GEOMATICS AND ENVIRONMENTAL ENGINEERING • Volume 12 • Number 2 • 2018

http://dx.doi.org/10.7494/geom.2018.12.2.63

Elena Neverova-Dziopak*, Zbigniew Kowalewski*

Foundation and Application of New Method of Trophic State Assessment

Abstract: One of the tools used to achieve the objectives of the Water Framework Directive is monitoring, which should provide information on the status of surface waters. The priority task of water protection is the prevention of the eutrophication process. Appropriate protection measures should be based on the reliable assessment of trophic levels. There are different indexes for estimating the trophic state of surface waters, but they are generally characterized by their large complexity and high cost of assessment. This paper presents a new method of trophic-level monitoring, based on numerical indicator ITS (Index of Trophic Status). ITS is elaborated to consider the main functional characteristics of any ecosystem – the state of biotic balance – and can be calculated by using routine measurements of the hydrochemical characteristics of water. The proposed criterion is the instrument that simplifies the solution of many applied tasks: express-monitoring of surface waters, retrospect analysis and eutrophication process prognosis, setting of regional ecological standards of biogenic matter, solving engineering tasks, and for the purposes of mathematical modeling. Verification of the ITS criterion was carried out under the conditions of different types of waters in different countries. Actually, this method is gaining more popularity as a simple, reliable, and low-cost tool for trophic status monitoring.

Keywords: eutrophication, ITS index, running waters, trophic status

* AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Environmental Management and Protection, Krakow, Poland

1. Eutrophication

Eutrophication is common known problem. Practically, it is unavoidable and a proceeding factor that affects water ecosystems. Nutrient load increase waters productivity. Excessive nutrient supply is the main cause of anthropogenic eutrophication. The concentration of nutrients in water is a basic eutrophication indicator. Development of the process of production is a consequence of rising nutrient concentration and depends on many abiotic factors: mainly hydrologic, thermal, morphologic, and others. An overplus of nutrients at some point of eutrophication may cause an infraction of the biotic balance. Primarily, it manifests as upsetting the natural balance between the production and decomposition of organic substances in water, and its leads to the accumulation of organic matter in an ecosystem. As a consequence, a delay in the ratio between heterotrophic and autotrophic organism development is observed in surface waters. Changes in the qualitative composition are visible. Finally, groups of bacteria disappear, and hard-to-decompose matter accumulates. Due to the increase in organic matter in water and at the bottom, sediments are intensifying the processes of its destruction, causing an increased consumption of dissolved oxygen in the water, changing the redox conditions of the environment and increased content in the bottom sediments of mineral labile forms of nitrogen and phosphorus. In eutrophic waters, it becomes an important source of secondary pollution in nutrients, and the eutrophication process begins to automatically accelerate. As a result of the anthropogenic eutrophication of the aquatic ecosystem, a reduction of species diversity begins to develop, and the dominance of a few species of hydrobionts occurs. Changes in aquatic ecosystems are very important, and the potential duration of recovery is very long. The adverse effects of eutrophication are most-vulnerable for freshwater lakes and reservoirs; but, as a result of intense economic activity in recent decades, this phenomenon is becoming more common in marine waters and flowing waters. Tracking eutrophication processes and assessing the state of the trophic status in water is an extremely important task in terms of research and application. Accordingly, the essential indicators that reliably allow us to determine the dynamics of the process are used to predict its state. Among the huge number of various indicators, most pragmatic are aggregated indicators.

2. Aggregated Methods of Trophic Status Assessment

In the world literature, numerous methods for assessing the trophic status of waters have been described. Among them, the most-popular and useful are aggregated indicators: the so-called indexes of eutrophication. The most-popular and applied indexes were TSI by Carlson and TRIX by Vollenweider. They are based on the assumption that the basic factors of eutrophication are nutrients (primarily nitrogen and phosphorus). The effect of eutrophication is increasing the content of chlorophyll-a, which is the result of algae biomass production; this is strongly correlated with the corresponding deterioration of water transparency measured by Secchi disc visibility.

TSI Index

The TSI (Trophic State Index) was developed by American researcher Robert Carlson in the late seventies of the 20th century. The construction of the index is based on the relationship between the transparency of the water and biomass of the algae. The index is between 0 and 100 (and up to 110 in some cases). When the mass of algae is doubled, the water transparency decreases, and the TSI index value increases by 10. Carlson thought that the trophic level expressed numerically gives more accuracy than a traditional descriptive evaluation. As additional parameters to calculate the index, Carlson suggested total phosphorus and chlorophyll-a, and its figures were based on correlation and regression analysis. The TSI index is calculated using the following formulas [2]:

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

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

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

where:

SD – Secchi disk visibility [m],
Chl – chlorophyll-a concentration [μg/dm^3],
TP – total nitrogen concentration [μg/dm^3].

TRIX index

In the late nineties of the 20th century, R. Vollenweider developed the TRIX index. It is based on the assumption that the trophic state is conditioned by the content of nutrients available for the aquatic vegetation. The TRIX index consists of four elements: the content of total phosphorus and total or inorganic nitrogen, chlorophyll-a (which reflects the biomass of phytoplankton) and water oxygen saturation as a deviation of one-hundred percent oxygen saturation (which is the characteristic intensity of the production processes). The TRIX index value is calculated based on the following equation [14]:

$$TRIX = \frac{(\log 10\,[Chl \cdot aD\%O \cdot minN \cdot TP] + k)}{m} \tag{4}$$

where:

Chl – chlorophyll-a concentration [μg/dm^3],
aD%O – oxygen saturation [100% – %O_2],
minN – mineral nitrogen [μg/dm^3],
TP – total phosphorus concentration [μg/dm^3],
k, m – scaling factors $k = 1.2$ and $m = 1.5$.

EI Index

Based on the studies carried out in the Saronic Gulf (Greece), I. Primpas, G. Tsirtsis, and M. Karydis developed the EI (Eutrophication index) based on the concentrations of mineral forms of nitrogen and phosphorus as well as chlorophyll-a. The index is calculated according to the following equation [12]:

$$EI = 0.279PO_4 + 0.261NO_3 + 0.275NH_3 + 0.214Chl \qquad (5)$$

where:

- PO_4 – phosphate concentration [μg/dm^3],
- NO_3 – nitrite concentration [μg/dm^3],
- NH_3 – ammonia concentration [μg/dm^3],
- Chl – chlorophyll-a concentration [μg/dm^3].

LCI Index

In the seventies of the 20th century for monitoring eutrophication occurring in the lakes of the US state of Wisconsin, P. Utomark and J. Wall developed the LCI index (Lake Condition Index). The index consists of four parameters: dissolved oxygen, Secchi disc visibility, level of fishing mortality, and visible algal blooms. The index ranges from 0 to 23 points. The authors developed a set of reference conditions for each indicator and a penalty point system providing a negative evolution. For each exceedance of specific reference conditions, penalty points are calculated. The maximum value (23 points) indicates a very advanced state of trophy (hypereutrophy). The system does not take into account traditional divisions such as mesotrophy or eutrophy [11].

TLI Index

The TLI index (Trophic Level Index) was formulated by N. Burns in order to assess the trophic status of lakes in New Zealand. There are two variants of this index: TLI 4 (consisting of total nitrogen, total phosphorus, chlorophyll-a, and Secchi depth) and TLI 3 (which does not include Secchi disc visibility). The Burns index is calculated by using the following formulas [1]:

$$TLn = -3.61 + 3.01\log10(TN) \qquad (6)$$

$$TLp = 0.218 + 2.92\log10(TP) \qquad (7)$$

$$TLs = 5.10 + 2.27\log 10\left(\frac{1}{SD} - \frac{1}{40}\right) \qquad (8)$$

$$TLc = 2.22 + 2.54\log10(Chl), \qquad (9)$$

$$TLI = \frac{(TLn + TLp + TLs + TLc)}{4} \qquad (10)$$

where:

SD – Secchi disk visibility [m],
Chl – chlorophyll-a concentration [μg/dm^3],
TP – total phosphorus concentration [μg/dm^3],
TN – total nitrogen concentration [μg/dm^3],

NIM Index

In China, to assess the trophic state of coastal waters, the NIM index (Nutrient Index Method) proposed by China National Environmental Monitoring Center is widely used. This index is based on a comparison of the results of measurements of the chemical oxygen demand, the concentrations of nitrogen, phosphorus, and chlorophyll-a from the reference values. If the index is greater than 4, the water can be considered eutrophic. The index is calculated using the following formula:

$$\mathrm{NIM} = \frac{\mathrm{CCOD}}{\mathrm{SCOD}} + \frac{\mathrm{CTN}}{\mathrm{STN}} + \frac{\mathrm{CTP}}{\mathrm{STP}} + \frac{\mathrm{CChl}}{\mathrm{SChl}} \tag{11}$$

where:

CCOD – chemical oxygen demand [mg/dm^3],
CTN – total nitrogen concentration [mg/dm^3],
CTP – total phosphorus concentration [mg/dm^3],
CChl – chlorophyll-a concentration[μg/dm^3],
SCOD – reference chemical oxygen demand value [mg/dm^3],
STN – reference total nitrogen value [mg/dm^3],
STP – reference total phosphorus value [mg/dm^3],
SChl – reference chlorophyll-a value [μg/dm^3].

NI Index

On a similar principle, the NI index is based on an index developed by J. Zou. The values of the index are based on the chemical oxygen demand and concentration of the dissolved mineral forms of nitrogen and phosphorus. The data is compared with the reference conditions. When the index has a value greater than 1, the water is considered to be eutrophic. The index is calculated using the following formula [15]:

$$\mathrm{NI} = \frac{\mathrm{CCOD} \cdot \mathrm{CDIN} \cdot \mathrm{CDIP}}{\mathrm{SC}} \tag{12}$$

where:

CCOD – chemical oxygen demand [mg/dm^3],
CDIN – dissolved inorganic nitrogen concentration [mg/dm^3],
CDIP – dissolved inorganic phosphorous concentration [mg/dm^3],
SC – reference conditions.

TNI index

For the purpose of monitoring lakes in China, an index of TNI (Total Nutrient Index) was developed. The equations by which the index value is calculated are nitrogen and phosphorus, BOD, COD, and chlorophyll-a [16].

$$TNI = \sum W_j \cdot TNI_j \tag{13}$$

$$W_j = \frac{r_{ij}^2}{\sum r_{ij}^2} \tag{14}$$

where:

- TNI_j – TNI index of *j* parameter,
- W_j – *j* parameter contribution in TNI index value,
- r_{ji}^2 – chlorophyll-a and another parameters ratio.

The aforementioned aggregated indicators are based on indicators reflecting the process of plant biomass production without taking into account its decomposition processes. Full information about the processes of trophic changes may be obtained only on the basis of the balance of production and decomposition in the waters.

3. Proposal of New Index – ITS

The ITS index theoretical concept is the change of the balance of the production processes and the decomposition of organic substances produced by algae during eutrophication. Changes in the biotic balance lead to changes in the gas in the waters (and consequently the quantitative ratios of the concentrations of oxygen and carbon dioxide). When the velocity of the decomposition of organic substances exceeds the velocity of its production, the concentration of carbon dioxide increases and oxygen concentration decreases; when the velocity of decomposition is lower than the production velocity, the concentration of carbon dioxide decreases and concentration of oxygen increases. This means that the change in the ratio of the content of these two gases reflects the changes in the water balance of the production and decomposition of organic substances. In an aqueous environment, oxygen concentration [mg/dm^3] may be expressed by the saturation of water with oxygen [%], and the CO_2 content [mg/dm^3] can be expressed by pH. Changing the concentration of CO_2 leads to changes in pH values due to the balance of the carbonate, which is the state of a certain proportion of bicarbonate ions that are represented by the following equation:

$$CO_2 + H_2 \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO^{3-} \leftrightarrow H^+ + CO_3^{2-} \tag{15}$$

In surface waters with low salinity in the temperate climate zone, pH levels typically have a value of 6.0 to 8.5. Under such conditions, all forms of the carbonate system may exist at the same time. Dissolved in water, carbon dioxide is mainly in the form of CO_2, only approx. 1% is as carbonic acid H_2CO_3. Changing CO_2 concentrations in surface waters leads to a shift of balance and changes in the carbonate concentration of hydrogen ions, and hence, the pH level of the water. When carbon dioxide is present in excess, carbonates dissolves; with a deficiency of CO_2, they are deposited. With a deficiency of nutrients and low production, CO_2 concentrations rise and the pH decreases. It follows that the trophy state can be described by the balance of CO_2 (measured as pH) and O_2 concentrations (measured as percent degree of oxygen saturation in water). The relationship between pH and the percentage of water saturation with oxygen of specific trophic conditions can be described by a linear relationship. If at the same time oxygen saturation and pH value are rising, the higher the trophic state is. These relationships are presented in Figure 1.

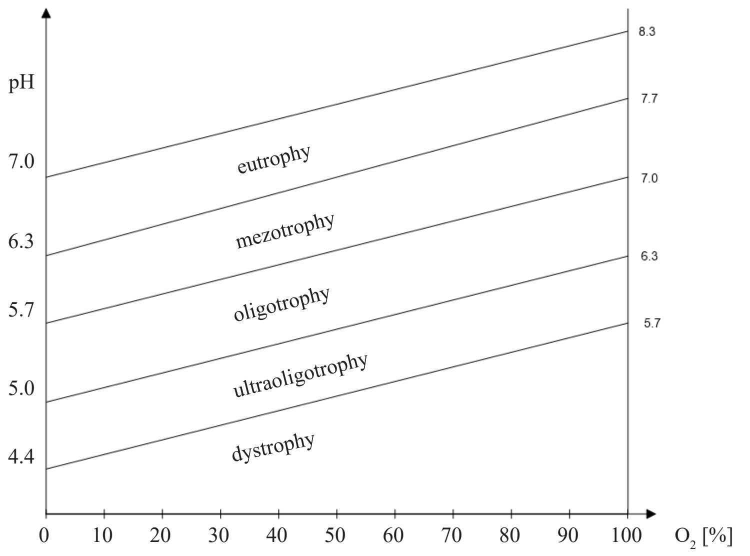

Fig 1. Relationship between pH and $\%O_2$ for different trophic states

The ITS index was created for the research processes of the eutrophication of the Baltic Sea, primarily to assess the trophic status of the Gulf of Nevsky and the eastern part of the Gulf of Finland. The waters of the bay are characterized by low depth, low salinity, and a relatively fast flow; therefore, Neva Bay can be equated to inland flowing waters. During the work over bay waters, variants of the ITS adapted to changing salinity and variable mineralization were also created. During the measurements in the Nevsky Gulf, ITS demonstrated the high dependence of traditional methods and the indexes of eutrophication and was also used for retrospective studies. Thanks to the historical data, it was possible to create a model of changes in the trophic status over the years [7, 10]. As the criterion of trophic status, the pH value in the normal one-hundred percent water oxygen saturation was selected. ITS index calculated by the following formula [7]:

$$\mathrm{ITS} = \sum \frac{\mathrm{pH}_i}{n} + a\left(100 - \sum \frac{[\%\mathrm{O}_2]}{n}\right) \tag{16}$$

where:

- pH_i – pH value,
- $[\%O_2]$ – water oxygen saturation measured with pH measurements synchronously,
- a – empirical coefficient (from linear regression),
- n – number of measurements.

The ITS index values corresponding to different trophic states are presented in Table 1.

Table 1. ITS index values for various trophic levels

Trophic status	ITS value
Dystrophy	<5.7–6.0
Ultraoligotrophy	6.0–6.6
Oligotrophy	6.7–7.3
Mesotrophy	7.4–8.0
Eutrophy	>8.0

4. Verification of Applicability of ITS Index

The legitimacy of the application of ITS for the surface waters of different kinds in different regions of Europe has been proven in numerous studies of pH dependence of O_2 and assessing the state of trophy under it. ITS has found wide application in Poland, which was initially used for the experimental monitoring of the Pilica and Warta Rivers. It found a special place in the monitoring of artificial reservoirs.

ITS was used to assess the trophy of the Tresna, Porąbka, and Czaniec Reservoirs situated on the Soła River. Soła is a mountain river located in southern Poland. The reservoirs have different capacities: from 94 million m^3 of the Tresna to 27 million m^3 of the Porąbka to 1.3 million m^3 of the Czaniec. During the research, the results obtained using ITS with the assessment made on the basis of the TSI index by Carlson and OECD normative were compared. All methods were consistent and indicated a state between mesotrophy and eutrophy. Similar studies have been conducted exclusively for the Tresna Reservoir, reaffirming the legitimacy of the use of the ITS index [4].

Another application for the ITS index was for the Rzeszow Reservoir located in southeastern Poland, which is powered by two lowland rivers: the Strug and Wisłok rivers. The reservoir has an area of 68 ha and an average depth of 10 m. In the case of ITS, the research index was calculated simultaneously with the Carlson index and indicators of the OECD and Nurnberg. The results were the same and pointed to eutrophy [3].

Another application of ITS is its use for determining the trophic status of reconstituted shallow water bodies located in the Olsztyn lake lands in northern Poland. Four lakes (Nowe Wloki, Setal, Dobrazek, and Gąsiorowskie) were tested for eutrophication. All four lakes are characterized by small size (3.7–15.2 ha) and shallow depths (1.5–4.0 m). All of the lakes have the same origin – in the 19th century, the areas on which they were dried, then filled again and restored between 1960 and 1980. In catchment, dominate agricultural areas. Research on trophy lasted for two years, and samples were taken every six weeks. Besides the standard for ITS (pH and oxygen saturation), total phosphorus, chlorophyll-a, and visibility of the Secchi disc were investigated during the period from May to September in years 2010–2012; these were later used to determine the Carlson index TSI. Studies made by the ITS have demonstrated high compatibility with the Carlson index (full with Lake Gąsiorowski), and in other cases, the ITS points to the same or a lower degree of trophic state. In addition, ITS was used to determine which nutrients completely dominate in the process of eutrophication and at what stage are the changes of the reservoirs' trophy [13].

ITS was also used to measure the trophic status of the Dobczyce Reservoir on the Raba River. Raba is a mountain river located in southern Poland. The lake has an area of 10.7 km^2 and an average depth of 10 m, and it is stratified. Data for the study came from routine monitoring of the Regional Inspectorate for Environmental Protection in Krakow from the years of 2002 and 2004. The reservoir is monitored at two measurement-control points at two depths. Data includes the pH value, saturation of water with oxygen, total nitrogen and phosphorus, and chlorophyll-a. The analysis results using ITS were confronted with the measurements by the Regional Inspectorate; in both cases, they indicated the meso-eutrophic nature of the reservoir [5].

Another type of water where the ITS index was used is the Szczecin Lagoon. It is a lagoon of the Baltic Sea that is also the mouth of the Oder River and several smaller rivers (such as the Gowienica and Wkra). The area of the basin is approximately 666 km^2, the average depth is 3.8 m, and the salinity is from 0.5 to 2 per mille. The study used data from the detailed monitoring carried out in 2003 by the Regional Inspectorate for Environmental Protection in Szczecin. The study was conducted at 11 points located in both the Polish and German parts of the basin. The 11 monitored parameters included pH, oxygen, water saturation, total phosphorus, phosphate, total nitrogen and form nitrites, nitrates and ammonia nitrogen, chlorophyll-a, Secchi depth, and salinity. The measurement results of the trophic status using ITS where compared with the TSI indications index and an TRIX index. The ratings by TSI and ITS showed full compliance for all of the measurement-control points. In the case of the TRIX index, the points considered by the ITS and TSI as eutrophic were classified as mesotrophic [8].

Another very important advantage of the ITS index is its ability to track the dynamics of the trophic status changes over time (with the possibility of prediction). This property was used to assess the trophic status of the rivers in the Podkarpackie province in southeastern Poland. Data from the monitoring of the San and Wisłok rivers came from the Regional Inspectorate for Environmental Protection in Rzeszow. This is data from the diagnostic monitoring conducted during the years 2000–2011 at measurement-control points located throughout the mileage of the rivers. Also, ITS was used to calculate trophic status in past years. As a result, it became clear that both the San's and Wisłoka's trophic levels have remained virtually unchanged and set between eutrophy and advanced mesotrophy [9]. Table 2 presents the results of research with the use of the ITS index in Polish waters.

Table 2. Cases of application of ITS index in Poland

Date	Author	Place	Pearson *r*	Coefficient *a*
2007–2009	A. Jaguś	Soła Dam Cascades	0.15–0.89	0.0032–0.032
2004–2008	A. Jaguś, E. Jachniak	Tresna Reservoir	0.37–0.89	0.018–0.032
2010–2012	A. Skwierawski	Restored lakes in Olsztyn lake land	0.356–0.936	0.00899–0.035
2013	R. Gruca-Rokosz	Rzeszow Reservoir	0.67	0.0221
2002–2004	E. Kowalczyk	Dobczyce Reservoir	0.36–0.79	0.0031–0.0099
2003	E. Neverova-Dziopak, Z. Kowalewski	Szczecin Lagoon	0.89	0.012
2000–2011	E. Neverova-Dziopak, Z. Kowalewski	Wisłoka River, San River	0.60–0.92	0.015–0.022

The ITS index was also used for a detailed examination of trophy in Polish rivers during the years of 2000 through 2010, with 402 measuring points located in more than 400 different rivers. The results of the ITS application were confronted with the TSI, TRIX, and TLI indexes and standard indicators of the trophic status. It showed a compliance of around 90% (in the case of evaluation based on the TSI and TRIX indexes) and 89% (in the case of evaluation based on the TLI index). The graph in the figure shows the percentage of conformity assessment results of the ITS index with the other indexes [6]. The graph in Figure 2 shows the rates of compliance in the results of the assessment of eutrophication between the ITS index and the following indexes: Carlson (TSI TP, Chl TSI TSI), Burns (TLI TN, TP TLI, TLI Chl, TLI) and Vollenveider (TRIX).

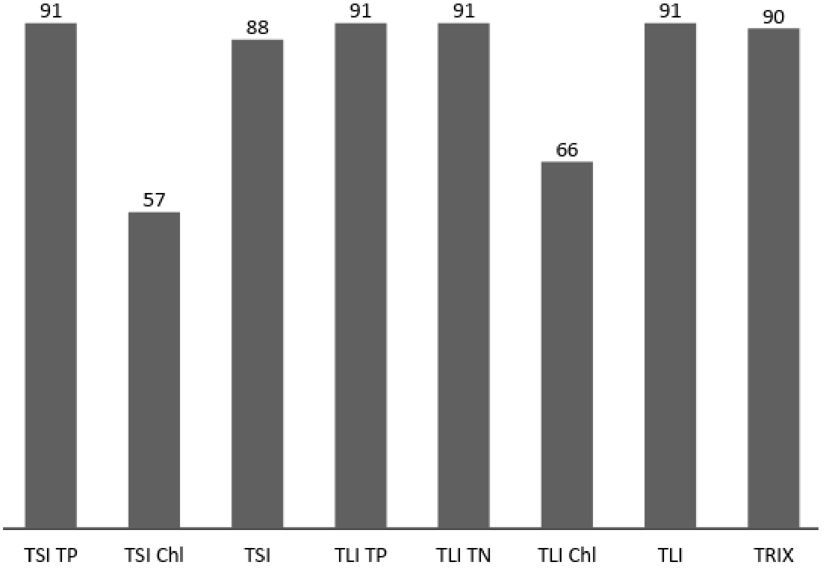

Fig. 2. Compliance in results of assessment between ITS and other indexes

5. How to Use ITS Index

The use of the ITS index is extremely simple and allows us to carry out express evaluations of the trophic status of waters, conduct continuous monitoring of the dynamics of the development of eutrophication processes on the basis of two water quality parameters measured during routine monitoring – pH, and water saturation of oxygen. The algorithm for the evaluation is as follows. The first step is the statistical treatment of the data: check the legality of the distribution ranks of pH and oxygen saturation with a normal distribution (Shaphiro–Wilk test); rejection of the results of outliers (Grubbs test). Further correlation analysis is performed in order to obtain linear regression equations describing the dependence of the pH on the water saturation of oxygen using the method of least squares. Correlation is considered to be significant at the Pearson correlation coefficient when it is greater than 0.5. When applying larger amounts of data aggregation methods like correlation tables, could be used. The use of the ITS index algorithm is shown in Figure 3.

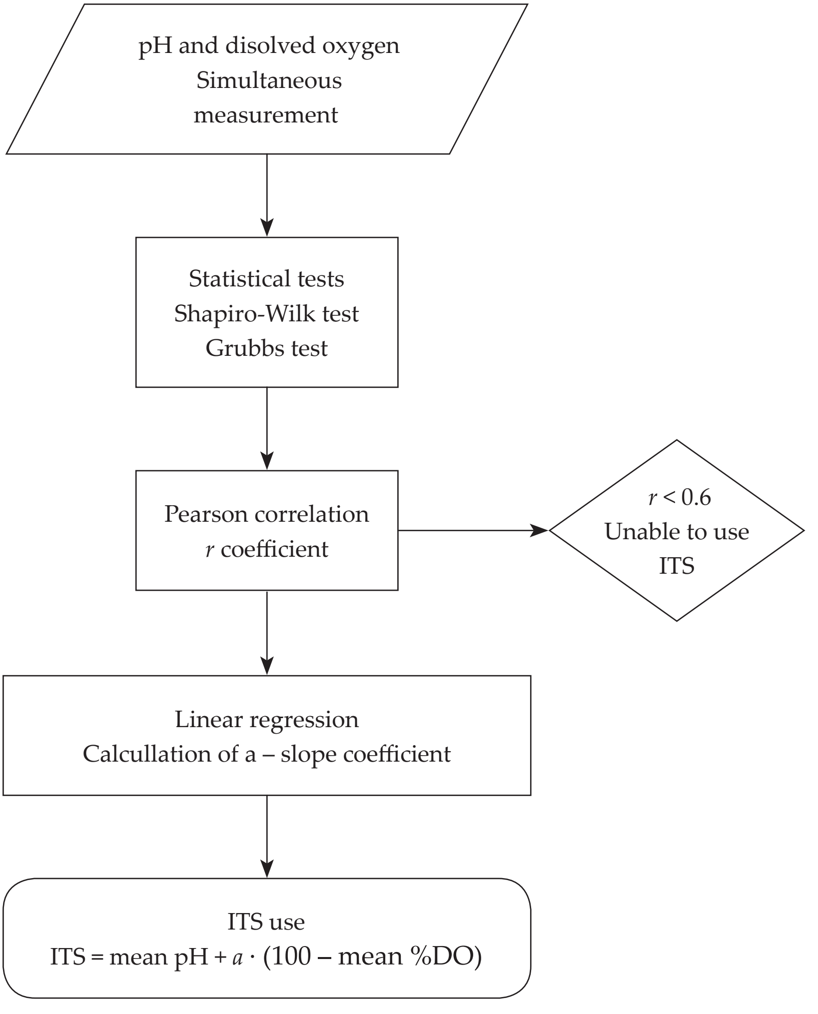

Fig 3. Algorithm of ITS usage

An example of the application of ITS to assess the trophic status of the Vistula River.

The output data comes from monitoring the Vistula River at the measurement-control point at Plock. This is the data collected from the Regional Inspectorate for Environmental Protection in Warsaw in 2012, representing a total of 12 sets of data from monthly intervals. The point is located on 307 km of the river, and its abiotic type is 21 – a large lowland river. During the measurements through the growing season, there were blooms of phytoplankton all of the time, the average content of chlorophyll-a was about 80 ug/dm^3, total nitrogen content average was 3.12 mg/dm^3, and total phosphorus of 0.13 mg/dm^3. According to the traditional indicators of the state of the river, it was assessed by the Regional Inspectorate as eutrophic. Results obtained by the Regional Inspectorate and based on ITS were compared. ITS performed based on the data of Table 3.

Table 3. Baseline data necessary to calculate ITS index on the Vistula River

Date	%DO	pH
2012-01-03	93	8.2
2012-03-05	85.7	8
2012-03-12	93.8	7.8
2012-04-02	97.1	8.1
2012-05-09	115.5	8.6
2012-06-04	110	8.8
2012-07-13	97.4	8.3
2012-08-08	100.1	8.5
2012-09-05	115.2	8.3
2012-10-17	92.2	8.2
2012-11-07	92.7	8.2
2012-12-05	82.5	7.8
mean	97.93	8.195

Both the pH and percentage of oxygen saturation are in accordance with the normal distribution. Linear regression is expressed by the formula:

$$pH = 6.118 + 0.0216 \cdot \text{percent oxygen saturation} \quad (17)$$

Dispersion of the pH and oxygen saturation relative to each other is shown in the scatterplot in Figure 4.

The Pearson correlation coefficient is 0.768, and so it is reasonable to use ITS. Using the equation, we can calculate the index value:

$$ITS = 8.195 + (100 - 97.933) \cdot 0.0216 \quad (18)$$

$$ITS = 8.24 \quad (19)$$

According to Table 1 it is eutrophic. So, the results are the same as the Regional Inspectorate's.

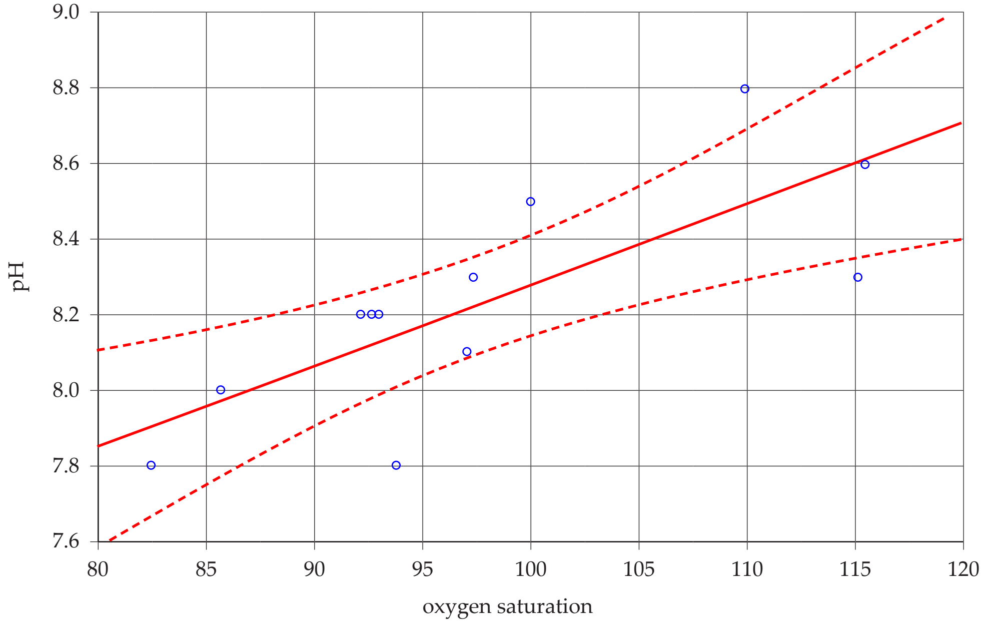

Fig. 4. pH, oxygen saturation scatterplot

6. Summary

The main advantage of ITS is its ease of use and low-cost evaluation of trophic status and the ability to be used in the so-called express monitoring. It is calculated on the basis of two routine water quality indicators: pH and water saturation of oxygen. They can be implemented directly in the field and are easy to measure. The table shows which parameters are needed for the use of the aggregate indicators of eutrophication. ITS can also be used to determine the trophy of historical data and to create predictive models. Table 4 compares the parameters to be measured in order to be able to apply individual indicators.

The use of only two parameters that can be measured by instrumental methods in the field significantly reduces the time and cost of monitoring. This is extremely important for departments dealing with environmental monitoring. In connection with the deterioration of trophy waters' increased eutrophication processes, there is a need for a swift and unambiguous method for assessing trophic status. In addition, the index should be as scalable as possible to adjust the results to the actual values prevailing in different conditions. The ITS index deals with the requirements for modern environmental indicators and can be used to assess the condition of surface water trophy.

Table 4. Comparison of data needed for different index calculations

Parameter	TSI	TRIX	EI	LCI	TLI	NIM	Ni	TNI	ITS
pH									*
%DO conc.		*		*					*
COD						*	*	*	
BOD								*	
TN					*	*		*	
NO_2		*					*		
NO_3		*	*				*		
NH_4		*	*				*		
TP	*	*			*	*		*	
PO_4			*				*		
Chl-a	*	*	*		*	*		*	
SD	*			*	*				
Fish mortality				*					
Blooms				*					
No parameters	3	6	4	4	4	4	5	5	2

* Parameters used in method.

References

[1] Burns N., Bryers G., Bowman E.: *Protocol for Monitoring Trophic Levels of New Zealand Lakes and Reservoirs*. Lakes Consulting, Pauanui, New Zealand 2000.

[2] Carlson R.E.: *A trophic state index for lakes*. Limnology and Oceanography, vol. 22, issue 2, 1977, pp. 361–369.

[3] Gruca-Rokosz R.: *Stan troficzny zbiornika zaporowego Rzeszów*. Czasopismo Inżynierii Lądowej, Środowiska i Architektury, z. 60, nr 3, 2013, pp. 279–291.

[4] Jachniak E., Jaguś A.: *Uwarunkowania i nasilenie eutrofizacji zbiornika Tresna*. Nauka, Przyroda, Technologie. Uniwersytet Przyrodniczy w Poznaniu, t. 5, nr 4, 2011, pp. 1–7.

[5] Kowalczyk E.: *Trophic State Assessment of Dobczyce Reservoir*. Geomatics and Environmental Engineering, vol. 4, no. 4, 2010, pp. 97–104.

[6] Kowalewski Z.: *Zastosowanie integralnego kryterium do oceny stanu troficznego wód płynących*. Wydawnictwa AGH, Kraków 2013.

[7] Neverova-Dziopak E.: *Ekologiczne aspekty ochrony wód powierzchniowych*. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów 2007.

[8] Neverova-Dziopak E., Kowalewski Z.: *Optymalizacja procedury oceny stanu troficznego wód przejściowych na przykładzie zalewu Szczecińskiego*. Czasopismo Inżynierii Lądowej, Środowiska i Architektury, z. 61, nr 3/I, 2014, pp. 171–181.

[9] Neverova-Dziopak E., Kowalewski Z.: *Dynamika rozwoju procesów eutrofizacji w rzekach województwa podkarpackiego*. Czasopismo Inżynierii Lądowej, Środowiska i Architektury, z. 60, nr 3, 2013, pp. 47–58.

[10] Neverova-Dziopak Ye.V., Tsvetkova L.I., Makarova S.V., Kiselev A.V.: *Ob ekologicheskoy bezopasnosti vodnykh ob'yektov*. Elektronnyy nauchnyy zhurnal Sovremennyye problemy nauki i obrazovaniya [Неверова-Дзиопак Е.В., Цветкова Л.И., Макарова С.В., Киселев А.В.: *Об экологической безопасности водных объектов*. Электронный научный журнал Современные проблемы науки и образования], no. 3, 2012, pp. 1–9, [on-line:] http://www.science-education.ru/103-6303.

[11] Premazzi G., Chiaudani G.: *Lake Condition Index*. [in:] Premazzi G., Chiaudani G., *Ecological Quality of Surface Waters: Quality Assessment Schemes for European Community Lakes*, EUR 14563, Commission of the European Communities Brussels, Luxemburg 1992, pp. 27–29.

[12] Primpas I., Tsirtsis G., Karydis M., Kokkoris G.D.: *Principal component analysis: Development of a multivariate index for assessing eutrophication according to the European water framework directive*. Ecological Indicators, vol. 10, issue 2, 2010, pp. 178–183.

[13] Skwierawski A.: *The use of the integrated trophic state index in evaluation of the restored shallow water bodies*. Ecological Chemistry and Engineering. A, vol. 20, nr 11, 2013, pp. 1275–1283.

[14] Vollenweider R. A., Giovanardi F., Montanari G., Rinaldi A.: *Characterization of the trophic conditions of marine coastal waters with special reference to the NW Adriatic Sea: Proposal for a trophic scale, turbidity and generalized water quality index*. Environmetrics, vol. 9, issue 3, 1998, pp. 329–357.

[15] Xiao Y., Ferreira J., Bricker S., Nunes J. et al.: *Trophic Assessment in Chinese Coastal Systems – Review of Methods and Application to the Changjiang (Yangtze) Estuary and Jiaozhou Bay*. Estuaries and Coasts, vol. 30, issue 6, 2007, pp. 901–918.

[16] Yang X., Wu X., Hao H., He Z.: *Mechanisms and assessment of water eutrophication*. Journal of Zhejiang University Science B, vol. 9, issue 3, 2008, pp. 197–209.

Powstanie i zastosowania nowego sposobu oceny stanu troficznego wód

Streszczenie: Jednym z narzędzi służących do osiągnięcia celów ramowej dyrektywy wodnej jest monitoring, który powinien dostarczać informacji na temat stanu wód. Zadaniem priorytetowym w zakresie ochrony wód powierzchniowych jest zapobieganie procesom eutrofizacji. Odpowiednie środki ochronne powinny być oparte na wiarygodnej ocenie poziomu troficznego. Istnieją różne wskaźniki szacowania stanu troficznego wód powierzchniowych, ale generalnie charakteryzują się one dużą złożonością i wysokimi kosztami oceny. W artykule przedstawiono nową metodę oceny poziomu troficznego, opartą na wskaźniku liczbowym ITS (*Index of Trophic Status*). ITS został opracowany z uwzględnieniem głównej charakterystyki funkcjonalnej dowolnego ekosystemu – stanu równowagi biotycznej i może być obliczony na podstawie pomiarów rutynowych parametrów hydrochemicznych. Proponowany wskaźnik jest instrumentem, który ułatwia m.in.: szybki monitoring wód powierzchniowych, retrospektywną i predykcyjną analizę stanu wód, ustanawianie regionalnych standardów emisji biogenów, rozwiązywanie zadań inżynieryjnych i modelowania matematycznego. Weryfikacja indeksu ITS zastała przeprowadzona dla wód powierzchniowych różnego typu w różnych krajach. Obecnie spsób ten zyskuje na popularności jako prosta, wiarygodna oraz niekosztowana metoda oceny stanu troficznego.

Słowa kluczowe: eutrofizacja, indeks ITS, wody płynące, stan troficzny