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Assessment of The Influence of Anthropogenic Pollution on Water Quality of the Ciemięga River

Krzysztof Jóźwiakowski[1*], Agnieszka Listosz[1], Agnieszka Micek[1], Michał Marzec[1], Magdalena Gizińska-Górna[1], Kamila Rybczyńska-Tkaczyk[2], Justyna Bohacz[2] , Mateusz Wójcik[3], Natalia Brodowska[3]

[1] Department of Environmental Engineering and Geodesy, University of Life Sciences in Lublin, ul. Leszczyńskiego 7, 20-069 Lublin, Poland

[2] Department of Environmental Microbiology, Laboratory of Mycology, University of Life Sciences in Lublin, ul. Leszczyńskiego 7, 20-069 Lublin, Poland

[3] Student Science Association of Environmental Engineering, University of Life Sciences in Lublin, ul. Leszczyńskiego 7, 20-069 Lublin, Poland

[*] Corresponding author's e-mail: krzysztof.jozwiakowski@up.lublin.pl

ABSTRACT

The aim of this paper was to evaluate the influence of anthropogenic pollution on the water quality of the Ciemięga River, which flows through the Jastków commune, located in the Lublin Province in the South-Eastern Poland. The analyses of the river water were conducted in the years 2019–2020. Each year, the samples for physicochemical analyses were collected seasonally (in February, May, August and November) from the seven selected Ciemięga River sampling points found in the following localities: Ożarów, Moszenki, Sieprawice, Jastków, Snopków and Jakubowice Konińskie. In addition, 3 series of microbiological analysis were conducted in 2020. Electrolytic conductivity, total phosphorus, nitrate-nitrogen and sulfates constituted the physicochemical indicators of poor water quality in the river. Their average values exceeded the standards for the 2nd class of water quality. High concentration of these indicators, especially of the total phosphorus, could have been related to the influx of domestic wastewater from agricultural holdings, wastewater flows from agricultural areas as well as soil erosion and leaching. The levels of *E. coli* bacteria and fecal coliform allocated the Ciemięga River waters to the 4th class of water quality and could result from domestic wastewater flow to the river. In order to improve the water quality of the Ciemięga River, it is necessary to reduce or eliminate point and non-point sources of pollution by means of streamlining of the agricultural areas fertilization, regulating the water and wastewater management, regulating of the waste management, as well as the appropriate spatial policy and landscaping of the water catchment areas.

Keywords: anthropogenic pollution, Ciemięga River, water quality, eutrophication

INTRODUCTION

For many years, the progressing economic development has had a negative effect on the environment. It poses a threat to natural ecosystems, especially to surface waters. Both point and non-point sources of pollution have an influence on the water quality. Water quality deterioration caused by the increased supply of the biogens, physicochemical and microbiological pollution from the water catchment area of a given river results from the degradation of the ecological status of rivers [Policht-Latawiec et al. 2015; Pytka et al. 2013; Gizińska-Górna et al. 2017].

The main sources of surface water pollution are: wastewater, inflow of pollutants from agricultural areas, precipitation, as well as soil erosion and leaching. Anthropogenic activity leads mostly to intensive flow of the biogenic substances (nitrogen and phosphorus) from the water catchment areas to surface water in the rural areas. They can migrate in an uncontrolled manner to the surface water or groundwater from the mineral and organic fertilizers used in the plant production or from the animal feces storage places, which were not secured properly [Pietrzak and Sapek 1998; Policht-Latawiec et al. 2015]. As a result of high biogenic load, highly unfavorable phenomenon of eutrophication takes place [Dąbrowska 2008]. The intensity of the eutrophication process depends on many factors, such as the catchment type (i.a. geological structure, the manner in which it is used which it is used), type of cultivation and used fertilizers, as well as on the watercourse resistance itself [Wiatkowski et al. 2012; Burzyńska 2016]. By contrast, in urban areas, a threat to the surface water quality is posed by using salt to de-ice the roads [Trowbridge et al. 2010; Mazur 2015; Jóźwiakowska et al. 2020].

In order to protect the surface and groundwater resources from degradation, it is necessary to build and expand the sanitary infrastructure [Bogusz et al. 2020; Jóźwiakowska et al. 2020; Micek et al. 2018; Gizińska-Górna 2020; Gizińska-Górna and Gawron 2020] as well as provide sustainable development of rural and urban areas [Lin et al. 2020; Lin et al. 2021].

The aim of this paper was to evaluate the influence of the anthropogenic pollution on the water quality of the Ciemięga River flowing through the Jastków commune located in the Lublin Province in the South-East Poland. The obtained results have a practical aspect since the Commune Office in Jastków is planning to build a reservoir of the total area of about 14 ha, in the Ciemięga River Valley. The reservoir will be supplied with the water from the river.

DESCRIPTION OF THE STUDY OBJECT

The research has been conducted in the catchment of the Ciemięga River, which is the left-bank tributary of Bystrzyca river. The Bystrzyca river ends in Spiczyn, where it flows into the Wieprz river – right-bank tributary of the Vistula river. The Ciemięga River flows through almost the whole Jastków commune. Its riverbed is narrow, deeply incorporated into the loess soil in some places. The river valley is deep and has steep slopes. The Ciemięga River flows from Motycz Leśny (at a height of 223 m.a.s.l.), in the Konopnica commune (Lublin poviat) and flows into the Bystrzyca river (tributary of the Wieprz river in its middle course) in Sobianowice (159 m a.s.l.). Its length equals 41.5 km and the height difference between the river source and the river mouth amounts to 64 m. In the upper course, the river receives only a small tributary and in other sections it is supplied by the water from sub-slope and near-bed springs [Michalczyk 1995].

The Ciemięga River basin occupies the area of 157.1 km^2 and it is situated in the north-east part of the Nałęczów Plateau, subregion of the Lublin Upland [Chałubińska and Wilgat 1954]. It spans over 30 km in length and its width in the upper part equals 10 km, whereas in the middle and bottom part it narrows down to 3–6 km. There are many groundwater outflows in the Ciemięga River basin; 50 of them are springs with concentrated water outlets. The majority of them are situated in the middle part of the catchment and they are mostly outlets with low efficiency, exceeding 1 dm^3·s^{-1} occasionally. The largest ones are located in Dys and Łagiewniki (both of them amount to several dm^3·s^{-1}) and in Baszki (from 17 to 38 dm^3·s^{-1}). Spring waters are characterized by high quality and their chemical composition results from the geochemical nature of the aeration zone [Michalczyk et al. 1997].

The catchment of the Ciemięga River is comprised of marl and bedrocks of the Upper Maastricht as well as Paleocene gaizes and marly limestones, which are lying on them. They are locally covered with sands, quartz slurry of the Oligocene, on which there are sands, clayey sands with gravel and glacial till. In the upper areas, loess can be found with the thickness ranging from several up to 25 m. The bottom of the valley is filled with aggregate mud, alluvial soils, peat and alluvial deposits [Michalczyk et al. 2019a]. In the hilltop areas there are loess sediments, which contributed to the development of fertile soils, currently occupied by the agricultural areas. On the edges or in the areas with greater downslopes, loess soils are deeply cut by the flowing waters and, in consequence, a network of gorges covered with trees and bushes developed there. The narrow bottom of the valley is occupied by meadows and comprises Holocene muds, alluvial soils and peat [Michalczyk et al. 2010].

The Jastków commune, through which the Ciemięga River flows, has very favorable natural conditions for the development of agriculture. Arable lands prevail in the land-use structure while meadows and forests constitute less than 10% of the river basin. Surface waters in the Ciemięga catchment are found only in the bottom of the valley, where the river and one permanent tributary flow. There are also small ponds of different sizes and tanks, as well as wetlands in the catchment area. There is also a network of drainage ditches in the upper part. The largest tanks are situated in Jastków, Snopków and Jakubowice. The total area of surface waters amounts to 39.4 ha [Michalczyk et al. 2019b].

Owing to the agricultural nature of the catchment, the Ciemięga River is prone to severe anthropogenic pressure. Point and nonpoint pollution, mainly surface flows from the urban areas, poor wastewater management, as well as inappropriate usage of the mineral and organic fertilizers, contribute to the degradation of the river.

MATERIALS AND METHODS

The studies on the quality of water from the Ciemięga River were conducted in 2019–2020 in different seasons (in February, May, August, and November). The sampling points on the Ciemięga River were established in vicinity of potential sources of anthropogenic pollution. The samples of water for analyses were collected from 6 points along the river (Figure 1). Sampling point no. 1 was located nearby the communication route in Ożarów (Photo 1), point no. 2 – in Moszenki (Photo 2), point no. 3 – in Sieprawice (Photo 3), point no. 4 – in Jastków (Point 4), point no. 5 – in Snopków (Photo no. 5), and point no. 6 – in Jakubowice Konińskie (Photo 6).

The investigations involved 7 series of analyses of the water samples from the Ciemięga River, in which the following physicochemical indicators were determined:

- pH value, concentration of dissolved oxygen and electrolytic conductivity were determined using an ORION Star A329 Set portable multiparameter meter by Thermo Scientific;
- total suspended solids were determined with the direct weighing method using filtration through paper filters;
- BOD_5 was determined via dilution and inoculation with allylothiourea on the basis of the measured concentration of dissolved oxygen, directly after sample collection and following 5 days of incubation (the oxygen content was determined using an ORION Star A329 Set portable multiparameter meter by Thermo Scientific;
- COD was determined with bichromate method with oxidation of the investigated sample in a thermoreactor at a temperature of 148°C (COD_{cr} determination was performed using a NANOCOLOR@UV/VIS spectrophotometer by Macherey-Nagel);
- Total nitrogen was determined by means of a NANOCOLOR@UV/VIS spectrophotometer by Macherey-Nagel, following prior oxidation of the investigated sample in a thermoreactor at a temperature of 120°C;
- Nitrite nitrogen, nitrate nitrogen, ammonia nitrogen, chlorides and sulfates were determined using a NANOCOLOR@UV/VIS spectrophotometer by Macherey-Nagel;
- Total phosphorus was determined using a NANOCOLOR@UV/VIS spectrophotometer by Macherey-Nagel following prior oxidation of the sample in a thermoreactor at a temperature of 120°C.

Moreover, 3 series of microbiological analyses of the water from the Ciemięga River

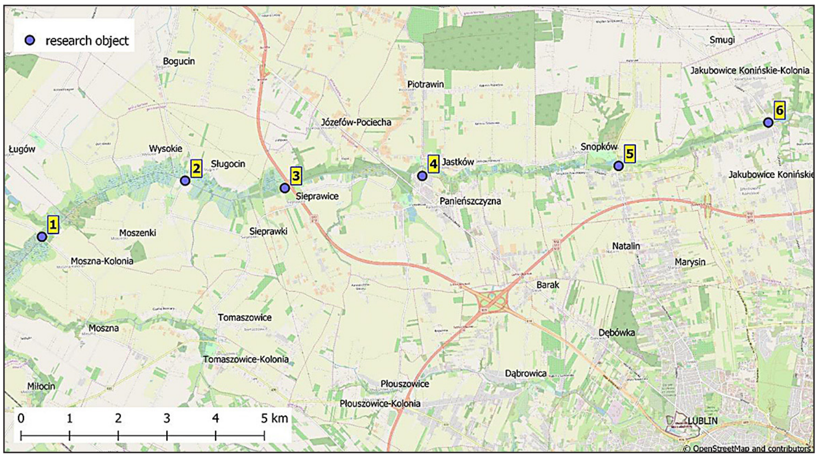

Figure 1. Location of water sampling points along the Ciemięga River

Photo 1. Sampling point no. 1
(photo: A. Listosz)

Photo 2. Sampling point no. 2
(photo: A. Listosz)

Photo 3. Sampling point no. 3
(photo: A. Listosz)

Photo 4. Sampling point no. 4
(photo: A. Listosz)

Photo 5. Sampling point no. 5
(photo: A. Listosz)

Photo 6. Sampling point no. 6
(photo: A. Listosz)

were conducted in 2020; they involved determining the presence of coliform bacteria with the fermentation method and the presence of fecal coliform bacteria using the membrane filtration method.

The physicochemical analyses were performed using the commonly employed methods [Hermanowicz et al. 1999]. On the basis of the obtained results, the mean, minimum, maximum, and median value, as well as standard deviation and coefficient of variability, were determined. The results of physicochemical investigations of the water from the Ciemięga River were compared with the maximum values of quality indicators, established in the Regulation of the Minister of Maritime Economy and Inland Navigation of 7th November 2019 on the classification of ecological status, ecological potential and chemical status, and the method of classification of the state of surface water bodies as well as environmental quality standards for priority substances. According to the Director of Regional Water Economy Management Board in Warsaw on the conditions for the use waters of the Middle Vistula water region [2015], the Ciemięga River is classified as upland carbonate stream with fine-grained substrate on loess and loess-like sediments (JCWP type).

The coliform and fecal coliform bacteria constitute one of the most important indicators of the bacteriological water quality [Saxena et al. 2015; Wen et al. 2020]. Since the microbiological indicators were not accounted for in the Regulation of the Minister of Environment of 2019, their values in the water of the Ciemięga River were compared with the limit values set out in the Regulation of the Minister of Environment of 11th February 2004 establishing the classification for the presentation of surface waters and groundwater condition, their monitoring and interpretation of results, and the presentation of the state of these waters.

Table 1. Water quality in Ciemięga River in 2019–2020

Parameters		Sampling points											
		1		2		3		4		5		6	
		min	max	min	max	min	max	min	max	min	max	min	max
		Cv	Me	Cv	Me	Cv	Me	Cv	Me	Cv	Me	Cv	Me
pH	-	7.06	7.67	7.16	7.62	7.22	7.74	7.57	7.84	7.52	7.83	7.46	7.87
		-	**7.36**	-	**7.42**	-	**7.57**	-	**7.77**	-	**7.72**	-	**7.72**
Dissolved oxygen	mg O_2·dm^{-3}	3.12	8.64	3.77	8.92	5.24	10.28	5.87	10.59	5.97	10.80	6.23	11.03
		38.7	**3.95**	29.4	**5.20**	23.4	**6.84**	17.3	**7.71**	20.1	**7.25**	19.5	**7.43**
Conductivity	μS·cm^{-1}	640	913	672	893	692	874	680	857	643	822	647	792
		10.1	**763**	9.2	**729**	7.4	**749**	7.2	**730**	7.8	**708**	6.1	**728**
Total suspended solids	mg·dm^{-3}	1.66	16.70	1.32	15.09	2.70	17.27	1.72	18.63	2.70	16.67	2.90	19.71
		51.5	**11.47**	58.0	**8.89**	37.7	**10.45**	64.4	**9.46**	47.7	**14.3**	43.9	**12.59**
BOD_5	mg O_2·dm^{-3}	1.12	2.62	0.49	2.59	0.96	2.76	0.31	2.19	0.81	3.25	0.80	5.16
		30.8	**1.53**	39.2	**2.03**	37.5	**1.36**	43.6	**1.37**	42.5	**1.58**	76.8	**1.42**
COD	mg O_2·dm^{-3}	20.0	38.9	18.0	38.6	17.0	36.0	14.0	32.6	15.2	32.5	18.0	42.0
		20.8	**36.1**	32.6	**21.9**	28.0	**22.6**	28.9	**21.2**	29.9	**19.9**	34.1	**23.4**
Total phosphorus	mg·dm^{-3}	0.108	5.76	0.061	3.01	0.055	0.898	0.065	1.70	0.11	3.23	0.153	5.50
		145.4	**0.16**	174.3	**0.21**	107.4	**0.15**	156.9	**0.14**	163.6	**0.21**	165.2	**0.31**
Total nitrogen	mg·dm^{-3}	1.02	2,12	0,93	2,17	0,90	1,71	0,67	1,53	1,00	1,61	1,00	3,49
		26.3	**1.19**	30.3	**1.26**	21.7	**1.33**	24.4	**1.20**	18.0	**1.52**	40.2	**1.78**
Ammonium nitrogen	mg·dm^{-3}	0,008	0.42	0.008	0.30	0.008	0.27	0.008	0.11	0.008	0.093	0.008	0.11
		100.6	**0.06**	111.9	**0.06**	106.3	**0.05**	90.8	**0.02**	75.2	**0.06**	74.6	**0.04**
Nitrate nitrogen	mg·dm^{-3}	0.023	0.181	0.045	0.45	0.068	0.23	0.09	0.27	0.11	0.40	0.09	0.60
		64.7	**0.09**	83.9	**0.10**	43.6	**0.10**	38.8	**0.16**	38.1	**0.29**	51.2	**0.29**
Nitrite nitrogen	mg·dm^{-3}	0.01	0.02	0.008	0.052	0.010	0.049	0.10	0.053	0.01	0.059	0.10	0.073
		35.1	**0.01**	77.1	**0.01**	50.8	**0.02**	54.5	**0.03**	49.2	**0.04**	61.3	**0.04**
Chlorides	mg·dm^{-3}	2.80	125.0	1.3	53.0	3.3	123.0	3.5	125.0	3.40	83.00	4.80	169.0
		156.0	**7.0**	121.1	**4.0**	164.6	**5.0**	157.5	**9.0**	133.5	**10.0**	165.8	**12.0**
Sulfates	mg·dm^{-3}	1	941	1	844	1	208	1	290	3	251	1	265
		152.9	**15.0**	210.4	**16.0**	185.3	**12.0**	137.9	**15.0**	129.1	**15.0**	119.7	**25.0**

RESULTS AND DISCUSSION

The values of physicochemical indicators of the water quality from the sampling points located on the investigated section of the Ciemięga River were presented in Table 1.

The **pH** of the analyzed waters from the Ciemięga River collected in all sampling points and in all measurement series, varied to a limited extent (Table 1). The values of pH in points no. 3–6 were within the range from 7.46 to 7.87 and corresponded to the 1st class of quality. Lower pH values (7.06 – 7.67) corresponding to the 2nd class of quality were found in points no.1–2 [Regulation of the Minister of Maritime Economy and Inland Navigation 2019]. On the basis of the conducted studies, an increase in the pH value was observed in water along the river. Previously, much higher pH values (8.00–8.49) were fund in the water of the Ciemięga River in Jastków, Dys, and Pliszczyn [Gorzel et al. 2018]. Relatively high pH values compared to the ones observed in the waters of the Ciemięga River, were noted by Pytka et al. [2013] in the waters of the Bochotniczanka river (7.29–8.29) as well as by Burzyńska [2016] in the waters of the Raszynka river (7.20–7.98).

Dissolved oxygen concentration indicates a relationship between temperature and gas solubility in water. In the course of the studies, an increase in dissolved oxygen concentration was observed in the water of the Ciemięga River in autumn and winter, whereas a decrease was noted in spring and summer. Simultaneously, a substantial increase in the oxygen concentration was observed along the river – from 4.69 $mgO_2 \cdot dm^{-3}$ in sampling point no. 1, to 7.89 $mgO_2 \cdot dm^{-3}$ in sampling point no. 6 (Figure 2); this may confirm high efficiency of the self-purification processes in river water. High oxygen concentration in the waters of the Ciemięga River in sampling points no. 4–6 may also result from the presence of small flow-through bodies of water in their vicinity, which are supplied with Quatenary streams and groundwaters.

The conducted studies indicate that the average concentration of dissolved oxygen in the waters of the Ciemięga River did not achieve the level typical for the waters of the 1st class of quality in any case, whereas in sampling points no. 4–6 it corresponded to the 2nd class of quality. In turn, in sampling points no. 1–3, the average concentrations of dissolved oxygen were lower than 7.6 $mgO_2 \cdot dm^{-3}$, i.e. the value determined for the 2nd class of quality. Moreover, in sampling points no. 1 and 2, a decrease in the dissolved oxygen concentration even below 4 $mgO_2 \cdot dm^{-3}$ was periodically noted in spring and summer at high temperatures. Such low dissolved oxygen concentration may indicate an influx of household wastewater to the Ciemięga River in its upper course. The concentration of dissolved oxygen in water below 4 $mgO_2 \cdot dm^{-3}$ is threatens fish and may contribute to their death [Kolada et al. 2018].

Earlier studies indicate that the concentration of dissolved oxygen in the waters of the Ciemięga River in Jastków, Dys, and Pliszczyn amounted to 7.9; 9.5 and 10.5 $mgO_2 \cdot dm^{-3}$, respectively [Gorzel et al. 2018]. In turn, the studies performed by Chotumowska and Wilamowski [2014] indicated that the average concentrations of oxygen in the waters of the Lutownia river located within the Białowieża Forest, ranged between 7.62 and 8.48 mg $O_2 \cdot dm^{-3}$.

Conductivity. The results of studies indicate relatively high salinity of natural surface waters. The observed mean values of conductivity in the water of the Ciemięga River significantly

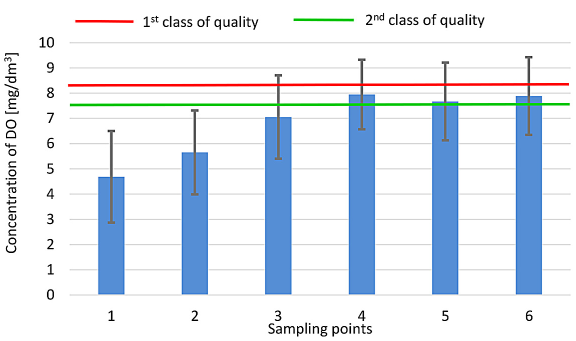

Figure 2. Average concentration (± SD) of dissolved oxygen in different points of the Ciemięga River

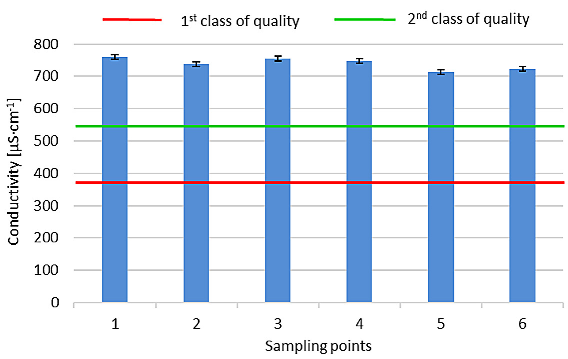

Figure 3. Average concentration of conductivity (± SD) in different points of the Ciemięga River

exceeded the level set for the I and II class of quality, reaching the values of 713–759 µS·cm^{-1} (Figure 3). The obtained results indicate the presence of dissolved pollutants, including the pollutants of agricultural or household origin.

On the basis of the results presented in Figure 3, a slight reduction in conductivity can be observed along the river, which may indicate the presence of pollution sources in the vicinity of sampling points located in the upper course of the river, and the self-purification of waters through dilution along the entire investigated segment of the Ciemięga River.

An increase in electrolytic conductivity in the water from the investigated river was observed in autumn and winter, when the value of this parameter in all sampling points usually exceeded 800 µS·cm^{-1}. High values of specific conductivity in winter were probably connected with the application of salt for de-icing of roads. A similar tendency was observed in the Bystrzyca Valley in Lublin [Jóźwiakowska et al. 2020].

Much lower conductivity values in the water of the Ciemięga River in Pliszczyn were previously observed by Grzywna et al. [2017] – 576 µS·cm^{-1}, on average. In turn, Gorzel et al. [2018] reported that the conductivity of the water of the Ciemięga River in Jastków, Dys and Pliszczyn reached 588–731 µS·cm^{-1}. Michalczyk et al. [2019a] stated that the specific conductivity of the stream in Pliszczyn, in the Ciemięga River catchment, amounted to 608 µS·cm^{-1}, on average. Therefore, the results of studies conducted in 2019–2020 indicate an increase in conductivity that occurred in recent years, which may indicate a negative anthropogenic impact.

Lower specific conductivity than that obtained in the water of the Ciemięga River was reported by Pytka et al. [2013] in the Bochotniczanka river (606–773 µS·cm^{-1}), as well as Wiatkowski et al. [2012] in the Stobrawa river (397–614 µS·cm^{-1}). The waters of the Bystrzyca river – which flows through Lublin and receives the waters from the Ciemięga River – also indicated much lower conductivity – 446–721 µS·cm^{-1} [Jóźwiakowska et al. 2020].

Total suspended solids. In the course of research, the values of total suspended solids (TSS) ranged widely from 1.66 to 19.71 mg·dm^{-3} (Table 1). The comparative analysis regarding the standard levels indicate that the majority of observed TSS values corresponded to the 2nd class of quality, with only singular instances attributed to the 1st class of quality, determined for upland carbonate rivers (Figure 4). The presence of TSS in flowing waters may result from numerous local factors, which determine the character of water flow as well as the transport of organic and mineral solids. In the case of the Ciemięga River, the TSS content could have been increased by fine particles of soil (loess) carried from agricultural fields to the riverbed. Figure 4 shows the tendency of a slight TSS increase in the water down the Ciemięga River.

The average TSS values in the waters of the Ciemięga River ranged from 8.2 to 12.7 mg·dm^{-3} (Figure 4). In turn, Gorzel et al. [2018] reported that the TSS content in the waters of the Ciemięga River in Jastków, Dys, and Pliszczyn was slightly lower and amounted to 6.1–9.7 mg·dm^{-3}, on average. Gizińska-Górna et al. [2017], who analyzed the waters of the Urzędówka River, reported the mean TSS concentration of 6.78 mg·dm^{-3}. Wiatkowski et al. [2012] obtained much higher TSS concentrations in the waters of the Strobrawa river (30.8–43.6 mg·dm^{-3}). Even higher TSS values (55–280 mg·dm^{-3}) were observed by Pytka et al. [2012] in the Bochotniczanka river.

BOD_5 and COD. The investigated waters from the Ciemięga River were characterized by moderate concentration of organic pollutants. The average BOD_5 values were usually within the range of 1.25–1.81 mg O_2·dm^{-3} and met the requirements for 1st class of quality (Figure 5). An increase in the BOD_5 value above 2.0 mg O_2·dm^{-3} was periodically noted in all investigated sampling points, excluding point no. 4; thus, the waters were allocated to the 2nd class of quality. A similar tendency was observed in the case of COD. The average COD values in sampling points no. 3–5 amounted to 21.4–24.2 mg O_2·dm^{-3} and met the requirements established for 1st class

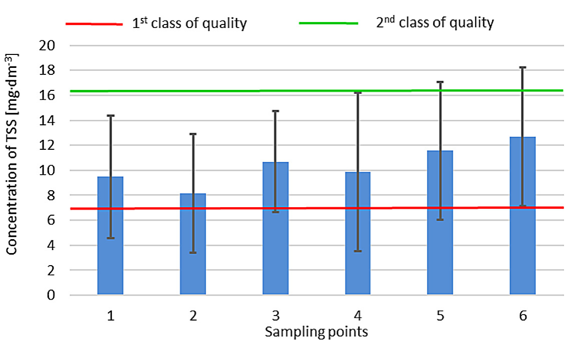

Figure 4. Average concentration of total suspended solids(± SD) in different points of the Ciemięga River

of quality (Figure 6). In turn, in sampling points no. 2 and 6, the average COD values were within the range of 25–30 mg $O_2 \cdot dm^{-3}$, meeting the requirements of the 2nd class of quality. The highest COD values > 30 mg $O_2 \cdot dm^{-3}$ were observed in sampling point no. 1; thus, the water from the Ciemięga River did not meet the requirements for the 2nd class of quality.

In the case of both BOD_5 and COD, a much higher level of pollution with organic compounds was usually observed in the upper course of the river, which might have been connected with the influx of anthropogenic pollution, as well as natural processes, e.g. intensified primary production and biological development in the stream.

Slightly higher BOD_5 values in the water of the Ciemięga River, i.e. 1.4–3.4 $mgO_2 \cdot dm^{-3}$, were previously obtained by Grzywna et al. [2017], as well as Gorzel et al. [2018]. The BOD_5 values in the waters of the Ciemięga River in own studies and reported by the afore-mentioned authors were much lower compared to the values obtained by Grzywna et al. [2016] in the Bystrzyca river flowing through Lublin, which reached 2.3–7.4 $mgO_2 \cdot dm^{-3}$. In turn, Wiatkowski et al. [2012] obtained the BOD_5 values of 2.6–6.2 $mgO_2 \cdot dm^{-3}$ in the waters of the Stobrawa river. Policht-Latawiec et al. [2013] found the BOD_5 concentrations of 6.2–7.0 $mgO_2 \cdot dm^{-3}$ in the San river, whereas Gizińska-Górna et al. [2017] reported the value of 0,4–2,4 $mgO_2 \cdot dm^{-3}$ in the samples of water from the Urzędówka river.

Pytka et al. [2013] stated that the COD values in the water of the Bochotniczanka river were higher than in the Ciemięga River, reaching 13.5–91.7 $mgO_2 \cdot dm^{-3}$. In turn, Policht-Latawiec et al. [2013] investigated the water in the San river and found the COD_{cr} values amounting to 19.8–22.6 $mgO_2 \cdot dm^{-3}$.

Nitrogen compounds. The total nitrogen values in the waters of the Ciemięga River were low, corresponding to the 1st class of quality (Figure 7). A slight increase in total nitrogen content was observed in sampling point no. 6, which is located beyond the discharge location of treated wastewater from the treatment plant in Snopków, which may indicate the possible beneficial effect of this object on the quality of water in the river.

The low total nitrogen concentrations in the waters of the Ciemięga River (1.4–2.4 $mg \cdot dm^{-3}$) were noted earlier by Gorzel et al. [2018]; Grzywna et al. [2017] reported the value of 2.3 $mg \cdot dm^{-3}$. In turn, Gizinska-Górna et al. [2017], who investigated the water from the Urzędówka river, found the value of 1.87 $mg \cdot dm^{-3}$. Slightly higher concentrations of total nitrogen, i.e. 2.5–3.8 $mg \cdot dm^{-3}$, were observed by Grzywna et al. [2016] in the waters of the Bystrzyca river. Much higher total nitrogen concentrations were noted by Policht-Latawiec et al. [2013] in the San river, as well as by Pytka et al. [2013] in the Bochotniczanka river.

The mineral forms of nitrogen (NH_4, NO_3, NO_2) in the water of the Ciemięga River were also present in low concentrations (Table 1). The concentration of ammonia nitrogen did not exceed the level of 0.35 $mg \cdot dm^{-3}$ in any case; hence, it was much lower than the permissible value for the 1st class of quality. The concentrations of ammonia in all measurement points were much lower than the value of 2.2 $mg \cdot dm^{-3}$ established for the 1st class of quality. Only the average values of nitrite nitrogen corresponded to the 2nd class of water quality. On the basis of the conducted studies, a reduction in the ammonia nitrogen concentration along the Ciemięga River was observed, as well as increased nitrite and nitrate nitrogen (Table 1),

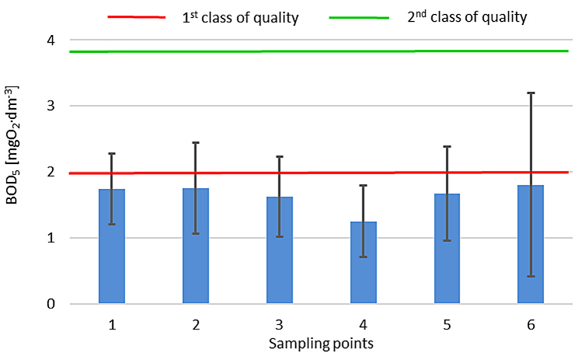

Figure 5. Average values of BOD_5 (± SD) in different points of the Ciemięga River

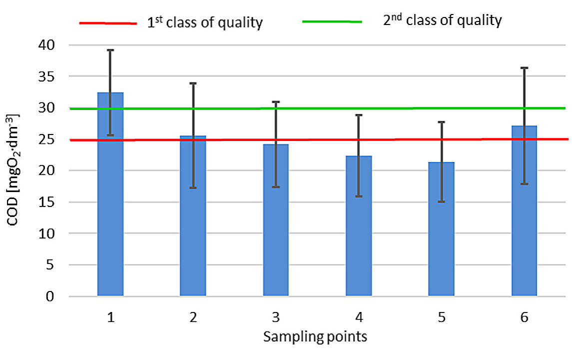

Figure 6. Average values of COD (± SD) in different points of the Ciemięga River

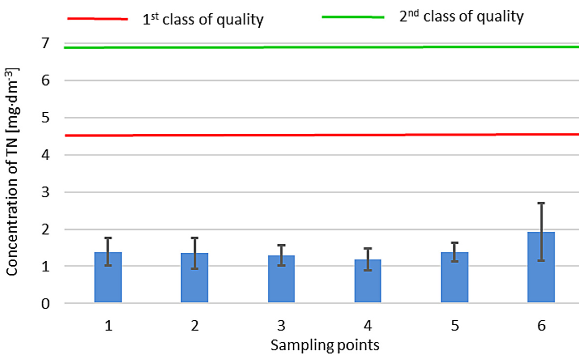

Figure 7. Average concentration of total nitrogen(± SD) in different points of the Ciemięga River

which may be connected with an elevated concentration of dissolved oxygen, which was mentioned earlier.

For comparison, much higher values of mineral forms of nitrogen were noted by Chomutowska and Wilamowski [2014] in the waters of the Łutownia river located in the Białowieża Forest. Higher concentrations of the analyzed nitrogen compounds were also obtained by Burzyńska [2016] in the Raszynka river, as well as Pytka et al. [2013] in the Bochotniczanka river.

Total phosphorus. The average concentrations of total phosphorus in all sampling points of the water of the Ciemięga River were higher than the standard established for the 2nd class of quality, amounting to 0.35 mg·dm^{-3}. In terms of total phosphorus content, only the water from sampling point no. 3 corresponded to the 2nd class of quality (Figure 8). During the study period, a decrease in phosphorus content was observed in autumn and winter, whereas an increase was noted in spring and summer. The highest total phosphorus concentration was observed in sampling point no. 1 – 1.69 mg·dm^{-3}, which may be caused by untreated household wastewater or the remains of

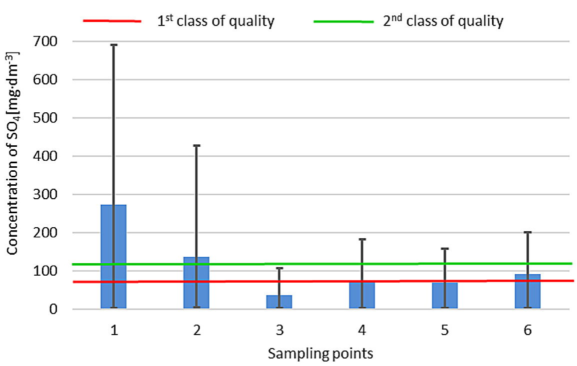

Figure 8. Average concentration of total phosphorus (± SD) in different points of Ciemięga River

phosphorus, flowing from fertilized agricultural lands. Phosphorus compounds are also leached and transported with the solid fraction of soil with surface runoff during intense rainfall. In turn, the high concentration of phosphorus in sampling point no. 6, amounting to 1.1 mg·dm^{-3} may be caused by the discharge of insufficiently treated wastewater treatment plant in Snopków.

Much lower total phosphorus concentrations in the waters of the Ciemięga River (0.13–0.15 mg·dm^{-3}) were previously noted by Gorzel et al. [2018] and Grzywna et al. [2017] – 0.16 mg·dm^{-3}. For comparison, Grzywna et al. [2016] reported that in Bystrzyca, for which Ciemięga is the left-bank tributary, the phosphorus content amounted to 0.15–0.21 mg·dm^{-3}. Relatively high concentrations of total phosphorus (0.92 mg·dm^{-3}) were also noted by Kiryluk and Rauba [2011] in the waters of the Ślina river. In this case, the high total phosphorus concentrations resulted from the presence of numerous livestock farms in vicinity, as well as surface run-off. Wiatkowski et al. [2012] also observed high concentrations of total phosphorus in the waters of the Stobrawa river, ranging from 1.91 to 2.84 mg·dm^{-3}.

Chlorides and sulfates. The average concentrations of chlorides in the waters of the Ciemięga River amounted to 14.2 to 33.5 mg·dm^{-3} and met all the requirements established for the 1st class of quality. However, the concentrations of chlorides were subject to significant seasonal variations (Figure 9). In May, the chloride concentrations substantially exceeded the level set for the 2nd class of quality (tab. 1). The Ciemięga River catchment at the investigated segment is affected by intense agricultural activity; therefore, the presence of chlorides in spring could have been connected with their migration from agricultural fields, on which chlorine is introduced mainly with natural fertilizers, as well as artificial, predominantly K fertilizers.

The average concentrations of sulfates in the water of the Ciemięga River were highly diversified in different sampling points, ranging from 37.7 to 273 mg·dm^{-3} (Figure 10). The highest concentration of sulfates was observed in sampling points no. 1 and 2 in the upper course of the river and they exceeded the limit value for the 2nd class of quality. In sampling points no. 4–6, the average content of sulfates enabled to classify the waters of the studied river to the 2nd class of quality. In turn, in sampling point no. 3, the water of the Ciemięga River

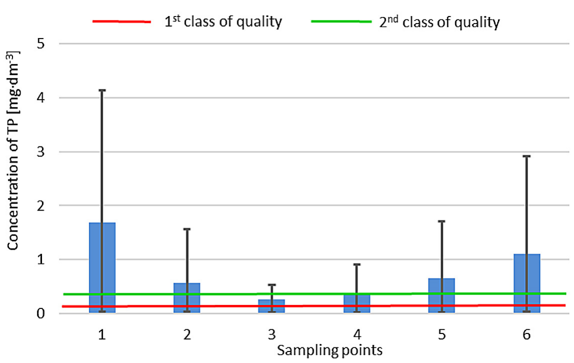

Figure 9. Average concentration of chlorides (± SD) in different points of the Ciemięga River

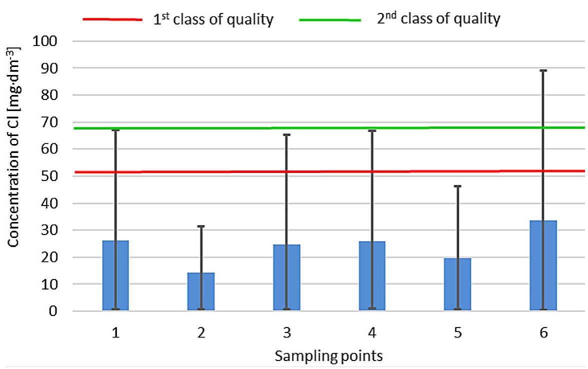

Figure 10. Average concentration of sulfates (± SD) in different points of the Ciemięga River

– in terms of the sulfate content – can be allocated to the 1st class of quality. The highest sulfate content was usually observed in November.

Much higher concentrations of chlorides and sulfates in the water of the Ciemięga River were previously reported by Gorzel et al. [2018], reaching 11.1–14.2 mg·dm^{-3} and 10.4–19.9 mg·dm^{-3}, respectively. In turn, the studies by Jóźwiakowska et al. [2020] indicate that the concentrations of chlorides and sulfates in the water of the Bystrzyca river, which is the recipient of Ciemięga, in 2019 amounted to 23–78 mg·dm^{-3} and 37–114 mg·dm^{-3}, respectively.

Microbiological indicators. Table 2 presents the values of microbiological indicators in the water of the Ciemięga River in 2020.

The presence of *Escherichia coli* was observed in the samples, ranging from 5 MPN/100 ml to more than 24000 MPN/100 ml. The presence of fecal coliform bacteria was confirmed as well, ranging from 40 to 12000 (tab. 2). The abundance of the selected indicator bacteria increased down the river. The highest abundance of *E. coli* bacteria was observed in May and August. The abundance of *E.coli* bacteria dropped in November in all measurement points. The highest, 80-fold reduction was observed in sampling point no. 6, from 24000 MPN/100 ml in May to 300 MPN/100 ml in November. Compared to the results from August, a reduction in the abundance of these bacteria was noted in November, which reached 22-fold decrease in sampling points no. 2 and 4, from 4500 MPN/100 ml in August to 200 MPN/100 ml in November (Tab. 2). In the case of fecal coliform bacteria, the highest abundance was observed in May, reaching 12000 MLN/100 ml in sampling point no. 5. Sampling point no. 1 constituted an exception, because no presence of fecal coliform bacteria was noted. In the remaining sampling points (no. 2–6), compared to May, the abundance of fecal coliform bacteria in August and November decreased significantly. The greatest drop in

Table 2. Values of microbiological indicators in the water of the Ciemięga River in 2020.

Parameter	Sampling point no.					
	1	2	3	4	5	6
May 2020						
Coliform bacteria (37°C) (cfu/100ml)	2100*	4600	2400	2400	1100	24000
Fecal coliform bacteria (44°C) (cfu/100ml)	none	4600	4600	1500	12000	2400
August 2020						
Coliform bacteria (37°C) (cfu/100ml)	4500*	4500	40	4500	2500	4500
Fecal coliform bacteria (44°C) (cfu/100ml)	450	250	40	250	250	450
November 2020						
Coliform bacteria (37°C) (cfu/100ml)	300*	200	300	200	300	300
Fecal coliform bacteria (44°C) (cfu/100ml)	100	brak	100	200	200	200

* Results obtained after 48h (colony-forming units).

the abundance of fecal coliform bacteria was observed in sampling points no. 3 and 5. In point no. 3, the abundance of these bacteria in August and November was 115-fold lower (from 4600 MPN/100 ml to 40 MPN/100 ml) and 45-fold lower (from 4600 MPN /100 ml to 100 MPN/100 ml), respectively. In point no. 5, compared to the results from May, a 48- and 60-fold reduction in the abundance of these bacteria was observed in August (from 12000 MPN/100 ml to 250 MPN/100 ml) and November (from 12000 MPN/100 ml to 200 MPN/100ml), respectively (Table 2).

Among the coliform bacteria, *Escherichia coli* – the genus which may contain both commensal strains which are harmless to people, as well as pathogenic strains causing food poisoning, urinary tract inflammation and meningitis – is dominant. Apart from food, which constitutes the main source of infection with *E.coli* bacteria, they are also present in water and wastewater [Cabral 2010; Anastasi et al. 2012]. The occurrence of these bacteria in the investigated waters of the Ciemięga River indicates the presence of feces, which limits the possibilities for the application of such water [Frąk et al. 2013]. The presence of *E.coli* bacteria may also be connected with inappropriate water and wastewater management in vicinity of agricultural holdings and seasonally-operated leisure infrastructure [Frąk 2010; Frąk and Kardel 2012]. In line with the Regulation of the Minister of Environment of 11th February 2004, the water of the Ciemęga river should be allocated to the 4th class of quality, which indicates strong anthropogenic influence and draws attention to the issue of household sewage discharge, which introduces bacteriological pollutants to the river. Similar results were obtained by Frąk and Jankiewicz [2013], who investigated the bacteriological status of the Upper Narew river and reported the presence of *E. coli* bacteria in all 7 sampling points. The abundance of these bacteria increased down the river. The authors indicate that the abundance of *E. coli* bacteria in the Upper Narew river may be connected with the illegal discharge of wastewater from leisure infrastructure or the dairy cattle grazing areas [Frąk and Jankiewicz 2013].

CONCLUSIONS

1. In terms of the physicochemical indicators, the general condition of the Ciemięga River at the investigated section should be considered as "less than good".
2. The values of all indicators, excluding total and ammonia nitrogen, exceeded the 1st class of quality standards for upland carbonate streams with varying frequency.
3. The indicators which contributed the most to the deterioration of the quality of water of the Ciemięga River included: conductivity, COD, nitrite nitrogen, total phosphorus and sulfates. The average values of these indicators periodically exceeded the standards established for 2nd class of quality. The dissolved oxygen content was at a similar level.
4. The spatial and seasonal variability of the pollution level in the waters of the Ciemięga River indicates a possible impact of pollutants from point and non-point sources from agricultural lands.
5. Elevated values of biogenic indicators in the lower part of the investigated section of the river indicate a possible influence of insufficiently treated wastewater from the Snopków treatment plant.
6. The presence of microbiological pollutants, especially fecal coliform bacteria, may indicate an influx of fecal pollutants from the areas with non-regulated water and wastewater management.
7. The obtained results indicate the necessity of limiting the anthropogenic pressure in the catchment of the Ciemęga river by rationalizing the fertilization of agricultural lands, regulating the waste and wastewater management, as well as appropriate spatial policy and landscaping. It is also necessary to constantly raise the ecological awareness of residents responsible for the condition of environment in the catchment of the Ciemęga river.

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