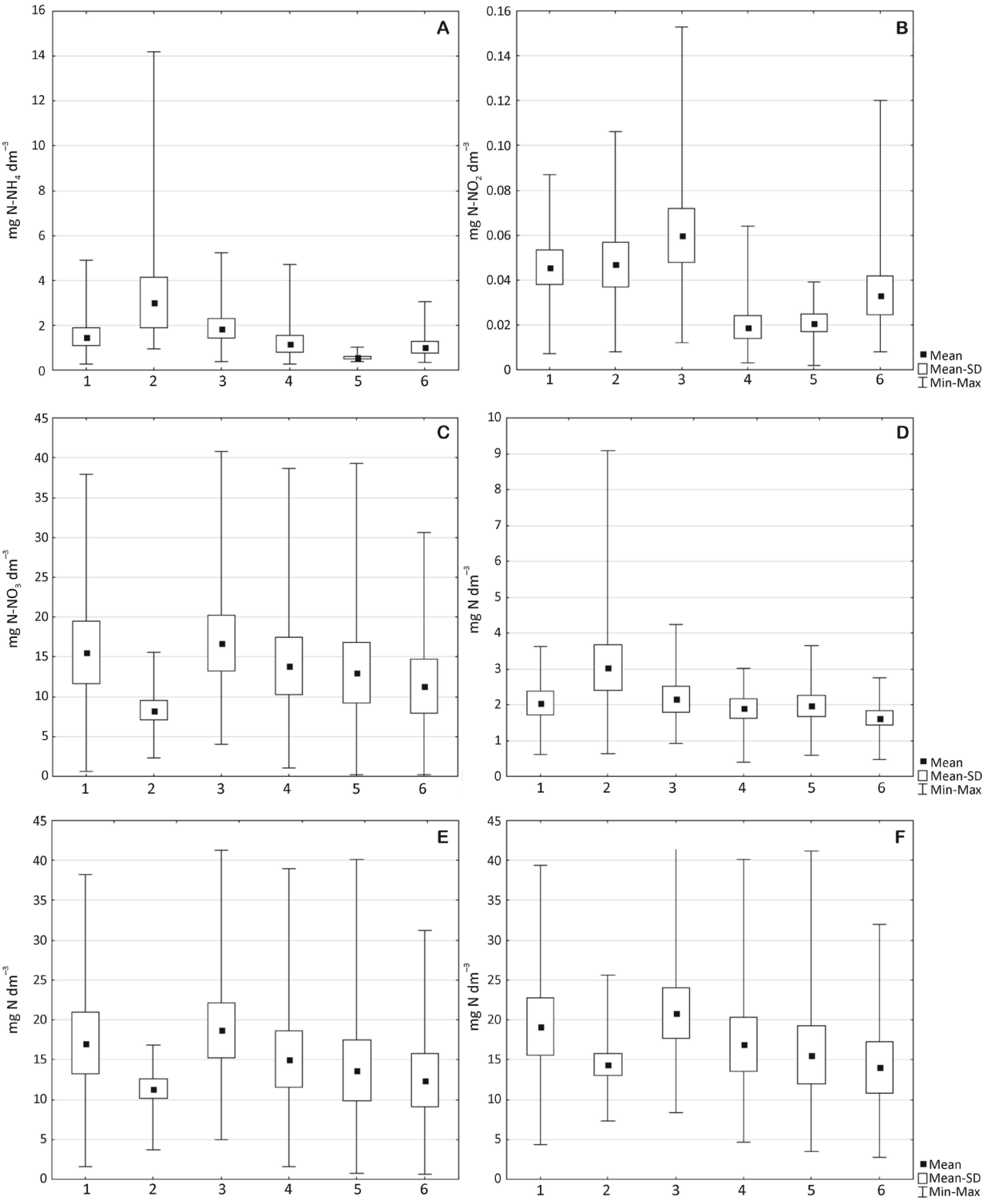

Fig. 6. Mean concentration of ammonium nitrogen (A), nitrites (B), nitrates (C) organic nitrogen (D), mineral nitrogen (E) and total nitrogen (F) in the River Pogona and Jeżewo Reservoir

from 2.8 (station 6 – April) to 42.5 mg N dm^{-3} (station 3 – December). Higher concentrations were found from January to May and from October to December. In summer, on the other hand, it remained at a lower level, not exceeding 15.4 mg N dm^{-3}. When analyzing the mean share of its individual forms it was found that mineral nitrogen dominated throughout the whole study period and at all sampling stations (Fig. 5C-D). However, when comparing the mean concentrations of its forms at the stations situated in the river course it was found that the highest value occurred at station 3 (20.9 ±10.9 mg N dm^{-3}) and the lowest at station 6 (14.0 ±11.2 mg N dm^{-3}) (Fig. 6F). As a result of the flow through the Jeżewo Reservoir, total nitrogen concentrations decreased, and the inflow of treated sewage led to its increase in the waters of the River Pogona.

During the study period significant fluctuations in orthophosphate concentrations were observed in the waters of the River Pogona and the Jeżewo Reservoir. Lower values were found in the period from January to May and in November and December, when they did not exceed 0.73 mg P dm^{-3}. The minimum value was found in April at station 6 (outflow of the River Pogona from the reservoir) – 0.001 mg P dm^{-3}. On the other hand, the period from June to October, when the maximum was 2.55 mg P dm^{-3} (station 2), was characterized by higher concentrations (Fig. 7A). When comparing the mean values of individual sampling stations, the highest level was stated at station 1 (0.688 ±0.62 mg P dm^{-3}) and the lowest at station 5, i.e., the Jeżewo Reservoir (0.12 ±0.11 mg P dm^{-3}) (Fig. 8A). The concentration of orthophosphates decreased as a result of flow through the Jeżewo Reservoir.

The concentration of total phosphorus during the study period on the River Pogona and the Jeżewo Reservoir varied from 0.032 to 2.70 mg P dm^{-3}. The maximum value was recorded in October at station 3 and the minimum in February at station 5 and in April at station 6 (Fig. 7B). When considering the variability of particular stations, it was found that the highest mean concentration of total phosphorus was recorded at station 1 (0.76 ±0.65 mg P dm^{-3}) and the lowest at station 6 (0.18 ±0.17 mg P dm^{-3}). As a result of the flow of the River Pogona through the dam reservoir the total phosphorus content significantly decreased (Fig. 8B).

The concentration of chlorophyll-a at all sampling stations in the River Pogona was seasonally

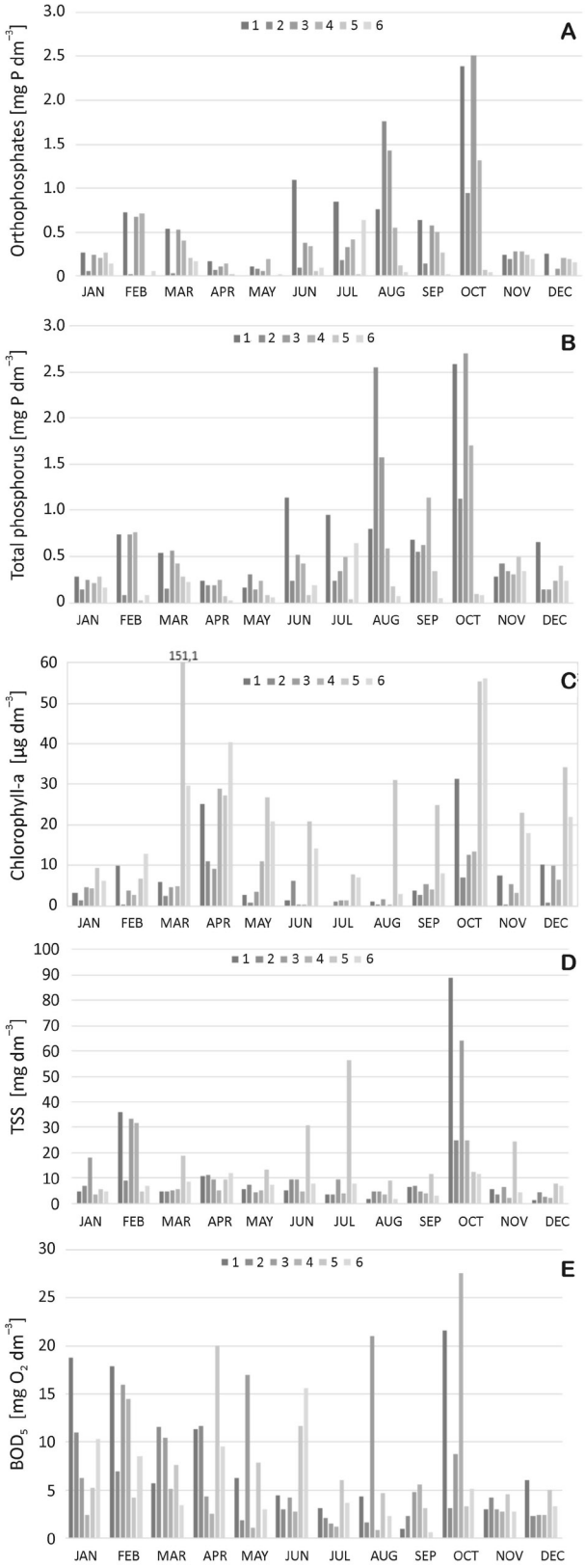

Fig. 7. Changes of concentration of orthophosphates (A), total phosphorus (B), chlorophyll-a (C), total suspended solids (D) and BOD_5 (E) during the study period at individual sampling stations

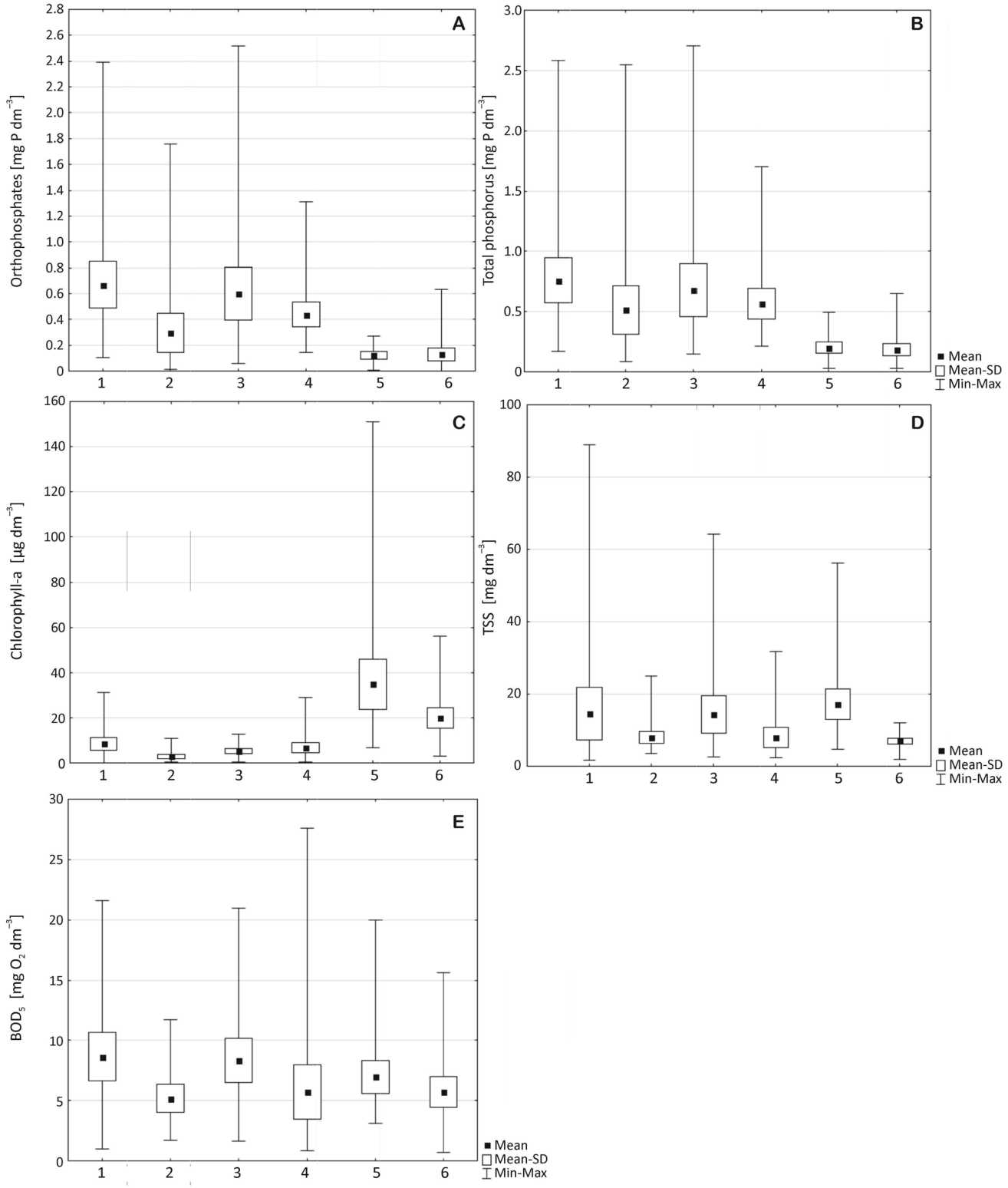

Fig. 8. Minimum, maximum and mean concentrations of orthophosphates (A), total phosphorus (B), chlorophyll-a (C), total suspended solids (D) and BOD_5 (E) at individual sampling stations during the study period

changed. In spring and autumn the content of this pigment was slightly higher, reaching 56.13 μg dm^{-3} at station 6, than in summer when it did not exceed 31.07 μg dm^{-3}. The highest concentration during the whole study period was observed in March at station 5 (Jeżewo Reservoir) – 151.08 μg dm^{-3}. The minimum concentration was noted in July at station 1 (0 μg dm^{-3}) (Fig. 7C). The lowest mean concentration of chlorophyll-a was found at station 2 (2.89 ±3.5 μg dm^{-3}) and the highest at station 5 (35.9 ±38.9 μg dm^{-3}) (Fig. 8C). The differences between the analyzed sampling stations were statistically significant (Kruskal-Wallis test $p < 0.05$) and as a result of the flow of the River Pogona through the reservoir the value of chlorophyll-a increased.

The highest level suspended solids were observed in October at station 1, when it reached as much as 89 mg dm^{-1} and the lowest in November and December at station 4 (inflow of the River Pogona to the Jeżewo Reservoir) – 2.4 mg dm^{-3} (Fig. 7D). When considering the mean number of suspended solids stations, it was found that the minimum occurred at station 4 (8.1 ±9.6 mg dm^{-3}) and the maximum at station 5 (17.1 ±14.5 mg dm^{-3}) (Fig. 8D). The differences between the analyzed sampling stations were statistically significant (Kruskal-Wallis test $p < 0.05$).

The values of BOD_5 during the research period varied quite significantly. A minimum of 0.68 mg O_2 dm^{-3} was noted at station 6 in September and a maximum of 27.6 mg O_2 dm^{-3} in October at station 4 (Fig. 7E). The highest mean value of BOD_5 during the whole study period was recorded at station 1 (8.63 ±7.0 mg O_2 dm^{-3}) and the lowest at station 2 (5.16 ±4.0 mg O_2 dm^{-3}) (Fig. 8E).

The assessment of the ecological state of the River Pogona (stations 1-4 and 6) carried out on the basis of selected physicochemical parameters (MŚ RP 2016) showed that at all sampling stations in class I there were only two parameters: water temperature and dissolved oxygen. At stations 4 and 6 in class I there were also suspended solids and at station 6 – total phosphorus. In class II there were 2 parameters (station 1 – suspended solids, station 4 – nitrite nitrogen). The majority of parameters at all sampling stations exceeded the norms defined for class II of water quality (MŚ RP 2016) – BOD_5, electrolytic conductivity, pH, ammonium nitrogen, Kjeldahl nitrogen, nitrate nitrogen, nitrite nitrogen, total nitrogen, orthophosphates, total phosphorus (Table 1). In the Jeżewo Reservoir (surface water, station 5), there was only one parameter in class I – dissolved oxygen, while the others exceeded the norms defined for quality class II (Table 2).

Table 1. Assessment of the ecological state of the River Pogona on the basis of selected biological and physico-chemical parameters

Parameter	Station 1		Station 2		Station 3		Station 4		Station 6	
	Mean	Class	Mean	Class	Mean	Class	Mean	Class	Mean	Class
Temperature [°C]	10.9	I	15.2	I	11.5	I	10.4	I	11.1	I
Suspended solids [mg dm^{-3}]	14.6	II	8.03	I	14.38	II	8.05	I	6.97	I
Oxygen [mg O_2 dm^{-3}]	10.2	I	9.5	I	10.2	I	9.2	I	10.6	I
BOD_5 [mg O_2 dm^{-3}]	8.6	>II	5. 2	>II	8.3	>II	5.8	>II	5.7	>II
Conductivity [μS cm^{-1}]	1022	>II	2817	>II	1509	>II	1166	>II	975	>II
pH	7.0-8.2	>II	7.1-8.0	>II	7.3-8.3	>II	7.3-8.3	>II	7.3-8.4	>II
Ammonium-nitrogen [mg N dm^{-3}]	1.69	>II	3.0	>II	2.05	>II	1.37	>II	1.25	>II
Kjeldahl-nitrogen [mg N dm^{-3}]	3.73	>II	6.04	>II	4.20	>II	2.94	>II	2.88	>II
Nitrate [mg N-NO_3 dm^{-3}]	15.56	>II	8.3	>II	16.79	>II	13.91	>II	11.32	>II
Nitrite [mg N-NO_3 dm^{-3}]	0.044	>II	0.050	>II	0.059	>II	0.019	II	0.33	>II
Total nitrogen [mg N dm^{-3}]	19.3	>II	14.4	>II	21.0	>II	17.2	>II	14.3	>II
Orthophosphate [mg PO_4 dm^{-3}]	2.04	>II	0.91	>II	1.83	>II	1.57	>II	0.40	>II
Total phosphorus [mg P dm^{-3}]	0.76	>II	0.51	>II	0.68	>II	0.57	>II	0.18	I

Table 2. Assessment of the ecological potential of the Jeżewo Reservoir (surface water) on the basis of selected biological and physico-chemical parameters

Parameter	Station 5 (Jeżewo Reservoir)	
	Mean	Class
Oxygen [mg O_2 dm^{-3}]	10.47	I-II
Conductivity [μS cm^{-1}]	856	>II
Total nitrogen [mg N dm^{-3}]	15.85	>II
Total phosphorus [mg P dm^{-3}]	1.198	>II

Discussion

The results showed how the inflow of treated wastewater from the sewage treatment plant, surface runoff from the catchment area and the dam reservoir formed in its course influence the quality of river waters.

The temperature of the River Pogona waters at individual research stations changed typically on a seasonal basis. However, an anthropogenic increase of this parameter was observed in the river course as a result of the discharge of treated wastewater from the treatment plant (station 2) and a natural change caused by the flow through the dam reservoir (station 5). The location of the shallow dam reservoir in the river course significantly modifies the thermal system of lowland rivers, increasing the mean, minimum and maximum values of water temperatures (Kajak 2001; Łaszewski 2015; Starmach et al. 1978), as was observed at the last sampling station located at the outflow from the reservoir.

The waters of the River Pogona and the Jeżewo Reservoir were characterized by a weakly alkaline pH at all research stations. The highest values were noted in the surface layer of the reservoir throughout the whole research period. This was caused by more intensive primary production here than in the river (Gołdyn 2000), as was confirmed by the observed concentrations of chlorophyll-a. Phytoplankton in the dam reservoir develops faster due to a longer retention time (Górniak and Kajak 2020). The maximum at this station was found in March, as a result of the spring phytoplankton bloom. Increased values of chlorophyll-a were also observed in August-October, caused by intensive primary production, higher than in the waters of the River Pogona. High concentrations of chlorophyll-a in the surface water of the Jeżewo Reservoir could also be evidence of its increased eutrophication. On the other hand, very low concentrations of this parameter were observed at the sewage outlet, where they did not exceed 11.07 μg dm^{-3} during the whole study period. This may indicate a negative effect of the sewage discharged on the growth of phytoplankton.

Another important parameter was the suspended soils, which also changed seasonally and at individual stations located in the river course. An unusual, very high level of suspended solids were observed in October at stations 1-4, with a maximum of 89 mg dm^{-3}. Such high values in that period were caused by the hurricane Grzegorz, occurring over this region of Poland, which, apart from strong wind, was accompanied by intensive precipitation which contributed to the inflow of a significant amount of suspended matter from the catchment area. On the other hand, during the whole study period (except for October), a higher content of suspended solids was observed in the Jeżewo Reservoir than in the River Pogona; a result of intensive primary production. The growing phytoplankton then exceeded the number of sedimentary suspensions transported with the tributary waters (Gołdyn 2000). In spring, quite a high content of suspended solids in the reservoir was caused by phytoplankton bloom, which was confirmed by the high concentration of chlorophyll-a and in summer by the presence of significant numbers of Rhizopods.

A significant influence of the inflow of treated wastewater on the quality of river waters was observed on the basis of changes in electrolytic conductivity. Its highest values were found at the place of inflow to the River Pogona of treated sewage from the treatment plant. With the course of the river up to the reservoir itself, the values of electrolytic conductivity decreased as a result of the process of self-treatment of river waters and dilution with

waters flowing from the catchment (Górniak and Kajak 2020). Similar variability was observed in the waters of the Jaszczurówka Stream (Kanownik and Rajda 2011). In the surface waters of the Jeżewo Reservoir conductivity was the lowest of all the analyzed stations during the whole study period, as a result of the consumption of nutrients by the growing phytoplankton. This has also been observed in other rivers and dam reservoirs created in their course (Wiejaczka 2011). In turn, the high values of this parameter in river waters already at station 1 were probably related to the inflow of mineral compounds from agricultural areas, especially in spring (Górniak and Kajak 2020).

The waters of the River Pogona were well oxygenated during the study period. In summer, the concentration was slightly lower than in winter, which was due to its shading and the consumption of this element in the decomposition processes (Allan 1998). In turn, as a result of the flow of the River Pogona through the dam reservoir an increase in oxygenation was observed which resulted from the intensive photosynthesis process carried out by phytoplankton organisms. Such a situation was also found in the waters of the Antoninek reservoir (Gołdyn et al. 2008). On the other hand, a slight decrease in the dissolved oxygen content in river water was observed below the outflow of wastewater from the treatment plant, which indicates a lower oxygen content in the treated wastewater or an increased oxygen uptake by microorganisms. Similar variability was found in Struga Kwilecka (Staniszewski et al. 2017). On the remaining river stations located behind the wastewater discharge the amount of oxygen increased as a result of self-treatment processes (Jarosiewicz 2007).

Biochemical oxygen demand (BOD_5) is a common indicator used to determine the concentration of organic pollutants in wastewater and to assess the performance of wastewater treatment plants and the biochemical processes taking place in them (Hermanowicz et al. 1999). The inflow of treated wastewater did not increase the value of this indicator in river waters, thus indicating the high efficiency of wastewater treatment. Relatively low values of this indicator near the outlet of treated wastewater (5.16 mg O_2 dm^{-3} on average) meant that organic matter flowing into the treatment plant was mineralized. These values were similar to those observed in treated wastewater reaching the River Raba (Miernik et al. 2016). In turn, as a result of the flow of the River Pogona through the reservoir, this parameter increased slightly in its surface waters as a result of higher primary production in stagnant waters than in flowing ones (Gołdyn 2000).

The highest mean concentration of ammonium nitrogen of all sampling stations was found at the station at the outflow from the sewage treatment plant, while at the next ones it was decreased. A similar process of water self-treatment was observed in the Jaszczurówka Stream and the ditch which is a tributary to the Obra and Struga Kicz rivers (Dondajewska et al. 2017; Kanownik and Rajda 2011; Lewandowska-Robak et al. 2011). Ammonium nitrogen occurs in wastewater due to the decomposition of organic nitrogen compounds. Ammonia content in urban wastewater may vary from several to several dozen mg dm^{-3} (Hermanowicz et al. 1999) and as a result of its treatment its amount decreases. In treated wastewater flowing into the River Pogona, only once in winter was a very high concentration of this form of nitrogen noted, which was most likely due to the reduced capacity of the plant to remove the ammonia form as a result of low temperatures (Bugajski 2011). The decrease in the concentration of the ammonium form further down the river was caused by nitrification processes under good oxygenation conditions. On the other hand, in the surface waters of the dam reservoir, the concentration of ammonia nitrogen was the lowest of all research stations which was related to the use of this compound by plankton organisms and the nitrification process under conditions of good oxygenation of its surface waters (Kajak 2001; Gołdyn 2000). The highest concentrations of nitrites were observed during the whole period of study at sampling stations located at the outflow and 100 m after the outflow of treated sewage from the treatment plant. Unpolluted waters usually contain less than 0.01 mg $N\text{-}NO_2$ dm^{-3} but when contaminated their content may increase to about 0.05 mg $N\text{-}NO_2$ dm^{-3} (Starmach et al. 1978). With the course of the river the concentration of nitrite nitrogen decreased, which indicates an efficient nitrification process.

The River Pogona was characterized by quite high nitrate concentrations which resulted from their production in the process of nitrification from ammonium and nitrite nitrogen from sewage and supply in significant amounts (especially in winter

and spring periods) from agricultural catchments. Precipitation may also be a source of nitrate ions but they mainly come from the inflow from agricultural areas and sewage (Starmach et al. 1978). Nitrate nitrogen was the dominant form of mineral nitrogen. Its mean annual concentrations above 10 mg $N\text{-}NO_3$ dm^{-3} confirmed the significant load of the river and reservoir with this form of nitrogen. A similar situation was noted in the waters of the river, which is a drinking water intake for the city of Kraków (Adamczyk and Jachimowski 2013).

The outlet of treated wastewater, in which low concentrations were observed, resulted in a decrease in the amount of wastewater in river waters only at a location near the inflow. In the dam reservoir, a slight decline in nitrate nitrogen concentration occurred as a result of its intake by the growing phytoplankton. In water reservoirs nitrate concentration is often dependent on biomass development. During the vegetation periods nitrate concentrations decrease to very small values to increase again in winter (Dojlido 1995). In the case of mineral nitrogen (defined as the sum of ammonium, nitrite and nitrate forms), the highest concentrations were observed in the autumn-winter period and the lowest in the summer. The seasonal variability of nitrogen content in water is closely related to cycling in phytoplankton growth. In the winter period, when primary production slows down, the reserves of dissolved nitrogen salts are rebuilt, to be used again in spring (Pliński 1992). Thus, the studies carried out on the waters of the River Pogona and the Jeżewo Reservoir indicate a decrease in the mean concentration of this form of nitrogen as a result of its flow through the dam reservoir, as a result of its uptake by phytoplankton (Gołdyn 2000). The inflow of treated sewage resulted in a decrease in the concentration of this form of nitrogen which was indicative of the effective removal of nitrogen compounds from sewage.

The concentrations of organic nitrogen in the River Pogona were not high. Higher concentrations of this form of nitrogen were found in summer and autumn as a result of more intensive primary production. When considering the variability of organic nitrogen concentration at individual stations, the highest mean value was observed at the outlet from the sewage treatment plant. In unpolluted waters the concentrations of organic nitrogen do not usually exceed 1 mg dm^{-3}; in surface waters polluted with sewage these amounts reach several mg dm^{-3} (Hermanowicz et al. 1999). With the course of the river the mean concentration of organic nitrogen at individual sampling stations decreased, which indicates a self-treatment process taking place. In the reservoir itself there was a small increase in the concentration of organic matter (phytoplankton).

Concentrations of total nitrogen in the waters of the River Pogona and the Jeżewo Reservoir fluctuated seasonally. The highest concentrations of this form of nitrogen were observed in the autumn-winter period as a result of the inflow of snowmelt water and larger surface runoff from the catchment area. In the summer period the total nitrogen content decreased owing to more intensive primary production in the whole catchment area. As a result of the river flowing through the reservoir, the concentration of this element decreased slightly (phytoplankton uptake), and the inflow from the treatment plant resulted in its more significant decrease at the station downstream of the sewage inflow (nitrogen removal in the treatment plant). The mean concentration of total nitrogen near the outlet of treated wastewater (14.4 mg N dm^{-3}) was similar to that in treated wastewater from the treatment plant in Myślenice (Miernik et al. 2016).

In a reservoir where water has a stagnant character intensive uptake of this element by organisms takes place, especially in the warmer seasons of the year, and thus in the present study a decrease in its concentration was observed both in the reservoir waters and in the outflowing river. A similar situation was also observed in the waters of the Antoninek Reservoir and the River Cybina flowing through it (Dondajewska 2007; Gołdyn et al. 2008).

The inflow of treated wastewater from the treatment plant to the River Pogona did not cause a significant increase in the concentration of dissolved phosphates and total phosphorus. A slight increase was found at the station behind the sewage inflow, and at the next ones; as a result of self-treatment processes, concentrations decreased. However, periodically at the sewage outflow and at the station situated 100 meters behind the treatment plant, increased phosphate values were recorded. They exceeded 2.52 mg P dm^{-3}. The mean concentration of total phosphorus at station 2 was 0.45 mg P dm^{-3} which was similar to that observed in treated wastewater flowing into the River Raba (Miernik et al. 2016). The treated wastewater is

dominated by the phosphate form which is easily absorbed by plants (Kajak 2001). Similar variability was found in Struga Kwilecka (Staniszewski et al. 2017). In the Jeżewo Reservoir, the concentration of both forms of phosphorus was decreasing. In the epilimnion, phosphorus is quickly absorbed by phytoplankton during the period of summer stagnation (Pliński 1992). Similar changes were recorded in the shallow Antoninek Reservoir located in the course of the River Cybina (Gołdyn et al. 2008). When comparing the mean values at individual sampling stations from the whole study period it can be concluded that sewage did not contribute to a significant increase in the content of either form of phosphorus in river waters which indicates their large inflow from spatial sources (agriculture). On the other hand, the dam reservoir functioned as a trap for this element, clearly reducing its concentrations.

Conclusion

The studies carried out on the waters of the River Pogona have shown that the supply of treated wastewater from the treatment plant in Karolewo causes an increase of water temperature, its electrolytic conductivity, the concentration of ammonium nitrogen, nitrites and organic nitrogen. On the other hand, the localization of the dam reservoir in its course resulted in an increase of water temperature, pH, dissolved oxygen, chlorophyll-a and nitrite concentration in the waters of the River Pogona flowing through it.

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