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Some issues in the assessment of eutrophication of river waters as a consequence of the construction of a storage reservoir (on the example of the Bystrzyca River)

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Abstract

The quality and its changes of the Bystrzyca River waters, related to the operation of the reservoir in Zemborzyce (Lublin area), were analysed. In the years 2005-2007, the following eutrophication indicators were analysed in the Bystrzyca River: total nitrogen, total phosphorus, nitrate, and chlorophyll *a* content. In accordance with the flowing waters criteria of the Polish law, the river waters did not show susceptibility to eutrophication or showed advanced water eutrophication. In the case of the criteria applicable to stagnant waters, the river waters showed high eutrophic potential. When constructing a reservoir on a river, water trophic potential based on the standing water criteria should be taken into account.

Key words: water quality, nutrients, surface waters.

1. Introduction

Eutrophication is one of the most serious threats of the natural environment resulting from human activity and impact. In Poland eutrophication, as defined in the act of the Water Law (Dz. U. 2005/239/2019), is the enrichment of the water with nutrients, especially nitrogen and phosphorus compounds, which cause accelerated growth of algae and higher forms of plant life, as a result of which undesired disturbances of water ecosystems and the deterioration of water quality take place. Nitrogen and phosphorus content in the waters is a commonly used hydrochemical index for the assessment of eutrophic potential of a river or lake. In the case of the river waters with the dominant underground feeding, nitrogen and phosphorus content in the water is limited by the inflow of groundwater. This fact should be taken into consideration in the assessment of the trophic potential of the river waters, especially in the case of dam construction on the river.

The construction of small retention reservoirs planned in Poland can unfavourably influence the river water quality in the case where their construction will not take into account the level of availability of nutrients in a river. In Poland, the assessment of eutrophic potential of river waters can be based on the criteria included in the Water Law Act (Dz. U. 2005/239/2019), resulting from

the implementation of the so called Nitrates Directive (91/676/EEC) and the Water Framework Directive (2000/60/EC). Thus, already at the stage of conceptual design for the construction of a reservoir, an environmental impact assessment should be prepared, which will define the final use of the planned construction project, hence, the sense of its implementation.

The main purpose of the paper is analysis of used in Polish law methods for eutrophication analyses of river water and verification of their applicability for assessment of trophic potential of river waters on the example of the Zemborzyce reservoir on the Bystrzyca River (Fig. 1).

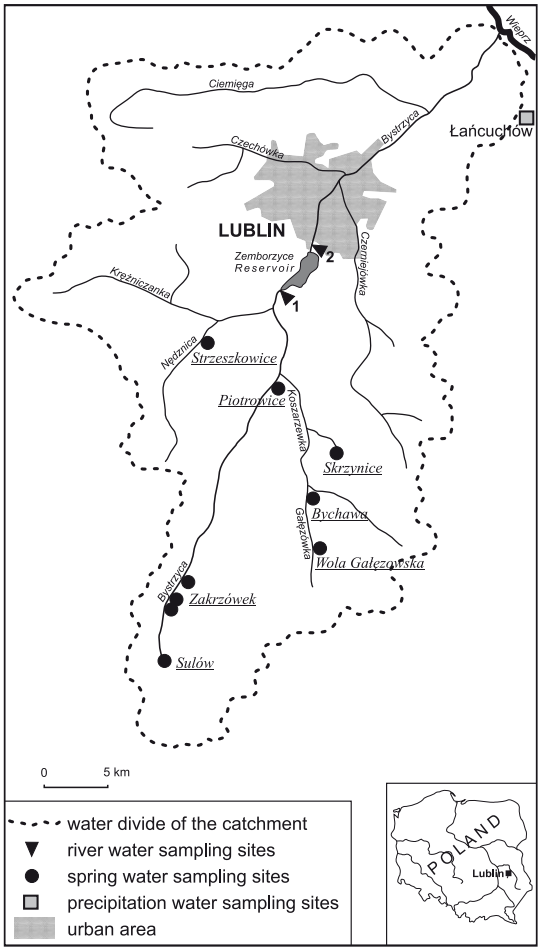

Fig. 1. Sites of water sampling for hydrochemical analysis.

2. Materials and methods

Study area

On the basis of studies of the Department of Hydrography and data of the Regional Inspectorate of Environmental Protection in Lublin, in the period 2005–2007 the eutrophic potential of the Bystrzyca River waters and their changes related to the operation of the Zemborzyce reservoir were analysed. In the previous years, the mass occurrence of Cyanobacteria was found (Pawlik-Skowrońska *et al.* 2004; Radwan 2006; Solis 2007). The Zemborzyce reservoir is a shallow dam reservoir constructed on the Bystrzyca River upstream of Lublin in 1974. The reservoir has an area of 282 ha, mean depth of about 2 m, maximal depth up to 5 m, capacity – 6.3 mln m^3, and water exchange time is about 25 days. The Bystrzyca River catchment up the reservoir has area of 748 km^2, of which 76% is used as arable land, 5% as meadows, 12% as forests, 6% as built-up areas, and 1% as other land use types.

The main groundwater reservoir in the Bystrzyca River catchment occurs in fissured rocks of Upper Cretaceous and Paleocene and in sandy-gravel Quaternary deposits in rivers' valleys (Michalczyk 1997). The feeding of the rivers from groundwater resources takes place through the springs and indirect channel drainage. The share of underground feeding in total outflow is about 76%, so it has a significant role in shaping the physico–chemical features of the river waters, especially in the periods of solely groundwater feeding. The minimum discharges of the Bystrzyca River upstream of the reservoir are at a level of 0.5 $m^3\ s^{-1}$, the average ones about 3.0 $m^3\ s^{-1}$, and the maximum values exceed 50 $m^3\ s^{-1}$.

Sampling and analyses

The trophic potential of the waters in the Bystrzyca River catchment was analysed with regard to the content of nitrogen and phosphorus in the hydrological cycle of the basin. The level of input of nitrogen and phosphorus from the bedrock and precipitation was determined on the basis of precipitation samples collected in Łańcuchów (single precipitation events in the years 2005–2007, 106 samples). The water from surface runoff was analysed using the water samples from episodic runoff on the slope surface (54 samples collected in the areas of different types of land use). The concentration of nitrogen and phosphorus in groundwater was determined based on water samples from 9 springs in the Bystrzyca River catchment. The content of nitrogen and phosphorus compounds in the river water was determined based on Department of Hydrography analysis of water samples collected to determine the content of total nitrogen and phosphorus, nitrates, nitrites, ammonium ions and phosphates. The collected data were supplemented with the results of analyses (chlorophyll *a* content) of the Regional Inspectorate of Environmental Protection in Lublin in 2005–2008 (http://www.wios.lublin.pl). Analysis of ion forms of nitrogen and phosphorus

was conducted at the Department of Hydrography using the ion chromatography method. Total phosphorus was determined according to the Hach 8190 method by means of the spectrophotometer Hach 2000. Total nitrogen was determined in mineralized samples (UV with addition of H_2O_2) as the sum of all forms of nitrogen determined conductometrically with the use of an chromatograph (MIC 3 of Metrohm); in column Metrosep C2 150 ammonium ion was determined; in column A SUPP 5 250 – nitrates and nitrites.

Three methods of eutrophic potential assessment of the waters of the Bystrzyca River were used, based on the criteria contained in the Water Law Act (Dz. U. 2005/239/2019) and resulting from the implementation of the Nitrates Directive (91/676/EEC) and the Water Framework Directive (2000/60/EC).

The Ordinance of the Minister of Environment (dated 23rd December, 2002), included in the Water Law (Dz. U. 2005/239/2019), determines the limit values of the basic indices of water eutrophication. The average annual concentrations of total nitrogen, total phosphorus, nitrate and chlorophyll *a* content for stagnant and flowing waters are used for the assessment. It is found that eutrophication occurs in the case when the limit value of even one index is exceeded.

The method resulting from the implementation of the Nitrates Directive (91/676/EEC) is determined by the Ordinance of the Minister of Environment (dated 23rd December, 2002) regarding the criteria for identifying waters vulnerable to pollution by nitrogen compounds from agricultural sources (Dz. U. 2002/241/2093). On the basis of this Ordinance, surface and groundwater can be considered to be polluted by nitrates when the concentration of NO_3 exceeds 50 mg dm^{-3}. Waters with a concentration of 25–50 mg dm^{-3} are considered to be eutrophication threatened.

The third method for the assessment of eutrophication has been developed by the Regional Inspectorate of Environmental Protection in Lublin in 2008 (http://www.wios.lublin.pl) on the basis of the Ordinance of the Minister of Environment dated 20th August, 2008 (Dz. U. 2008/162/1008) regarding the method of classification of the status of uniform parts of surface waters. In accordance with the assumptions of the Water Framework Directive and the guidelines contained in the abovementioned Ordinance, in the assessment of the status of water for each sampling station, the ecological status/potential is determined on the basis of physico-chemical and biological analyses. In this Ordinance five classes of ecological status/potential are defined: high, good (both characterized by the absence of eutrophication), moderate (eutrophication risk), poor and bad ecological status (subjected to eutrophication).

3. Results

Nitrogen

The average content of nitrogen in rainwater in the years 2005–2007 was determined to be 1.4 mgN dm^{-3} (Table I). The highest concentration (for all the examined mineral nitrogen forms) was observed for ammonium ion (0.83 mgN dm^{-3} on average), slightly lower values for nitrate ion (0.55 mgN dm^{-3}), and the lowest value for nitrite ion (0.02 mgN dm^{-3}).

In surface runoff waters, the average content of nitrogen was at a level of up to 2 mgN dm^{-3}. In these waters, the ammonium ion was characterized by the highest content (1.08 mgN dm^{-3} on average), nitrate ions had slightly lower values (0.75 mgN dm^{-3} on average), and nitrite ions had the lowest concentration (0.08 mgN dm^{-3} on average).

In the groundwaters examined in the springs, nitrates dominated with the average concentration of 1.75 mgN dm^{-3}. The content of ammonium and nitrite ions did not exceed, respectively, 0.02 mgN dm^{-3} and 0.002 mgN dm^{-3}.

Nitrogen content in the years 2005–2007 for the Bystrzyca River waters at the sampling station

Table I. Nitrogen, phosphorus and chlorophyll *a* in the waters of the Bystrzyca River catchment (minimum-maximum/average values in the years 2005–2007).

Index	Precipitation (106 samples)	Surface runoff (54 samples)	Groundwater (9 springs)	The Bystrzyca River upstream of the reservoir*	The Bystrzyca River downstream of the reservoir*
N – total $mg \cdot dm^{-3}$	0.1-6.1/ 1.4	0.3-14.6/ 2.31	0.5-5.4/ 1.75	2.33-5.11/ 2.91	0.84–3.41/ 2.09
NO_3 $mg \cdot dm^{-3}$	0.5-16/ 2.4	0.1-25/ 3.3	4.5-17.8/ 7.6	3.1–12.7/ 6.6	<0.1–6.2/ 0.4
P - total $mg \cdot dm^{-3}$	<0.01-0.58/ 0.02	<0.01-7.08/ 0.28	0.05-0.15/ 0.32	0.1–0.49/ 0.23	0.01–0.40 /0.16
Chlorophyll *a* $\mu g \cdot dm^{-3}$	Not analysed	Not analysed	Not analysed	<25	19-236/ 110

*data of the Regional Inspectorate of Environmental Protection in Lublin and of the Department of Hydrography.

upstream of the reservoir was 3.3 mgN dm^{-3} on average, mineral nitrogen accounted for ¾ of total nitrogen (2.2 mgN dm^{-3}). The concentration of total nitrogen downstream of the reservoir was much lower, 1.19 mgN dm^{-3} on average, out of which mineral forms accounted for approx. 44%.

Phosphorus

In the wet deposition, the concentration of phosphorus was at a level of 0.02 mgP dm^{-3}. Much higher values were measured in the surface runoff waters, where the phosphorus concentration varied, from below 0.01 to over 5.0 mgP dm^{-3}, with an average value of 0.28 mgP dm^{-3}.

In the groundwaters, the phosphorus concentration was 0.15 mgP dm^{-3}. This value was lower than that for the river waters upstream of the reservoir, where the average concentration was 0.23 mgP dm^{-3}. Much lower average values of total phosphorus were in the river waters downstream of the reservoir, 0.16 mgP dm^{-3}.

Chlorophyll *a*

The content of chlorophyll *a* in the Bystrzyca River waters upstream of the reservoir usually did not exceed 25 μg dm^{-3}. In the water flowing out of the reservoir, the level of the index significantly increased and its concentration was 19–239 μg dm^{-3}, 110 μg dm^{-3} on average.

Nitrogen and phosphorus balance

The calculated nitrogen and phosphorus balance for the Bystrzyca River catchment at the Zemborzyce Reservoir water gauge shows that the main input of substances causing eutrophication comes from organic and mineral fertilizers (Table II). Fertilizers make up more than 90% of nitrogen input to the ground; the rest comes from atmospheric deposition and sewage discharge.

The level of agricultural nitrogen output was determined to be 61.5 kg ha^{-1} yr^{-1}, which gives about 2/3 of the nitrogen input. The level of nitrogen output by the river system was 3.27 kg ha^{-1} yr^{-1} (about 3.5% of nitrogen input). The remaining amount, 28 kg ha^{-1} yr^{-1}, comprises nitrogen fixed in soil and subjected to denitrification processes.

The Zemborzyce reservoir plays an important role in nitrogen and phosphorus circulation. The analysed material shows that 93.6 tonne $year^{-1}$ (332 kg ha^{-1} yr^{-1}) of nitrogen was deposited in the reservoir in the years 2005–2007, and in the case of phosphorus deposition it was determined to be 5.9 tonne $year^{-1}$ (21 kg ha^{-1} yr^{-1}). Results of researches conducted in the autumn season of 1999 (Ligęza *et al.* 2007) also indicate the high level of deposition of nitrogen and phosphorus in the bottom deposits of the Zemborzyce reservoir.

4. Discussion

Three methods for the assessment of eutrophic potential of the Bystrzyca River waters were used, based on the criteria contained in the Water Law Act (Dz. U. 2005/239/2019), resulting from implementation of the Nitrates Directive (Dz. U. 2002/241/2093) and the Water Framework Directive (Dz. U. 2008/162/1008). The results show that, in accordance with the provisions related to the Nitrates Directive (Dz. U. 2002/241/2093), the groundwaters and river waters of the Bystrzyca River catchment and the Zemborzyce reservoir are not threatened by nitrate pollution (Table III). In the case of the assessment of eutrophic potential according to the Water Framework Directive (Dz. U. 2008/162/1008), eutrophication processes were not found in the river waters and groundwaters upstream of the reservoir, however, the waters downstream of the reservoir are characterized by eutrophication features (http://www.wios.lublin.pl).

In the case of the guidelines contained in the Water Law (Dz. U. 2005/239/2019), developed for flowing and stagnant waters, essential differences in the assessment of trophic potential are noticeable. The groundwaters and the Bystrzyca River waters upstream of the Zemborzyce reservoir, evaluated on the basis of the criteria for flowing waters, do not show susceptibility to eutrophication. The content of chlorophyll *a* in the waters downstream of the reservoir show advanced eutrophication.

Table II. Simplified nitrogen and phosphorus balance in the hydrological cycle of the Bystrzyca River catchment in the years 2005–2007 (precipitation 628 mm = evapotranspiration 515.7 mm + underground outflow 84.2 mm + surface outflow 28.1 mm).

Element	Input to catchment from ($kg \cdot ha^{-1} \cdot yr^{-1}$)		Output from catchment via ($kg \cdot ha^{-1} \cdot yr^{-1}$)				
			River outflow				Agriculture
	Precipitation	Fertilizers: mineral + organic	Total	Groundwater feeding	Surface runoff	Balance difference (including sewage)	
Nitrogen	8.79	56.0 + 28.0	3.27	1.47	0.65	1.8	61.5
Phosphorus	0.13	25.0 + 5.2	0.26	0.13	0.08	0.05	13.0

Table III. Evaluation of the trophic state of the water in the Bystrzyca River catchment.

Trophic index	Nitrates Directive	Water Framework Directive (http://www.wios.lublin.pl)	Water Law (Dz. U. 2005/239/2019)	
			Flowing waters	Stagnant waters
Spring waters	Not threatened	Good ecological status / no eutrophication	no eutrophication	Eutrophication
River water upstream of the reservoir	Not threatened	Good ecological status/ no eutrophication	no eutrophication	Eutrophication
River water downstream of the reservoir	Not threatened	Bad ecological status/ eutrophication risk	Eutrophication	Eutrophication

Thus, it is not possible to assess the eutrophic potential of the flowing waters stored in the reservoir according to the criteria of the Minister of Environment defined for flowing waters (Dz. U. 2002/241/2093). On the basis of the criteria for stagnant waters (Dz. U. 2002/241/2093), the waters of the Bystrzyca River upstream as well as downstream of the Zemborzyce reservoir show high eutrophic potential. Therefore, for the assessment of any possible eutrophication of the waters of rivers flowing through storage reservoirs (or planned to be constructed), it is necessary to use the criteria for stagnant waters (Dz. U. 2002/241/2093).

Conclusions

The present study on the trophic potential of the waters in the Bystrzyca River catchment, based on the methods defined in Polish law, unequivocally indicates the uselessness of the eutrophication assessment methods developed for flowing waters. The trophic potential of waters, based on the limit values of the indices used for the assessment of eutrophication of inland surface waters as determined for stagnant, not flowing waters, should be taken into account in environmental impact assessments of storage reservoirs damming up river waters! The methods commonly used in the assessment of the trophic state of lakes, e.g. the OECD methods or Carlson's index, identifying the susceptibility of dam reservoirs to degradation, will also be useful.

5. References

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