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ECOLOGICAL WATER QUALITY

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Water quality – is a description of water’s chemical and biological composition and physical properties, which characterize it as an abiotic component of aquatic ecosystem and determine its suitability for specific consumption purposes.

Ecological water quality (environmental water quality) – refers to the ecological well-being of an aquatic ecosystem, with the main focus on protection of the aquatic environment and human life and health. It comprises a complex of physical, chemical, biological and other parameters reflecting specific features of abiotic and biotic components of aquatic ecosystems.

The requirements for physical, chemical and biological properties of water are set in the water quality standards, which may be developed by particular countries or introduced by international organizations.

Ecological water quality depends upon natural and human factors. Natural factors are in their turn divided into abiotic (for example, geological, meteorological, hydrological) and biotic (for example, the ratio of primary production and organic matter destruction). The main human factors affecting water quality include artificial modification of aquatic ecosystems’ hydrological conditions and their pollution with diverse chemical compounds.

There are a lot of approaches to ecological water quality assessment according to both abiotic (physical and chemical) and biological parameters. Physical and chemical methods take into account such parameters as water transparency, suspended particulate matter concentration (turbidity), ion composition, water hardness, total dissolved salts content, nutrients and organic matter content, dissolved gases concentration, pH. Biological methods are based upon assessing the living organisms’ (biological indicators’) response to mineral and organic substances, present in water. Various living organisms can be used as biological indicators: algae, in particular – diatoms, higher aquatic plants, different species of aquatic invertebrates and fishes. While physical and chemical methods characterize water quality at the moment of sampling, biological methods provide an integral picture of water quality for a certain time period. Besides, biological methods are more informative, because they reflect the aquatic ecosystem’s response to pollution.

On the whole, the most reliable data on ecological water quality can be obtained by combining physical, chemical and biological methods.

Keywords: water, ecological quality, properties.

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ЕКОЛОГІЧНА ЯКІСТЬ ВОДИ

Н.Є. Семенюк

Якість води – опис хімічного та біологічного складу та фізичних властивостей води, які характеризують її як абіотичний компонент водної екосистеми та визначають її придатність для конкретних цілей споживання.

Екологічна якість води (екологічна якість води) – відноситься до екологічного благополуччя водної екосистеми з головною увагою до захисту водного середовища та життя та здоров'я людини. Вона включає комплекс фізичних, хімічних, біологічних та інших параметрів, що відображають особливості абіотичних і біотичних компонентів водних екосистем.

Вимоги до фізичних, хімічних і біологічних властивостей води викладені в стандартах якості води. Такі стандарти можуть розроблятися у різних країнах чи запроваджуватись міжнародними організаціями.

Екологічна якість води залежить від природних і антропогенних чинників. Природні чинники в свою чергу діляться на абіотичні (наприклад, геологічні, метеорологічні, гідрологічні) і біотичні (наприклад, співвідношення продукційно-деструкційних процесів). Основні антропогенні чинники, які впливають на якість води, включають штучну зміну гідрологічного режиму водних екосистем та їх забруднення різними хімічними речовинами.

Існує багато підходів до оцінки екологічної якості води як за абіотичними (фізичними і хімічними), так і за біотичними показниками. Фізичні і хімічні методи враховують такі показники як прозорість води, вміст завислих часток (каламутність), іонний склад, жорсткість води, мінералізація води, вміст біогенних елементів і органічних речовин, концентрація розчинних газів, рН. Біологічні методи базуються на оцінці відгуку живих організмів (біологічних індикаторів) на мінеральні й органічні речовини, присутні у воді.

Як біологічні індикатори можуть бути використані різноманітні живі організми: водорості, зокрема, діатомові вищі водяні рослини, різні види водних безхребетних і риб. У той час як фізичні і хімічні методи характеризують якість води в момент відбору проб, біологічні методи дозволяють побачити інтегральну картину якості води за певний період часу. Окрім того, біологічні методи є більш інформативними, оскільки вони відображають реакцію водної екосистеми на забруднення.

У цілому, найдостовірніші дані щодо екологічної якості води можна отримати шляхом поєднання фізичних, хімічних і біологічних методів.

Ключові слова: вода, екологічна якість, властивості.

Introduction

To achieve the UN Sustainable Development Goal No. 6 (to ensure clean water and sanitation for all) it is necessary to protect aquatic ecosystems from pollution and to maintain their natural undisturbed state. In this respect, water quality assessment is of great importance.

The water quality standards set requirements to its physical, chemical and biological properties. In Europe such standards can be developed in the EU Member States, they can be introduced by the European Council or European Parliament or issued by international organizations, such as the World Health Organization. For example, the World Health Organization published "Guidance for Drinking Water Quality" (2011).

In the European Union the water quality standards are primarily set forth

in three Directives: *Directive on Urban Waste Water Treatment* (91/271/EEC) as of May 21st, 1991; *Drinking Water Directive* (98/83/EC) as of November 3rd, 1998; *Water Framework Directive* (2000/60/EC) as of October 23rd 2000, concerning water resources management.

Organizations setting the water quality standards must take into consideration water use purposes, because physical, chemical and biological requirements to water for drinking, industry, and agriculture differ significantly. The main goal pursued by the water quality standards is to protect the end user, which may be a human population, a community of aquatic organisms, industry or agriculture etc. The main attention, though, must be paid to protection of human life and health and aquatic environment (Parameters of water quality, 2001). For

example, drinking water quality is estimated proceeding from presence of such pollutants as inorganic compounds (salts, ions of metals), toxic organic substances (petroleum products, pesticides, herbicides), microorganisms (viruses, bacteria, protozoa), as well as radionuclides.

The water quality assessment from the environmental protection viewpoint comprises a complex of physical, chemical, biological and other parameters reflecting specific features of abiotic and biotic components of aquatic ecosystems. The list of these parameters includes dissolved oxygen content, pH, water transparency, composition of salts, concentration of nutrients, specific toxic and radioactive substances and other parameters (Romanenko, 2001).

Factors Affecting Ecological Water Quality. The surface and ground waters composition depends upon natural and human factors.

Natural factors are in their turn divided into abiotic and biotic. Abiotic factors encompass geological, meteorological, hydrological conditions in the catchment area and may vary due to seasonal fluctuations of the river flow, weather, water levels etc. (Bartram and Balance, 1996). For example, dissolved salts content and ion composition are affected by such factors as water exchange, transition of salts into water during wave disturbance of bottom sediments, diffusion of salts from ground waters, atmospheric precipitations and evaporation.

Biotic factors make a significant effect upon water quality. For example, the primary production/organic matter destruction ratio determines the dissolved oxygen concentration patterns, pH, the content of organic matter, suspended particulate matter, abundance of phytoplankton and bacterial plankton. Algae and higher aquatic plants assimilate nitrogen, phosphorus and other chemical substances in course of photosynthesis. However, if the primary production exceeds the organic matter destruction

considerably, a large amount of organic matter passes into water, causing water quality deterioration.

Human factors include artificial modifications of water ecosystems' hydrological conditions by way of dam construction or flow diversion, wetlands drainage and contamination of water bodies. The latter is brought about by discharging domestic and industrial sewage or using chemical compounds, such as pesticides or mineral and organic fertilizers in agricultural lands within a catchment area (Bartram and Balance, 1996).

Materials and methods

The approaches to ecological water quality assessment are divided into two major groups: 1) physical and chemical; 2) biological.

Physical and chemical methods take into account such parameters as water transparency, suspended particulate matter concentration (turbidity), ion composition, water hardness, total dissolved salts content, nutrients and organic matter content, dissolved gases concentration, pH.

Biological methods are based upon assessing the living organisms' (biological indicators') response to mineral and organic substances, present in water.

Various living organisms can be used as biological indicators: algae, in particular – diatoms, higher aquatic plants, different species of aquatic invertebrates and fishes.

Biological methods of water quality assessment have the following advantages as compared with physical and chemical methods. Firstly, biological methods provide accurate and unbiased information on water quality, because they use aquatic organisms constantly exposed to physical and chemical factors depending upon the pollution type and level (Szczepocka et al., 2014). Secondly, findings obtained by biological methods are less affected by momentary, unpredictable changes in the environmental conditions. Physical and chemical parameters, on the contrary,

may fluctuate due to such accidental events as rains, floods or melting of snow (Pligin et al. 1998, Szczepocka et al. 2014). Thirdly, physical and chemical methods assess water quality only at the moment of sampling. Such assessment is incomplete, because water quality may change within a short time period, for example, at the moment of sewage discharge (Pligin et al., 1998).

Organisms used for biological indication must comply with the following requirements (Semenchenko, 2004, Shcherbak and Semenyuk, 2011): their communities must be marked by high taxonomical and ecological diversity, they must be widespread in various water bodies, play an important role in water ecosystems' functioning, and their structural and functional parameters must be closely related to ecological factors.

Results and discussions

Saprobiological assessment of water quality is one of the most widely used biological indication method. *Saprobity* is an organism' capability to live in water bodies with a particular concentration of organic matter. This term can also be defined as the level of a water body's pollution with organic compounds. *Saprobity system* is a system of aquatic organisms (bacteria, plants and animals) which, by their presence, reflect different levels of water quality (Sládeček 1973).

The following saprobity zones are distinguished: xenosaprobic (χ -saprobic) – “very clean” water; oligosaprobic (σ -saprobic) – “clean” water; β -mesosaprobic – “quite clean – mildly polluted” water; α -mesosaprobic – “moderately polluted – dirty” water; polysaprobic (ρ -saprobic) – “very dirty” water.

Each saprobity zone has a list of indicator organisms. For example, the ρ -saprobic zone list includes about 30 species, among which there are bacteria, fungi, protists, some rotifers, oligochaetes, dipteran maggots. For β - α -meso- and oligosaprobic zones these lists are much larger. Today the lists of saprobity indicators contain over two thousand species of plants and animals.

Saprobiological component of water quality can be assessed with the help of two major approaches: according to the indicator species ratio and according to the saprobic index.

When the first approach is used, it is necessary to count the number of indicator species of each saprobity zone and to calculate its percentage share in the total number of indicator species. This approach makes it possible to find, which saprobity zone most indicator species refer to. Thus, it is possible to make a conclusion about the water quality.

The more accurate assessment is provided by applying the Pantle-Buck saprobic index (1955) modified by V. Sládeček (1965). This method takes into account species-specific saprobic indexes of indicator organisms and their abundance (number or biomass) in a sample. The saprobic index is calculated in accordance with the following equation.

$$S = \frac{\sum_{i=1}^N s_i h_i}{\sum_{i=1}^N h_i},$$

where

S – saprobic index of the community;

s_i – species-specific saprobic index of an indicator species i ;

h_i – number or biomass of an indicator species i .

In χ -saprobic zone the saprobic index is ≤ 1.0 , in σ -saprobic – 1.1–1.5, in β -mesosaprobic – 1.6–2.5, in α -mesosaprobic – 2.6–3.5, in ρ -saprobic 3.6–4.0.

The following figure illustrates the long-term dynamics of the Sládeček saprobic index of epiphytic algal communities in the Kyiv Water Reservoir (the Dnieper River, Ukraine) (Fig. 1). As one can see, the saprobic index fluctuates between 1.60 ± 0.05 and 1.72 ± 0.08 , thus the water quality in the Kyiv water reservoir refers to β -mesosaprobic zone (“quite clean – mildly polluted” water).

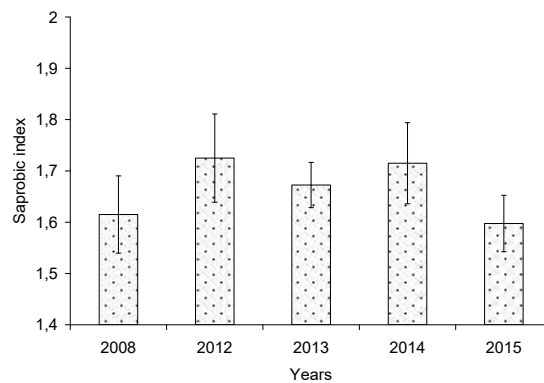


Fig. 1. Long-term dynamics of the Sládeček saprobic index of epiphytic algal communities in the Kyiv Water Reservoir (the Dnieper River, Ukraine) (unpublished field data of the author).

The results of this biological assessment are confirmed by published hydrochemical data (Yakushin et al., 2017), according to which the ammonium nitrogen concentration in the Kyiv Water Reservoir varies from 0.137 ± 0.007 to 0.453 ± 0.030 mg N \times dm⁻³ and inorganic phosphorus concentration – from 0.012 ± 0.002 to 0.107 ± 0.005 mg P \times dm⁻³, corresponding to β -mesosaprobic zone.

An important modification of the saprobic index was made by Zelinka and Marvan (1961), who introduced a term “saprobic valency” of indicator species. The Zelinka-Marvan method is based upon the idea, that a separate species cannot be a representative indicator of only one saprobic zone; instead, its distribution across saprobic zones is described by a normal curve, corresponding to its tolerance to organic pollution. The form of this curve and the area enclosed by it defines a species’ “saprobic valency”. The Zelinka-Marvan index is calculated in accordance with the following equation:

$$S = \frac{\sum_{i=1}^N s_i v_i h_i}{\sum_{i=1}^N v_i h_i},$$

where

S – saprobic index of the community;

s_i – species-specific saprobic index of an indicator species i ;

v_i – saprobic valency of an indicator species i ;

h_i – number or biomass of an indicator species i .

Both Sládeček index and Zelinka-Marvan index can be calculated for communities of aquatic organisms relating to different trophic levels (algae, invertebrates) and ecological groups (plankton, benthos, periphyton, nekton).

However, there are also different methods of water quality assessment, which are based upon the specific group of aquatic organisms: diatoms, macroinvertebrates, higher aquatic plants and fishes.

Diatoms as Water Quality

Indicators. Diatoms are reliable biological indicators of environmental changes, including eutrophication, organic pollution and oxygen regime changes, as well as climatic fluctuations. Benthic (periphytic) diatom communities are most commonly used for this purpose, especially when assessing water quality in rivers. It is explained by the fact that benthic (periphytic) diatoms are attached to substrata and, unlike planktonic algae, remain in one and the same section of the river all the time. So, they reflect the water quality parameters in that very section of the river, where they live (Martin and Fernandez, 2012).

The advantages of using diatoms as biological indicators are the following. Firstly, diatoms can be identified to the species or infraspecies taxa level without the necessity to use algal cultures.

Secondly, diatoms are widespread in water bodies and watercourses of different types and marked by high taxonomic diversity. Thirdly, due to their siliceous frustules, permanent slides of diatoms can be stored for an indefinitely long time. Fourthly, ecological characteristics of many diatom species are well known and a lot of diatom indices have been developed.

There is wide range of water quality assessment methods with using diatoms, and the most of them are based upon calculation of the so called diatom indices. These indices are classified depending upon the research aim and the way of expressing the findings obtained. One should distinguish the following groups of diatom indices (Prygiel and Coste, 2000): saprobic indices indicating the level of water pollution with easily oxidable organic compounds; trophic indices indicating the level of water enrichment with nutrients; water acidification indices; complex water quality indices, integrating the level of water pollution with organic compounds, nutrients and other parameters, such as chlorides content, conductivity, pH (Prygiel and Coste, 2000).

Most of these indices are based upon the equation of the Zelinka-Marvan saprobic index (1961). Various diatom indices differ mainly by the number of taxa involved (species and infraspecific taxa, genera, other taxonomical units) and the values of species-specific indices of pollution sensitivity and indicator valencies. Large-scale studies with using diatom indices were conducted in France (Prygiel and Coste, 2000), Great Britain (Kelly and Whitton 1995), Finland (Eloranta and Soininen, 2002). The species-specific indices of pollution and indicator valencies are taken from autecological lists, which, in particular, were compiled in France (Prygiel and Coste 2000), Germany (Lange-Bertalot, 1979) and the Netherlands (Van Dam et al., 1994).

For example, the paper written by H. Van Dam with co-authors (1994) represents the list of 948 species and infraspecific taxa, where each of them has a specific indicator value in relation to pH,

salinity, oxygen concentration, nitrogen, organic matter content. The most numerous among these taxa are species from the genera *Navicula* (a genus distinguished by very broad ecological amplitude) and *Nitzschia* (a genus containing a lot of pollution-tolerant species). Each taxon is provided with a unique eight-letter code, facilitating computer processing of data obtained. The most widespread diatom indices used in many countries include the IPS (the Pollution Sensitivity Index), the IBD (the Biological Diatom Index), the EPI-D (the Eutrophication/Pollution Index Diatom-Based), the TDI (the Trophic Diatom Index) and many others.

Some diatom indices were developed with consideration taken of the specific hydrobiological parameters of a particular aquatic ecosystem or a particular catchment area. For example: the PDI (the Pampean Diatom Index) is used to assess water quality in Argentinian rivers (Gomez and Licurci, 2001), the Di-CH (the Swiss Diatom Index) – to assess water quality in Switzerland (Nurlimann, Neiderhauser, 2006), the IO-Diatom Index – the index adapted for monitoring rivers in Poland (Szczepocka et al., 2014).

One should point out that calculating diatom indices is quite a time-consuming and labor-intensive process, because this approach can be applied only if the diatoms are precisely identified to the level of species and infraspecific taxa. Therefore, it requires involving highly-qualified and experienced research personnel, using expensive equipment and chemical reagents. This is why a researcher from Taiwan (Wu, 1999) proposed a simplified diatom index – the so called Generic Diatom Index (GDI), which requires diatoms to be identified only to the level of genus. The Generic Diatom Index is calculated in accordance with the following equation:

$$GDI = \frac{\% \text{ of sensitive taxa}}{\% \text{ of tolerant taxa}}$$

The lists of sensitive and tolerant taxa are provided in published papers

(Van Dam et al., 1994; Wu, 1999; Hill et al. 2001, 2003).

A similar approach was applied in the paper describing water quality assessment in the rivers of the Upper

Prypiat catchment area (Ukraine) (Shcherbak et al., 2012) (Table 1), based upon the list of sensitive and tolerant taxa set forth in (Van Dam et al., 1994; Hill et al., 2001, 2003).

Table 1

Comparative assessment of water quality in the rivers of the Upper Prypiat catchment area (Ukraine) according to Generic Diatom Indices (Shcherbak et al., 2012)

Rivers	GDI of organic pollution sensitivity	GDI of oxygen regime	Siltation index
Prypiat River (with Liubiaz Lake)	1.75	2.33	7
Stokhid River	1.04	1.47	17
Korostianka River	0.93	1.54	22

The above table shows that the highest values of the organic pollution sensitivity index and the oxygen regime index, as well as the lowest siltation index were observed in the Prypiat River, which is characterized by undisturbed conditions. The minimal organic pollution sensitivity index and the maximal siltation index were recorded in the artificial Korostianka River, which is actually a soil reclamation canal. The minimal oxygen regime index is registered for the Stokhid River, which can be explained by the impact of Liubeshov Town. So, the Prypiat River is distinguished by the best water quality among the rivers under study (Shcherbak et al., 2012).

The Generic Diatom Index was shown to correlate with organic matter content in rivers (Wu, 1999), thus it can be used for representative assessment of their water quality.

Bottom Invertebrates as Water Quality Indicators. Many countries in Europe use bottom invertebrates as biological indicators. Bottom indicator organisms are divided into two groups: sensitive species, whose abundance decreases with pollution, and tolerant species, whose abundance increases with pollution. The first group of species comprises maggots of insects from orders Ephemeroptera, Trichoptera, Plecoptera. The second group of species includes, in particular, the isopod *Asellus aquaticus* (L.), the amphipod *Gammarus pulex* (L.).

A review of some widely used water quality indices based on bottom invertebrates is provided in a paper by N. Szczerbińska and M. Gałczyńska (2015). They include, in particular:

Trent Biotic Index (TBI). The index is based upon the number of identified taxa of bottom invertebrates in relation to six key taxa, detected in the fauna at the sampling site. The indicator taxa are the following: types – Platyhelminthes, Annelida, Mollusca, subtypes – Crustacea, orders – Plecoptera, Ephemeroptera, Trichoptera, Neuroptera, Coleoptera, families – Chironomidae, Simuliidae, Elayidae. The advantage of this index consists in possibility to identify organisms to the level of family, genus or species. However, this index also has a disadvantage – its value may be affected by presence of drift organisms. Besides, the index does not reflect the inorganic pollution level.

Chandler Biotic Index – macroinvertebrates are identified, counted and each individual group is provided with its own score. The following taxa are used as bioindicator organisms: orders Ephemeroptera, Tricladida, Diptera, families Taenopterygidae, Perlidae, Perlodidae, Isoperliade, Chloroperlidae, Leucrtridae, Capniidae, Nemouridae, Glossiphoniidae, Simuliade. The index correlates with organic matter content in water. The disadvantage of the index is that organisms sorting, identification and counting requires much time.

Besides, the index does not reflect the inorganic pollution level.

Biological Monitoring Working Party Score (BMWP Score). When this approach is used, bottom invertebrates are identified to the level of family, and after that each family is provided with a score from 1 to 10. The index is calculated as a sum of scores for each family, represented in the sample. The indicator organisms include the following families: Planariidae, Neritidae, Piscicolidae, Astacidae, Siphonuridae, Perlidae, Calopterygidae, Pleidae, Scirtidae, Sialidae, Psychomyiidae, Simuliidae, Chironomidae, Oligochaeta. This index correlates with chemical composition of water and can reflect the pollution during a certain time period. However, this index applies only to bottom invertebrates inhabiting European rivers.

Fishes as Water Quality Indicators. On the grounds of indicator characteristics of fishes, the Index of Biotic Integrity (the IBI) was proposed. This index takes into account species composition, trophic relations, size and condition of fishes. Water quality is classified into three classes (Klimaszyk and Trawinski, 2007).

The list of the most sensitive biological indicators to water pollution includes trout *Salmo trutta* L., roach *Rutilus rutilus* (L.), and pikeperch *Sander lucioperca* (L.). Somewhat less sensitive indicator species comprise carp *Cyprinus carpio* L., bream *Abramis brama* (L.), and perch *Perca fluviatilis* L. On the grounds of the IBI the European Fish Index was developed (EFI+), which was calculated from data collected at over 14000 observation sites located on 2700 rivers in 15 European countries (EFI+ Manual, 2009; Szczerbińska and Gałczyńska, 2015). This index makes it possible to assess water quality according to fish fauna diversity.

Higher Aquatic Plants as Water Quality Indicators. Higher aquatic plants can also serve as biological indicators of water quality. In accordance with the Water Framework Directive 2000/60/EC macrophytes are

acknowledged to be important components of aquatic ecosystems' state assessment. When using higher aquatic plants as water quality indicators, it is necessary to keep in mind that their indicator values may vary depending upon the water-body type. Therefore they are not suitable for determining the difference in the species ecological tolerance in different countries of Europe (Szczerbińska and Gałczyńska, 2015).

In European countries there are a lot of indices using macrophytes for water quality assessment, in particular: the Biological Macrophyte Index (IBMR) in France, the Ecological State Macrophyte Index (ESMI) and the Macrophyte River Index in Poland, the Macrophyte Index (MI) in Germany. For example, the Macrophyte Index (MI) (Melzer, 1999) was developed for Alpine lakes. The catalogue contains 45 species of submerged macrophytes relating to 9 indicator groups. The average MI of the lake was found to correlate with the total phosphorus concentration in water. The Ecological State Macrophyte Index (ESMI) was developed for charophyte-colonized stratified and unstratified lakes in Poland. The index takes into account two aspects of higher aquatic plants communities: taxonomic composition and abundance. The plants are examined along transects 20–30 m wide, and the number of transects depends upon the shoreline length and the lake area. The index varies from 0 to 1, where 1 stands for undisturbed conditions, and 0 – for degraded water bodies (Szczerbińska and Gałczyńska, 2015).

Conclusions

Therefore, ecological water quality – is well-being of an aquatic ecosystem, with the main focus on protection of the aquatic environment, and human life and health. The requirements for physical, chemical and biological properties of water are set in the water quality standards, which may be developed by particular countries or introduced by international organizations.

Ecological water quality depends upon natural and human factors. Natural factors are in their turn divided into abiotic (for example, geological, meteorological, hydrological) and biotic (for example, the ratio of primary production and organic matter destruction). The main human factors affecting water quality include artificial modification of aquatic ecosystems' hydrological conditions and their pollution with diverse chemical compounds.

There are a lot of approaches to ecological water quality assessment

according to both abiotic (physical and chemical) and biological parameters. While physical and chemical methods characterize water quality at the moment of sampling, biological methods provide an integral picture of water quality for a certain time period. Besides, biological methods are more informative, because they reflect the aquatic ecosystem's response to pollution. On the whole, the most reliable data on ecological water quality can be obtained by combining physical, chemical and biological methods.

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