Monika **PUCHLIK** • Izabela **SONDEJ** • Kamil **BERNATOWICZ** • Dariusz **TYMOSIAK** • Tomasz **OSZAKO** • Janina **PIEKUTIN**

THE IMPACT OF FOREST AREAS ON CHANGES IN SELECTED WATER PARAMETERS – CASE STUDY OF THE ROMNICKA FOREST IN CENTRAL EUROPE

Monika PUCHLIK (ORCID: 0000-0002-3456-7377) – Faculty of Construction and Environmental Sciences, Department of Silviculture and Forest Utilisation, Bialystok University of Technology

Izabela SONDEJ (ORCID: 0000-0001-8548-9738) – Department of Natural Forests, Forest Research Institute and Faculty of Construction and Environmental Sciences, Bialystok University of Technology

Kamil BERNATOWICZ (ORCID:0009-0007-0117-938X) – Gołdap Forest District

Dariusz TYMOSIAK (ORCID: 0009-0006-7379-7155) – Department of Geotechnics, Roads and Geodesy, Bialystok University of Technology

Tomasz OSZAKO (ORCID: 0000-0003-4688-2582) – Forest Protection Department, Forest Research Institute

Janina PIEKUTIN (ORCID: 0000-0001-6192-7449) – Department of Technology in Environmental Engineering, Bialystok University of Technology

Correspondence address:
Wiejska Street 45A, 15-351 Bialystok, Poland
e-mail: m.puchlik@pb.edu.pl

ABSTRACT: This paper presents the results of a two-year study (2020 and 2021) of physico-chemical parameters of water samples on the example of two rivers of eastern Poland, the Żytkiejmska Struga and the Błędzianka, as well as a preliminary analysis, which are located in an area generally considered to be free of negative industrial influences. Based on the results, 55% of the analysed water samples did not correspond to purity classes I and II (quality below good) compared to previous years. The analysis of our own research shows that the need to include forest habitats in comprehensive studies of surface water quality is essential, as they can play an important role in reducing pollution, stabilising ecosystems and mitigating climate change.

KEYWORDS: anthropogenic disturbances, physical and chemical parameters of water, forest ecosystem

Introduction

The increasing development of industrial and living human activities leads to an increase in the demand for clean water, clean air and thus better protection of the environment (Ramm & Smol, 2024). The factors of water pollution are a number of chemicals and micro-organisms contained in water (Bashir & Abdelrahman, 2023; Sondej et al., 2024). They are not natural components of water, or if they are, they occur in nature in larger layers (Lampert & Sommer, 2000). Nitrogen, carbon and phosphorus are the most important elements responsible for negative changes in the environment (Borowiec & Zabłocki, 1996; Piekutin & Kotowska, 2021; Buta et al., 2023). They originate from point sources, i.e. municipal and industrial wastewater, and from soil sources, i.e. agricultural land. It is estimated that about 50% of the nutrients that pollute lakes and rivers are the result of diffuse pollution (Daniszewski, 2012; Pytka et al., 2013; Tomczyk et al., 2024). The transport of carbon and nitrogen via rivers has a strong impact on the functions of terrestrial and aquatic ecosystems, but is itself influenced by changes in land cover and land use. In addition, the chemical properties of water severely limit the existence and development of plants that convert the mineral components of water into organic matter that is utilised by animals and heterotrophic bacteria (Degórska, 2017).

Population growth and increased industrial activities, which lead to an excess of nutrients in water bodies, are important causes of eutrophication (Conley et al., 2009; Wang et al., 2017). Algal growth can be inhibited and algal blooms stopped by controlling the levels of the main nutrients nitrogen (N) and phosphorus (P) in the water column (Wang et al., 2017; Zhu et al., 2018). The content of biogens in water bodies depends on the nutrient load, and quantifying the load is an important first step towards their management (Elbanowska et al., 1999; Józefaciuk & Józefaciuk, 1996; Zhu et al., 2020). The climate and the nature of the catchment area have a significant influence on the formation of the natural chemical composition of water bodies, the hydrological structure of surface waters, the formation of bottom sediments and the occurrence of suspended matter (Degórska, 2017; Puchlik & Ignatowicz, 2017; Puchlik et al., 2022; Halkos, 2022). The aim of this study was to find out whether negative consequences of human activities also occur in a forest area that is considered the lungs of Poland and Europe. Whether nature is able to cope with them, especially in view of the observed climate change.

Characteristics of the research area

The commune of Dubeninki is a rural commune in the north-eastern part of the Warmian-Masurian Voivodeship in the district of Gołdap (Figure 1). The coordinates defining the geographical location of the Goldap Forest District: 54°14` – 54°22` north latitude and 22°09` – 22°48` east longitude (Dubeninki Municipality, 2017). According to the 2010 regionalisation of Polish natural forests, the forests of the forest district are located in the Second Natural Forest Region – Masuria-Podlaskie, mesoregions: Romincka Forest, Ełk Lake District, Suwalskie Lake District (Figure 1).

The borders of Poland, Lithuania and Russia meet in the north-eastern part of Europe. The area of the municipality is 205.18 km^2, which corresponds to 27% of the area of the Gołdap district, which is characterised by an agricultural character and a large forest area (Kłos, 2014). The analysed area is protected in many respects. This has an impact on the limited opportunities for growth in production activities. At the same time, it enables the development of tourism services thanks to land development that takes into account the needs of nature conservation and increases the attractiveness of the area for tourism (Gmina Dubeninki, 2020). The commune is largely covered by the Romnicka Forest (the largest forest complex) of the Gołdap Forest District and the forests in the southern part – by the Olecko Forest District (Winiarski & Janeczko, 2011). The Romincka Forest Landscape Park, with an area of 146.2 km^2 and a buffer zone of 85 km^{2,} is located in the north-easternmost part of the Warmian-Masurian Voivodeship, on part of the territory of the municipalities of Dubeninki and Gołdap. 80% of this area is covered by forest, which locally resembles a taiga. The park is crossed by the valleys of the Błędzianka, Bludzia and Czerwona Struga rivers (Żurek & Kłos, 2012). The Polish-Russian border coincides with the northern border of the park. In the village of Stańczyki, there are two 36.5 metre high bridges crossing the Błędzianka Valley (Krzywicki, 2000). The vegetation is unique and has many peculiarities due to the harsh climatic conditions (Fałtynowicz, 2000). In the forest, there

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is a characteristic plant community typical of the taiga: boreal spruce forests, moist, dark and covered with a thick carpet of mosses. The hills and slopes are covered with deciduous forests of lime, maple, hornbeam and elm. A mixed spruce and hazel forest grows on sandy hills. Peaty stream valleys are characterised by ash and alder riparian forests with a protected ostrich plume. The lake lowlands are covered with species-rich peat bogs with rare and protected plants (Wołkowycki & Pawlikowski, 2017). Six nature reserves protect particularly valuable parts of the park (Dembek, 1991). The most characteristic is the Żytkiejmska Struga Nature Reserve (467.07 ha), where 91.3 ha are covered with peat bogs occurring in the valley of the Żytkiejmska Struga River. The river is a 26.4 km long right tributary of the Błędzianka, 15.4 km of which flows into Poland (Rąkowski, 2004).

Figure 1. The location of the water sampling points Żytkiejmska Struga (1) and Błędzianka (2) rivers is in the Gołdap and Olecko Forest District of the Regional Directorate of State Forests, Białystok, Poland

The Natura 2000 area is a very varied landscape, consisting mainly of hilly plateaus of clay and worked sands. Kema hills and dead ice moraines are widespread. Interesting elements of the landscape are the valleys of rivers and smaller watercourses. They flow northwards, the Błędzianka and its tributaries – Bludzia, Czerwona Struga, Czarna and Żytkiejmska Struga with tributaries (Fig. 1). These watercourses are characterised by their natural character. They meander or flow in valleys cut deep into the ground. The largest river in the forest is the Błędzianka – it has developed on the outskirts of the city (Figure 1). There are often depressions at the bottom of the valley (Dubeninki Municipality, 2017). The municipality has the characteristics of a marine-continental transitional climate, with a characteristically high variability of weather conditions from day to day and from year to year. The reason for this phenomenon is the meeting of dry continental air masses with humid air masses from the Atlantic. The average annual amplitude of the air temperature ranges from 19 to 22°C, while the average annual air temperature is between 6 and 8°C. The warmest months are July and August, the coldest are December and January. The average annual frequency of calm and light winds below 2 m/s is between 20% and 50%. Westerly winds prevail in the municipality. The average annual sunshine duration is 1500-1600 hours/year. The climatic conditions favour the use of wind and solar radiation to generate energy (Niaz et al., 2022).

The climate rating for agriculture is below the national average (Pawlikowski & Siwak, 2009). Soils of assessment classes III and IV dominate, accounting for about 70% of all soils. In addition, there is also a large amount of class I soils, which make up about 14% of all areas, and class II soils, which make up about 17% of the km^2. Wooded and scrubland areas cover an area of 8 783 ha, i.e. 42.79% of the municipal territory. Agricultural land makes up 47.97% of the total area of the com-

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mune, forests and wooded areas – 42.79%, water – 2.03%. Other land and fallow land 7.21%. This area is therefore typically characterised by agriculture. It is also characterised by a low degree of urbanisation and low economic development in the non-agricultural sector, particularly in industry and the service sector (Kłos, 2014).

Materials and Methods

The study is based on field data for the region (as of 2016). Two rivers, Zytkiejmska Struga and Bledzianka, were selected, which are characterised by high forest cover (42.79%) and low population density. The article presents the results of the parameters of the 2-year study (2020 and 2021) of physicochemical water samples. The sampling points for water samples were determined depending on the type of catchment area: 1 – areas within small settlements and forest areas; 2 – forest areas; 3 – typically agricultural and forest areas. Water samples were taken according to PN-ISO 5667-5: 2017-10 in two years: in autumn (October), early spring (March) and spring (May) of 2020 and 2021. In the analysed river water samples, the following was determined according to the applicable methodology: Turbidity [NTU] (PN-EN ISO 7027-1: 2016-09 without point 5.4); pH (PN-EN ISO 10523: 2012); Conductivity [µS/cm] (PN-EN 27888: 1999); Nitrate nitrogen [mg/L] (PN-ISO 7150-1: 2002); TOC [mg C/L] (PN-EN 1484: 1999); Nitrate nitrogen [mg/L] (PN-EN ISO 10304-1:2009+ AC:2012); Nitrite nitrogen [mg/L] (PN-EN ISO 10304-1:2009+ AC:2012); Hardness [mg $CaCO_3$ /L] (PN-ISO 6059: 1999); Chlorides [mg/L] (PN-EN ISO 10304-1:2009+ AC:2012); Sulphates [mg/L] (PN-EN ISO 10304-1:2009+ AC:2012), Magnesium [mg/L] (PN-EN ISO 7980: 2002 only for samples with a sulphate content <250 mg/L), Calcium [mg/L], Sodium [mg/L] (PN-ISO 9964-1: 1994+Ap1: 2009), Manganese [µg/L] (PN-EN ISO 15586:2005).

Analyses and physico-chemical measurements of water were carried out in the accredited laboratories of Białystok Waterworks Sp. z o. o. (Physico-chemical analyses and measurements of water were carried out in the accredited laboratories of Bialystok Waterworks Ltd. The laboratory has an approval for the quality system of testing water intended for human consumption by Decision No. HKN-272/2022 of the District State Health Inspectorate in Ciechanów, valid until 31 December 2024).

The analyses were carried out in accordance with the Regulation of the Minister of the Environment on "The quality of water intended for human consumption" (Regulation, 2017) and fulfils the requirements of PN-EN ISO / IEC 17025: 2018-02" General requirements for the competence of testing and calibration laboratories" and in accordance with the methodology described in the Polish standards.-

In addition, a regression analysis was conducted in which the independent variable is the sum of daily precipitation, and the dependent variable is the average water level (p=0,05).

Results and discussion

According to Niaz et al. (2022), the deficiency of precipitation and its related impacts have severe effects on weather-related events, natural ecosystems, forestry, economy, agriculture, and environment. The results of our own research on basic parameters in three research seasons (March-May; June-August; September-November) over two years showed the dependence of the influence of temperature and season on the increase in environmental pollution on their quality. The results of the physicochemical analyses of the river water made it possible to analyse the changes in water quality during the study period. In addition, meteorological and hydrological data for the Gołdap poviat from 2005 to 2021 in terms of average daily precipitation and surface water levels (Figures 2 and 3) were obtained for comparison with our own research (Institute of Meteorology and Water Management in Poland, 2022). The data obtained, both the sum of daily precipitation (Figure 2) and the water level of the river in the Gołdap district (Figure 3), clearly show a downward trend, which means that the amount of precipitation and thus the condition of the surface waters will decrease.

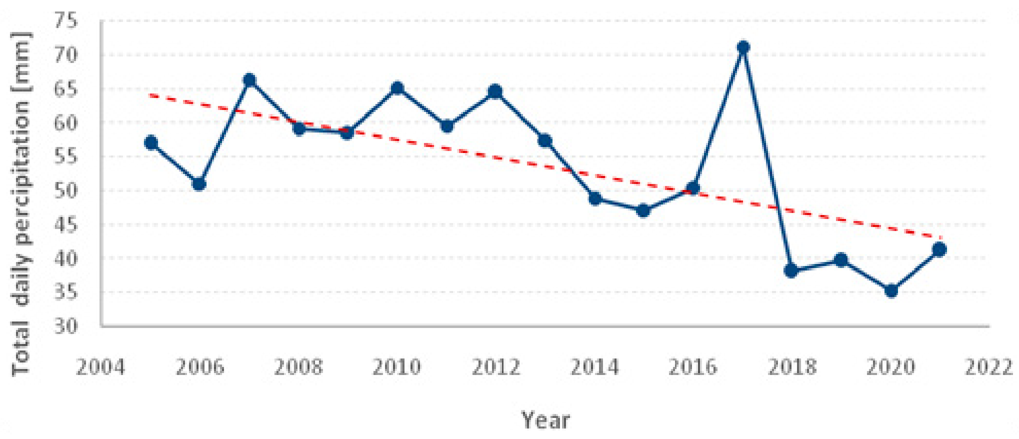

Figure 2. Average daily precipitation in the Gołdap region in Poland in the period 2005-2021
Source: authors' work based on data from the Institute of Meteorology and Water Management in Poland (2022).

Figure 3. Surface water levels in the Gołdap region in Poland in the years 2005-2021
Source: authors' work based on data from the Institute of Meteorology and Water Management in Poland (2022).

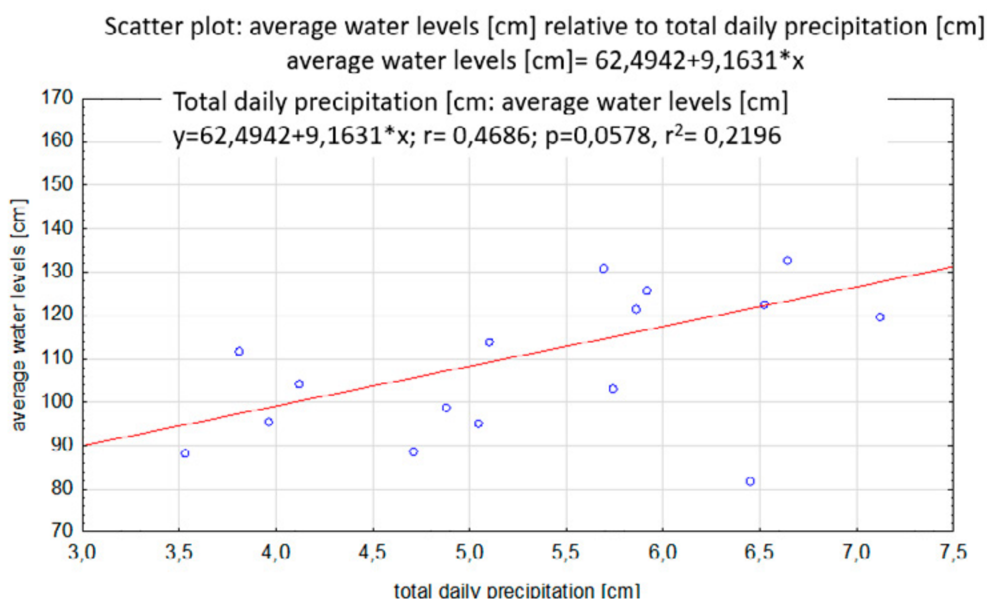

Figure 4. Scatter plot: average water levels

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Statistical analyses were performed at the accepted test probability level of p = 0.05. Regression analysis was performed, where the independent variable is total daily precipitation, and the dependent variable is average water levels (Figure 4).

A linear regression model was considered according to the equation:

$$y = a + bx \pm \varepsilon \tag{1}$$

where:
a – free expression,
b – directional coefficient,
ε – standard error of estimation.

The obtained regression model, with the coefficient of determination $R^2 = 0.220$ (Table 1), has the following. Form (marked red line in the Figure 4): average water levels = 62.494 + 9.163 * total daily precipitation ± 19.173 (Pearson's correlation coefficient r = 0.4686; testing probability p = 0.0578).

Table 1. Results from Statistica 13 program from the performed regression analysis of the obtained model.

Statistics	Summary statistics: dependent variables water levels [cm]
	Value
R multiple	0.468601388
R^2 multiple	0.219587261
R^2corrected	0.167559745
F(1,15)	4.22059859
p	0.057789892
Standard error of estimation	19.173333

In addition, the significance of the free expression a and the directional coefficient b of the obtained model were checked, and the results from the Statistica 13 program is shown in Table 2.

Table 2. Results from summary of regression of variable: total daily precipitation.

N=17	Summary of regression of variable: total daily precipitation [cm] R=.46860139 R^2=.21958726 corr. R2.16755974 F(1,15)=4.2206 p<.05779 Standard error of estimation: 19.173					
	b*	Standard error with b*	b	Standard error with b	t(15)	p
Free expression			62.49424	24.35507	2.565964	0.021506
Total daily precipitation [cm]	0.468601	0.228095	9.16312	4.46022	2.054410	0.057790

Designations: N – number of cases

The expressions a and b of the equation are statistically significant when the test probability p < 0.05. From Table 2 above, it can be seen that the free expression a of the linear regression equation is statistically significant at a test probability value of p = 0.022; the directional coefficient b of the equation is statistically insignificant, as p = 0.058. Thus, the resulting model is considered statistically insignificant.

Most of the water samples (48%) were categorised in purity class II, 41% in class I and 11% in class II (Tab. 4), which means that the condition of the Żytkiejmska Struga is less good (Tab. 2). Turbidity ranged from 1.3 to 5.2 NTU in the analysed periods. The lowest value (1.3 NTU) was measured in season II. The highest value was observed in season III (5.2 NTU). The sharp increase in the value by 3.9 (NTU) is most likely related to the typically agricultural character of the catchment area at collection point no. 3.

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Table 3. Average values, minimum and maximum values, median and standard deviation of selected physicochemical parameters of the Błędzianka river from 2020 and 2021

Intake	Sampling point	Turbidity [NTU]	pH	NH_{4+} [mg/L]	NO_{3-} [mg/L]	NO_{2-} [mg/L]	Cl^- [mg/L]	PO_4^{3-} [mg/L]	SO_4^{2-} [mg/L]	TOC [mg /L]	Mg^{2+} [mg/L]	Ca^{2+} [mg/L]	Na^+ [mg/L]	Mn^{2+} [mg/L]
I	1	6.0	7.9	0.1	3.0	0.2	7.6	0.2	12.5	5.1	15.0	88.0	-	0.2
	2	3.0	8.1	0.1	3.0	0.2	5.6	0.2	10.7	4.8	15.0	88.0	-	0.1
	3	2.8	8.2	0.1	3.0	0.2	5.6	0.2	10.8	5.0	15.0	86.0	-	0.1
II	1	1.0	7.9	0.8	6.7	0.1	4.7	16.4	23.7	15.2	35.7	162.9	8.8	0.1
	2	4.4	8.1	0.8	4.7	0.1	5.0	22.2	27.3	21.2	36.7	166.0	9.2	0.1
	3	2.1	8.1	0.6	5.8	0.1	5.1	23.4	24.8	15.7	33.4	150.1	8.7	0.0
III	1	9.3	8.2	0.2	2.3	0.2	4.8	-	13.3	52.2	14.9	79.3	3.7	-
	2	7.4	8.2	0.2	2.1	0.2	7.2	-	17.2	29.4	17.3	85.9	5.1	-
	3	10.9	8.2	0.1	2.2	0.2	4.6	-	13.3	30.8	15.3	81.3	4.3	-
Min-Max		1.0-10.9	7.9-8.2	0.1-0.8	2.1-6.7	0.1-0.2	4.6-7.6	0.2-23.4	10.7-27.3	4.8-52.2	14.9-36.7	79.3-166.0	3.7-9.2	0.0-0.2
Standard deviation		3.41	-	0.31	1.68	0.05	1.1	11.46	6.50	15.66	9.99	37.8	2.53	0.06
Median		4.4	-	0.2	3.0	0.2	5.1	8.3	13.3	15.7	15.3	88.0	6.9	0.1

- lack of measurement.

Table 4. Average values, minimum and maximum values, median and standard deviation of selected physicochemical parameters of the Żytkiejmska Struga river from 2020 and 2021

Intake	Sampling point	Turbidity [NTU]	pH	NH_{4+} [mg/L]	NO_{3-} [mg/L]	NO_{2-} [mg/L]	Cl^- [mg/L]	PO_4^{3-} [mg/L]	SO_4^{2-} [mg/L]	TOC [mg /L]	Mg^{2+} [mg/L]	Ca^{2+} [mg/L]	Na^+ [mg/L]	Mn^{2+} [mg/L]
I	1	2.0	7.9	<0.10	6.2	0.4	18.2	0.5	26.1	8.0	16.0	99.0	-	0.2
	2	1.5	8.2	<0.10	<3.0	0.2	11.0	0.5	20.0	7.3	16.0	98.0	-	0.0
	3	3.8	8.0	<0.10	<3.0	0.2	6.6	0.2	8.7	8.2	14.0	92.0	-	0.1
II	1	3.1	7.9	0.2	0.8	0.1	12.0	14.8	41.6	10.3	31.0	136.7	7.8	0.0
	2	1.7	8.0	0.2	0.8	0.2	5.0	32.7	34.8	13.4	31.2	139.2	8.3	0.0
	3	1.3	7.9	0.14	0.71	0.2	7.2	31.9	66.0	10.7	31.0	138.0	8.0	0.1

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Intake	Sampling point	Turbidity [NTU]	pH	NH_{4}^{+} [mg/L]	NO_{3}^{-} [mg/L]	NO_{2}^{-} [mg/L]	Cl^{-} [mg/L]	PO_{4}^{3-} [mg/L]	SO_{4}^{2-} [mg/L]	TOC [mg /L]	Mg^{2+} [mg/L]	Ca^{2+} [mg/L]	Na^{+} [mg/L]	Mn^{2+} [mg/L]
III	1	2.6	8.3	0.6	7.1	0.0	4.8	-	15.5	64.2	12.6	65.8	3.1	-
	2	2.6	8.3	0.6	13.2	0.0	4.7	-	15.4	42.9	12.9	67.7	3.2	-
	3	5.2	8.1	0.13	0.8	0.11	4.09	-	13.02	30.7	12.7	69.5	3.5	-
Min-Max		1.3-5.2	7.9-8.3	0.13-0.6	0.71-13.2	0.0-0.4	4.09-18.2	0.2-32.7	8.7-66.0	7.3-64.2	12.6-31.2	65.8-139.2	3.1-8.3	0.0-0.2
Standard deviation		1.25	-	0.23	4.84	0.12	4.7	15.64	18.17	20.11	8.61	30.69	2.62	0.08
Median		2.6	-	0.2	0.8	0.2	6.6	7.65	20.0	10.7	16.0	98.0	5.65	0.05

- lack of measurement.

Table 5. Comparison of the physico-chemical parameters of our own investigations of the Błędzianka River from 2020 and 2021 with the data of the Main Inspectorate of Environmental Protection in Olsztyn from 2016 and 2019

Source	Year	pH	NH_{4}^{+} [mg/L]	TOC [mg /L]	NO_{3}^{-} [mg/L]	NO_{2}^{-} [mg/L]	Cl^{-} [mg/L]	SO_{4}^{2-} [mg/L]	Mg^{2+} [mg/L]	Ca^{2+} [mg/L]	PO_{4}^{3-} [mg/L]	Conductivity [µS/cm]	Hardness [mgCaCO$_3$/L]
GIOS Olsztyn	2009	7.8	0.1	11.2	0.95	0.01	-	-	-	-	0.06	443	246
		8.2	0.05	8.8	0.28	0.01	-	-	-	-	0.07	425	228
		8.1	0.03	9.7	0.4	0.01	-	-	-	72.9	0.06	419	231
	2010	7.9	0.14	7.9	0.96	0.006	-	-	-	-	0.096	398	236
		7.8	0.02	15.2	0.28	0.009	-	-	-	-	0.135	220	161
		8.0	-	7.1	0.18	0.05	-	-	-	-	0.6	415	281
	2011	7.8	0.13	-	-	0.01	-	-	-	-	-	-	208
		8.1	0.03	7.7	0.64	0.01	<5.0	<10.6	12.0	69.3	0.03	371	222
		7.8	<0.016	9.2	0.17	0.001	<5.0	<10.6	12.5	81.7	0.06	421	255
Own research	2020/2021	8.2	<0.100	5.0	<3.00	0.18	5.6	10.8	15.0	86.0	0.2	537	289
		8.1	0.64	15.7	5.82	0.08	5.1	24.85	33.37	150.14	23.44	-	-
		8.2	0.13	30.8	2.24	0.22	4.62	13.29	15.32	81.35	-	-	-

- lack of measuremen.

The response ranged from 7.9 to 8.30 and showed no significant differences in the seasons analysed. Large differences in water quality can be seen in the concentration of nitrogen compounds. The highest concentrations were measured at sampling sites in agricultural areas and near human settlements, while the lowest concentrations were measured in water samples taken in forested areas (Tab. 4). Similar results were obtained in the studies by Jekatierynczuk-Rudczyk et al. (2006) in which the water quality of urban and forested rivers was analysed – it was found that the forest river had the lowest levels of biogenic compounds. The ammonium ion showed the highest values in the water samples in spring and the lowest in autumn (<0.10 mg/L) (Tab. 4). The highest concentrations of nitrate-nitrogen were measured in spring (13.2 mg/L). Nitrite nitrogen fluctuated between 0 and 0.4 mg/L and reached its highest value in autumn. It can therefore be concluded that the Żytkiejmska Struga is quite rich in nitrogen compounds. It can be influenced by runoff from the surrounding agricultural land and by point sources of pollution from illegal wastewater discharges from the nearby inhabitants of Żytkiejmy. The location of the measuring and control points deserves attention. The first point is located below the mouth of the river into the lake and may have retained some of the pollution.

According to Moniewski (2015) and Muholland (1997), changes in the physicochemical properties of water largely depend on the structure of the hydrographic network of the catchment. An important factor influencing their transformation is the presence of flow-through lakes and artificial reservoirs (ponds). They increase the capacity of the water catchment area, reduce the dynamics of runoff and the extent of flooding. At the same time, they stabilise the groundwater level in the valley. The large area of the water table in relation to the watercourse increases the direct runoff. It absorbs rainwater with different physicochemical properties from river water. Near the first site (Figure 1), there is also a settlement consisting of several houses and farms with numerous arable fields. Collection site no. 3 is located between the sources of pollution – on the one hand, the river is surrounded by farmland and meadows, and on the other by forests. The highest concentrations of nitrogen compounds were measured at this point – they probably originate from runoff from arable land. Point 2, on the other hand, is located in the forest landscape, close to peat bogs. The forest is a buffer that protects against pollution and captures many pollutants (Chełmicki, 2001; Han & Bu, 2023) – therefore, nitrogen compounds were lowest at this point. Other authors (Górecki & Olejnik, 2005) also emphasise that the large forest cover of the catchment helps to limit the infiltration of pollutants into water bodies from the area's sources. This type of catchment is characterised by the fact that the concentration of nutrients in the river water decreases as it flows through the watercourses. A process called self-purification of water takes place in them. The TOC (total organic carbon) concentration values were significantly higher at each of the collection points in season III, ranging from 30.77 to 64.23 mg/L (Tab. 4). This could be related to the increased decomposition processes of dead organic matter due to the increased water temperature and the flooding of the river during this period. In addition, a characteristic feature of the water in the analysed agricultural catchment – sampling sites No. 1 and 2, an increase in TOC concentration can be observed (Table 4). According to Eckchard and Moore (1990) and Zieliński (2004), meadow ecosystems are capable of producing a similar amount of annual biomass as forest ecosystems – therefore, these areas also produce a considerable amount of organic matter that enters the rivers together with rainwater runoff. In addition, natural rivers with a low degree of anthropogenic transformation, as in the case of Żytkiejmska Struga collection site No. 2, show the ability to homeostasis and low variability of TOC content. This is confirmed by the concentration of this parameter in point 2 of Żytkiejmska Struga, which is located in the centre of the forest complex (range from 7.3 to 42.9 mg/L). These values increased from autumn to spring, which is confirmed by the aforementioned increase in water temperature and the intensification of decomposition of dead organic matter accumulated in autumn. According to Mulholland (1997), the carbon content in river water is an important indicator of the hydrological and biogeochemical processes taking place in small catchment areas. The chloride concentrations varied. The highest concentration values were observed in catchment I (from 6.6 to 18.2 mg /L) and the lowest in season III (from 4.09 to 4.77 mg/L) (Tab. 4). According to the Regulation of the Minister of Infrastructure of 25 June 2021 (Regulation, 2021), most chloride concentrations were classified in water purity class I (Regulation, 2021). The highest chloride concentrations were measured in point 1 of the studied river from the period of all three seasons in autumn, with a value of 18.20 mg/L and in early spring – 11.95 mg/L. It should be noted that collection point no. 1 is located below the settlement and is crossed by roads for local residents. According to Hillbricht-Ilkowska (1999), pollution caused by this type of human activity reaches water bodies. The ecosystems of rivers are connected to the catchment area. According to Starck (2002), it is also known that the content of chloride and sodium entering surface waters, especially from linear sources, accumulates in them, as aquatic macrophytes are hardly able to transform and utilise these compounds. Magnesium and calcium were the highest in season II: magnesium in the range of 30.95 to 31.21 mg\L), calcium (from 136.70 to 139.23 mg\L) (Tab. 4). It should be emphasised that the natural river waters of Europe are characterised by the highest calcium content (from 3.0 to 110.0 mg/L) and a much lower magnesium content (from 0.1 to 24.0 mg/L). According to Allan (1998), their molar concentration accounts for at least half of the total cations in the water. The increase in the concentration of the analysed ions is probably due to surface and soil runoff from the catchment area. The largest number of them was measured in season II – in early spring, when the snow began to melt. In the case of the Żytkiejmska Struga River, sodium concentrations ranged from 3.13 to 8.31 mg/L. Kanownik and Pijanowski (2002) found similar values for sodium concentration in water flowing from an agricultural and forestry catchment area, Rajda and Kanownik (2007) even found an average of 50% more in wastewater from an urbanised catchment area. The lowest values of calcium, magnesium and sodium concentrations were found in the samples of season II (end of May, spring) – this can be explained by the enormous activity of aquatic plants, which absorb these elements for their development. It is important to emphasise that high concentrations of calcium and magnesium do not have a toxic effect on living organisms, but contribute to an increase in water hardness, which reduces the economic quality of the water. Therefore, the content of these parameters meets the requirements of the Regulation of the Minister of Health of 2017 (Regulation, 2017). In turn, according to the Regulation of the Minister of Infrastructure of 25 June 2021 (Regulation, 2021), the concentration of calcium was classified as class I of water purity only in the samples of the 3rd collection, the rest significantly exceeds the standards and belongs to class below II. In the case of magnesium, the concentration of this element was also significantly exceeded in practically every sample – classified below purity class II, only in the third sampling, in points 1 and 2, the concentration of this element could be assigned to purity class II. When analysing the composition of water pollution in the Żytkiejmska Struga River at the turn of 2020 and 2021, it is worth comparing the concentrations of some parameters with the results of previous years from the same months. According to Ilnicki (2004), the degree of pollution of surface waters with nutrients and the intensity of eutrophication of these waters depend on many natural and economic factors. At present, ever higher doses of fertilisers are being used for cultivation, more and more cars are being driven on the roads, and the population is using more and more chemicals in their households. All this has an impact on the environment, which is reflected in an increase in pollution indicators in water bodies. The deterioration of water quality is mainly caused by the weather extremes observed in the research area, i.e. increased air temperature, reduced precipitation, especially in summer, and snow cover in winter.

Based on the results in Table 1, it was found that 55% of the water samples analysed were classified as Class I and II water. It was also found that 37% of the analysed samples belonged to purity class 1 and only 8% to purity class 2. It was thus established that the Błędzianka belongs to the rivers with a less favourable conditions. Turbidity was highest in the spring season (from 7.4 to 10.9 NTU) (Table 3). This could be related to the high water level during this period due to heavy rainfall. According to many authors, turbidity increases with increasing water level (Table 3) (Rzętała, 2008). On the other hand, the lowest turbidity values are found in samples collected in the riverbed in early spring (from 1.0 to 4.4 NTU) (Szczykowska & Siemieniuk, 2010). The changes in water turbidity are thus closely related to the flushing of soil particles and the intensity of their movement in the riverbed. This phenomenon occurs most effectively on steeply sloping surfaces. In winter, the soil is less varied and covered with decaying organic residues and offers little resistance to snowmelt or rainwater, while in summer, intense rainfall increases the effectiveness of flushing (Rzętała, 2008). It is worth mentioning that due to the greater susceptibility of weakly bound particles, an increase in water turbidity was also observed in spring. The pH of the water showed no significant fluctuations throughout the research period and ranged between 7.9 and 8.2 (Table 3). However, its increase with the next consumption period deserves attention. It was found that the dispersion of the results is favoured by the agricultural character of the Błędzianka River catchment and the zone of point or areal pollution

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of the water. These results could be influenced by the intense rainfall in May and the growing river vegetation, which absorbs carbon dioxide and lowers the pH of the water.

The research showed a seasonal variability of the analysed parameters. The highest concentration of ammonium nitrogen was measured in early spring, with 0.64 to 0.78 mg/L, the lowest in autumn with less than 0.1 mg/L (Table 3). A similar trend was observed for ammonium nitrogen in spring (range of 4.68 to 6.73 mg/L) and below 3.0 mg/L in early spring. The situation was different for nitrite nitrogen. Lower concentrations were found in the early spring samples (range 0.08 to 0.12 mg/L), while they were similar in autumn and spring. The sources of nitrogen compounds are the processes of reduction of nitrite-nitrogen (III) and nitrate-nitrogen (V), processes of biochemical decomposition of organic nitrogen compounds (plant, animal and synthetic) or from discharged municipal and industrial wastewater. The concentrations of ammonium nitrogen in surface waters range from hundredths to several mg/L, and its presence in surface waters in higher concentrations (in the order of several or more mg/L) is considered an indicator of pollution from domestic and industrial wastewater (Szczykowska & Siemieniuk, 2010; Puchlik et al., 2022). It should be emphasised that the tested water did not exceed the concentration of 1 mg/L of ammonia nitrogen.

Clean surface waters are generally characterised by negligible concentrations of nitrite nitrogen that do not exceed thousandths of a milligramme per litre. Higher concentrations are found in polluted waters and in waters flowing from swampy areas. The increased content of nitrite nitrogen proves that the processes of biochemical oxidation of nitrogenous organic compounds have not yet been completed or that anaerobic conditions have developed in the water (Wijesiri et al., 2020; Barbieri et al., 2023; Bashir et al., 2023). The source of nitrate nitrogen (V) in surface waters is wastewater and runoff from fields that have been fertilised with nitrogen fertilisers. Their important characteristic is that they belong to the (biogenic) nutrient compounds that are necessary for plant life (Starck, 2002; Wielgat, 1984). Therefore, the concentrations of nitrates (V) fall to low levels in times of increased vegetation. This is consistent with the results of our own investigations: The highest concentrations of nitrate nitrogen (V) were found in the season II samples, and due to the increased plant vegetation in May, the concentration decreased in the samples in spring (Table 1).

In the Błędzianka River, a clear upward trend in the concentrations of total organic carbon was observed with the season. In autumn, the values of TOC concentrations at all points (1-3) were between 4.75 and 5.04 mg/L, while the highest values were recorded in spring (from 29.41 to 52.19 mg/L) (Table 3). This could be related to the increase in water temperature and the increased decomposition processes of pborowieclant residues in the previous season. In the case of the river studied, chloride concentrations ranged from 4.62 mg/L to 7.60 mg/L (Table 3). The concentration decreased in spring. This was due to the inflow of weakly mineralised water from the melting snow cover and increasing precipitation. When analysing the concentrations of magnesium, calcium and chloride, dependencies can be identified. At 33.37 to 36.67 mg/L, the magnesium concentration was clearly in favour, especially in early spring (Table 3). Calcium, like magnesium, showed the highest values in season II (from 150.14 to 166.04 mg/L). The highest value of magnesium and calcium concentration in early spring results from the period of deposition and melting of snow cover, which generates the flow of meltwater with a large amount of pollutants. Based on data from the Main Inspectorate for Environmental Protection in Olsztyn from 2009, 2010 and 2011 (Table 5), the change in concentrations of selected physicochemical parameters was compared with data from 2020 and 2021 (own research).

In any case, the indicators have risen every year. The highest values were reached at the turn of 2020 and 2021 – as in the case of the Żytkiejmska Struga (Table 4). This distribution of results is influenced by the ongoing pollution of the environment by humans. The results of many previous studies indicate that the accumulation of chemical components in watercourses is the result of anthropogenic pollution, which depends on the utilisation of the catchment area and usually increases with the flow velocity of watercourses. Kanownik and Rajda (2010) investigated several small catchments in the northern part of the Beskid Mały in 1998-2001. Changes in water quality are also the result of climate change in forested and less urbanised areas. Ryberg and Chanat (2022) have shown that the quality of surface waters can change in response to climatic disturbances, such as changes in the frequency of heavy rainfall or droughts, through direct effects such as dilution and concentration and through physical processes such as bank erosion. According to Han et al., climate change has significantly influenced in recent decades the water quality of lakes of Baiyangdian Lake (China) in

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the past 30 years (1991–2020). The results show that water quality grade, chemical oxygen demand (COD), total phosphorus (TP) concentrations, and annual average and minimum air temperatures of the lake showed significant differences (Han & Bu, 2023). Water quality can also change through indirect mechanisms, such as changes in water demand or changes in the interaction between runoff and organic matter in the landscape. Ongoing urbanisation has a number of ecological consequences. The fragmentation of the landscape and important natural structures as well as the excessive consumption of arable land and soil sealing, are most frequently mentioned in the world literature (Berry, 2008). Changes in the water quality were significantly influenced by the season and land use (Połeć & Grzywna, 2023). The environmental burden arising from the excessive use of fertilisers and nutrient contamination is acknowledged by the United States Environmental Protection Agency (EPA) and the European Union (EU) as a part of the major challenges of water preservation and sustainability (Cyganowski et al., 2024).

The continuous deterioration of water quality is a global phenomenon that manifests itself in extensive reactive chemical pollution, increasing eutrophication, dangerous algal blooms and faecal contamination associated with microbial threats and antibiotic resistance. Against this backdrop, climate change and the associated extreme events are exacerbating the negative trends in water quality (Wandelt, 2015; Wan et al., 2019; Wang et al., 2020). According to Wielgat (1984), Berry (2008) and Barbieri et al. (2023) despite the growing interest in climate change and water security, research on the relationship between climate change and groundwater quality is still in its infancy. According to Porębska et al. (2021) extreme precipitation increases the amount of nitrogen leached from agricultural systems and poses a greater threat to the ecological stability of water bodies. Urbanisation increases the generation of pollutants in catchment areas and their transport to receiving waters (Bhat & Janaszek, 2024). Changes in precipitation patterns, especially in times of climate change, make pollution control a difficult task. Understanding how precipitation characteristics can influence changes in stormwater pollutant runoff is important for developing effective pollution control strategies (Wijesiri et al., 2020; Guan et al., 2022).

Conclusions

- The decrease in the sum of daily precipitation and the water level of the river in the Gołdap district clearly shows a downward trend, which leads to a significant deterioration in the quality of surface water. Based on the results obtained, it was found that 55% of the water samples analysed were classified as not corresponding to purity classes I and II (quality below good) compared to previous years.
- Lower concentrations of organic carbon in forest habitats: The research showed that forest habitats at the first and second sampling points of the two rivers analysed had lower TOC concentrations (Błedzinka River 4.8-27.3 mg/L, Żytkiejmska Struga – 7.3-13,4 mg/L) than agricultural areas (Błedzinka river basin 29.4-52.2 mg/L, Żytkiejmska Struga 30.7-64.2 mg/L), which indicates that forests can perform a buffering function in reducing water pollution regardless of the sum of daily precipitation and average water levels, as shown by the regression statistical analysis performed ($p=0.05$).
- The results of the research point to the need to include forest habitats in comprehensive studies on surface water quality, as they play a potential role in reducing pollution and stabilising ecosystems. Research should be continued, especially because of the possibility of increasing the carbon sequestration of forest ecosystems. It is important to sensitise society to the impacts of climate change on water and soil quality and to enable them to adapt to these impacts.

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The contribution of the authors

Conceptualization, M.P., J.P. and K.B.; methodology, M.P. and K.B.; validation, M.P., I.S. and T.O.; formal analysis, M.P. and K.B.; investigation, M.P. and K.B.; resources, M.P. and K.B.; data care, M.P., K.B. and D.T.; writing – preparation of original draft, M.P.; writing – review and editing, M.P., T.O. and J.P.; visualization, K.B.; supervision, M.P.; fundraising, M.P.

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Monika PUCHLIK • Izabela SONDEJ • Kamil BERNATOWICZ • Dariusz TYMOSIAK • Tomasz OSZAKO • Janina PIEKUTIN

WPŁYW OBSZARÓW LEŚNYCH NA ZMIANY WYBRANYCH PARAMETRÓW WODY – STUDIUM PRZYPADKU PUSZCZY ROMNICKIEJ W EUROPIE ŚRODKOWEJ

STRESZCZENIE: W artykule przedstawiono wyniki dwuletnich badań (2020 i 2021 r.) parametrów fizykochemicznych próbek wody na przykładzie dwóch rzek wschodniej Polski, Żytkiejmskiej Strugi i Błędzianki, które znajdują się na obszarze powszechnie uważanym za wolny od negatywnych wpływów przemysłowych. Na podstawie uzyskanych wyników 55% analizowanych próbek wody nie odpowiadało klasom czystości I i II (jakość poniżej dobrej) w porównaniu do lat ubiegłych. Analiza naszych własnych badań pokazuje, że potrzeba uwzględnienia siedlisk leśnych w kompleksowych badaniach jakości wód powierzchniowych jest niezbędna, ponieważ mogą one odgrywać ważną rolę w zmniejszaniu zanieczyszczenia, stabilizacji ekosystemów i łagodzeniu zmian klimatu.

SŁOWA KLUCZOWE: zanieczyszczenia antropogeniczne, parametry fizyczne i chemiczne wody, ekosystem leśny