The development of the eutrophication process in Dobczyce reservoir

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Abstract. Eutrophication is currently a global threat to all types of aquatic ecosystems leading to a disturbance of their ecological balance and a deterioration of water quality. This problem is especially true for dam reservoirs, which play a key role in the economy of each country, being an important source of water supply. It is also a primary problem for all types of surface waters in Poland. Effective eutrophication abatement strategies should be based on reliable information about the actual trophic status of waters which in turn should be obtained with fast, accurate and low-cost monitoring. The aim of this paper is to investigate the possibility of the application of aggregated numerical indicators as an effective tool for the assessment of water trophic status and prove it using the example of the trophic state assessment of the Dobczyce dam reservoir. For this purpose, three numerical indicators elaborated by different authors were used.

1 Introduction

The most obvious manifestation of the ecological balance disturbance in surface waters is anthropogenic eutrophication, which in the second half of the 20th century became a global problem and caused the deterioration of the quality of all types of water. Eutrophication is in first place on a list of problems related to surface waters protection and constitutes the greatest threat to their ecological safety and consumption value. Eutrophication is recognized as the most current problem caused by a high degree of the unfavorable anthropogenic impact on the aquatic environment and now affects all types of surface waters [1].

An increase in the trophic state of aquatic ecosystems is closely related to the deterioration of a number of the most important water quality properties, such as increasing phytoplankton abundance and biomass, increasing organic matter content and water turbidity, deterioration of the organoleptic properties of water leading to the appearance of toxic substances and pathogenic microflora. Considering these negative consequences, the protection of dam reservoirs against eutrophication is the key problem because of their role and functions in water management.

The necessity to pay special attention to eutrophication processes in dam reservoirs and water quality management is primarily caused by a practical aspect. Most of the existing

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and newly constructed dam reservoirs are intended for comprehensive use, and the priority is the potable water supply for the population.

The intensive development of hydraulic structures for the purpose of water retention and solving the problems of water supply stimulated the beginning of research of artificial reservoirs ecosystems. An analysis of the results of research on the ecology of dam reservoirs, their hydrological regime and hydrochemical properties allowed disproving the existing opinion that dam reservoirs as hydrological objects represent a transitional ecosystem between rivers and lakes, yet have a complicated specific hydrological structure. The ecosystems of artificial reservoirs are the systems that differ from lakes and rivers and is characterized by individual characteristics and properties [2].

Taking into account the specificity of dam reservoirs and their multifunctionality, it becomes very current to develop and apply the proper classification systems and indicators to assess their trophic status. The indicators, developed with consideration for dam reservoir ecosystems specificity, will allow not only the implementation of continuous trophic status monitoring and tracking the dynamics of eutrophication development, but will form the basis for the formulation of mathematical forecasting models as a basis for the development of appropriate protective measures against eutrophication and its consequences. The indicators that most closely match these tasks are the numerical integrated indicators, which were developed on the basis of the relationship between various eutrophication factors and parameters reflecting aquatic ecosystem response to an increase in the trophic level. Based on such indicators, it is possible to obtain reliable information on real trophic conditions in dam reservoir water in a simple and inexpensive way [2].

The aim of this paper is the comparative analysis of the applicability of three methods for assessing the trophic state, based on aggregated numerical indicators developed by different authors and the selection of an optimal assessment method. Based on the chosen method, the analysis of the long-term dynamics of the eutrophication process in the Dobczyce dam reservoir was carried out.

2 Characteristics of the research object

The object of research was the Dobczyce reservoir. It is an artificial reservoir constructed on the Raba River, situated 30 km to the south of the city of Krakow, in Poland. The maximum surface area of the reservoir is 1065 ha and the maximum volume is 141.7 billion m^3. The average depth is 10.3 m, and the maximum depth is 28 m [3]. The Raba River is a right-bank tributary of the upper Vistula River. It is 131.7 km long and has an average decline of 4.4‰. [4]. The Dobczyce reservoir is a source of drinking water for Kraków and a few smaller cities.

3 Research methodology and database

The research database was the result of long-term water monitoring carried out by the Regional Inspectorate for Environmental Protection in Kraków during the period 2004-2017, at three measurement points situated in the reservoir: point 1 – near the water intake, point 2 – at the depth of 5 meters under the surface near the water intake, point 3 – on the water surface in the centre of the reservoir. The location of measuring points is shown in Fig. 1.

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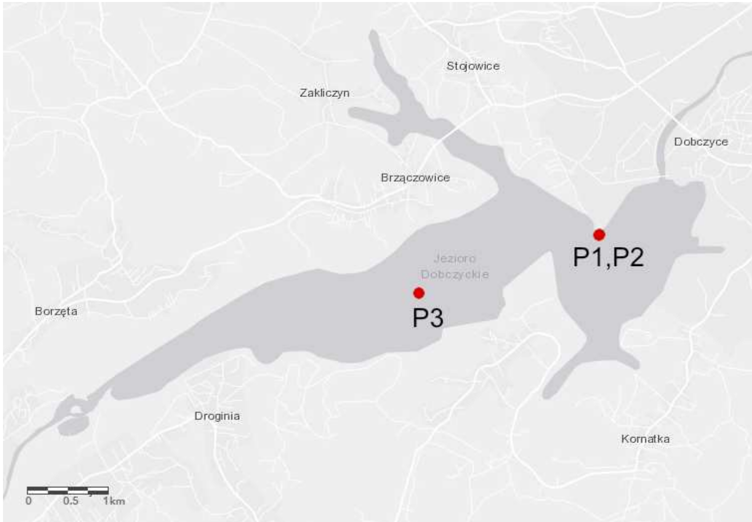

Fig. 1. The localization of measuring points.

The changes of the following water quality parameters (indicators of eutrophication) within the 14-year monitoring period were analyzed: the pH value, the saturation of water with oxygen (O2, %), total nitrogen (TN), total phosphorus (TP) and the content of chlorophyll-a (CHL). In total, 1452 parameters were analyzed. The distribution of the examined parameters values within the period 2004-2017 at the three measurement points are presented in Fig. 2.

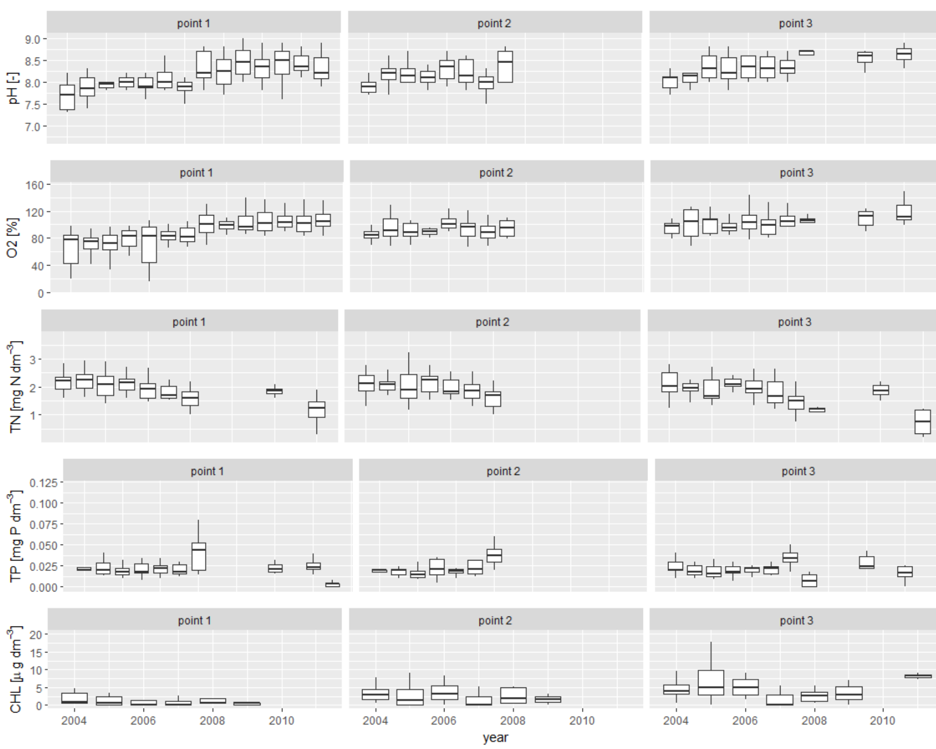

Fig. 2. Distribution of the average annual values of the examined parameters.

At measurement points 1 and 3, monitoring was carried out during the period 2004-2017. However, at measurement point 2 monitoring was conducted in 2004-2010. The scope and frequency of monitoring in terms of all examined parameters were not always complete. Only the values of pH and oxygen saturation of water were tested regularly once a month throughout the research period; the nitrogen and phosphorous content were examined monthly up to 2010, then no measurements of this indicator were observed. The measurements of chlorophyll-a content ware carried out a few times per year and only in the period of 2004-2010. The values of the studied parameters and their dynamics are closely related to the changes in water trophic state and are mutually connected. The Precisel correlation dependence between the mentioned eutrophication factors served as the basis for the development of numerical indicators formulated by different authors and used in this research.: TSI, ITS, and TRIX.

The Trophic State Index (TSI) was elaborated by Robert Carlson in 1977 [5]. The TSI index consists of three equations reflecting the correlation dependence of the Trophic State Index value on water transparency and the content of chlorophyll and total phosphorus (equation 1,2,3,):

$$TSI(SD) = 60 - 14.41\ ln(SD) \tag{1}$$

$$TSI(CHL) = 9.81\ ln(CHL) + 30.6 \tag{2}$$

$$TSI(TP) = 14.42\ ln(TP) + 4.15 \tag{3}$$

where: SD is Secchi depth [m], TP is total phosphorous [µgP dm^{-3}], and CHL is chlorophyll-a concentration [µg dm^{-3}]. For TSI calculation, single values or average annual values can be used. The results obtained from each equation should be interpreted separately, but it is possible to calculate one averaged index value on the base of the three individual values: TSI (SD), TSI (CHL), and TSI (TP). Boundary index values for various trophic states are shown in Table 1.

Table 1. TSI value attributes.

TSI value	Trophic state
<30	oligotrophic
40 – 50	mesotrophic
50 – 60	eutrophic
70 – 80	hypereutrophic

The TRIX Index was elaborated by professor Richard Vollenweider and his team in 1998 for coastal waters, but it could be also used for inland waters, lakes, and rivers [6]. The value of this index can be calculated according to the equation (4)[7]:

$$TRIX=(log10[CHL*aD\%O2*minN*TP]*1.5)/1.2 \tag{4}$$

where: CHL is chlorophyll-a concentration [µg dm^{-3}], aD%O2 means absolute of normal conditions minus the percent of oxygen saturation, abs(100% - oxygen concentration [%]), minN is the mineral form of nitrogen [µgN dm^{-3}], TP is the total phosphorous [µgP dm^{-3}]. Reference values of TRIX for different trophic status are presented in Table 2.

Table 2. TRIX value attributes (on base of [7]).

TRIX value	Trophic state
<4	oligotrophic
4 – 5	mesotrophic
5 – 6	meso-eutrotrophic
>6	eutrophic

The ITS index was elaborated in 1995 by Elena Neverova-Dziopak, it was primarily used for the trophic status assessment of the the low-mineralized western part of the Gulf of Finland, but now it is widely used for rivers, lakes and reservoirs [8]. ITS is based on the established correlation dependence between the pH and saturation of water with oxygen which arises during eutrophication development. The ITS value can be calculated on the basis of equation (5):

$$ITS=pH + a*(100\% - \%O2) \tag{5}$$

where: pH is the mean pH value [-], %O2 is the mean value of the percent of oxygen saturation, a is a linear regression pH=f(%O2) slope factor. The reference values of ITS index for different trophic status are shown in Table 3.

Table 3. ITS reference values in water of the different trophic state.

ITS value	Trophic state
<6.0	dystrophic
6.0 – 6.6	ultraoligotrophic
6.6 – 7.3	oligotrophic
7.3 – 8.0	mesotrophic
>8.0	eutrophic

Scatterplots with the linear regression of pH and oxygen for the three measurement points are shown in Fig. 3.

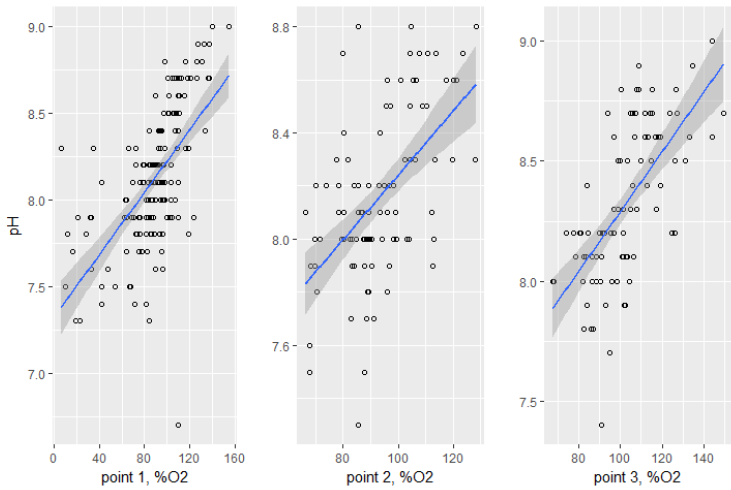

Fig. 3. Scatterplot of pH and water saturation with oxygen correlation at three measurement point in the Dobczyce reservoir.

In connection with the fact that the condition for ITS application is the existence of a linear relationship between pH and water saturation with oxygen, the possibility of using this indicator in the present research was the verification of the type of this correlation dependence in the examined water reservoir. Pearson R is higher than 0.5, which testifies to the strong positive linear relationship between the parameters and confirms the possibility of ITS index application for eutrophication status assessment in the Dobczyce dam reservoir. The slope coefficient a, the Pearson correlation coefficient and significance test (as p-value, significance level α=0.05) are presented in Table 4.

Table 4. Pearson R, p-value and slope coefficient.

	point 1	point 2	point 3
R – Pearson correlation	0.61	0.54	0.64
p-value	0	0	0
a slope coefficient	0.009	0.012	0.012

4 Research results

The trophic state of the Dobczyce–dam reservoir and long-term dynamics of its changes were examined through means of the three assessment tools outlined above: TSI, TRIX and ITS. Trophic state assessment and eutrophication process dynamics were assessed for each examined measurement points. The result of the trophic status assessment at three measurement points with the use of three different indexes is presented in Table 5. The assessment was based on the average annual values of the examined parameters obtained during a 13-year monitoring.

Table 5. The results of the generalized assessment of the dam reservoir trophic state.

Years	Measurement points											
	Measurement point 1				Measurement point 2				Measurement point 3			
	ITS	TSI TP	TSI CHL	TRIX	ITS	TSI TP	TSI CHL	TRIX	ITS	TSI TP	TSI CHL	TRIX
2004	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**m**	**e**	**m**	**m**	**m**
2005	**m**	**e**	**m**	**m**	**e**	**m**	**m**	**m**	**e**	**m**	**m**	**m**
2006	**m**	**m**	**m**	**m**	**e**	**m**	**m**	**m**	**e**	**m**	**m**	**m**
2007	**m**	**m**	**m**	**m**	**e**	**m**	**m**	**m**	**e**	**m**	**m**	**m**
2008	**m**	**m**	**m**	**m**	**e**	**m**	**m**	**m**	**e**	**m**	**m**	**m**
2009	**m**	**m**	**m**	**m**	**e**	**e**	**m**	**m**	**e**	**m**	**m**	**m**
2010	**m**	e	—	—	**m**	**e**	—	—	**e**	**e**	—	—
2011	**e**	—	—	—	**e**	—	—	—	**e**	**e**	**m**	—
2012	**e**	—	—	—	—	—	—	—	—	—	—	—
2013	**e**	—	—	—	—	—	—	—	—	—	—	—
2014	**e**	**e**	—	—	—	—	—	—	**e**	**e**	—	—
2015	**e**	—	—	—	—	—	—	—	—	—	—	—
2016	**e**	**m**	—	—	—	—	—	—	**e**	**e**	—	—
2017	**e**	—	—	—	—	—	—	—	—	—	—	—

- **e** – eutrophic
- **m** – mesotrophic
- "—" – lack of research in the framework of monitoring

In turn, the long-term dynamics of water reservoir trophic status changes obtained as the result of the assessments made using the various indicators at three measurement points is shown in Fig. 4.

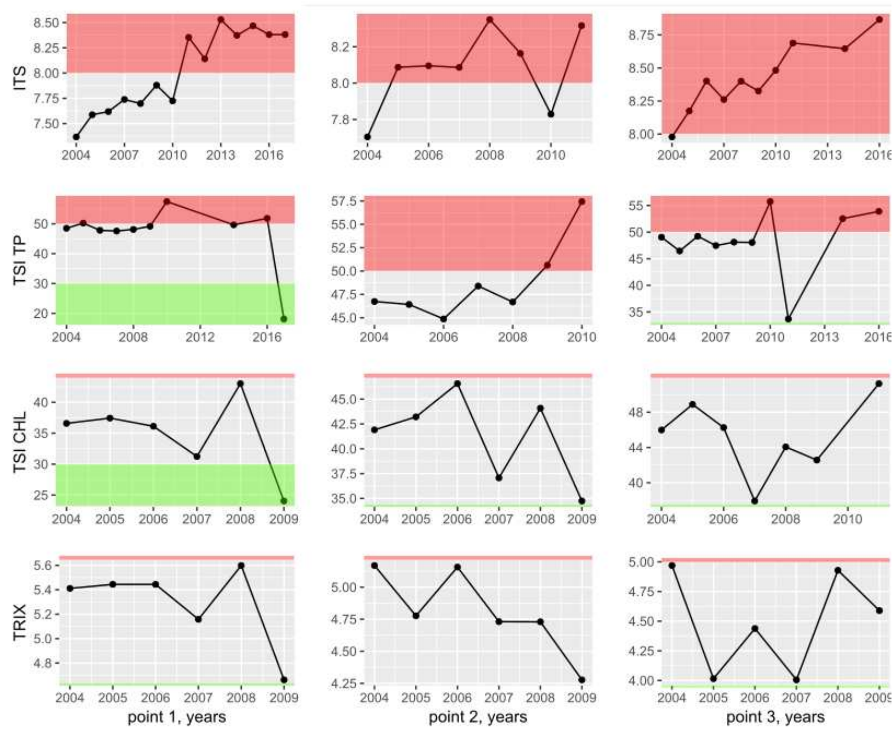

Fig. 4. Results of the trophic status assessment based on TSI, TRIX, and ITS at three measurement points (green color – oligotrophic, grey color – mesotrophic state, red color – eutrophic state).

5 Discussion of the results

After analysing the results of the trophic state assessment obtained by means of 3 different aggregated indicators (table 5) and the dynamics of eutrophication development within the period of 14 years (fig. 4), the following conclusions can be drawn:
- the assessment of the Dobczyce dam reservoir made on the basis of three different indicators allows assessing its trophic status generally as mesoeutrophic;
- the most reliable result was obtained for measuring point 1, which is located close to the water intake, therefore it is regularly monitored, which allowed basing the assessment on a sufficient number of data. For this point, almost 100% agreement of trophic state assessment was obtained on the basis of all three indicators. However, due to the discontinuation of regular measurements of CHL and TP at the measurement points after 2010, the use of the TSI and TRIX indicators has ceased to be possible. In contrast, the ITS indicator still served as a reliable assessment tool. Just the application of ITS itself allowed determining the stages of eutrophication development and capturing the reservoir transition from the mesotrophic to the eutrophic state in 2011, as well as observing the annual trophic state fluctuations;
-the same conclusions regarding the results of the assessment of the trophic state and its dynamics can be extended to measuring points 2 and 3. It should be noted that the use of the above-mentioned aggregated indicators to assess the water trophic state at various

measuring points, and especially ITS application, allowed deducing that even within one dam reservoir, the dynamics of eutrophication development differ depending on the different abiotic conditions at the examined measurement points.

6 Conclusions

The conducted trophic state assessment of the Dobczyce dam reservoir made it possible to observe a steady increase in water trophic conditions from mesotrophic through mesoreutrophic to eutrophic in the last 14 years during the period from 2004-2017.This growing trend is alarming due to the fact that the reservoir serves one of the basic sources of drinking water supply for the residents of Krakow and the surrounding area. Therefore, the protection of the Dobczyce reservoir against the intensification of the eutrophication process and its negative consequences requires special attention and the development of effective comprehensive protective measures.

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