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Trophic State Assessment of Dobczyce Reservoir

1. Introduction

Over the last 50 years, eutrophication and its negative consequences have become a significant problem related to the quality of surface water. Eutrophication is a natural process that proceeds slowly in surface water. Unfortunately, because of irrational human activities, the speed of this process has been significantly increased, which disturbs many natural process taking place in surface water, making eutrophication one of the major issues when considering the state and the quality of surface water.

Eutrophication disrupts a number of natural processes that take place in surface water, thus causing the disturbance of the ecosystem's functioning and the deterioration of the utilitarian water quality. In particular, it reduces remarkably the number of species inhabiting an ecosystem and disrupts the mechanisms of water self-purification. As a result, it brings about many negative ecological, economic, and social consequences, such as ecological disturbance of aquatic ecosystems and the conditions of different types of surface water usage, extensive financial costs required for water purification and waste water treatment.

The most sensitive for eutrophication are ecosystems of limnic ecosystems water such as: lakes and artificial water reservoirs.

2. Object of the Research

This paper presents the results of the trophic state research of Dobczyce Reservoir. Dobczyce Reservoir is situated in Małopolska Voivodeship, in Powiat of Myślenice, between two towns, namely, Myślenice and Dobczyce [3]. This large (maximum capacity larger than 100 mln m^3) and deep (i.e., with the average depth

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exceeding 10 m) artificial reservoir is characterized by a long retention period (i.e., more than 100 days) and a regular water run-off from the hypolimnion layer [5, 7]. The reservoir dam, situated on the 60.1 km of the Raba River, closes an indirect drainage basin of 768 km^2, whereas the direct drainage basin for the tank amounts to 78.2 km^2 [2].

The eutophication process in the Dobczyce Reservoir is particularly enhanced by a large size of the drainage basin compared with the reservoir's overall area (over 80 times larger) and an inappropriate management in the drainage basin, such as using cesspools instead of local sewage systems [3, 4].

3. Methods of Trophic State Assessment of Surface Waters

3.1. Traditional Indices of the Trophic State

Traditionally, the water trophic state is characterized by the complex of abiotic and biotic components as a qualitative description, and often it does not reflect the balance of organic matter production-destruction processes which decides about trophic level in surface water. The water trophic state can be evaluated using many hydrobiological and physicochemical trophical indices, such as chlorophyll *a*, nitrogen, phosphorus, water transparency, and many others [6]. Table 1 presents those indices that are widely used in practice together with the respective limit values for various trophical types of surface water.

Table 1. Values of trophic state indices for different types of water

Trophical degree	P_{tot} [μg/dm^3]	Chl *a* [μg/dm^3]	Chl a_{max} [μg/dm^3]
Ultra-oligotrophic	<4.0	<1.0	<2.5
Oligotrophic	<10.0	<2.5	<8.0
Mesotrophic	10–35	2.5–8.0	8–25
Eutrophic	35–100	8.0–25	25–75
Hipertrophic	>100	>25	>75

P_{tot} [μg/dm^3] – annual concentration of total phosphorus.
Chl *a* [μg/dm^3] – annual concentration of chlorophyll *a*.
Chl a_{max} [μg/dm^3] – maximum concentration of chlorophyll *a* observed within a year.

Table 2. Range of the values for selected trophic indices (on the basis of [6])

Criterion	Trophical state			
	O	M	E	H
Chl *a* [μg/dm³]	0–4.3	1–20	6–100	>20
Chl a_{max} [μg/dm³]	6–16	8–60	25–75	>75
$P_{tot\ max}$ [μg/dm³]	8.0	26.7	84.4	>1200
P_{tot} [μg/dm³]	5–20	5–50	25–100	>100
$N_{tot\ max}$ [μg/dm³]	661	753	1875	72 444
N_{tot} [μg/dm³]	5–400	80–600	500–1500	>1500
N_{min} [μg/dm³]	200–400	300–650	500–1500	>1500
Relation N:P	30–40	25–30	15–25	12–15
P_{min} [mg P/dm³]	0.00–0.03	0.01–0.25	>0.02	–
pH in summer	6.9–7.2	7.2–8.0	8–9.5	–
Contamination of oxygen [%]	95–105	50–155	<50	–

O – oligotrophic, M – mesotrophic, E – eutrophic, H – hypertrophic.

The scattering of values for individual criterions that are used to assess the water trophical state are presented in table 2. Due to the overlapping ranges of parameter values, the assessment of the trophical state does not always allow for an unambiguous evaluation of the trophical state, which often leads to different classifications of the trophical state by various researchers. A significantly more accurate evaluation is possible using aggregate indices, which are formulated on the basis of a few parameters characterizing the water trophic state, such as the index of trophic state (ITS).

3.2. Index of Trophic State

Index of Trophic State (ITS), also known as integral criterion, allows to estimate the trophical state in reservoirs on the basis of the organic matter production-destruction balance (biotic balance) in surface water. The state of biotic balance in water can be reflected by the ratio between the amount of carbon dioxide and oxygen in ecosystems [6]. The numerical integral criterion, used in this research, is based on the assumption that in the case of disturbances in the balance between the organic matter production-destruction processes the ratio of concentration of oxygen and carbon dioxide changes accordingly.

In surface water, the ratio between carbon dioxide and oxygen concentrations is given by means of quantitative dependence of pH value and oxygen saturation. Such a dependence of the pH value with carbon dioxide concentration CO_2 is a direct consequence of the carbonate balance.

Biotic balance (i.e., the balance between the speed of the manufacturing and decomposition of organic matter processes) is a function of pH value and water saturation by oxygen. For a given value of oxygen saturation, a higher value of pH value is obtained for a higher trophic level.

Integral criterion is defined by [6]:

$$IC = \sum_{i=1}^{n} \mathrm{pH}_i / n + a \cdot \left(100 - \sum_{i=1}^{n} [\mathrm{O}_2\,\%]_i / n \right) \tag{1}$$

where pH_i denotes pH value of the reservoir over the period of time t, O_2% is water saturation over the same time period with pH measurement over t, n denotes the number of measurements over t, and a is an empirical index formulated as:

$$a = \frac{\sum_{i=1}^{n} \{[\mathrm{O}_2\,\%]_i \cdot \mathrm{pH}_i\} - \sum_{i=1}^{n} [\mathrm{O}_2\,\%]_i \cdot \sum_{i=1}^{n} \mathrm{pH}_i / n}{\sum_{i=1}^{n} [\mathrm{O}_2\,\%]_i^2 - \left\{ \sum_{i=1}^{n} [\mathrm{O}_2\,\%]_i / n \right\}^2} \tag{2}$$

The respective values for different trophic states of freshwater are provided in table 3.

Table 3. ITS values for various water trophic levels [6]

Trophical degree ITS	Values
Dystrophic	5.7 ± 0.3
Ultraoligotrophic	6.3 ± 0.3
Oligotrophic	7.0 ± 0.3
Mesotrophic	7.7 ± 0.3
Eutrophic	8.3 ± 0.3

4. Results of the Research

The evaluation of the trophic state in Dobczyce Reservoir is based on the weekly monitoring data collected in years 2002 and 2004 from a monitoring point situated next to the water intake at a depth of 3.55 m. The total number of such measurements amounts to 288.

4.1. Trophic State Estimation on the Base of Traditional Indices

Mean values of trophic indicators and estimated trophic status in the period of 2002 and 2004 are presented in table 4. In 2002 the total phosphorus concentration indicates the eutrophical state, whereas the annual and maximum concentration of chlorophyll a indicates the mesotrophic state, respectively. On the other hand, in the year 2004, the eutrophic state is shown by the total phosphorus concentration. The annual and maximum concentration of chlorophyll a indicates the mesotrophic state.

Table 4. Trophical state in Dobczyce Reservoir in years 2002 and 2004

Indicators	2002		2004	
	mean value	trophical state	mean value	trophical state
P_{tot} [μg/dm^3]	76	eutrophic	65.6	eutrophic
Chl *a* [μg/dm^3]	6.1	mesotrophic	7.7	mesotrophic
Chl a_{max} [μg/dm^3]	17.1	mesotrophic	24.9	mesotrophic

4.2. Trophic State Estimation on the Base of ITS

Index of Trophic State is estimated from equation (1). Prior to applying the integral criterion for the evaluation of the trophic level of a given reservoir, the appropriateness of its application was checked, i.e., it was investigated the character of correlation between pH reaction and oxygen saturation figures 1 and 2 present the dependence of pH value on water saturation for 2002 and 2004; linear correlation charts (i.e., Pearson's correlation coefficient values) and regression lines were generated in *Statistica ver. 8.0* program.

Pearson's coefficient of correlation amounts to 0.79 and 0.37 in 2002 and 2004, respectively. These results indicate a significant dependence of pH value on water saturation by oxygen.

Due to the linear dependence between pH and water saturation obtained from correlation analysis, the ITS index could have been applied in order to estimate the trophical state of the investigated reservoir. ITS index value can be calculated by inserting an empirical index *a*, which describes the slope of a line characterizing the dependence of pH on water saturation O_2 and can be conveniently obtained from the regressive equation provided by *Statistica*, into equation (1), which amounts to 8.26.

From the presented analysis, it can be concluded that Dobczycki Reservoir (in epilimnion layer) in 2002 was strongly eutrophic. In 2004 ITS index amounts to 8.07, which also means that Dobczycki Reservoir was eutrophic.

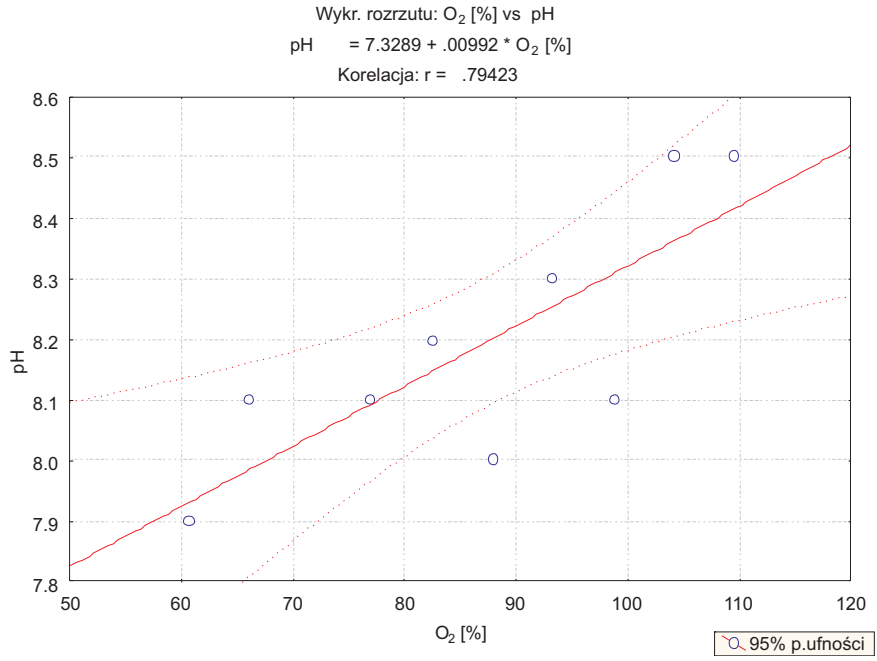

Fig. 1. Dependence of pH value on water saturation (2002)

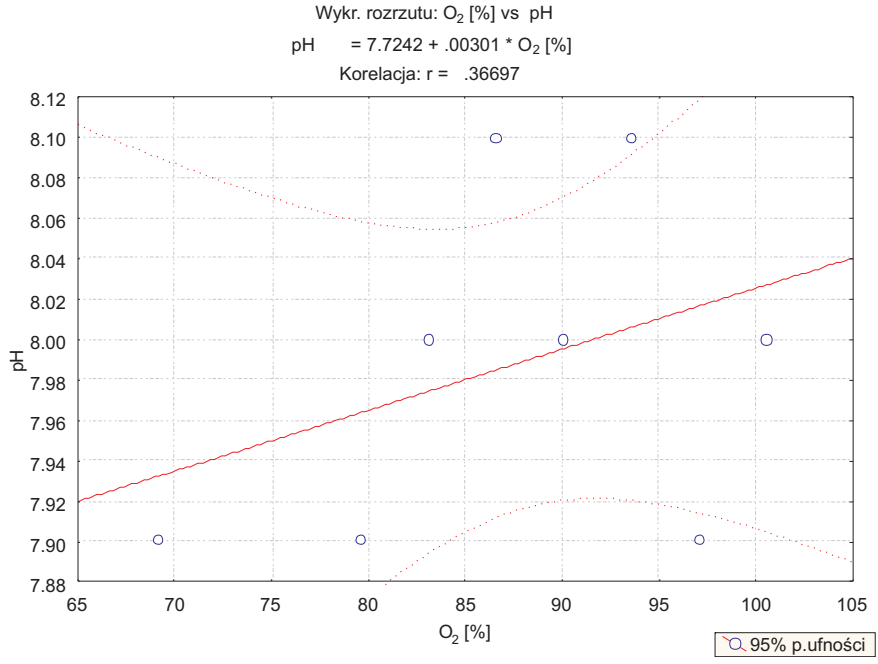

Fig. 2. Dependence of pH on water saturation (2004)

The comparison of results obtained from traditional indices of trophical state and the ITS index leads to the conclusion that both traditional indices of the trophical state and the ITS index yield similar results, and thus the ITS index can be used as a criterion for the assessment of the state of eutrophication processes. Table 5 presents the comparison of the assessment carried out on the base of traditional indicators and the ITS index.

Table 5. Trophical state in Dobczyce Reservoir in 2002 and 2004 estimated on the base of traditional indices and ITS

	Traditional trophical indicators	Index ITS
2002	meso-eutrophic	eutrophic
2004	meso-eutrophic	eutrophic

5. Conclusions

The evaluation of the trophical state of Dobczyce Reservoir based on traditional trophic indicators and the numerical eutrophication criterion (Index of Trophical State) allowed on formulation of the following conclusions:

1) The evaluation of the trophical state using traditional trophical indicators is not clear-cut. Large difference in results obtained using a set of indicators make it uneasy to unambiguously classify the trophical state in surface water. The main reason for such problems stem from the fact that the vast majority of the available literature provides parameter values for natural reservoirs situated in different geographical zones, which are characterized by distinct morphometric characteristics, and hydrological and hydrobiological conditions.
2) On the other hand, the use of the numerical aggregated indices, such as Index of Trophic State ITS, enables unambiguous evaluation of the trophical state. Its main advantage is that the biotic balance is captured by one single value, which allows for a fast and convenient estimate of the trophic state, directly taking into account the balance between organic matter production--destruction processes which determines the trophic status of water body.
3) From the presented analysis it can be concluded that Dobczycki Reservoir in the year 2002 and 2004 was eutrophic. The total phosphorus concentration decreased from 76 $\mu g/dm^3$ to 66 $\mu g/dm^3$. Whereas, the annual and maximum concentration of chlorophyll a indicates the mesotrophic state increased. In spite of the variability of separate indices of trophic state, the general tendency of eutrophication process development remained at the same meso-eutrophic level.

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