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Andrzej JAGUŚ[1]

ASSESSMENT OF TROPHIC STATE OF INLAND WATER (THE CASE OF THE SOLA CASCADE DAM RESERVOIRS)

OCENA STANU TROFICZNEGO WÓD ŚRÓDLĄDOWYCH (NA PRZYKŁADZIE KASKADY SOŁY)

Abstract: The objective of the study was to assess the trophic state of water in the hydrographic system of the Sola cascade, situated in the Carpathian region in southern Poland. Analyses included inflowing and retained water in dam reservoirs: Tresna, Porabka and Czaniec. The level of eutrophication of water was estimated basing on its physicochemical parameters. Out of all methods used in determining the trophic state, the selected methods included the norms determined in the Polish regulations, the Neverova-Dziopak index (ITS – *Index of Trophical State*) and the Carlson index (TSI – *Trophic State Index*). Analyses of data from years 2007–2009 showed that water quality reflected characteristic parameters for mesotrophy and eutrophy. Unfavorable trophic state concerned almost all waters that were studied, including waters of the lowest reservoir of the cascade – Czaniec reservoir, which is part of the municipal water supply system. That emphasizes the need for protection of the catchment of the cascade with regards to reduction of contamination load discharged to surface waters.

Keywords: inland water, Sola cascade dam reservoirs, water quality, eutrophication, trophic index

One of the major factors that set limitations on the use of disposable water resources is the process of eutrophication, related to excessive supply of nutrients in water. It diminishes the quality of water and causes sanitary threat resulting from anaerobic decomposition of organic matter and toxicity of metabolism products of phytoplankton organisms [1, 2]. It is therefore reasonable to establish monitoring of water trophic state in order to determine the need for protection of water from eutrophication. The most important in Poland is monitoring of water quality in the mountains, as these waters play a strategic role in nationwide water supply [3, 4]. Water reserves that occur there (about 30 % of national reserve) should be retained and transferred to lower areas without loss of quality. Geosystems of dam water reservoirs need particular care in terms of control and measurements, as their self-purification capabilities are lower than

[1] Institute of Environmental Protection and Engineering, University of Bielsko-Biala, ul. Willowa 2, 43–309 Bielsko-Biała, Poland, email: ajagus@ath.bielsko.pl

those of running watercourses, and at the same time they serve as water reservoirs for municipal and economic needs. Due to the fact that mountainous catchments include head-springs of rivers, water retained in those reservoirs should be of high quality, reflecting the oligotrophic (low fertility) or, possibly, mesotrophic state (moderate fertility). The eutrophic state (high fertility) should be considered as unfavorable.

The trophic state of inland water is determined using various methods, which usually consist in analysis of specific physicochemical or biological parameters. Measured values of parameters are compared – directly or after processing – with threshold values of trophic states. The most commonly used parameters include total phosphorus, phosphates, total nitrogen, nitrates(V), ammonia, oxygen, chlorophyll α, transparency of water (*Secchi disk visibility*), reaction, conductivity, etc. Of importance are also biological parameters, namely characteristics of macroinvertebrates, ichthyofauna, macrophytes and phytoplankton. The worldwide classification system for the trophic state of water was suggested by the *Organisation for Economic Co-operation and Development* (OECD) [5] and the *European Environment Agency* (EEA) [6], among others. A range of index-based methods and national norms have also been established for assessment of the trophic state of water [4, 7, 8]. The choice of the method for evaluation of the trophic state of water depends on the scope, period and frequency of quality analyses of water.

The objective of the paper was to assess the trophic state of water in the hydrographic system of the Sola cascade, composed of three dam reservoirs: Tresna, Porabka, Czaniec (Fig. 1). The dams cross the valley of the Sola river in its southern section across the Beskid Maly mountain range in the Carpathian region of southern Poland [9]. The reservoirs serve multiple functions, and the lowest one (Czaniec) is a municipal water system reservoir for Bielsko-Biala and cities of the Silesian conurbation. The reservoirs can store about 122 Mm^3 of water (Tresna – 94.6 Mm^3, Porabka – 26.6 Mm^3, Czaniec – 1.3 Mm^3) drained from the area of 1,119 km^2 [10, 11]. The cascade is mainly fed with waters from the Sola, although the reservoirs also have direct tributaries. Field observations of the catchment area show that main sources of possible contamination of water include: wastewater from regions without sewage systems, fertilizers used in agriculture, unmanaged animal waste and erosion runoff.

Methods

The research made it possible to determine the trophic state of both running waters feeding the reservoirs and standing waters in the reservoirs. The author used the values of physicochemical parameters of waters from the database of the state monitoring of the environment from years 2007–2009.

With regards to running waters, the research included the following sites (Fig. 1):

– the estuary of the Sola to Tresna reservoir;
– the estuary of the Zylica to Tresna reservoir;
– the estuary of the Lekawka to Tresna reservoir;
– the estuary of the Ponikwia to Porabka reservoir;
– the estuary of the Wielka Puszcza to the Sola.

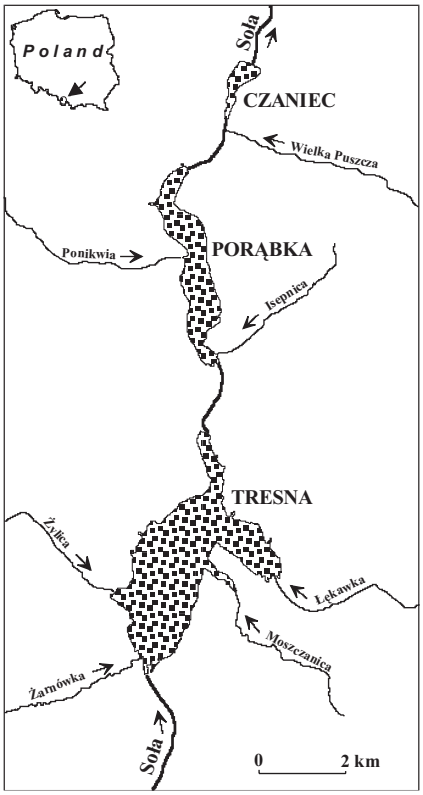

Fig. 1. Sketch of the Sola cascade

Physicochemical analyses of running waters were carried out once a month, which gave 36 measurement series. That made it possible to determine the trophic state according to the rules set forth in the Polish regulations, which require that mean yearly concentrations of some substances be determined [12]. The trophic state of running waters was also determined according to the ITS index (*Index of Trophical State*) suggested by Neverova-Dziopak [13]. The use of the ITS index consists in evaluation of concentrations of oxygen and carbon dioxide in water, expressed by oxygen saturation in water and its reaction. The index is only calculated if there is a linear relation between the values of reaction (pH) and percentage of oxygen saturation of water ($\%O_2$), according to the following formula [13]:

$$\mathrm{ITS} = \Sigma \mathrm{pH}/n + a \cdot (100 - \Sigma \%O_2/n)$$

where: n – number of measurements;
a – coefficient of linear regression between pH and $\%O_2$.

According to the formula, the coefficient of correlation between pH and $\%O_2$ was calculated for each year. The test of correlation relevance was carried out using

Student's t-distribution table (for $n - 2 = 10$ and $\alpha = 0.05$). Then, a linear equation was worked out to describe the correlation between pH and oxygen saturation. Relevance of the described function was tested by means of multiple regression analysis using Snedecor's F-distribution table (for $n - 2 = 10$ and $\alpha = 0.05$).

The studies of reservoir waters were carried out in near-dam zones in summer seasons of years 2007–2009, which gave 3 measurement series. Thus, the trophic state of waters was determined according to the mentioned Polish legal norms [12], which require, in case of standing waters, measurement of physicochemical parameters during the vegetative season. Additionally, the trophic state was determined by calculating Carlson's three-variable *Trophic State Index* (TSI) [14], based on measurements of total phosphorus concentrations (TSI_{TP}), chlorophyll α concentrations (TSI_{Chl}) and water transparency measured using Secchi disc (TSI_{SD}). The following formulas were used in calculations [14]:

$$TSI_{TP} = 14.42 \cdot \ln(TP \cdot 1000) + 4.15$$

$$TSI_{Chl} = 9.81 \cdot \ln(Chl) + 30.6$$

$$TSI_{SD} = 60 - 14.41 \cdot \ln(SD)$$

where: TP – total phosphorus concentration [mg/dm^3];
Chl – chlorophyll α concentration [μg/dm^3];
SD – Secchi disc visibility [m].

The conditions are favorable when all three elements of the index (TSI_{TP}, TSI_{Chl}, TSI_{SD}) for three parameters of water measured at the same time have similar values. It is worth mentioning that the TSI index should not be used in estuary zones of water reservoirs (especially in areas with high relief) due to too high influence of inflowing debris on the state of parameters which are considered in calculations.

The trophic state of running waters

According to the directives for classification of running waters as eutrophic, included in the Regulation of the Minister of Environment [12], waters of the Sola river and other tributaries of the reservoirs did not show the eutrophic state. That is confirmed by the fact that the recorded mean yearly values of concentrations of index substances (Table 1) – total phosphorus, total nitrogen, nitrate(V)-nitrogen and nitrates(V), were lower than the set thresholds (it is also recommended that concentrations of chloro - phyll α, whose threshold mean yearly concentration is 25 μg/dm^3, be measured). These waters, however, flowed into limnic water areas, which are the environment with higher vulnerability to eutrophication. The biogenic elements (P, N) present in running waters occurred in amounts which could stimulate the growth of biological life in limnic geosystems [15].

Table 1

The mean yearly values of eutrophication indices in the flowing waters related to the maximum values of eutrophication (based on data from WIOS in Katowice)

Total phosphorus [mg/dm^3]			Total nitrogen [mg/dm^3]			Nitrate(V)-nitrogen [mg/dm^3]			Nitrates(V) [mg/dm^3]*		
2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009
Sola											
0.034	0.032	0.053	1.165	1.222	1.408	0.861	0.954	1.006	3.808	4.221	4.450
Zylica											
0.043	0.050	0.065	1.866	2.126	2.130	1.567	1.851	1.767	6.972	8.188	7.816
Lekawka											
0.038	0.079	0.055	1.486	1.400	1.782	1.154	1.122	1.345	5.106	4.962	5.950
Ponikwia											
0.031	0.061	0.051	1.450	1.382	1.392	1.219	1.183	1.118	5.394	5.231	4.948
Wielka Puszcza											
0.031	0.045	0.043	1.210	1.062	1.151	0.988	0.861	0.955	4.369	3.808	4.225
Occurrence of eutrophication [12]											
> 0.25			> 5.0			> 2.2			> 10.0		

* Concentration of nitrates(V) ions.

Calculation of the ITS index was only possible for waters of the Sola and the Lekawka, as those cases showed the linear correlation between the values of pH and percentage of oxygen saturation in water. The results showed an unfavorable trophic condition of waters of the Sola and the Lekawka (Table 2).

Table 2

Correlation between pH and oxygen saturation ($n - 2 = 10$, $\alpha = 0.05$) and values of the ITS index for waters of the Sola and the Lekawka (based on data from WIOS in Katowice)

Correlation factors	Sola			Lekawka		
	2007	2008	2009	2007	2008	2009
Correlation coefficient	0.89	0.69	0.15	0.77	0.89	0.79
Correlation relevance	yes	yes	no	yes	yes	yes
Linear regression coefficient	0.032	0.032	0.003	0.030	0.040	0.026
Linear regression relevance	yes	yes	no	yes	yes	yes
ITS	8.217	8.297	—	7.998	8.252	8.047
Trophic state [13]	eutrophy	eutrophy	—	mesotrophy	eutrophy	eutrophy

Those waters, flowing to Tresna reservoir, presented eutrophic characteristics in two out of three years that were researched – the eutrophic state occurs when the value of ITS > 8.3 ± 0.3 [13]. All the researched running waters (Sola, Zylica, Lekawka, Ponikwia, Wielka Puszcza) were characterized by alkaline reaction. Mean yearly values

of reaction ranged between pH 7.78 and 8.30. The highest pH values, generally exceeding 8, were reported in waters of the Sola and the Lekawka. Whereas oxygen saturation in the researched waters ranged close to normal saturation values – mean yearly values ranged from 91.96 to 101.29. All that proves the tendency of the environment towards biological production.

The trophic state of reservoir waters

With regards to the threshold values for eutrophication indices for standing water, as set forth in the Regulation of the Minister of Environment [12], waters of near-dam zones of reservoirs were not generally eutrophicated. Only transparency of water in Czaniec reservoir was unsatisfactory, thus suggesting eutrophication processes (Table 3). According to the norms by OECD [5], water transparency in Czaniec reservoir qualified it in subsequent years as the mesotrophic and eutrophic water area, while reservoirs Tresna and Porabka showed characteristics of oligotrohic and mesotrophic water areas in that respect. Concentrations of phosphorus and nitrogen compounds were similar in waters of all reservoirs. These elements occurred in amounts which allow for water blooming. According to Vollenweider [16], water blooming may occur with the concentration of nitrogen compounds over 0.3 mg TN/dm^3, and phosphorus compounds over 0.015 mg TP/dm^3, whereas waters of the reservoirs under discussion nitrogen concentrations were recorded at 0.74–1.31 mg TN/dm^3, and phosphorus concentrations at 0.03–0.05 mg TP/dm^3.

Table 3

Physicochemical parameters of the Sola cascade dam waters related to the maximum values of eutrophication (based on data from WIOS in Katowice)

Parameter	Year	Tresna reservoir	Porabka reservoir	Czaniec reservoir	Occurrence of eutrophication [12]
Total phosphorus [mg/dm^3]	2007	0.03	0.03	0.03	> 0.1
	2008	0.03	0.03	0.04	
	2009	0.05	0.04	0.05	
Total nitrogen [mg/dm^3]	2007	0.96	0.74	0.77	> 1.5
	2008	1.22	1.21	1.14	
	2009	0.98	0.96	1.31	
Chlorophyll α [µg/dm^3]	2007	6.2	12.7	10.3	> 25.0
	2008	—	—	—	
	2009	8.7	—	2.3	
Transparency [m]	2007	2.4	3.8	**1.8**	< 2.0
	2008	4.0	2.8	**1.4**	
	2009	3.2	3.0	3.0	

Calculations of the Carlson index [14] showed that the trophic state of the reservoirs was most frequently on the border of mesotrophic and eutrophic states (Table 4). That

was particularly visible in the index calculated basing on the concentration of phosphorus in water, as its values exceeded 50 units in the following scale:

– TSI < 40 – oligotrophy;
– TSI from 40 to 50 – mesotrophy;
– TSI from 50 to 60 – meso-eutrophy;
– TSI > 60 (to 80) – eutrophy.

The index values calculated basing on the transparency, in turn, suggested the highest fertility of water in Czaniec reservoir. That is related to the smallest depth of this reservoir in comparison with the others, which fosters warming up of water and growth of phytoplankton. Mass occurrence of algae can be observed in all three reservoirs, however, which confirms their unfavorable trophic condition showed by index calculations.

Table 4

Trophic state of waters in Sola cascade dam reservoirs according to the Carlson index [14] (based on data from WIOS in Katowice)

Reservoir	Year	TSI_{TP}		TSI_{Chl}		TSI_{SD}	
		value	trophic state	value	trophic state	value	trophic state
Tresna	2007	53.2	meso-eutrophy	48.5	mesotrophy	47.4	mesotrophy
	2008	53.2	meso-eutrophy	—	—	40.0	mesotrophy
	2009	60.6	eutrophy	51.8	meso-eutrophy	43.2	mesotrophy
Porabka	2007	53.2	meso-eutrophy	55.5	meso-eutrophy	40.8	mesotrophy
	2008	53.2	meso-eutrophy	—	—	45.2	mesotrophy
	2009	57.3	meso-eutrophy	—	—	44.2	mesotrophy
Czaniec	2007	53.2	meso-eutrophy	53.5	meso-eutrophy	51.5	meso-eutrophy
	2008	57.3	meso-eutrophy	—	—	55.2	meso-eutrophy
	2009	60.6	eutrophy	38.8	oligotrophy	44.2	mesotrophy

Conclusions

1. According to the recommendations from legal regulations, regarding classification of eutrophy, the flowing and standing waters of the hydrographic system of the Sola were not considered eutrophicated.

2. Calculations of indices of the trophic state worked out according to scientific methodology showed that the researched waters were characterized by the mesotrophic or eutrophic state, which is particularly unfavorable for Czaniec reservoir, as it is part of the municipal water system. In particular, the eutrophic state concerned flowing waters feeding the reservoir.

3. Due to high socioeconomic importance of the reservoirs of the Sola river, it is important to reduce the load of wastewater coming from the catchment in order to improve the quality of retained water.

4. It is necessary to work out and popularize universal criteria for determining the trophic state of inland flowing and standing waters, which would be obligatory to use for national services and environment researchers.

References

[1] Kasza H.: Zbiorniki zaporowe – znaczenie, eutrofizacja, ochrona. ATH, Bielsko-Biała 2009.

[2] Kabziński A.K.M. and Kabziński T.K.A.: *Toksyczne zakwity sinicowe. Efekty środowiskowe zakwitów sinicowych (część V).* Bioskop 2005, **4**, 10–16.

[3] Dynowska I.: *Współczesne środowisko przyrodnicze – obieg wody*, [in:] Geografia Polski. Środowisko przyrodnicze, Starkel L. (ed.). PWN, Warszawa 1991, 355–387.

[4] Twardy S., Kopacz M., Kostuch M., Kuźniar A., Smoroń S., Mazurkiewicz-Boroń G., Szarek-Gwiazda E., Jarząbek A., Kowalik A., Książyński W.K., Sarna S. and Twaróg B.: Kryteria wyznaczania wód i obszarów wrażliwych na zanieczyszczenie związkami azotu pochodzącymi ze źródeł rolniczych (na terenie RZGW w Krakowie). IMUZ, Kraków 2003.

[5] Vollenweider R.A. and Kerekes J.J.: Eutrophication of waters – monitoring, assessment and control. OECD, Paris 1982.

[6] The European Environment Agency's Monitoring and Information Network for Inland Water Resources (EUROWATERNET), Technical Report No 7. EEA, Copenhagen 1998.

[7] Kubiak J. and Tórz A.: *Eutrofizacja. Podstawowe problemy ochrony wód jeziornych na Pomorzu Zachodnim.* Słupsk. Prace Biol. 2005, **2**, 17–36.

[8] Soszka H.: *Problemy metodyczne związane z oceną stopnia eutrofizacji jezior na potrzeby wyznaczania stref wrażliwych na azotany.* Woda – Środowisko – Obszary Wiejskie 2009, **9**(1), 151–159.

[9] Kondracki J.: Geografia regionalna Polski. PWN, Warszawa 1998.

[10] Chudy Ł.: *Hydrowęzeł beskidzki. Cz. I.* Gazeta Obserwatora IMGW 2005, **3**, 15–20.

[11] Atlas Podziału Hydrograficznego Polski, Część 2 – zestawienia zlewni, Czarnecka H. (ed.). IMGW, Ministerstwo Środowiska, NFOŚiGW, Warszawa 2005.

[12] Rozporządzenie Ministra Środowiska z dn. 23 grudnia 2002 r. w sprawie kryteriów wyznaczania wód wrażliwych na zanieczyszczenie związkami azotu ze źródeł rolniczych. DzU 2002, nr 241, poz. 2093.

[13] Neverova-Dziopak E.: Ekologiczne aspekty ochrony wód powierzchniowych. Polit. Rzeszowska, Rzeszów 2007.

[14] Carlson R.E.: *A trophic state index for lakes.* Limnol. Oceanogr. 1977, **22**(2), 361–369.

[15] Kajak Z.: Hydrobiologia – Limnologia. Ekosystemy wód śródlądowych. PWN, Warszawa 1998.

[16] Vollenweider R.A.: Scientific fundamentals of the eutrophication of lakes and flowing waters with particular references to nitrogen and phosphorus as factors in eutrophication, Technical Report DAS/CSI/68.27. OECD, Paris 1968.

OCENA STANU TROFICZNEGO WÓD ŚRÓDLĄDOWYCH (NA PRZYKŁADZIE KASKADY SOŁY)

Instytut Ochrony i Inżynierii Środowiska, Wydział Nauk o Materiałach i Środowisku
Akademia Techniczno-Humanistyczna w Bielsku-Białej

Abstrakt: Celem badań było rozpoznanie stanu troficznego wód w systemie hydrograficznym kaskady Soły, położonej w obszarach karpackich Polski południowej. Analizowano wody dopływające oraz retencjonowane w zbiornikach zaporowych: Tresna, Porąbka i Czaniec. Na podstawie parametrów fizykochemicznych wód ustalono stopień ich eutrofizacji. Spośród stosowanych metod ustalania stanu trofii wybrano normy określone w polskich przepisach prawnych, wskaźnik Neverovej-Dziopak (ITS – *Index of Trophical State*) oraz wskaźnik Carlsona (TSI – *Trophic State Index*). Analizy danych z lat 2007–2009 wykazały, że jakość wód odpowiadała parametrom charakterystycznym dla mezotrofii oraz eutrofii. Niekorzystny stan trofii dotyczył niemal wszystkich badanych wód, w tym wód najniższego zbiornika kaskady – wodociągowego zbiornika Czaniec. Wskazuje to na potrzebę ochrony zlewni kaskady pod kątem ograniczenia ładunku zanieczyszczeń dostających się do wód powierzchniowych.

Słowa kluczowe: wody śródlądowe, kaskada Soły, jakość wód, eutrofizacja, wskaźnik trofii