

# Journal of Geology, Geography and Geoecology

Journal home page: [geology-dnu.dp.ua](http://geology-dnu.dp.ua)

ISSN 2617-2909 (print)  
ISSN 2617-2119 (online)

Journ. Geol. Geograph.  
Geology,  
30(4), 622–431.

doi: [10.15421/112157](https://doi.org/10.15421/112157)

Bezsonnyi V.L., Ponomarenko R.V., Tretyakov O.V., Asotskiy V.V., Kalynovskiy A.Y. Journ. Geol. Geograph. Geoecology, 30(4), 622–631

## Regarding the choice of composite indicators of ecological safety of water in the basin of the Siversky Donets

Vitalii L. Bezsonnyi<sup>1,2</sup>, Roman V. Ponomarenko<sup>3</sup>, Oleg V. Tretyakov<sup>4</sup>, Vitalii V. Asotskiy<sup>3</sup>, Andrii Y. Kalynovskiy<sup>3</sup>

<sup>1</sup>V. N. Karazin Kharkiv National University, Kharkiv, Ukraine, [bezsonny@gmail.com](mailto:bezsonny@gmail.com)

<sup>2</sup>Simon Kuznets Kharkiv National University of Economics, Kharkiv, Ukraine, [bezsonny@gmail.com](mailto:bezsonny@gmail.com)

<sup>3</sup>National University of Civil Defence of Ukraine, Kharkiv, Ukraine, [asotskiy@nuczu.edu.ua](mailto:asotskiy@nuczu.edu.ua)

<sup>4</sup>IPRIS-PROFIL LTD, Kharkiv, Ukraine, [mega\\_ovtr@ukr.net](mailto:mega_ovtr@ukr.net)

Received: 14.01.2021

Received in revised form: 07.02.2021

Accepted: 11.02.2021

**Abstract.** The lack of effective mechanisms of the methods of basin management, control of and responsibility for the ecological state of surface sources of drinking water leads to the fact that the main man-made objects that determine the ecological state of surface water sources are most often located in one oblast, while the production and consumption of the

drinking water from those sources occur in the territory of other oblasts, which complicates the effective management of environmental safety of surface water sources. This is especially true for the regions of Ukraine which are poor in surface water resources, located in the basin of the Siversky Donets River, the water bodies of which are the main sources of water supply in the eastern regions of the country. The main consumer of water is Donetsk Oblast (over 50% of the annual volume), and Kharkiv and Luhansk Oblasts together consume approximately the same volume of water per year (up to 50% of the annual volume). Therefore, it is important to substantiate the integrated indicators of the ecological status of the water body to improve the environmental safety of surface water sources. The paper shows that oxygen indicators play an important role in the ecology of a water body. They are associated with the assimilative ability of water, the ability of water to decompose organic matter. Therefore, the content of dissolved oxygen and biochemical oxygen consumption in water is of great interest not only in terms of life development, but also as a composite measure of the ecological status of the aquatic environment. The relationship between the value of the combined index of water pollution and the value of biochemical oxygen consumption makes the indicator of biochemical oxygen consumption important for the integrated assessment of water contamination with various organic substances. For the tasks for which we justify the choice of composite measures of the ecological condition of surface waters, it is more important to identify the effects of contamination not directly at the site of contamination, but at some distance from it and after some time. Therefore, the use of the amount of dissolved oxygen and biochemical oxygen consumption as indicators that characterize the oxidation of pollutants present in water is the most appropriate for the tasks of timely monitoring of water bodies. Therefore, as a composite indicator for characterizing the condition of the watercourse and conducting timely monitoring, we chose oxygen indicators.

*Keywords:* ecological safety of surface waters, composite water quality indicator, complex water quality index

## До питання вибору інтегральних показників екологічної безпеки стану вод басейну Сіверського Дінця

В.Л. Безсонний<sup>1,2</sup>, Р.В. Пономаренко<sup>3</sup>, О.В. Третьяков<sup>4</sup>, В.В. Асоцький<sup>3</sup>, А.Я. Калиновський<sup>3</sup>

<sup>1</sup>Харківський національний університет імені В.Н. Каразіна, Харків, Україна, [bezsonny@gmail.com](mailto:bezsonny@gmail.com)

<sup>2</sup>Харківський національний економічний університет імені Семена Кузнеця, Харків, Україна, [bezsonny@gmail.com](mailto:bezsonny@gmail.com)

<sup>3</sup>Національний університет цивільного захисту України, Харків, Україна, [asotskiy@nuczu.edu.ua](mailto:asotskiy@nuczu.edu.ua)

<sup>4</sup>ТОВ «Іпріс-профіль», Харків, Україна, [mega\\_ovtr@ukr.net](mailto:mega_ovtr@ukr.net)

**Анотація.** Відсутність діючих механізмів басейнового принципу управління, контролю і відповідальності за екологічний стан поверхневих джерел питного водопостачання призводить до того, що частіше за все основні техногенно-небезпечні об'єкти, які обумовлюють екологічний стан поверхневого джерела води, розташовані на території одних областей, а виготовлення і споживання питної води з цього джерела відбувається на території інших, що ускладнює ефективне управління екологічною безпекою поверхневих джерел водопостачання. Особливо це характерно для малозабезпечених поверхневими водними ресурсами регіонів України, розташованих у басейні р. Сіверський Донець, водні об'єкти якого є головними джерелами водопостачання східних областей держави. При цьому основним споживачем води є Донецька область (понад 50% річного обсягу), а Харківська і Луганська області споживають приблизно однаковий об'єм води на рік (до 50% річного обсягу). Тому є актуальним обґрунтування інтегральних показників екологічного стану водного об'єкта для підвищення екологічної безпеки

поверхневих джерел водопостачання. В роботі показано, що, кисневі показники відіграють важливу роль в екології водного об'єкта. З ними пов'язана асимілююча здатність вод, тобто здатність вод до розкладання органічної речовини. Тому вміст розчиненого кисню та біохімічного споживання кисню у воді становить великий інтерес не тільки з погляду розвитку життя, але і як інтегральний показник екологічного стану водного середовища. Зв'язок, що існує між величиною комбінаторного індексу забрудненості води і величиною біохімічного споживання кисню, робить показник біохімічного споживання кисню важливим для інтегральної оцінки забруднення вод різними органічними речовинами. Для задач, щодо яких ми обґрунтовуємо вибір інтегрального показника екологічного стану поверхневих вод, більш важливим є виявлення наслідків забруднення не безпосередньо в місці забруднення, а на деякій відстані від нього і через деякий час. Тому використання саме величини розчиненого кисню та біохімічного споживання кисню, як показників, що характеризують процес окислення уже наявних забруднювачів у воді, є найбільш доцільним для задач оперативного моніторингу водних об'єктів. Тому в якості інтегрального показника для характеристики стану водотоку та проведення оперативного моніторингу, обрано показники кисневої характеристики.

*Ключові слова: екологічна безпека поверхневих вод, інтегральний показник якості води, комплексний індекс якості води*

### Introduction.

Almost 80% of drinking water in the country is provided from surface sources. Therefore, quality and condition of water in surface water objects are significant factors of sanitary and epidemic safety of the population (Bezsonnyi, Tretyakov, Khalmuradov, Ponomarenko, 2017).

Over the recent years, the problem of ecological safety of surface water has been exacerbated as a result of the unsatisfactory condition of water resources. Among the reasons for this, we should underscore absence of effective mechanisms of managing water resources, control and responsibility. This situation is conditioned by the historical development and location of industrial objects. The main polluters of the surface sources of drinking water are located in one territory (oblast), while the water is processed and consumed in another territory.

The Siversky Donets is the largest river and the most important source of freshwater in eastern Ukraine. The basin of the river is located in the territories of Kharkiv, Donetsk and Luhansk Oblasts of Ukraine and is an urbanized region with highly developed industry and agriculture. The structure of water use which has developed in the basin of the Siversky Donets is represented by all the types of water use, including those with large amounts of water consumption and ecologically harmful productions.

Problems of ecological conditions of the Siversky Donets have been described in a number of studies; particularly, according to the results of the studies (Grischenko, Vasenko, Kolysnyk, 2011), the condition of water in the upper part of the river within Kharkiv Oblast is assessed as “good” in terms of ecological condition and “quite clean” by the level of purity; water appropriate to be used for providing drinking water is only found in the region of the Siversky Donets, in the upper current (approximately 850 km higher) in the conditions of applying intense methods of water purification.

Studies of the influence of large cities of the region on the development of oxygen water regime in the basin of the Siversky Donets have revealed the ability

of the ecosystem of the basin to self-purify. On some sites, the process of self-purification are slowed. The oxygen content in the drain below the city of Kharkiv is lower by 30% due to powerful technogenic pressure (Ukhan, Osadcha, 2010).

As an approach to integrated assessment and timely prediction of technogenic pressure, an article (Ponomarenko, Plyatsuk, Hurets, Polkovnychenko, Grigorenko, Sherstiuk, Miakaiev, 2020) proposed using the approximate required level of decrease in harmful effect of inflow of polluting substances on the area of a surface water object. Based on retrospective analysis, composite measures of ecological condition of the Dnipro were modeled mathematically.

Researchers (Zadniprovskii, Maximenko, 2003) note that water that flows from Belgorod Oblast (according to the data for the borderline drain in Staraia Tavolzhanka village of Belgorod Oblast) during recent years was characterized as moderately polluted: copper content equaled 2.83 TLV, nitrites – 1.75 TLV, total iron – 1.78 TLV, phosphorus – 1.39 TLV, and the value of BOD<sub>5</sub> – 1.2 TLV. A study (Ukhan, Osadchiy, Osadcha, Manchenko, 2002) revealed that the development of the chemical composition of the surface waters in the north part of the basin (the River Siversky Donets in the region from Ohirtseve village to the city of Izium and the Uda, Lopan, Vovcha, Oskil rivers) is dominated by natural factors. Physical-geographic conditions of the basin and hydrological regime of the rivers are determined as seasonal, as well as multi-dynamic overall mineralization and separate elements of chemical composition of surface waters.

It has been established (Bezsonnyi, Tretyakov, Khalmuradov, Ponomarenko, 2017) that technogenic factors play a significant role in development of chemical composition of surface waters in the central and southern parts of the basin (the Siversky Donets in the section from the city of Izium to Kruzhylivka village, left-bank tributaries – the Chervona, Borova rivers and right-bank tributaries – the Suhy Torets, Kazenny Torets, Luhan, Bahmut, Mokra Plotva, Bilenka rivers).

Drawing on the conducted assessments, the studies (Buts, Asotskiy, Krainyuk, Ponomarenko, Kovalev, 2019) developed mathematical models for the influence of heavy metals on the development of composite indicators of the condition of water bodies, determining the conditions of migration and concentration of compounds of heavy metals, and composing an equation for calculating concentration of mobile forms of heavy metal compounds.

Integrated assessments of the ecological condition of a water environment may be based on absolute measurements of the monitoring system, indicators of degree of change in the condition of water objects in space and time, identified level of influence on recipients, effect and anthropogenic pressure on aquatic environment, criteria of the condition of aquatic ecosystem. Aquatic objects are identified to classes or categories of quality according to the values of excess of the actual level of the concentration of substances, their threshold limit values (TLV) or ecological norms, ratio of actual level to background level, mean or absolute differences between those levels (Kuzin, 1996).

We shall analyze the main approaches to integrated assessment of the quality of the environment, including aquatic objects: hygienic and ecological. The fundamental difference between those approaches is that the hygienic regulations are aimed at protecting the health of a population, while the ecological regulations aim at protecting the life environment for maintaining stability of the natural ecosystems. This fundamental difference makes it impossible to use the methods of hygienic regulations in ecological regulations. Both ecological and sanitary-hygienic regulations are based on knowledge of factors that cause various effects on living organisms. However, a scientifically-substantiated hygienic regulation can be used anywhere, for the adaptive abilities of certain individuals may vary depending on socio-economic and other factors, but generally speaking the protective abilities of the human organism are practically the same. Ecosystems have unique properties, having abiotic and biotic characteristics, different resistance to anthropogenic pressure, and therefore ecological regulations should be developed in a territorially differentiated way taking into account adaptive reserves based on the relationship between the conditions of biota in ecosystems and the environment (Vasenko, Ribalova, Artemyev, Gorban, Korobkova, Polozentseva, Kozlovskaya, Matsak, Savichev, 2015).

In Ukraine and other countries, there is currently a fairly large amount of criteria for integrated assessment of ecological condition of aquatic objects. Some classifications (Shitikov, Rosenberg, Zinchenko, 2003) are based on the assessment of bacteriological and physiological-chemical parameters, while others are

based on hydrobiological assessment of water pollution. Each of the criteria provides important information, and using them all together helps in assessing aquatic environment from ecological perspectives.

Integrated assessment of indicators of ecological safety of surface water according to chemical criteria is considered quite a laborious task, for it is based on comparing mean concentrations that are observed at the water control points and the established norms of threshold limit values for each substance. Most of the currently proposed composite parameters (Zhuk, Korobkova, 2015) have been obtained by uniting and generalizing numerous complex indicators in one composite indicator that may characterize various conditions of aquatic objects.

As of now, there is a number of methods to characterize the degree of contamination of water using one generalized indicator (contamination index  $I_c$ ), which equals mean arithmetic ratio (Losev, Milka, 2011):

$$I_3 = \frac{1}{n} \sum_{i=1}^n \frac{C_i}{TLV_i}, \quad (1)$$

for substances with values of  $C_i/TLV_i > 1$ ,  
 where  $C_i$  – actual concentration of  $i$  chemical indicator, mg/m<sup>3</sup>;  
 $TLV_i$  – threshold limit concentration of  $i$  chemical component, mg/m<sup>3</sup>;  
 $n$  – amount of substances.

The main threat is manifestation of synergism, when presence of one substance increases toxicity of another substance or when two toxic compounds form a compound with much higher toxicity than the initial ones had (for example, compounds of ions of heavy metals and other organic acids). Studies (Shitikov, Rosenberg, Zinchenko, 2003) suggest identifying the complex ecological index of the condition of river ecosystem  $I$  depending on values of various parameters:

$$I = \sum_{i=1}^n \frac{C_{i_{\text{факт}}} / C_{i_{\text{норм}}}}{n}, \quad (2)$$

де  $C_{i_{\text{actual}}}$  – actual concentration of  $i$  hydrochemical or trophosaprobological factor, mg/m<sup>3</sup>;  
 $C_{i_{\text{standard}}}$  – regulation-established concentration of  $i$  hydrochemical factor, mg/m<sup>3</sup>.

Moreover, the qualitative condition of natural water is assessed using complex indicators: water contamination index (WCI) (Baranovsky, Bardov, Omelchuk, 2000) and contamination coefficient (CC). Comparing those two complex parameters revealed

superiority of CC. The Ministry of Ecological Resources adopted the method (Zhuk Korobkova, 2015) of assessing CC of natural water. CC is a generalized indicator that characterizes the degree of contamination overall according to water quality parameters that had been numerously measured at several points (drains) of monitoring of aquatic objects. Furthermore, ecological assessment of quality of surface water is performed using corresponding criteria. It allows one to perform comparative assessment of ecological condition of surface waters in various aquatic objects (regardless of the content of contaminating compounds), identification of tendency of its quality over years, facilitating and significantly improving the form of presenting the information, including in the form of maps.

The problem of selecting indicators that are used for ecological assessment of surface water was described in-detail in the study (Shitikov, Rosenberg, Zinchenko, 2003). The solutions for this issue were classified by the authors into three groups:

- using all parameters for which TLVs are determined;
- using a small amount of regulation-established parameters;
- account of some regulation-established parameters and also compounds that characterize processes affecting the water quality.

Implementing the parameters of the first group would be the best variant, but this is practically impossible.

Suggestions from the second group are reflected in research and regulations. In general, the circle of obligatory parameters is limited within the range from ten to twenty.

Parameters of the third group are based not only on the necessity of assessing but also the necessity of

predicting changes of ecological condition of surface waters. At the same time, such parameters are taken into account, the change in concentrations which due to physical, chemical and biological reasons automatically affect the values of other indicators.

Combined index of water contamination, which is calculated according to (RD, 2002) and is currently recommended (Zhuk, Korobkova, 2015), allows one to obtain integrated assessment of the ecological condition of surface water based on the extent of excesses of TLVs of individual compounds and will be analyzed below.

Practice and regulatory activity related to monitoring surface waters indicate the necessity to minimize the resources to obtain integrated assessment of the ecological safety of a water body. Therefore, the necessity arises of selecting one or two parameters that would provide integrated assessment of the ecological condition of an aquatic object in general, without the necessity of performing numerous analyses.

Therefore, the objective of this study was substantiation of choosing the biochemical consumption of oxygen as an integrated indicator of ecological safety of water in the Siversky Donets. For this purpose, we needed to characterize the ecological condition in the studied area using combined index of water contamination (CIWC) and determine the relationship between this index and biochemical consumption of oxygen.

## Materials and methods.

The study draws from the materials of multi-year monitoring of the ecological condition of surface waters above the place of discharge, at the place of discharge and below the place of discharge of wastewater into the River Siversky Donets from the cleaning stations in the city of Iziium. The data are given in Table 1.

**Table 1.** Values of differences of mean annual values of the parameters of ecological condition of the River Siversky Donets in the area affected by wastewater.

Months	January	February	March	April	May	June
Ammonium salt	0.13575	0.0455	0.026	0.0055	-0.0215	0.0035
BOD <sub>5</sub>	0.505	0.4125	0.3075	0.31	0.235	0.3125
Overall iron	0.00,125	0.00525	0.011	0.0135	0.01125	0.009
Oil products	0	0	0	0	0	0
Nitrates	0.97	0.6025	-0.3725	0.7675	0.8475	0.7525
Nitrites	0.00375	0.02	0.00775	0.006	-0.002	0.00025
Surfactants	0.00775	0.0075	0.01475	0.0065	0.00775	0.0055
Sulfates	-2.835	-10.85	-9.835	9.17	-4.0075	-2.75
Dry residue	-10.29	-3.3325	-22.4175	-13.847	-60.46	-14.002
Phosphates	0.185	0.1725	0.145	0.0955	0.1055	0.1325
Chlorides	4.38	5.1925	1.15	1.6075	2.9275	2.7075
COD	0.7675	1.5925	0.795	1.4975	1	1.1275
Dissolved oxygen	0.0025	0.0175	0.0975	-0.0225	-0.1875	-0.1475
Ammonium salt	0	0.01275	0.0175	0.0115	-0.00425	0.02025
BOD <sub>5</sub>	0.2875	0.48	0.2975	0.5025	0.28	0.475
Overall iron	0.01	0.009	0.00925	0.005	0.011	0.00975

Continuation of Table 1

Months	January	February	March	April	May	June
Oil products	0	0	0	0	0	0
Nitrates	0.4725	0.9375	1.045	0.7075	0.9525	0.6775
Nitrites	0.002	0.0045	0.00325	0.00225	0.00175	-0.001
Surfactants	0.00725	0.006625	0.00475	0.007875	0.007	0.00575
Sulfates	-3.085	-2.62625	-3.4825	-5.3825	-5.04	-3.2475
Dry residue	-14.275	-10.4275	-11.3425	-17.65	-18.875	-11.8775
Phosphates	0.18075	0.185375	0.15	0.0975	0.115	0.1425
Chlorides	3.3075	3.54875	4.0875	3.7925	3.555	3.725
COD	1.1675	1.34375	1.235	1.08	0.825	0.69
Dissolved oxygen	-0.1575	-0.18375	-0.1725	-0.1975	-0.1725	-0.14

The methods of integrated assessment of contamination of surface water which exist today are divided into two basic groups: the first comprises methods that allow assessment of the quality of water using the general hydrochemical, hydrophysical, hydrobiological, microbiological parameters; the second one – methods related to the calculation of complex indices of water contamination.

Let us perform a more detailed analysis of one of the commonest indicators – combined index of water contamination according to (Zhuk Korobkova, 2015), which is currently recommended (RD, 2002). This index provides an integral assessment of the ecological condition of surface water, based on degree of excess of TLVs for individual substances.

Combined index of water contamination is used to determine the extent of the pollution according to the complex of contaminating compounds. The index may be calculated for any drain or point of monitoring of surface water condition, for an area or entire aquatic object. The informativeness and representativeness of the index in conditions of sufficient amount of information is quite high.

Prior to calculations, the period for which the generalization is made is chosen, depending on the purposes and sufficiency of the amount of initial data. Combined index of water contamination may be calculated for any period of time: day, decade, month, quarter, half a year, year, or multi-year period if there is a sufficient amount of samples.

Calculation of the combined index of water contamination and relative assessment of ecological condition of the surface waters were performed in two stages: first according to each studied substance and parameter of ecological condition of surface water, then we analyzed the entire complex of contaminating compounds simultaneously, calculating the resulting value.

According to each substance, for the period of assessment of the selected object, we determined the following characteristics:

1) repetition of cases of pollution  $\alpha_{ij}$ , i.e. frequency of identification of concentrations that exceed TLVs (RD, 2002):

$$\alpha_{ij} = \frac{n'_{ij}}{n_{ij}} \cdot 100\%, \tag{3}$$

where  $n'_{ij}$  is the amount of results of the chemical analysis according to  $i$  substance in  $j$  drain for the analyzed period of time, in which their content or value exceeded the allowable TLVs;

$n_{ij}$  – total amount of results of the chemical analysis for the analyzed period of time according to  $i$  compound in  $j$  drain.

By the values of repetition, the pattern of water pollution was determined according to the stability of pollution in correspondence to Table 2.

2) Mean value of multiplicity of TLV excess of  $\bar{\beta}'_{ij}$  was calculated using the results of the analysis of samples where such an excess was seen. Results of the analysis of samples in which the concentration of contaminant was below TLV were not included in the calculation. The calculation was carried out using the formula

$$\bar{\beta}'_{ij} = \frac{\sum_{f=1}^{n'_{ij}} \beta_{iff}}{n'_{ij}}, \tag{4}$$

where  $\beta_{iff} = C_{iff}/TLV_i$  is multiplicity of TLV excess according to  $i$  compound in  $f$  result of chemical analysis for  $j$  drain;

$C_{iff}$  – concentration of  $i$  compound in  $f$  result of chemical analysis for  $j$  drain, mg/dm<sup>3</sup>.

Multiplicity of excess of the normative for dissolved oxygen was determined using the formula

$$\beta_{O_2fi} = \frac{\Gamma DK_{O_2}}{C_{O_2fi}}, \tag{5}$$

According to excesses of TLVs, we determined the level of water contamination, as indicated in Table 2.

**Table 2.** Classification of water in water object according to repetition of pollutions

Repetition,%	Characteristic of water pollution	Partial assessing point according to repetition, $S_{\alpha ij}$	Share of partial assessing point per 1 % of repetition
[1*; 10)	Singular	[1; 2)	0.11
[10; 30)	Irregular	[2; 3)	0.05
[30; 50)	Characteristic	[3; 4)	0.05
[50; 100)	Regular	4	–

\* In values of repetition less than one, we consider  $S_{\alpha ij} = 0$ .

Note. Intervals are indicated as follows: number on the right – beginning of the interval; number on the left – end of the interval; parentheses indicate that the number near it is not in the interval; square bracket – the value is included in the interval

According to mean multiplicity of TLV excess of  $\bar{\beta}'_j$  and data in Table 3, we assessed partial assessing point for excess of  $S_{\beta ij}$ . The points were determined using linear interpolation.

**Table 3.** Classification of water objects according to multiplicity of LTV

Multiplicity of TLV excess	Characteristic of pollution level	Partial assessing point according to multiplicity of TLV excess, $S_{\beta ij}$	Share of partial assessing point per unit of multiplicity of TLV excess
(1; 2)	Low	[1; 2)	1.00
[2; 10)	Average	[2; 3)	0.125
[10; 50)	High	[3; 4)	0.025
[50; ∞]	Extremely high	4	–

Note: Intervals are indicated as follows: number on the right – beginning of the interval; number on the left – the end of the interval; parenthesis indicates that the number near it is not in the interval; square bracket – values is in the interval. For dissolved oxygen, the following conditional gradations of multiplicity of the pollution level are used: (1; 1,5] – low; (1,5; 2] – mean; (2; 3] – high; (3; ∞] – extremely high. If the concentration of dissolved oxygen in a sample equals 0, we consider it to equal 0.01 mg/dm<sup>3</sup> for calculation.

3) Generalized assessment point  $S_{ij}$  for each compound was calculated as product of assessment points according to repetition of pollutions and mean multiplicity of excess of TLV:

$$S_{ij} = S_{\alpha ij} \cdot S_{\beta ij} \tag{6}$$

where  $S_{\alpha ij}$  – partial point according to repetition of pollutions with *ith* substance in *jth* drain for the period of time which is analyzed;

$S_{\beta ij}$  – partial point according to multiplicity of excess of TLV of *ith* compound in *jth* drain for the analyzed period of time.

Generalized assessment point allows calculation of values of the studied concentrations and frequency of detecting the cases of TLV excesses for each compound at the same time.

The value of generalized assessment point for each substance individually may vary 1 to 16 for different waters. Its higher value corresponds to higher degree of water contamination.

Further, we determined the combined index of water pollution using the following formula:

$$S_j = \sum_{i=1}^{N_j} S_{ij} \cdot w_i, \tag{7}$$

where  $S_j$  – combined index of water pollution in *j* drain;  $N_j$  – amounts of compounds taken into account in the assessment,

$w_i$  – weight coefficients that take into account the significance of *i* compound,  $w_i$  in this calculation = 1/*N*.

**Results and their analysis.**

According to the data of multi-years monitoring, we researched seasonal changes in CICP for three points of monitoring: place of discharge of wastewater from water-cleaning structures, 1,000 m above and 500 m below the place of discharge. As seen from the provided graphs, graphs (Fig. 1), wastewater from cleaning structures worsens the condition of water in the Siversky Donets, for the CICP values 300 m below the outfall are greater than the CICP above the outfall.

The analysis of annual seasonal dynamics of difference between CICP 500 m lower and 1,000 m higher than the outfall of wastewater indicates constant positive difference between the values, except for some cases where wastewater that had run through treatment constructions dissolved polluted river water, as revealed by comparison to the initial data.

The presented graphs also indicate seasonal fluctuations of the difference between CICP values, which may be associated with increase in the surface

runoff as a result of snow melting in spring and rains in autumn, and therefore increase in the amount of polluted wastewater from the treatment constructions.

Let us determine the presence of interrelation between CICP and BOD.

Water quality in the basin of the Siversky Donets was monitored through more than thirty hydrochemical parameters. The results of the monitoring allows us only to state that the water quality currently corresponds to the requirements, i. e. there are no excesses of TLVs (Bezsonnyi, Tretyakov, Khalmuradov, Ponomarenko, 2017). In such a case, it is impossible to perform the complex assessment of the ecological condition of surface water according to hydrochemical indicators.

Also, it is impossible to make judgements about the changes that take place in water under the impact of anthropogenic factors. Therefore, the parameters of the third group, which are not mentioned in the literature as much as they deserve, are worthy of attention and research (Bezsonnyi, Tretyakov, Kravchuk, Statsenko, 2016).

Optimum conditions for the development of most microorganisms, plants and animals depend not only on the presence of food, but also combination of abiotic factors of aquatic environment: temperature, pH-environment, salinity, water turbidity, illumination, aerobic conditions.

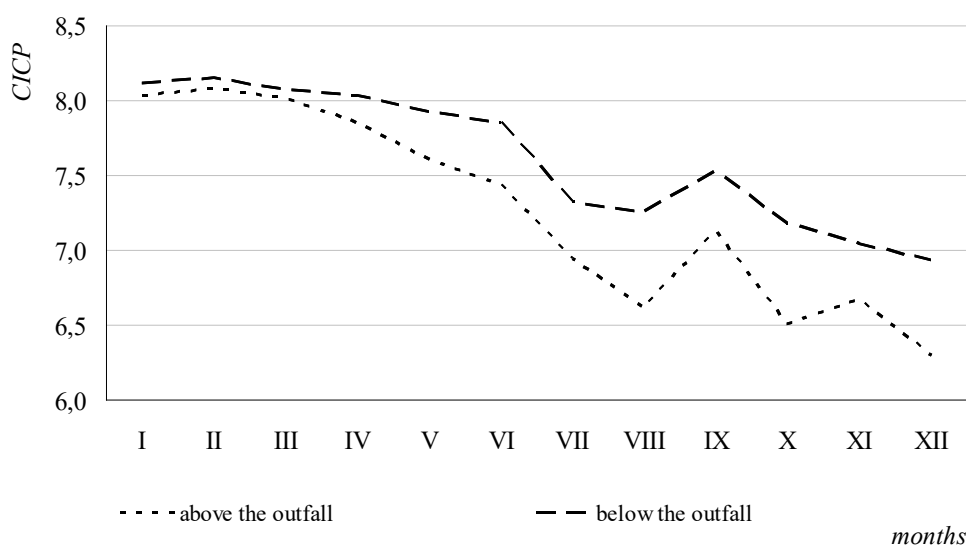


Fig. 1. Seasonal mean annual dynamics of CICP above and below the outfall of wastewater

Vitality of aquatic organisms is to a large degree determined by the content of dissolved oxygen in water. For example, minimum content of DO, which provides the normal development of fish, equals about 5 mg/dm<sup>3</sup>. Its decrease down to 2 mg/dm<sup>3</sup> causes mass death of fish. Oversaturation (over 120%) of water with oxygen also has an unfavourable effect on their condition. It should be also mentioned that assessment of the ecological wellbeing of an aquatic environment rarely takes into account the relative content of oxygen. However, oversaturation of water with oxygen usually occurs in cases of concentrations that are far from critical, for example 11 mg/dm<sup>3</sup> in the water temperature of 15 °C or 10 mg/dm<sup>3</sup> in the water temperature of 22 °C.

Concentration of oxygen in water depends on its physical characteristics (temperature and salinity), and also biochemical factors (photosynthesis and oxygen consumption in the conditions of aerobic oxidation of organic compounds). Intensity of photosynthesis depends on light and temperature, and oxidation – on the amount of organic matter, microorganisms and, again,

temperature. Other than the considered mechanisms, the concentration of oxygen in water may change under the influence of hydrodynamic factors – transfer (advection) by currents, vertical wavy mixing, etc.

Ingress of oxygen into an aquatic object may be limited by its solubility in water. At a certain water temperature and pressure, a strictly limited amount of oxygen can be dissolved.

Concentration of DO in water also depends on its consumption during oxidation of organic matter, i. e. biochemical factors. In aerobic environments, biochemical oxidation of organic compounds takes place under the effect of bacteria according to the following pattern: organic compounds + oxygen → water + carbon dioxide + other compounds. Decomposition of organic compounds may be considered an equivalent to the oxidation reaction, which reduces DO in water and causes ecological imbalance.

The criterion that characterizes the overall content of organic compounds in water is the indicator of oxygen consumption, which expresses the amount of oxygen

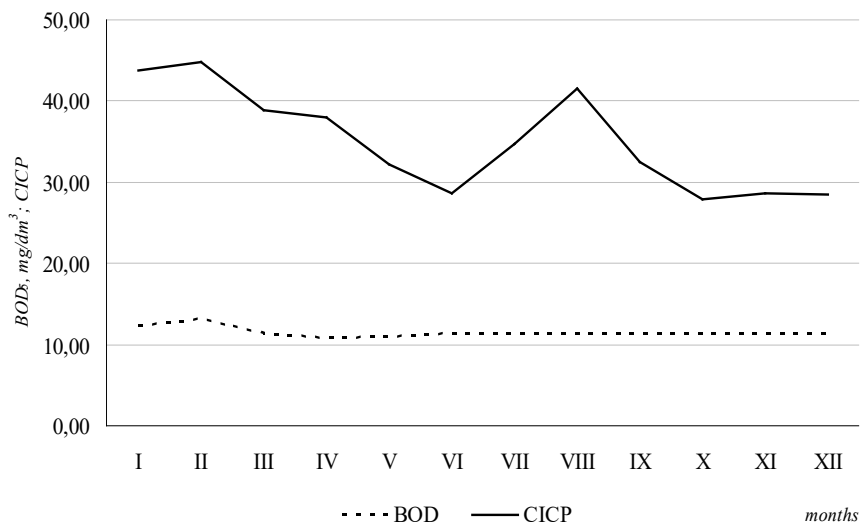


Fig. 2. Seasonal dynamics of mean annual parameters of BOD<sub>5</sub> and CACP at the outfall

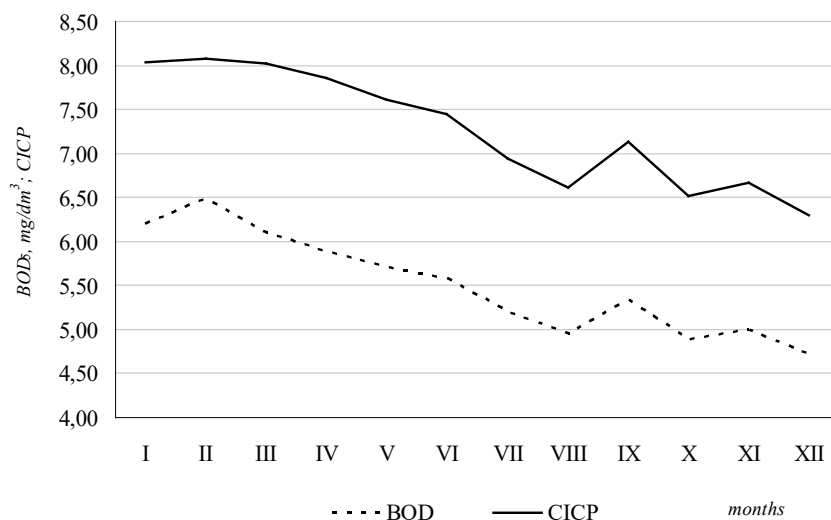


Fig. 3. Seasonal dynamics of mean annual parameters of BOD<sub>5</sub> and CACP above the outfall

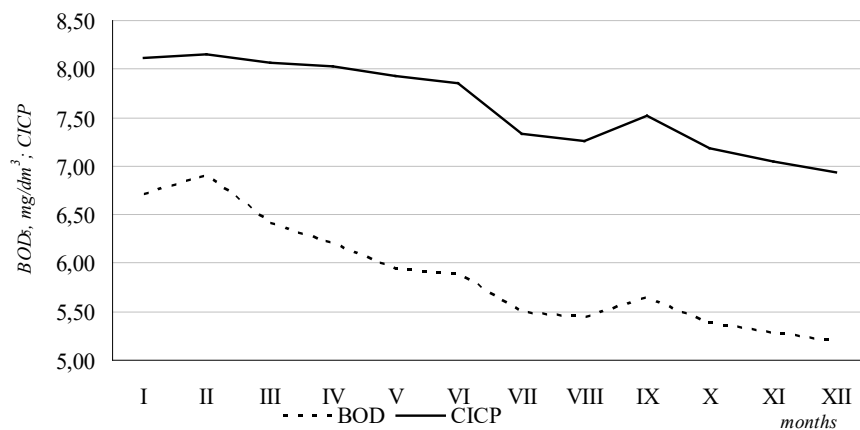


Fig. 4. Seasonal dynamics of mean annual parameters of BOD<sub>5</sub> and CACP below the outfall



(mg) needed for biochemical oxidation of organic compounds held in water, for a certain interval of time. The norm indicator of BOD<sub>5</sub> is the amount of oxygen consumed in five days in the process of oxidation of organic compounds present in analyzed water. Values of BOD<sub>5</sub> (mg/dm<sup>3</sup>) are calculated as difference between oxygen content at the moment when sample was taken and 5 days after.

Therefore, there are reasons for selecting oxygen indicators in a watercourse, namely BOD<sub>5</sub> and dissolved oxygen, which is related to it, as indicative (signaling) of ecological condition of surface waters. To confirm this assumption, we checked for presence of correlation between CICP and BOD<sub>5</sub>.

We compared three points of control – the outfall of wastewater and places above and below it.

The graphs (Fig. 2) present the seasonal dynamics of mean annual parameters of BOD<sub>5</sub> and CICP in the place of discharge of wastewaters. Correlation coefficient between the indicated values equals 0.57.

The graphs (Fig. 3) demonstrate seasonal dynamics of mean annual of parameters of BOD<sub>5</sub> and CICP above the place where wastewater is discharged. Correlation coefficient between the said parameters equals 0.98.

The graphs (Fig. 4) show the seasonal dynamics of mean annual of parameters of BOD<sub>5</sub> and CICP below the outfall of wastewater. Correlation coefficient between those parameters equals 0.94.

The analysis of seasonal dynamics of parameters and the relationship between these values suggests that determining factor of CICP development below

the contamination source is particularly the BOD<sub>5</sub> parameter, as confirmed by correlation coefficient. Right at the place of wastewater discharge, excesses of TLVs of several contaminants caused CICP to various extents.

## Conclusions.

Thus, oxygen indicators play an important role in the ecology of aquatic object. They are associated with the assimilating ability of water, i.e. ability of water to decompose organic matter. Therefore, the content of dissolved oxygen and biochemical consumption of oxygen in water is of great interest not only from the perspective of development of life, but also as composite indicators of the ecological condition of an aquatic environment. The relationship that exists between CICP and BOD<sub>5</sub> makes BOD<sub>5</sub> important for indicative assessment of water pollution with various organic compounds. Therefore, as a composite indicator of the condition of watercourse and for carrying out timely monitoring, we selected parameters of oxygen characteristics.

Detecting consequences of contamination at some distances from it and after a certain time, and directly in the place of pollution is the main goal for substantiation of choosing composite indicators of ecological condition of surface water. Therefore, we consider it most expedient to select such indicators for purposes of timely monitoring of aquatic objects, which characterize intensity of processes of water contamination.

## References

- Baranovskiy, V.A., Bardov, V.G., Omelchuk, S.T., 2000. *Ukrayina. Ekolohichni problemy pryrodnykh vod [Ukraine. Ecological problems of natural waters]*. K.: Center for Eco-awareness and Information. (In Ukrainian).
- Bezsonny, V.L., Tretyakov, O.V., Kravchuk, A.M., Statsenko, Yu.F., 2016. *Prohnozuvannya kysnevoho rezhymu richky Sivers'kyi Donets' metodamy matematychnoho modelyuvannya [Predicting the oxygen regime of the River Siversky Donets by the methods of mathematical modeling]*. Business, material knowledge, machinery!building: zb. sciences. good. Vip. 93. DVNZ "Pridnpr. holding academy of bud-va and architecture «Seriya: Bezpeka zhittediyalnosti. Dnipro. 113–119. (In Ukrainian).
- Bezsonnyi, V., Tretyakov, O., Khalmuradov, B., Ponomarenko, R., 2017. *Examining the dynamics and modeling of oxygen regime of Chervonooskil water reservoir*. Eastern-European Journal of Enterprise Technologies, 5/10 (89), 32–38.
- Buts, Y., Asotskyi, V., Kraynyuk, O., Ponomarenko, R., Kovalev, P., 2019. *Dynamics of migration property of some heavy metals in soils in Kharkiv region under the influence of the pyrogenic factor*. Journal of Geology, Geography and Geoecology, 28(3), 409–416. <https://doi.org/https://doi.org/10.15421/111938> (In Ukrainian).
- Gritsenko, A.V., Vasenko, O.G., Kolisnik, A.V., 2011. *Suchasnyy ekolohichnyy stan ukrayinskoyi chastyny richky Siverskyi Donets (ekspedytsiyni doslidzhennya) [The current ecological condition of the Ukrainian part of the River Siversky Donets (expedition study)]*. Kharkiv: Runway «Contrast». 340 p. (In Ukrainian).
- Kuzin, A.K., 1996. *Kontseptsyya okhrany vod. Problemy okhrany okruzhayushchey pryrodnoy sredy: sbornyk nauchnykh trudov [The concept of water protection. Problems of environmental protection: collection of scientific works]*, UkrNTSOV. Kharkov, 23–29. (In Russian).
- Losev, M. Yu., Milka, I.V., 2011. *Otsinka yakosti poverkhnivykh vod baseynu richky Salgir [Estimation of surface water quality in the Salgir river basin]*. Information processing systems. 3 (93), 199–202. (In Ukrainian).

- Ponomarenko, R., Plyatsuk, L., Hurets, L., Polkovnychenko, D., Grigorenko, N., Sherstiuk, M., Miakaiev, O., 2020. Determining the effect of anthropogenic loading on the environmental state of a surface source of water supply. *Eastern-European Journal of Enterprise Technologies*, Vol 3, 10 (105), 54–62. doi: <https://doi.org/10.15587/1729-4061.2020.206125>.
- RD 52.24.643–2002., 2002. Metod kompleksnoy otsenky stepeny zahryaznennosti poverkhnostnykh vod po hydrokhymycheskym pokazatelyam [Method for a comprehensive assessment of the degree of contamination of surface waters using hydrochemical indicators]. Retrieved from: <http://meganorm.ru/Index2/1/4293831/4293831806.htm> (In Russian).
- Rekomendatsyy po provedenyyu obobshchenoho pokazatelya dlya otset urovnya zahryaznennosti pryrodnykh vod [Recommendations for the generalized indicator for assessing the level of contamination of natural waters], 1984. Collection of scientific works of VNIIVO. Kharkiv. 76–79. (In Russian).
- Shitikov, V.K., Rosenberg, G.S., Zinchenko, T.D., 2003. Kolychestvennaya hydroekologyya: metody systemnoy ydentyfikatsyy [Quantitative Hydroecology: Methods for Systemic Identification]. Togliatti: IEVBRAN, 463 p. (In Ukrainian).
- Vasenko, O.G., Ribalova, O.V., Artemev, S.R., Gorban, N.S., Korobkova, G.V., Polozentsva, V.O., Kozlovska, O.V., Matsak, A.O., Savichev, A.A., 2015. Intehralni ta kompleksni otsinky stanu navkolyshnoho pryrodnoho seredovyscha: monohrafiya [Integral and complex assessments of the future of the natural environment: monograph]. X: NUGZU. 419 p. (In Ukrainian).
- Ukhan, O.O., Osadcha, N.M., 2010. Kharakterystyka kysnevoho rezhymu poverkhnelykh vod baseynu r. Siverskyy Donets [Characteristics of the oxygen regime of surface waters in the basin of the Siverskiy Donets River]. *Naukovi pratsi UkrNDGMI*. Vip. 259, 199–216. (In Ukrainian).
- Ukhan, O.O., Osadchyy, V.I., N.M. Osadcha, N.M., Manchenko, A.P., 2002. Osoblyvosti formuvannya khimichnoho skladu poverkhnelykh vod baseynu r. Sivers'kyy Donets [Features of the development of chemical composition of the surface waters in the basin of the River Siverskiy Donets]. *Naukovi pratsi UkrNDGMI*. Vip. 250, 262–279. (In Ukrainian).
- Zadniprovsky, V.V., Maksimenko, N.V., 2003. Problemy i dynamika ekolohichnoho stanu baseynu r. Siverskyy Donets na Kharkivshchyni. [Problems and dynamics of the ecological condition of the Siverski Donets River in Kharkivshchyna]. *Naukovi pratsi UkrNDGMI*. Vip. 252, 150–153. (In Ukrainian).
- Zhuk, V.M., Korobkova, G.V., 2015. Intehralna otsinka suchasnoho yakisnoho stanu r. Sivers'kyy Donets u mezhakh Kharkivskoyi oblasti [Integral assessment of the current qualitative condition of the Siversky Donets in Kharkiv Oblast]. *Lyudina and Dovkilla. Problems of neoecology*. 1–2, 103–109. (In Ukrainian).