Rocznik Ochrona Środowiska

Volume 23 | Year 2021 | ISSN 1506-218X | pp. 795-810

https://doi.org/10.54740/ros.2021.054 open access

Received: 01 July 2021 Accepted: 03 November 2021 Published: 06 December 2021

Analysis of the Physicochemical Quality of Water Within the Hydropower Plant on the Ślęza River in Wrocław, Poland

Paweł Tomczyk
Wrocław University of Environmental and Life Sciences, Poland
https://orcid.org/0000-0002-2483-0143

corresponding author's e-mail: pawel.tomczyk@upwr.edu.pl

Abstract: The aim of the article was the analysis of the physicochemical quality of water within the hydropower plant on the Ślęza River in Wrocław (south-west Poland) in the context of the European Union's classification of water quality, as well as an assessment of the potential impact of hydropower plants on this quality. The study uses the results of monthly tests from three measurement points within the hydropower plant on the Ślęza River in the city of Wrocław (points upstream and downstream the hydropower plant and the reference point), from the period June 2018 to May 2020. The analyses covered 10 physicochemical parameters, i.e.: pH, electrical conductivity (EC), water temperature, turbidity, NH_4-N, NO_3-N, NO_2-N, total phosphorus, dissolved oxygen and BOD_5. The conducted analysis showed that the hydropower plant has no clear influence on the physicochemical quality of the water in the Ślęza River, other interactions present in the catchment area are more important. From the effects visible in the results, a decrease in the amplitudes of water temperature downstream the hydropower plant compared to the other points was noted, as well as a lower median of its value (statistically significant changes). An additional noticeable effect was the increase in water oxygenation below the damming, but it was not statistically significant. It has been shown that the physicochemical condition of water at the tested points does not meet the assumed standards for 8 out of 9 parameters (except for water temperature). The largest exceedances of the limit values concerned NO_2-N (up to 923% of the norm), and the most consistent, almost constantly occurring – EC (23 out of 24 months). The reason for the high NO_2-N content was most probably surface runoff from the fields and the re-suspension of sediments rich in nutrients, while in the case of EC, its high values result from the specificity of the catchment area.

Keywords: water quality, hydropower plants, environmental impacts, renewable energy sources, Water Framework Directive

1. Introduction

Hydropower plants are a renewable energy source, the use of which is associated with a number of benefits, but it is also not without its drawbacks (Operacz 2021, Kasperek & Wiatkowski 2014). The literature describes the impact of hydropower on society, economy and the environment (Kuriqi et al. 2021, Tomczyk & Wiatkowski 2020). In the context of environmental research, particular attention is paid to the impact of hydropower plants on the conditions for the migration of aquatic organisms (Puzdrowska & Heese 2019, Virbickas et al. 2021), on the accumulation and erosion processes below the damming (Soininen et al. 2018, Kibler & Tullos 2013), but mainly on the hydrological conditions not only within hydropower facilities, but also at longer distances (Bejarano et al. 2017, Chiogna et al. 2016, Fantin-Cruz et al. 2015).

In the context of the physicochemical quality of water, this influence concerns the modification of oxygen, thermal and trophic conditions (Tomczyk & Wiatkowski 2021a). In the first case, due to the formation of whirling motion due to the phenomenon of hydraulic recoil downstream hydropower plants (Wu et al. 2018), an increase in water saturation with oxygen is visible (Da Cruz et al. 2021). In the second, in water reservoirs located downstream the dams, there may be disturbances in seasonal thermal stratification (Preece & Jones 2002, Magadza 2010), as well as reduction of temperature amplitudes within hydropower plants (Pimenta et al. 2012). The trophic changes concern the possible remobilization of phosphorus accumulated in bottom sediments below hydropower facilities (Winton et al. 2019), which may contribute to the intensification of the eutrophication phenomenon (Smith et al. 1999, Zbierska et al. 2015). On the other hand, the accumulation of bottom sediments above damming levels favors the accumulation of biogenic compounds in them (Bogen & Bønsnes 2001) – e.g. it is estimated that 15% of the river's phosphorus load is upstream dams (Maavara et al. 2015). This accumulation is associated with changes in the transport of suspended sediment, which is also a carrier of trace elements (e.g. heavy metals) (Sojka et al. 2018, Sojka et al. 2009, Obolewski & Glińska-Lewczuk 2013, Wdowczyk & Szymańska-Pulikowska 2021). Mentioned changes in access to the food base have further consequences, including with changes in the functioning of water-related ecosystems and in the living conditions of aquatic organisms (Wiatkowski et al. 2017, Kjaerstad et al. 2018, Camargo 2018, Česonienė et al. 2021).

The aim of the article is to analyze the physicochemical quality of water in the Ślęza hydropower plant in the city of Wrocław in the context of the current water quality classification, as well as to estimate the potential impact of hydropower plants on this quality. It should be added that the full assessment of the quality of surface water in the light of the applicable provisions of the European Union law (Water Framework Directive) includes the assessment of the chemical status and the ecological status (or ecological potential) of water bodies (state – natural waters, potential – artificial or heavily modified) (EPC 2000, MMEIN 2019). The article focuses on the state of physicochemical elements that complement the assessment of the ecological status (potential) (biological elements are considered leading in the assessment, while physicochemistry and hydromorphology support this assessment; in the assessment of the chemical status, priority substances are taken into account, i.e. especially hazardous to the aquatic environment).

2. Materials and Methods

2.1. Study area

The research area covers the lower section of the Ślęza River in the city of Wrocław (the left tributary of the Odra River, south-western Poland), near the "Sobolewski" hydropower plant. It is located at km 3.014 from the mouth of the watercourse, it was built in 1992. It is classified as a small hydropower plant (0.024 MW) with a low damming height (4.0 m). It is equipped with one Kaplan-type turbine, it does not have a fish pass (Wiatkowski & Tomczyk 2018). There are three sampling points: 50 m upstream (point 1) and 50 m downstream the hydropower plant (point 2), as well as a reference point (comparative; point 3, 500 m upstream the hydropower plant). Figure 1 shows the location of the research area.

2.2. Field studies and laboratory analyzes

Field studies were carried out monthly, from June 2018 to May 2020. Water samples were scooped from the subsurface layer, then transferred to bottles and transported in a refrigerator to the Environmental Research Laboratory of the University of Life Sciences in Wrocław. The analyzes were performed within 24 hours from the time of collection (Szymańska-Pulikowska & Wdowczyk 2021). The scope of determinations concerned 10 physicochemical parameters, the characteristics of which are presented in Table 1.

Fig. 1. Location of the research area

Table 1. Methods for determining the physicochemical parameters of water

No.	Parameter	Unit	Name of the method
1.	Temperature of water	°C	Temperature sensor
2.	pH	–	Potentiometric method
3.	Electrolytic conductivity (EC)	µS/cm	Conductometric method
4.	Turbidity	NTU	Nephelometric method
5.	Ammonium nitrogen (NH_4-N)	mg/L	Spectrophotometric method
6.	Nitrate nitrogen (NO_3-N)		
7.	Nitrite nitrogen (NO_2-N)		
8.	Total phosphorus (TP)		
9.	Dissolved oxygen (DO)		Electrochemical sensor
10.	Biochemical oxygen demand (BOD_5)		Dilution method

2.3. Analysis of the results

The results of the above-described physicochemical analyzes were further analyzed. It was based on checking the statistical significance for individual parameters between the analyzed points using the ANOVA test for repeated measurements for $p < 0.05$ (SPSS Statistics 26, IBM), performing basic statistical analyzes (Statistica 13, Dell), characterizing the variability in parameter values (Excel 2013, Microsoft) and classifying the results in in the context of the current quality requirements for surface waters (in this case, their physicochemical status) in water bodies, in accordance with the implementation of the requirements of the Water Framework Directive to Polish conditions. The studied points are located in a heavily modified surface water body – Ślęza from Mała Ślęza to Odra (PLRW60001913369), which is classified as a lowland sandy loam river (abiotic type 19). The information about the classification of the physicochemical quality of water in the analyzed points is shown in Table 2.

Table 2. Information for the classification of the physicochemical quality of water at the tested measuring points on the Ślęza River, belonging to the abiotic type 19 (MMEIN 2019)

Classification / Parameter (unit)	Limit values		
	1st class (very good status)	2nd class (good status)	Below good status
Temperature (°C)	≤ 22.0	22.1-24.0	> 24.0
pH (-)	7.4-8.0	6.7-8.1	< 6.7, > 8.1
EC (µS/cm)	≤ 411	412-553	> 553
NH_4-N (mg/L)	≤ 0.170	0.171-0.553	> 0.553
NO_3-N (mg/L)	≤ 1.6	1.7-2.5	> 2.5
NO_2-N (mg/L)	≤ 0.01	0.02-0.03	> 0.03
TP (mg/L)	≤ 0.20	0.21-0.30	> 0.30
DO (mg/L)	≥ 7.0	6.6-6.9	< 6.6
BOD_5 (mg/L)	≤ 2.6	2.7-3.7	> 3.7

For a more complete comparison of the results, an analysis was also performed using the Universal Water Quality Index – UWQI (Boyacioglu 2007, Tomczyk & Wiatkowski 2021b). It is calculated based on each parameter's equations and the weights assigned to them (Table 3). The 90th percentile of parameter values is used for the calculation (for dissolved oxygen, the 10th percentile due to the inversely proportional relationship between its concentration and water quality), which takes into account possible measurement errors.

After calculating mentioned elements, the final index value is determined from the formula (1):

$$\mathrm{UWQI} = \sum_{i=1}^{n} I_i W_i$$

where UWQI is the final index value, I_i is the sub-index value for each parameter (in the range from 0 to 100), W_i is the weight value for each parameter, and n is the number of parameters considered in the calculations.

The final classification consists of five classes ranging from excellent to poor, based on the index's final value on a scale of 0 to 100. The point scale is as follows: 95-100 – excellent water quality, 75-94.9 – good, 50-74.9 – moderate, 25-49.9 – poor, 0-24.9 – bad.

Spatial analyzes concern the comparison of the results between the examined points, located within the hydroelectric power plant, and the temporal – the variability in the analyzed two-year research period.

Table 3. Determination of sub-indices values for Universal Water Quality Index – UWQI (Boyacioglu 2007, Tomczyk & Wiatkowski 2021b)

Parameter	Weightage	Value range	Equation
pH	$W_{pH} = 0.085$	6.6-8.5	$I_{pH} = 100$
		5.5-6.4 and 8.6-9.0	$I_{pH} = 50$
		< 5.5 and > 9.0	$I_{pH} = 0$
NO_3[1]	$W_{NO3} = 0.251$	≤ 5.0 mg/L	$I_{NO3} = 100$
		5.1-10.0 mg/L	$I_{NO3} = -10(NO_3) + 150$
		10.1-20.0 mg/L	$I_{NO3} = -4.5(NO_3) + 95$
		> 20.0 mg/L	$I_{NO3} = 0$
TP	$W_{TP} = 0.166$	≤ 0.02 mg/L	$I_{TP} = 100$
		0.021-0.16 mg/L	$I_{TP} = -357.14(TP) + 107.14$
		0.161-0.65 mg/L	$I_{TP} = -91.837(TP) + 64.964$
		> 0.65 mg/L	$I_{TP} = 0$

Table 3. cont.

Parameter	Weightage	Value range	Equation
DO	$W_{DO} = 0.332$	≥ 8.0 mg/L	$I_{DO} = 100$
		6.0-7.9 mg/L	$I_{DO} = 25(DO) – 100$
		3.0-5.9 mg/L	$I_{DO} = 15(DO) – 40$
		< 3.0 mg/L	$I_{DO} = 0$
BOD_5	$W_{BOD} = 0.166$	< 3.0 mg/L	$I_{BOD} = 100$
		3.0-4.9 mg/L	$I_{BOD} = -25(BOD) + 175$
		5.0-6.9 mg/L	$I_{BOD} = -22.5(BOD) + 162.5$
		≥ 7.0 mg/L	$I_{BOD} = 0$

Designations in the table: [1] – NO_3 = 4.43 NO_3-N

3. Results and discussion

3.1. Basic statistics

Table 4 presents the basic results of the physicochemical analyzes performed. The greatest differences in the values between the points concerned temperature and DO. In the case of temperature, it can be seen that below the hydropower plant it fluctuated in a narrower range than in the other points (respectively: point 2 – from 0 to 21.5°C, point 1 and 3: 0-22°C and 0-21.9°C; standard deviation: 7.58, 7.78 and 7.76°C), which is also reflected in the lower median. In the case of dissolved oxygen, there is an increase in its amount below the damming, as a result of the aforementioned hydraulic bounce (median values: point above the hydropower plant – 7.6 mg/L, point below the hydropower plant – 8.15 mg/L, reference point – 7.3 mg/L). Other parameters did not show as much variability as the above – in the context of the convergence of the amplitudes of the values and the median values (e.g. for EC, despite the greater range of results in points 2 and 3 compared to 1, no large differences were found between the median of its value; similar relationships can be seen for turbidity or NO_3-N).

Table 4. Basic results of the conducted physicochemical analyzes

Points	Statistics	Parameters (unit)									
		Temperature (°C)	pH (-)	EC (μS/cm)	Turbidity (NTU)	NH_4-N (mg/L)	NO_3-N (mg/L)	NO_2-N (mg/L)	TP (mg/L)	DO (mg/L)	BOD_5 (mg/L)
1 – upstream Ślęza HP	min	0.0	7.0	466	1.30	0.090	0.5	0.015	0.060	4.8	0.8
	max	22.2	8.8	1680	18.50	1.030	10.5	0.304	0.460	12.0	10.8
	med.	10.7	8.2	1104	4.10	0.205	1.7	0.030	0.285	7.6	2.3
	x̄	11.9	8.1	1119	5.02	0.267	2.5	0.049	0.271	7.9	3.4
	SD	7.8	0.5	272	3.95	0.204	2.3	0.061	0.098	2.3	2.6
2 – downstream Ślęza HP	min	0.0	7.0	466	1.20	0.030	0.5	0.015	0.170	5.8	1.0
	max	21.5	8.8	1772	20.80	1.030	10.6	0.307	0.500	12.6	12.8
	Med.	10.5	8.2	1104	3.80	0.205	1.5	0.029	0.285	8.2	2.5
	x̄	11.7	8.1	1121	5.09	0.268	2.5	0.054	0.300	8.3	3.4
	SD	7.6	0.5	287	4.79	0.205	2.5	0.066	0.080	1.9	2.8
3 – reference point	min	0.0	6.9	468	1.10	0.010	0.6	0.012	0.160	4.6	0.9
	max	21.9	8.8	1770	25.60	1.040	8.6	0.289	0.510	10.9	9.3
	med.	10.7	8.2	1113	3.99	0.195	1.6	0.027	0.295	7.3	2.4
	x̄	11.9	8.1	1123	5.49	0.249	2.5	0.047	0.295	7.8	3.2
	SD	7.7	0.5	284	5.56	0.219	2.3	0.059	0.083	2.0	2.2

Designations in the table: med. – median, x̄ – mean, SD – standard deviation

3.2. Temporal and spatial variability of parameter values at the analyzed points – ANOVA for repeated measures

In order to reliably determine whether the values of the considered physicochemical parameters actually change in a specific, ordered way over time, the ANOVA analysis was performed (Table 5). It shows that only for temperature statistically significant variability is visible, which is reflected in the pairwise comparison, in which the results were found to be significant between points 1 and 2 and 2 and 3, and also in the highest effect size of all analyzed parameters (η_p^2 = 0.169). Moreover, in the pairwise comparison for DO and NH_4-N between points 2 and 3 as well as 1 and 3 showed statistically significant relationships. However, they will be omitted from the analysis as they do not relate to the assessment of the impact of a hydropower plant.

Table 5. Summary of the results of the within-group analysis of variance for repeated measures (ANOVA)

Parameter	d*f*	Error d*f*	F	p (< 0.05)	η_p^2
Temperature	1.801	41.426	4.666	0.018* (1/2, 2/3)	0.169
TP	1.157	26.619	3.249	0.078	0.124
DO	1.447	33.280	2.895	0.084 (2/3)	0.112
NH_4-N	1.382	31.783	1.569	0.224 (1/3)	0.064
Turbidity	1.141	26.248	1.370	0.258	0.056
pH	1.895	43.578	1.183	0.314	0.049
NO_2-N	1.061	24.395	0.972	0.339	0.041
EC	1.288	29.622	0.171	0.745	0.007
BOD_5	1.841	42.337	0.161	0.835	0.007
NO_3-N	1.164	26.764	0.035	0.885	0.002

Designations in the table: d*f* – degrees of freedom, F – F-value (variance of the group means / mean of the within group variances), p – statistical significance, ηp^2 – effect size for the parameter (comparison between the sum of squares of an effect for one parameter and the sum of squares error in the ANOVA), * – statistically significant value ($p < 0.05$), the numbers in parentheses – statistical significance between the points in the pairwise comparison

Checking the temporal variability of the water temperature between the points above and below the hydropower plant on the Ślęza River showed that in 14 out of 24 months below the damming structure, the water cooled, and in the next 10 months – warmed or its temperature did not change any changes were found in 5 months). The scope of these changes ranged from -0.95°C to +0.4°C at the lower stand of the hydropower plant. If there was a heating of water below a hydropower facility, it usually took place in the winter half-year (November 2018, January, November and December 2019, February 2020), while cooling – in the summer half-year (especially from June to September). These dependencies are shown in Figure 2.

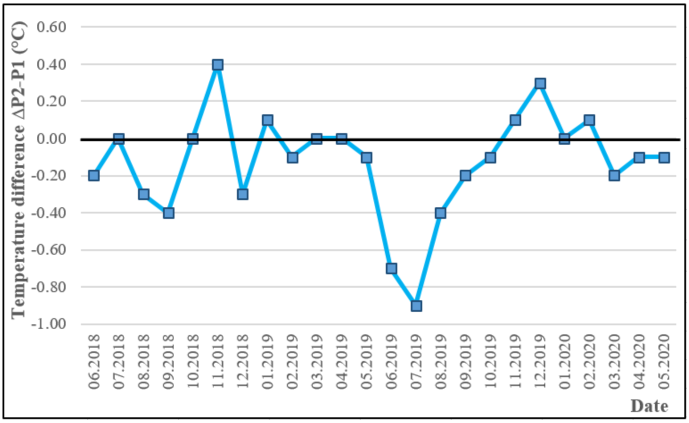

Fig. 2. The temperature difference variability between the points downstream (P2) and upstream the hydropower plant (P1) on the Ślęza River in Wrocław, June 2018 – May 2020

3.3. Assessment of the physicochemical quality of water within a hydropower plant based on WFD classification

The physicochemical quality of water in the area of the Ślęza hydropower plant does not meet the assumed standards (Table 6). Exceedances of the limit values were recorded for 8 out of 9 assessed parameters (except for temperature). The factor deteriorating the physicochemical condition of water is primarily the constantly high conductivity values, which remained outside the assumed standards in 23 out of 24 months (the maximum value of exceedances was 220% of the standard). As for the amount of exceedances, the most outlier parameter is NO_2-N – depending on the point, the amount of exceedances ranged from 865% to 923% in relation to the limit value; the standards were not met in 11 of the 24 surveyed months. In the case of other parameters, the scale of exceedances of the limit values was not so large (in terms of the size, NO_3-N can also be mentioned – from 245% to 319%, as well as BOD_5 – from 151% to 246% of exceedances compared to the norm; in terms of the number of exceeded pH – 12 or 13 out of 24 months with exceedances of the limit value).

The presented results are consistent with the results obtained from the water quality monitoring data for the measuring point Ślęza – estuary to the Odra River, belonging to the same body of surface water as the analyzed points (PIEP 2017). In relation to 2016, the most exceedances were recorded for EC – 100% (maximum exceedance by 130% compared to the standard), while the maximum exceedances against the standard – for NO_2-N (1593% compared to the limit value, 66.7% exceedances per year). The remaining parameters reached intermediate values - in relation to the percentage of exceedances, it was as follows: NO_3-N = TP > pH > DO > BOD_5 > NH_4-N > temperature of water (respectively: 58.3% > 37.5% > 25.0% > 12.5% > 8.33% > 0.00%).

Table 6. Classification of the physicochemical quality of water at points within the hydropower plant on the Ślęza River in Wrocław, June 2018 – May 2020

Parameter (unit)	Limit value for 2nd class	Point numer	Number of exceedances	The maximum value of the parameter	The maximum amount of exceeding the limit values
Temperature (°C)	≤ 24.0	1	0	22.2	0
		2	0	21.5	0
		3	0	21.9	0
pH (-)	6.7 – 8.1	1	12 (50.0%)	8.8	8.64%
		2	13 (54.2%)	8.8	8.64%
		3	12 (50.0%)	8.8	8.64%
EC (µS/cm)	**≤ 553**	**1**	**23 (95.8%)**	**1680**	**204%**
		2	**23 (95.8%)**	**1772**	**220%**
		3	**23 (95.8%)**	**1770**	**220%**
NH_4-N (mg/L)	≤ 0.553	1	2 (8.33%)	1.03	86.3%
		2	2 (8.33%)	1.03	86.3%
		3	2 (8.33%)	1.04	88.1%
NO_3-N (mg/L)	≤ 2.5	1	9 (37.5%)	10.47	319%
		2	9 (37.5%)	10.57	323%
		3	9 (37.5%)	8.64	245%
NO_2-N (mg/L)	**≤ 0.03**	**1**	**11 (45.8%)**	**0.304**	**913%**
		2	**11 (45.8%)**	**0.307**	**923%**
		3	**11 (45.8%)**	**0.289**	**865%**
TP (mg/L)	≤ 0.30	1	8 (33.3%)	0.46	53.3%
		2	10 (41.7%)	0.50	66.7%
		3	10 (41.7%)	0.51	70.0%
DO (mg/L)	≥ 6.6	1	7 (29.2%)	4.8*	27.2%
		2	4 (16.7%)	5.8*	12.1%
		3	7 (29.2%)	4.6*	30.3%
BOD_5 (mg/L)	≤ 3.7	1	8 (33.3%)	10.8	192%
		2	6 (25.0%)	12.8	246%
		3	8 (33.3%)	9.3	151%

Designations in the table: * – the minimum value of the parameter,
bold font – parameters analyzed later in the article

As can be seen in Figure 3, except for April 2020, exceedances in the EC values occurred constantly. Comparing the results in similar catchments (e.g. the Bystrzyca river, which is also the left tributary of the Odra River, with similar size and characteristics - in the lower section, EC values ranged between 312 and 961 µS/cm, with a median of 495 µS/cm; Tomczyk & Wiatkowski 2021), it can be concluded that this is a feature of this catchment, which is the result of its use, geological structure, anthropogenic interactions (for example, the presence of levees on both sides of the river and reinforcements of the riverbanks and riverbed in the vicinity of the hydropower plant) and its other features. The presence of a hydropower plant has no major impact on the variability of the value of this parameter (the median difference between the upper and lower stands in the analyzed period was 0.25%).

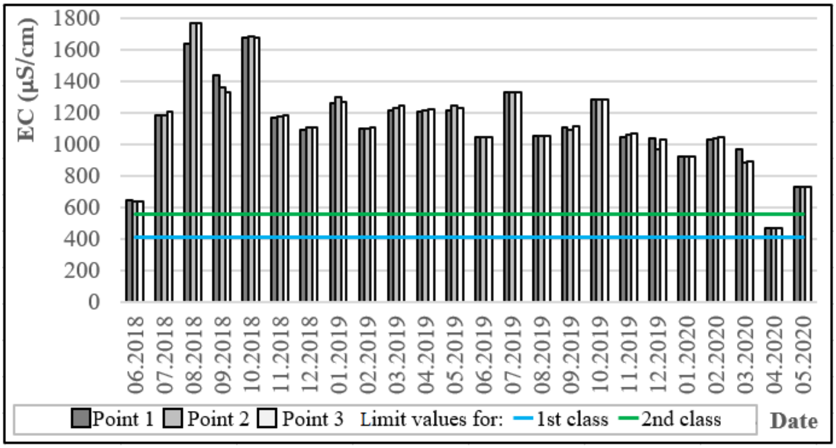

Fig. 3. Electrical conductivity values within the hydropower plant on the Ślęza River according to the classification of physicochemical water quality, June 2018 – May 2020

With regard to NO_2-N, the exceedances were less frequent, but much more pronounced (Figure 4) – they were especially visible in April and May 2020. The reason for the high values of NO_2-N in that period was primarily intense rainfall, carrying large loads pollution from the entire catchment area of the Ślęza River flowing down the watercourse. The catchment area of the Ślęza River in its upper and middle reaches is of an agricultural nature, therefore in these areas more fertilizers and plant protection products are used, which contain higher levels of nitrogen compounds, and along with surface runoff, these compounds can get into the river water. In addition to April and May 2020, in July 2019, a water pollution incident of NO_2-N also occurred downstream the hydropower plant – the reason could be the release of sediments accumulated on the damming of the damming structure, and then their resuspension as a result of the vortex movement at the bottom site, and finally the release of the stored in them NO_2-N. These types of sediment resuspension phenomena have been studied, for example, within a reservoir hydropower plant in the French Alps (Monnin et al. 2018) or on hydraulic models imitating individual technical elements of hydropower plants (e.g. pressure sand traps, Richter et al. 2021).

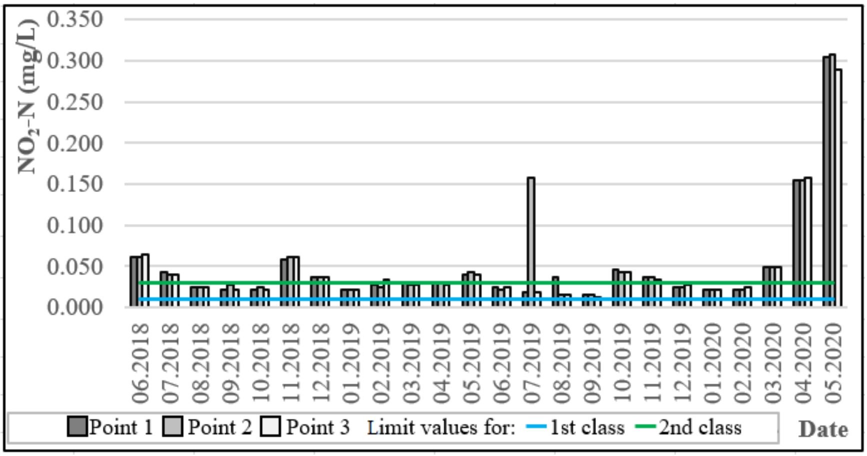

Fig. 4. Concentrations of NO_2-N within the hydropower plant on the Ślęza River in the context of the classification of physicochemical water quality, June 2018 – May 2020

3.4. Universal Water Quality Index (UWQI)

The results of the calculated water quality index indicate that in each of the analyzed points, the water quality was moderate (the third class out of five possible; Table 7). The best quality was achieved at the point below the hydroelectric power plant on the Ślęza River (point 2), while the weakest – at the reference point (point 3). The parameter significantly improving the result for point 2 were the higher values of dissolved oxygen in the research period. In the context of other results, there is a noticeable difference between the BOD_5 values between points 1, 2 and 3, and also between NO_3 concentrations (in the first case, less favorable values in points 1 and 2, in the second – in point 3, compared to the rest of the points). The overall results of water quality expressed by UWQI do not differ significantly (they are around 7%).

The presented results for UWQI are consistent with the results for reservoir hydropower plants: Michalice in Poland (Tomczyk et al., 2021), Bakun in Malaysia (Ling et al. 2016) and Gongguoqiao in China (Luo et al. 2019). In these cases, better water quality was noted, expressed by the water quality index below the hydrotechnical structures. A different result was achieved for the Irapė hydroelectric power plant in Brazil, where the calculated result was the weakest below the damming structure (De Oliveira et al. 2021). With regard to run-of-river hydroelectric power plants, such analyzes have hardly been carried out (however, physicochemical studies have been performed, e.g. Álvarez et al. 2020, Fantin-Cruz et al. 2015, Česonienė et al. 2021).

Table 7. Universal Water Quality Index (UWQI) calculated for at points within the hydropower plant on the Ślęza River in Wrocław, June 2018 – May 2020

Para-meter	Research points		
	1 – upstream Ślęza HP	2 – downstream Ślęza HP	3 – reference point
pH	8.50	8.50	8.50
NO_3	25.10	25.10	22.59
TP	4.88	4.82	4.82
DO	12.22	15.75	12.96
BOD_5	5.61	5.42	6.69
UWQI	**56.31**	**59.60**	**55.57**

4. Conclusions

As a result of the research, the following conclusions can be drawn:

1. The Ślęza hydropower plant significantly influences changes in temperature and dissolved oxygen.
2. Water temperature amplitudes below the hydropower plant have decreased compared to other points, and the median value is lower. An additional noticeable effect is the increase in water oxygenation below the damming.
3. Statistically significant changes for the examined points were shown for the water temperature – in most months (in 14 out of 24) the hydropower plant caused its decrease (especially in the summer half-year). Changes in temperature differences in the lower station compared to the upper one ranged from –0.95°C to +0.4°C.
4. The physicochemical status of water in the tested points does not meet the standards for 8 out of 9 parameters (except the water temperature).
5. The highest exceedances of the limit values concerned NO_2-N (up to 923% of the norm), and the most consistent, almost constantly occurring – EC (23 out of 24 months). The reason for the high NO_2-N content was most probably the surface runoff from the fields and the resuspension of sediments rich in nutrients, and in the case of EC, its high values result from the specificity of the catchment area.
6. The calculated Universal Water Quality Index indicated moderate water quality at each point (the most favorable below the hydropower plant, the least – at the reference point).
7. This research is a pilot study on the impact of hydropower plants on changes in water quality.

References

Álvarez, X., Valero, E., Torre-Rodríguez, N. D. L., & Acuña-Alonso, C. (2020). Influence of small hydroelectric power stations on river water quality. *Water, 12*(2), 312.

Bejarano, M.D., Sordo-Ward, Á., Alonso, C., Nilsson, C. (2017). Characterizing effects of hydropower plants on sub-daily flow regimes. *J. Hydrol., 550*, 186-200.

Bogen, J., Bønsnes, T.E. (2001). The impact of a hydroelectric power plant on the sediment load in downstream water bodies, Svartisen, northern Norway. *Science of the Total Environment, 266*, 273-280.

Boyacioglu, H. (2007). Development of a water quality index based on a European classification scheme. *Water SA, 33*(1), 101-106.

Camargo, J.A. (2018). Responses of aquatic macrophytes to anthropogenic pressures: Comparison between macrophyte metrics and indices. *Environmental Monitoring and Assessment, 190*, 173.

Česonienė, L., Dapkienė, M., Punys, P. (2021). Assessment of the Impact of Small Hydropower Plants on the Ecological Status Indicators of Water Bodies: A Case Study in Lithuania. *Water, 13*, 433.

Chiogna, G., Majone, B., Paoli, K.C., Diamantini, E., Stella, E., Mallucci, S., Lencioni, V., Zandonai, F., Bellin, A. (2016). A review of hydrological and chemical stressors in the Adige catchment and its ecological status. *Science of the Total Environment, 540*, 429-443.

da Cruz, R.F., Hamilton, S.K., Tritico, H.M., Fantin-Cruz, I., de Figueiredo, D.M., Zeilhofer, P. (2021). Water quality impacts of small hydroelectric power plants in a tributary to the Pantanal floodplain, Brazil. *River Res Appl, 37*, 448-461.

De Oliveira, K.L., Ramos, R.L., Oliveira, S.C., Christofaro, C. (2021). Water quality index and spatio-temporal perspective of a large Brazilian water reservoir. *Water Supply, 21*(3), 971-982.

Fantin-Cruz, I., Pedrollo, O., Girard, P., Zeilhofer, P., Hamilton, S.K. (2015). Effects of a diversion hydropower facility on the hydrological regime of the Correntes River, a tributary to the Pantanal floodplain, Brazil. *Journal of Hydrology, 531*, 810-820.

Kasperek, R., Wiatkowski, M. (2014). Hydropower Generation on The Nysa Klodzka River. *Ecological Chemistry and Engineering S, 2*1(2), 327-336.

Kibler, K.M., Tullos, D.D. (2013). Cumulative biophysical impact of small and large hydropower development in Nu River, China. *Water Resour Res 49*(6), 3104-3118.

Kjaerstad, G., Arnekleiv, J.V., Speed, J.D.M., Herland, A.K. (2018). Effects of hydropeaking on benthic invertebrate community composition in two central Norwegian rivers. *River Research and Applications, 34*, 218-231.

Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., Bejarano, M.D., Garrote, L. (2021). Ecological impacts of run-of-river hydropower plants – Current status and future prospects on the brink of energy transition. *Renew. Sust. Energy Rev. 142*, 110833.

Ling, T.Y., Soo, C.L., Heng, T.L.E., Nyanti, L., Sim, S.F., Grinang, J. (2016). Physicochemical Characteristics of River Water Downstream of a Large Tropical Hydroelectric Dam. *Journal of Chemistry*, *7895234*.

Luo, X., Xiang, X., Huang, G., Song, X., Wang, P., & Fu, K. (2019). Bacterial abundance and physicochemical characteristics of water and sediment associated with hydroelectric dam on the Lancang River China. *International Journal of Environmental Research and Public Health, 16*(11), 2031.

Maavara, T., Parsons, C.T., Ridenour, C., Stojanovic, S., Dürr, H.H., Powley, H.R., Van Cappellen, P. (2015). Global phosphorus retention by river damming. *Proceedings of the National Academy of Sciences of the United States of America, 112*, 15603-15608.

Magadza, C.H.D. (2010). Environmental state of Lake Kariba and Zambezi River Valley: Lessons learned and not learned. *Lake Reserv. Manag. 15*, 167-192.

Minister of Maritime Economy and Inland Navigation (MMEIN 2019). Regulation of the Minister of Maritime Economy and Inland Navigation of 11 October 2019 on the Classification of Ecological Status, Ecological Potential and Chemical Status and the Method of Classifying the Status of Surface Water Bodies… (OJ 2019 item 2149, in Polish), Prime Minister of Poland: Warsaw, Poland, 2019.

Monnin, L., Ciffroy, P., Garnier, J.M., Ambrosi, J.P., Radakovitch, O. (2018). Remobilization of trace metals during laboratory resuspension of contaminated sediments from a dam reservoir. *Journal of Soils Sediments 18*, 2596-2613.

Obolewski, K., Glińska-Lewczuk, K. (2013). Distribution of heavy metals in bottom sediments of floodplain lakes and their partent river – a case study of the Słupia. *Journal of Elementology, 18*(4), 673-682.

Operacz, A. (2021). Possibility of Hydropower Development: A Simple-to-Use Index. *Energies, 14*, 2764.

Pimenta, A.M., Albertoni, E.F., Palma-Silva, C. (2012). Characterization of water quality in a small hydropower plant reservoir in southern Brazil. *Lakes & Reservoirs Research & Management, 17*, 243-251.

Preece, R.M., Jones, H.A. (2002). The effect of Keepit Dam on the temperature regime of the Namoi River, Australia. *River Research and Applications, 18*, 397-414.

Provincial Inspectorate for Environmental Protection in Wrocław (PIEP) (2017). Results of surface water quality tests: Ślęza from Mała Ślęza to Odra at the control point of Ślęza – estuary to the Oder.

Puzdrowska, M., Heese, T. (2019). Experimental Studies on the Spatial Structure and Distribution of Flow Velocities in Bolt Fishways. *J. Ecol. Eng., 20*, 82-99.

Richter, W., Vereide, K., Mauko, G., Havrevoll, O.H., Schneider, J., Zenz, G. (2021). Retrofitting of Pressurized Sand Traps in Hydropower Plants. *Water, 13*, 2515.

Smith, V., Tilman, G., Nekola, J. (1999). Eutrophication: Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution, 100*, 179-196.

Soininen, N., Belinskij, A., Vainikka, A., Huuskonen, H. (2018). Bringing back ecological flows: Migratory fish, hydropower and legal maladaptivity in the governance of Finnish rivers. *Water International, 44*, 321-336.

Sojka, M., Siepak, M., Jaskuła, J., & Wicher-Dysarz, J. (2018). Heavy Metal Transport in a River-Reservoir System: a Case Study from Central Poland. *Polish Journal of Environmental Studies, 27*(4).

Sojka, M., Zioła-Frankowska, A., Siepak, M., & Murat-Błażejewska, S. (2009). Distribution of heavy metals in the Mała Wełna River system (western Poland). *Oceanological and Hydrobiological Studies, 38*(2), 51-61.

Szymańska-Pulikowska, A., Wdowczyk, A. (2021). Changes of a Landfill Leachate Toxicity as a Result of Treatment With Phragmites australis and Ceratophyllum demersum – A Case Study. *Frontiers in Environmental Science, 9*.

The European Parliament and the Council (EPC). Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for Community Action in the Field of Water Policy, Brussels, Belgium, 2000.

Tomczyk, P., Wiatkowski, M. (2020). Shaping changes in the ecological status of watercourses within barrages with hydropower schemes – Literature review. *Archives of Environmental Protection, 46*, 78-94.

Tomczyk, P., Wiatkowski, M. (2021a). The Effects of Hydropower Plants on the Physicochemical Parameters of the Bystrzyca River in Poland. *Energies, 14*, 2075.

Tomczyk, P., Wiatkowski, M. (2021b). Impact of a small hydropower plant on water quality dynamics in a diversion and natural river channel. *Journal of Environmental Quality, 50*(5), 1156-1170.

Tomczyk, P., Wiatkowski, M., Gruss, Ł., Buta, B., Kasperek, R., Głowski, R., Rembielak, K. (2021). Hydropower impact on water quality: a case study on the Michalice Reservoir, Poland. *Environmental Engineering and Management Journal 5*(5), 725-738.

Virbickas, T., Vezza, P., Kriaučiūnienė, J., Akstinas, V., Šarauskienė, D., Steponėnas, D. (2021). Impacts of low-head hydropower plants on cyprinid-dominated fish assemblages in Lithuanian rivers. *Scientific Reports, 10*, 21687.

Wdowczyk, A., Szymańska-Pulikowska, A. (2021). Analysis of the possibility of conducting a comprehensive assessment of landfill leachate contamination using physicochemical indicators and toxicity test. *Ecotoxicol. Environm. Saf. 221*, 112434.

Wiatkowski, M., Rosik-Dulewska, C., Tomczyk, P. (2017). Hydropower Structures in the Natura 2000 Site on the River Radew: An Analysis in the Context of Sustainable Water Development. *Annual Set the Environment Protection, 19*, 65-80.

Wiatkowski, M., Tomczyk, P. (2018). Comparative Assessment of the Hydromorphological Status of the Rivers Odra, Bystrzyca, and Ślęza Using the RHS, LAWA, QBR, and HEM Methods above and below the Hydropower Plants. *Water, 10*, 855.

Winton, R.S., Calamita, E., Wehrli, B. (2019). Reviews and syntheses: Dams, water quality and tropical reservoir stratification. *Biogeosciences, 16*, 1657-1671.

Wu, J.-H., Zhou, Y., Ma, F. (2018). Air entrainment of hydraulic jump aeration basin. *Journal of Hydrodynamics, 30*, 962-965.

Zbierska, J., Ławniczak, A.E., Zbierska, A. (2015). Changes in the trophic status of Lake Niepruszewskie (Poland). *Journal of Ecological Engineering, 16*, 65-73.