DOI: 10.2429/proc.2014.8(2)076 2014;8(2)

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ANALYSIS OF EUTROPHICATION PROCESS IN UPLAND AND LOWLAND STREAMS IN POLAND

ANALIZA PRZEBIEGU PROCESU EUTROFIZACJI W CIEKACH KRAJOBRAZÓW WYŻYNNYCH I NIZINNYCH NA OBSZARZE POLSKI

Abstract: Transformations occurring in the aquatic environment as a result of anthropogenic discharge of nutrients lead to intensification of eutrophication processes and secondary pollution of surface waters. An effect of this phenomenon is the deterioration of physical, chemical and biological characteristics of water. The increasing intensity of eutrophication processes and the specificity of their course in various types of water bodies require the development of specific control methods and ways to protect aquatic ecosystems. In view of the fact that eutrophication is a process that is characterized by high dynamism and depends on many interacting factors such as: morphological, hydrological, hydrobiological, climatic and other conditions, the assessment of trophic status of water is a very complicated task. In particular, it concerns the rivers and streams, because the symptoms of this process and its course vary according to the type of the river. Traditionally eutrophication is assessed on the basis of the boundary values of indicators or indices developed by various authors mostly for stagnant waters or estuaries. Among the various ways of trophic status assessment it is definitely a strong lack of a reliable and simple assessment methods for running waters. The paper presents the results of research concerning the course of eutrophication and evaluation of trophic state in selected rivers and streams in the upland and lowland areas of Poland on the base of the author's methodology. The method used is fundamentally different from traditional approach and based on the definition of trophic status as the existing state of the biotic balance in waters. It is characterized by easy interpretation of results and low costs. Comparative analysis of different methods for assessing the trophic status of running waters is also presented. Long-term dynamics of trophic state changes in the investigated upland and lowland rivers is also described.

Keywords: biogenic substances, anthropogenic eutrophication, upland and lowland rivers, biotic balance, eutrophication indices, trophic state assessment

Introduction

The problem of eutrophication since the seventies of the last century takes on a global scale because of its negative consequences, which could result in total loss of economic and biospheric functions of aquatic ecosystems.

In European Union water policy the problem of eutrophication is regarded as a priority issue. Many EU directives contain a requirement of assessment and control of this process and the necessity of water protection measures implementation in order to prevent its development. These requirements are contained, for example, in Directive 91/271/EEC (Directive on Urban Waste Water Treatment), Directive 91/676/EEC (Directive concerning the nitrates from agricultural land) and Directive 2000/60/EEC (Water Framework Directive). These directives contain neither uniform definition of eutrophication, no universal approach for assessing the trophic state [1-3].

In Poland the requirements of EU directives are reflected in the Water Act and three Regulations of the Ministry of Environment, according to which the evaluation of trophic

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[*]Contribution was presented during ECOpole'14 Conference, Jarnoltowek, 15-17.10.2014

status is carried out on the base of traditional indicators in the frames of general water state assessment, and only in terms: "subjected to eutrophication" or "not subjected to eutrophication". Moreover, different Regulations contain divergent normative values of eutrophication indicators [4-6].

Specific characteristics of eutrophication in running waters

Length of the river network in Poland is quite large and amounts 74,714 km, 52% of which are regulated rivers. Positive feature of river regulation is responding the economy needs, however such a drastic interference into environment leads to the loss of natural values of the river, changes of structure of riverine biota, and consequently - to decrease of self-purification ability, progressing eutrophication and secondary contamination.

Eutrophication process pattern is best studied in stagnant waters. Much less is known the eutrophication processes in running water ecosystems which are functioning in different way due to the following specific features:

- flow of water, which plays a significant role as a limiting factor of eutrophication;
- more intensive exchange between water and land, that makes the rivers to be an "open ecosystem" with heterotrophic type of metabolism;
- more uniform distribution of dissolved oxygen in rivers and therefore the lack of thermal or chemical stratification [7].

Specific features of river ecosystems condition the different course of eutrophication process as compared to limnetic ecosystems, and therefore it cannot be described accurately on the basis of methods established for lakes and coastal areas.

Materials and methods

The approach proposed by the authors of this paper is different from generally used methods, which focus mainly on nitrogen and phosphorus enrichment and primary production. The proposed method starts from the assumption, that trophic state can be reflected by the state of biotic balance, *ie* the balance between the processes of production and destruction of organic matter synthesized by water plants. Hence, the indicator of trophic status of aquatic ecosystem should reflect the integral result of processes of organic matter production and destruction. Similar view is presented also by other authors [8-11].

Dystrophic waters are characterized by exceeding of organic matter decomposition rate (V_d) in relation to the rate of its production (photosynthesis) (V_p), and then $V_p/V_d < 1$; while oligotrophic are characterized by the balanced rates of these processes: $V_p/V_d \approx 1$; and in waters subjected to eutrophication the rate of organic matter production is higher than the rate of decomposition, so $V_p/V_d > 1$ [12].

Index of trophic status of waters ITS (Index of Trophic State) proposed by the authors is based on theoretical assumptions, according to which the imbalance of the rates of water vegetation production and its decomposition in any water ecosystems leads primarily to changes in the quantitative ratios of the concentrations of O_2 and CO_2. The details of the theoretical foundations of ITS index are presented in [12, 13].

In the light of this assumption the problem seems to be the choice of indicator, which reflects the balance between the production and destruction of organic matter in surface waters during the annual cycle. Index of Trophic State can be calculated according to equation:

$$ITS = \sum pH_i/n + a\left(100 - \sum [O_2\%]/n\right) \quad (1)$$

where: pH_i - pH value; $[O_2\%]$ - oxygen saturation measured synchronously with pH; a - an empirical coefficient; n - number of measurements [13].

The state of biotic balance and the values of ITS in waters of different trophic conditions are shown in Table 1.

Table 1

Values of ITS in fresh waters of different trophic state [13]

State of biotic balance (V_p/V_d)	Trophic state	ITS
Negative ($V_p/V_d < 1$)	Dystrophic Ultraoligotrophic	< 5.7 ± 0.3 6.3 ± 0.3
Balanced ($V_p/V_d = 1$)	Ologotrophic	7.0 ± 0.3
Positive ($V_p/V_d > 1$)	Mezotrophic Eutrophic	7.7 ± 0.3 > 8.3 ± 0.3

The researches were carried out in order to use Index of Trophic State for the purposes of trophic state assessment of running waters. The assessment was realized for different types of running waters determined in Poland according to Frame Water Directive [1]. There were appointed 26 types of courses in Poland, among them are: 3 types of mountain streams, 12 types of upland rivers, 7 types of lowland rivers, 4 types of rivers independent on ecoregion and group of indefinite types.

Table 2

Measurement points analyzed in the research

Type of the river	Measurement point	Period of monitoring	Description of river type
5	Katowice Bolina before Przemsza 0.3 km	2000-2009	Upland landscape: small silicate stream with fine-grained substrate
6	Kielce Silnica Bialogon 0.9 km	2000-2009	Upland landscape: small carbonate stream with fine-grained substrate
9	Krakow Rudawa Podkamycze 9.3 km	2000-2009	Upland landscape: small carbonate river
10	Lodz Pilica Sulejow 159.8 km	2000-2009	Upland landscape: middle river
14	Krakow Czarna Orawa Jablonka 25 km	2000-2009	Upland landscape: small river on flysc structures
17	Bialystok Krynka bondary profile 4.5 km	2000-2009	Lowland landscape: small sand stream
20	Olsztyn Guber Sepopol 76 km	2000-2009	Lowland landscape: medium gravel river
21	Warszawa Narew Pultusk 64 km	2000-2008	Lowland landscape: great river in the plains
22	Gdansk Lupawa Rowy 0.7 km	2001-2009	Estuary part of the river under the influence of saline water
23	Lublin Czyzowka Janow Podlaski 4.2 km	2000-2009	Small streams in the valleys or large lowland rivers under the influence of peat-forming processes
24	Zielona Gora Pliszka before Odra 0.3 km	2000-2008	Small rivers in the valleys or large lowland rivers under the influence of peat-forming processes

The researches were carried out for selected measurement points located on the rivers of different types on the base of long-term monitoring database obtained in the frames of Polish State Monitoring System (Table 2).

The results of comparative trophic state assessment carried out on the base of ITS and boundary values of traditional indices, elaborated by different authors, presented in Table 3. The assessment was made on the base of average annual values of parameters measured during 10-year monitoring period [14].

Table 3

Results of comparative trophic state assessment in measurement points
(o - oligotrophic, m - mesotrophic, e - eutrophic)

	Type of the river	**5**	**6**	**9**	**10**	**14**	**17**	**20**	**21**	**22**	**23**	**24**
Indicators of trophic state	ITS value	m	e	m	e	e	m	e	e	e	m	m
	N - Burns	e	e	e	e	e	e	e	e	e	e	e
	P- Burns	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Burns	e	e	m	e	m	m	e	e	e	e	e
	P - Carlson	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Carlson	m	e	o	m	o	m	m	e	e	m	m
	P - Chapra Dobson	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Chapra Dobson	m	e	o	m	m	m	e	e	e	e	e
	P - DillonRigler	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - DillonRigler	e	e	m	e	m	m	e	e	e	e	e
	N - Dodds	e	e	e	e	m	e	e	e	e	e	m
	P - Dodds	e	e	e	e	m	e	e	e	e	e	e
	Chl-a - Dodds	o	m	o	o	o	o	m	m	e	o	m
	N - Forsberg Ryding	e	e	e	e	e	e	e	e	e	e	e
	P - Forsberg Ryding	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Ryding	m	e	o	m	o	o	e	e	e	m	e
	P - OECD	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - OECD	m	e	o	m	m	m	e	e	e	e	e
	P - New Hampshire	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - New Hampshire	m	e	o	m	o	o	m	e	e	m	m
	N - Nurnberg	e	e	e	e	e	e	e	e	e	e	e
	P - Nurnberg	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Nurnberg	m	e	o	m	o	m	e	e	e	e	e
	N - Vant	e	e	e	e	e	e	e	e	e	e	e
	P - Vant	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Vant	e	e	o	e	o	o	e	e	e	e	e
	P - Vollenweider	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Vollenweider	m	e	m	m	m	m	e	e	e	e	e
	P - Welch Lindell	e	e	e	e	e	e	e	e	e	e	e
	Chl-a - Welch Lindell	o	m	o	o	o	o	o	m	e	o	m

Results of the research

Analysis of Table 3 shows high compliance of assessments made on the basis of ITS and boundary values of traditional indicators of eutrophication, developed by different authors. On the base of the assessment conducted by ITS for selected points located on rivers of 5, 9, 17, 23 and 24 types, it can be concluded, that these measurement points belong to mesotrophic waters. However, water in the points located on the rivers of 6, 10, 14, 20, 21 and 22 types are characterized as eutrophic. Wherein, the measurement points located on small silicate streams and carbonate rivers of upland landscape, small sandy rivers of lowland landscape and small streams and rivers in the peaty areas were classified as mesotrophic waters. Waters in the points on small and medium rivers of upland landscape, medium and large rivers of plains and estuarine rivers under the influence of saline waters were classified as eutrophic waters. Trophic state assessment realized on the base of ITS index allowed to follow the long-term dynamics of trophic level in selected measurement points (Figs. 1, 2).

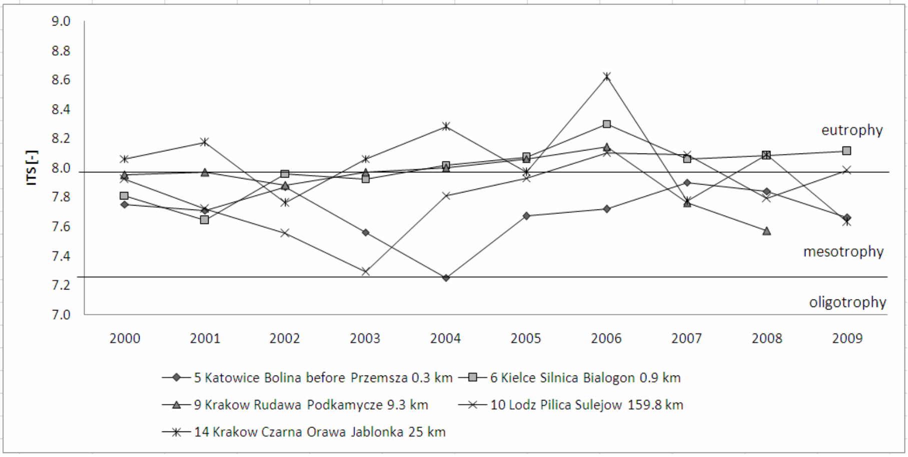

Fig. 1. Long-term dynamics of trophic level in measurement points on upland rivers

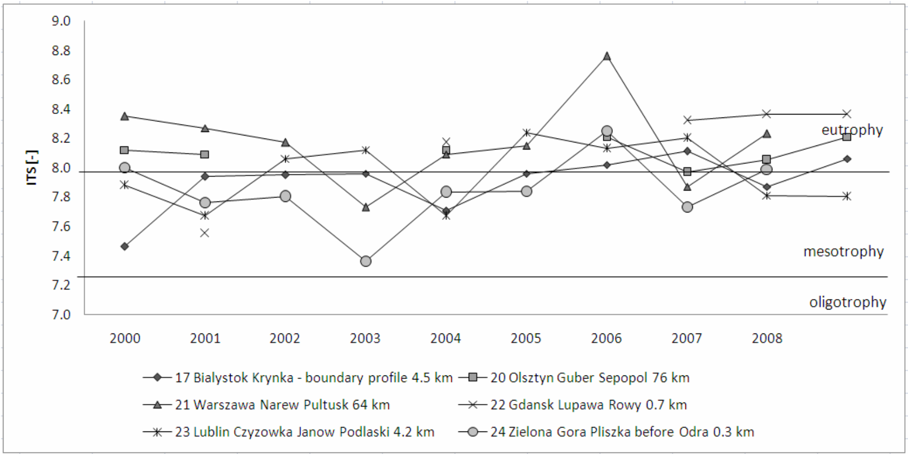

Fig. 2. Long-term dynamics of trophic level in measurement points on lowland rivers

Discussion

The conducted studies showed that the examined water monitoring points are characterized by a high content of total nitrogen and phosphorus, qualifying these waters as eutrophic. But it was also stated that the enrichment of river waters in nutrients does not always lead to a corresponding increase of primary production. Chlorophyll content indicated the mesotrophic conditions, and in some cases - oligotrophic conditions. These findings correlate with the results obtained by other authors concerning the limiting role of nitrogen and phosphorus in eutrophication process in the rivers [8, 15]. Assessment of trophic status made on the basis of ITS in the majority of measurement points agrees with the assessments based on chlorophyll content. It can be explained by the fact that both of these indicators reflects the integrated ecosystems response to the effects of pressure factors, whereas the content of nitrogen and phosphorus - only the eventuality of plant biomass growth.

The above mentioned considerations mean that nutrient content may not always be a reliable indicator of eutrophication, as trophic status is determined not only by the content of these substances, especially in riverine ecosystems. Other authors also confirm the diversity of eutrophication processes in running waters [8, 16]. The concentration of chlorophyll-a also may lead to low reliability of trophic level assessment in running water due to its high seasonal volatility, mobility in rivers and large variety of factors determining the development of aquatic vegetation [7, 10, 17]. This indicator can be used rather for eutrophication assessment in so called “chlorophyll-type rivers”. In Poland there are only 5 types of such rivers: 21 (great lowland rivers), some rivers of 19 type (lowland sandy-clay rivers), 20 (medium lowland gravel rivers), 24 (small valleys rivers under the influence of peat-forming processes) and 25 (lakes connecting rivers).

Due to the complex nature of eutrophication in running waters further studies are needed in order to verify the preliminary results of the researches.

Conclusion

The studies presented in this paper were devoted to very complicated problem of trophic state assessment of running waters. The results of statistical analysis based on long-term monitoring data concerning the rivers of different types allowed to verify the possibility of ITS usage and to state its conformance with modern requirements to environmental indicators. It allowed in simple and low-cost way to assess the trophic state and to evaluate the changes and tendency of eutrophication development in different types of rivers during 10-year period.

References

[1] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for community action in the field of water policy (in Polish: Dyrektywa 2000/60/WE Parlamentu Europejskiego i Rady z dnia 23 października 2000 r. ustanawiająca ramy wspólnotowego działania w dziedzinie polityki wodnej). http://eur-lex.europa.eu.

[2] Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (in Polish: Dyrektywa Rady z dnia 12 grudnia 1991 r. dotycząca ochrona wód przed zanieczyszczeniami powodowanymi przez azotany pochodzenia rolniczego 91/676/EWG). http://eur-lex.europa.eu.

[3] Council Directive 91/271/EEC of 21 May 1991 concerning urban waste-water treatment (in Polish: Dyrektywa Rady z dnia 21 maja 1991 r. dotycząca oczyszczania ścieków komunalnych 91/271/EWG). http://eur-lex.europa.eu.

[4] Journal of Laws No. 115, item. 1229, Water Law Act of 18 July 2001 (in Polish: Dziennik Ustaw, Nr 115, poz. 1229, Ustawa z dnia 18 lipca 2001 r. Prawo wodne). http://isap.sejm.gov.pl.

[5] Journal of Laws No. 162, item 1008, Regulation of the Ministry of Environment of 20 August 2008 on the classification of the status of surface water (in Polish: Dziennik Ustaw, Nr 162, poz. 1008, Rozporządzenie Ministra Środowiska z dnia 20 sierpnia 2008 r. w sprawie sposobu klasyfikacji stanu jednolitych części wód powierzchniowych). http://isap.sejm.gov.pl.
[6] Journal of Laws No. 241 item 2093, Regulation of the Ministry of Environment of 23 December 2002 on the criteria for designation waters susceptibility to pollution by nitrogen compounds from agricultural sources (in Polish: Dziennik Ustaw, Nr 241, poz. 2093, Rozporządzenie Ministra Środowiska z dnia 23 grudnia 2002 r. w sprawie kryteriów wyznaczania wód wrażliwych na zanieczyszczenie związkami azotu ze źródeł rolniczych). http://isap.sejm.gov.pl.
[7] Zheng L, Paul MJ. Effects of Eutrophication on Stream Ecosystems. Tetra Tech Inc.; 2003. http://n-steps.tetratech-ffx.com.
[8] Dodds WK. Eutrophication and trophic state in rivers and streams. Limnolog Oceanogr. 2006;51(1):671-680. DOI: 10.4319/lo.2006.51.1_part_2.0671.
[9] Odum EP. Fundamentals of Ecology. Third edition. Philadelphia-London-Toronto: W.B. Saunders Company; 1971.
[10] Rossolimo LL. Changes of Limnetic Ecosystems under the Influence of Anthropogenic Factors (in Polish: Zmiany ekosystemów limnicznych pod wpływem czynników antropogenicznych). Moskwa: Izd „Nauka"; 1977.
[11] Zheng-Gang J. Hydrodynamics and Water Quality: Modeling Rivers, Lakes and Estuaries. Hoboken, New Jersey: John Wiley and Sons, Inc.; 2008. DOI: 10.1002/9780470241066.
[12] Neverova-Dziopak E. Ecological aspects of surface water protection (Ekologiczne aspekty ochrony wód powierzchniowych). Rzeszów: Oficyna Wyd Politechniki Rzeszowskiej; 2007.
[13] Neverova-Dziopak E. Fundamentals of Anthropogenic Eutrophication Management (Podstawy zarządzania eutrofizacją antropogeniczną). Monografia. Kraków: Wyd AGH; 2010.
[14] Kowalewski Z. Verification of the integral criterion applicability for the assessment of trophic status of waters [PhD Thesis]. (Weryfikacja możliwości zastosowania integralnego kryterium do oceny stanu troficznego wód). Kraków: AGH; 2012.
[15] García de Jalón D, González del Tánago M. River restoration in Spain: Theoretical and practical approach in the context of the European Water Framework Directive. Environ Manage. 2012;50(1):123-39. DOI: 10.1007/s00267-012-9862-1.
[16] Lamberti GA, Ashkenas CV, Gregory AD, Steinman SV, Macintire CD. Productive capacity of periphyton as a determinant of plant-animal interactions in stream. Ecology. 1989;70:1840-1856. DOI: 10.2307/1938117.
[17] Goering JJ, Wallen DD, Nauman RM. Nitrogen uptake by phytoplankton in the discontinuity layer of the eastern subtropical Pacific Ocean. Limnol Oceanogr. 1970;15:789-796. DOI: 10.4319/lo.1970.15.5.0789.

ANALIZA PRZEBIEGU PROCESU EUTROFIZACJI W CIEKACH KRAJOBRAZÓW WYŻYNNYCH I NIZINNYCH NA OBSZARZE POLSKI

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Abstrakt: Transformacje zachodzące w środowisku wodnym w wyniku antropogenicznego dostarczania związków biogennych prowadzą do intensyfikacji procesów eutrofizacji i wtórnego zanieczyszczenia wód powierzchniowych. Skutkami tego zjawiska jest pogorszenie ich właściwości fizycznych, chemicznych i biologicznych. Nasilającą się intensywność procesów eutrofizacji oraz specyfika ich przebiegu w wodach różnego typu wymagają opracowania specjalnych metod kontroli i sposobów ochrony ekosystemów wodnych. W związku z tym, że eutrofizacja jest procesem, który charakteryzuje się dużą dynamicznością i zależy od zespołu wielu współdziałających między sobą czynników morfologicznych, hydrologicznych, hydrobiologicznych, klimatycznych i innych, ocena stanu troficznego wód jest zadaniem bardzo skomplikowanym. Zwłaszcza dotyczy to rzek i strumieni, ponieważ objawy tego procesu i jego przebieg różnią się w zależności od typu rzeki. Tradycyjnie eutrofizację wód przyjęto oceniać na podstawie granicznych wartości zespołu wskaźników lub indeksów opracowanych przez różnych autorów przeważnie dla wód stojących lub estuariów. Wśród rozmaitych sposobów oceny stanu troficznego zdecydowanie brakuje wiarygodnych i prostych sposobów jego oceny w wodach płynących. W pracy przedstawiono wyniki badań nad przebiegiem procesu eutrofizacji i oceny statusu troficznego w wybranych ciekach na obszarach wyżynnych i nizinnych Polski na podstawie autorskiej metody. Zastosowana metoda zasadniczo różni się od metod tradycyjnych i opiera się na definicji stanu troficznego jako stanu istniejącego bilansu biotycznego w wodach. Charakteryzuje się ona łatwą interpretacją wyników oraz niskimi kosztami. Przedstawiono analizę porównawczą różnych metod oceny stanu troficznego wód rzecznych. Opisano wieloletnią dynamikę zmian stanu troficznego badanych rzek wyżynnych i nizinnych.

Słowa kluczowe: substancje biogenne, eutrofizacja antropogeniczna, rzeki krajobrazów wyżynnych i nizinnych, bilans biotyczny, wskaźniki eutrofizacji, ocena stanu troficznego