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ANALYSIS OF THE IMPACT OF GLOBAL CLIMATE CHANGE TRENDS ON THE BLOOMING OF THE DNIPRO RIVER IN THE DNIPRO-DONBAS CANAL AREA

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Abstract. *The hydrodynamic properties of a reservoir can affect the potential for cyanobacterial blooming. Slow-flowing or stagnant waters are more conducive to blooming stability. Therefore, water with a faster flow, more intensive mixing, or higher rotation speed is less likely to develop cyanobacterial blooming. The Kremenchutske and Kamianske reservoirs have an essential impact on the blooming of the Dnieper River in the Dnieper-Donbas Canal area. Their temperature regime in the warm season favors the development of zooplankton and phytoplankton. Aquatic vegetation is most common in shallow water. Water blooming is observed in summer, and this process covers up to 70 % of the area of reservoirs, especially in the southern part and bays, deteriorating water quality. Higher frequency and intensity of precipitation, accompanied by longer periods of drought, can create contribute greater nutrient mobility. Longer periods of high temperatures also contribute to this process, at that there is no mixing of water layers. Cyanobacteria can quickly utilize nutrients that enter water bodies due to rainfall. Strong winds can also affect the cyanobacteria population, pushing cyanobacterial cells and colonies towards the banks, where they accumulate.These reservoirs are located in the temperate continental climate zone and belong to water bodies that warm up well. That is due to their width, which makes wind mixing possible in the middle and lower parts of the reservoirs, as a result of which the temperature is distributed evenly and horizontally. To confirm and supplement the results of field studies, statistical processing of water quality indicators of the Dnipro River in the area of the Dnipro-Donbas Canal was carried out. Trends were determined by regression analysis of time series of water quality indicators. The distribution was checked for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests. Correlation analysis was performed using the Pearson parametric method and the Spearman nonparametric method. The fluctation period was determined using the spectral Fourier transform method. The comprehensive analysis made it possible to establish the factors that are the main cause of water blooming in the studied area, which makes it possible to control the necessary water treatment processes.*

Keywords: *water resources, climate change, cyanobacteria, water blooming, water quality*

Relevance of the research. Rising temperatures and climate change, which affect the intensity and duration of droughts, can strongly influence cyanobacterial growth rates and algae blooming. Rising air temperatures can lead to higher water temperatures, longer ice-free seasons, and increased thermal stratification. Conversely, low winter temperatures combined with cold springs can lead to more intensive mixing of water in a reservoir and the resuspension of sediment nutrients [1]. Climatic factors can also counteract the development of cyanobacterial populations, for example, through winds and precipitation, which promote water mixing, washout, destabilization, and blooming propagation. The timing and duration of cyanobacterial blooming are also influenced by climatic conditions and other factors such as the size and location of the inoculum.

A general concern is that rising global temperatures caused by climate change could further expand the geographic distribution of toxin-producing cyanobacterial blooming in temperate regions, as well as an overall global increase in the frequency and intensity of blooming. It is supposed that rising global temperatures is at least partly responsible for the spread of certain cyanobacterial species outside of tropical and subtropical climates. The adaptation of cyanobacteria to cold has been proven by researchers as they were detected at temperatures below 20 °C. There are conflicting opinions among researchers about the effects of higher temperatures on cyanobacteria compared to other phytoplankton, so further research is needed on this issue [2].

Analysis of recent studies and publications. Some cyanobacteria grow at optimal temperatures above 25 °C, which are higher than other phytoplankton species. *Cylindrospermopsis* can thrive at temperatures from 20° to 35 °C, with maximum growth at 30 °C [3]. It has been suggested that tolerance to this temperature range helps to explain the occurrence of *C. raciborskii* in temperate regions during the summer months and the year-round blooming in some tropical and subtropical regions [4–6]. On the other hand, *Microcystis* and many other taxons are also able to survive in sediments and can survive more than a single overwintering period. This has important implications, as overwintering populations of toxin-producing cells can then re-inoculate the reservoir during the spring thaw or during the growing season during resuspension [7–9].

There is little information on the relative survival of toxic strains versus non-toxic strains under these conditions. The toxic potential of *Microcystis* cells was well preserved during overwintering, but it is unlikely that these toxic cells had a competitive advantage. *Cylindrospermopsis raciborskii* can form resting stages called akinetes that may protect the organism at adverse temperatures. Some authors state that increasing temperatures confer a direct advantage on cyanobacteria because they prefer higher growth temperatures [10–13]. Others suggest that cyanobacteria benefit indirectly from the rise of temperatures by increasing stratification, water column stability, and lengthening the growing season [14; 15]. In many cases, all of these factors may likely contribute to cyanobacterial blooming.

Many cyanobacteria have photoadaptive characteristics that allow them to lead other phytoplankton in the competition for light sources. They have numerous photosynthetic pigments that allow utilizing wavelengths of light that are not favorable to many competing phototrophic species [16]. They also function at extreme light levels and thus can outcompete other phytoplankton found in high-light conditions (e.g., at the surface), in deeper or turbid waters, or bottom sediments. Some cyanobacteria regulate their buoyancy and can optimize their position in the water column according to the amount of available light or move (slide) to more illuminated areas of the bottom substrate [17].

Light requirements vary among cyanobacterial species. For example, *Microcystis* species prefer environments with higher light levels, while others, such as *Planktothrix agardhii* and *Cylindrospermopsis raciborskii*, prefer low light levels [18]. *Cylindrospermopsis* is known to be less buoyant than other cyanobacteria, and deeply mixed water bodies may favor its dominance [19]. This and other cyanobacteria, such as *Gloeotrichia*, can acclimatize and utilize nutrient-rich deeper layers or low-light bottom areas [20]. Then as a result of water layers mixing, these taxons can increase their primary production when they move to the upper, more light-rich layers. For benthic populations, sufficient light capable of penetrating to the bottom of the water layer is an important criterion for determining the depth of cyanobacterial growth occurring [21].

Purpose of the study is to make a comprehensive analysis of the impact of global climate change on local trends of the Dnieper River blooming in the Dnieper-Donbas Canal area. That will allow us to determine the need for changes in operating the necessary water treatment processes in the study area.

Materials and methods of the study. During the study, the following water quality indicators at the observation post of the Dnipro-Donbas Canal (0,5 km, Shulhivka village, after the main catchwater canal of the Dnipro-Donbas Canal) of the Dnipro River were analyzed for the period from 2016 to 2018: biomass, mg/dm^3; biochemical oxygen consumption for 5 days, mgO_2/dm^3; odor, points; dissolved oxygen, mgO_2/dm^3; transparency, cm; temperature, degrees C; phytoplankton, thousand cells/dm^3. For statistical processing of experimental data, the STATISTICA 10 comprehensive statistical analysis package, developed by StatSoft, was used. The STATISTICA 10 package implements procedures for data analysis, data management, data extraction, and data visualization. Trends were determined by the regression analysis method of time series of water quality indicators. The distribution was checked for normality using the Kolmogorov-Smirnov and Shapiro-Wilk tests.

Correlation analysis was made using the parametric Pearson method and the nonparametric Spearman method. The fluctation period was determined using the spectral Fourier transformation method.

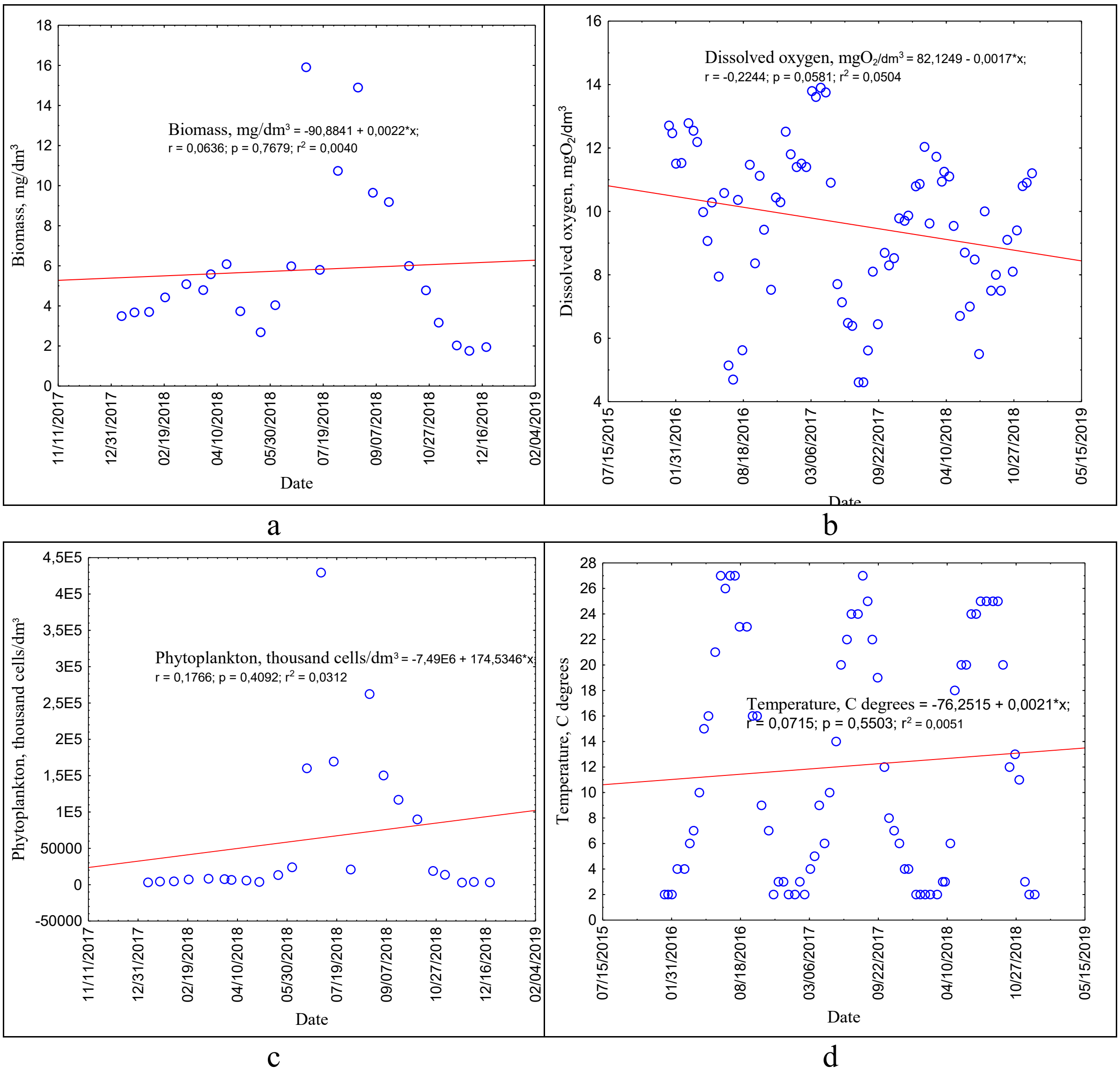
Results of the study and their discussion. The thermal regime of the Kremenchuk and Kamianskereservoirs, which have the biggest impact on the blooming of the Dnieper River in the area of the Dnieper-Donbas Canal, is characterized by uneven distribution of water temperature along the length, width, and depth, and has an unstable nature. Intensive warming of the reservoirs occurs first near the tributaries' mouths. The temperature in spring rises much faster than it decreases in autumn. The maximum heat is observed in the July – August period and the least – in the December – March period.

The catchment area belongs to typical humus-rich black and gray forest soils. Suspended matter in these reservoirs is formed under a sharp decrease in flow transportation capacity, which leads to a noticeable water clearing compared to river conditions. One of the reasons of the turbidity of reservoir water is the impact of wind waves on the bank zone. In addition, when waves approach the banks obliquely, along-bank sediment flows are formed. Silt enters the reservoirs from the outside, and it is also formed in the reservoirs, as a result of bank and bottom abrasion influenced by wind waves and the development and death of phytoplankton. The hydrochemical regime of these reservoirs is formed under the influence of external and internal factors.

External factors include river runoff, soil, and vegetation type in the river catchment, precipitation, and the ingress of various pollutants into the water in the process of human activity. Internal factors include decreasing flow velocity, increasing productivity and hyperproduction of some types of algae, changes in the quantitative and qualitative composition of organic matter, etc.

To confirm and supplement the results of field studies, water quality indicators were statistically processed in the studied area of the Dnipro River. Trends were determined by a regression analysis method of time series of water quality indicators.

The obtained model equations and their characteristics are shown on the graphs of qualitative indicators observations (Fig. 1). The applied regression analysis method of time series made it possible to determine that the trends of such qualitative indicators as biomass, phytoplankton, odor, and temperature are directed towards increasing concentrations.



a

b

c

d

Fig. 1 Graphs of water quality indicators observations during 2016–2018

Verifying the distribution compliance with the normal was performed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The built graphs and histograms of the studied indicators enabled us to specify that no indicator corresponds to the common distribution law. Therefore, the values of most indicators related to the organic component are determined mainly by the temperature cycle.

Given that most of the data do not follow a normal distribution, both the parametric Pearson method (Table 1) and the nonparametric Spearman method (Table 2) were used to determine correlations. The correlation results are presented in the form of correlation tables.

The fluctation period was determined using the spectral method of Fourier transforms (Fig. 2). One mark on the Period axis corresponds to half a month, i.e. the scale corresponds to a semi-monthly discreteness.

Correlation analysis, which used parametric and nonparametric methods, revealed a significant relationship between biochemical oxygen consumption for 5 days, odor, phytoplankton, water clarity, and biomass with temperature and dissolved oxygen. Determining the fluctuation period, performed using the spectral transformation method of Fourier, enabled us to establish that such indicators as biochemical oxygen consumption for 5 days, odor, dissolved oxygen, water clarity, and temperature have a seasonal nature of fluctuation due to the temperature cycle. The periodicity of the key fluctuations peak is in the range of 11,1–11,5 months.

1. Indicators correlation by the Pearson method to normal correlation

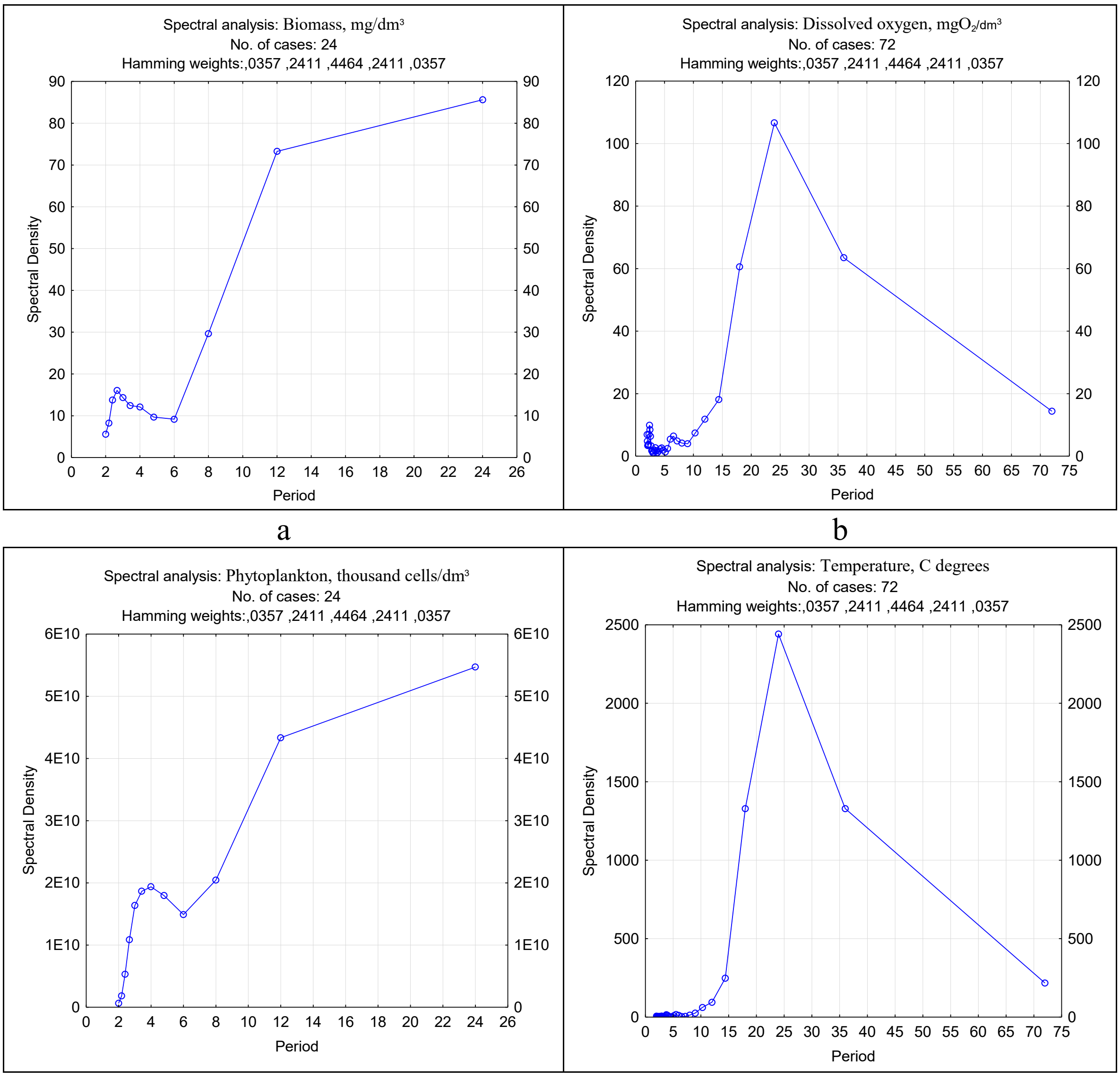
	Biomass, mg/dm^3	**Biochemical oxygen consumption for 5 days, mgO$_2$/dm^3**	**Odor, points**	**Dissolved oxygen, mgO$_2$/dm^3**	**Water clarity, cm**	**Temperature, C degrees**	**Phyto-plankton, thousand cells/dm^3**
Biomass, mg/dm^3	1,000	0,396	0,667	–0,524	–0,617	0,631	0,833
Biochemical oxygen consumption for 5 days, mgO$_2$/dm^3	0,396	1,000	0,037	–0,128	–0,497	0,186	0,264
Odor, points	0,667	0,037	1,000	–0,836	–0,604	0,782	0,809
Dissolved oxygen, mgO$_2$/dm^3	–0,524	–0,128	–0,836	1,000	0,444	–0,903	–0,786
Water clarity, cm	–0,617	–0,497	–0,604	0,444	1,000	–0,472	–0,520
Temperature, C degrees	0,631	0,186	0,782	–0,903	–0,472	1,000	0,812
Phytoplankton, thousand cells/dm^3	0,833	0,264	0,809	–0,786	–0,520	0,812	1,000

Note: The red values in the table correspond to normal correlation.

2. Indicators correlation by the Spearman method

	Biomass, mg/dm^3	**Biochemical oxygen consumption for 5 days, mgO$_2$/dm^3**	**Odor, points**	**Dissolved oxygen, mgO$_2$/dm^3**	**Water clarity, cm**	**Temperature, C degrees**	**Phyto-plankton, thousand cells/dm^3**
Biomass, mg/dm^3	1,000	0,755	0,721	–0,354	–0,368	0,666	0,772
Biochemical oxygen consumption for 5 days, mgO$_2$/dm^3	0,755	1,000	0,194	0,045	–0,299	0,306	0,578
Odor, points	0,721	0,194	1,000	–0,526	–0,485	0,609	0,750
Dissolved oxygen, mgO$_2$/dm^3	–0,354	0,045	–0,526	1,000	0,513	–0,713	–0,729
Water clarity, cm	–0,368	–0,299	–0,485	0,513	1,000	–0,613	–0,380
Temperature, C degrees	0,666	0,306	0,609	–0,713	–0,613	1,000	0,816
Phytoplankton, thousand cells/dm^3	0,772	0,578	0,750	–0,729	–0,380	0,816	1,000

Note: The red values in the table correspond



a b

c d

Fig. 2 Determining the fluctation period using the spectral transformation method of Fourier

Conclusions. A comprehensive analysis of the impact of global climate change on local trends in the Dnipro River blooming in the Dnipro-Donbas Canal area revealed the presence of a corresponding correlation. The features of the life cycle of cyanobacteria, which are the main cause of water blooming, are influenced by such factors as: temperature regime, climatic zone, catchment area, conditions of suspended matter formation, hydrochemical regime of the reservoir, etc. Statistical processing of water quality indicators in the studied area showed that most indicators related to the organic component have a trend toward increasing concentrations.

Correlation regression analysis revealed a significant relationship between biomass, phytoplankton, water clarity, odor, biochemical oxygen consumption for 5 days, and temperature and dissolved oxygen, which correlates with global trends in climate change. Most of the studied indicators are of a seasonal nature of fluctuations due to the temperature cycle. These dependencies, combined with the impact of global climate change on local trends in the Dnipro River blooming in the area of the Dnipro-Donbas Canal make it possible to predict changes in the specified indicators during the calendar year to manage the necessary water treatment processes in the studied area.

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АНАЛІЗ ВПЛИВУ ГЛОБАЛЬНИХ ТРЕНДІВ ЗМІН КЛІМАТУ НА ЦВІТІННЯ РІЧКИ ДНІПРО В РАЙОНІ КАНАЛУ ДНІПРО–ДОНБАС

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Анотація. *Гідродинамічні властивості водойми можуть впливати на потенціал розвитку цвітіння ціанобактерій. Повільно текучі або стоячі води більше сприяють стабільності цвітіння. Тому вода зі швидшим потоком, сильнішим змішуванням або вищою швидкістю обертання має меншу ймовірність розвитку цвітіння в ній ціанобактерій. Найбільший вплив на цвітіння р. Дніпро в районі каналу Дніпро–Донбас мають Кременчуцьке та Кам'янське водосховища. Їх температурний режим у теплий період року сприяє розвитку зоо- та фітопланктону. Водяна рослинність найпоширеніша на мілководді. Влітку спостерігається цвітіння води. Цей процес охоплює до 70 % площі водосховищ, особливо у південній частині та затоках, погіршуючи якість води. Вища частота та інтенсивність опадів, що супроводжуються більш тривалими періодами посухи, можуть створити більшу рухливість поживних речовин і триваліші періоди високих температур без змішування. Ціанобактерії здатні швидко використовувати поживні речовини, що надходять до водойм внаслідок дощів. Сильні вітри також можуть впливати на популяцію, приштовхуючи клітини та колонії ціанобактерій до берегів, де вони накопичуються. Ці водосховища розташовані у помірно континентальній кліматичній зоні й належать до водойм, які добре прогріваються. Цьому сприяє їх ширина, завдяки якій спостерігається інтенсивне вітрове перемішування в середній і нижній частинах водосховищ, унаслідок чого температура розподіляється рівномірно і горизонтально. З метою підтвердження та доповнення результатів натурних досліджень було проведено статистичну обробку якісних показників води р. Дніпро в районі каналу Дніпро–Донбас. Визначення трендів проведені методом регресійного аналізу часових рядів якісних показників води. Перевірку відповідності розподілу до нормального виконували за тестами Колмогорова–Смірнова та Шапіро–Уілка. Кореляційний аналіз було проведено за допомогою параметричного методу Пірсона та непараметричного методу Спірмана. Визначення періоду коливань виконано за допомогою спектрального методу перетворень Фур'є. Проведений комплексний аналіз дав можливість встановити чинники, що є головною причиною цвітіння води в досліджуваному районі, що дає змогу керувати необхідними процесами водопідготовки.*

Ключові слова: *водні ресурси, зміни клімату, ціанобактерії, цвітіння води, якість води*