

UDC 502.51(476.7)

## COMPREHENSIVE ASSESSMENT OF THE ECOLOGICAL STATE OF RESERVOIRS IN THE URBANIZED TERRITORIES OF THE SOUTH-WEST OF BELARUS

L. A. Kirichenko<sup>1</sup>, A. A. Volchak<sup>2</sup>

<sup>1</sup> Senior Lecturer of the Department of Engineering Ecology and Chemistry; Brest State Technical University, Brest, Belarus, e-mail: lakobrinetch@mail.ru

<sup>2</sup> Doctor of Geographical Sciences, Professor, Professor of the Department of Environmental Managements, Brest State Technical University, Brest, Belarus, e-mail: volchak@tut.by

### Abstract

The current state of reservoirs in urban areas is one of the characteristics of the ecology of the urban system and its social attractiveness. Therefore, the development of criteria for a comprehensive assessment of reservoirs in urbanized areas in order to develop recommendations for rehabilitation and maintenance in a good ecological condition is a rather urgent task.

The purpose of the work is to develop criteria for assessing the comprehensive index of the ecological state of reservoirs in urbanized territories, taking into account the recreational and aesthetic load on the example of water bodies in the south-west of Belarus. The objects of the study are typical reservoirs of urban areas in the southwest of the Belarus.

Based on the analysis of the results of our own expeditionary and laboratory studies and existing information on reservoirs in the urbanized territories of the south-west of Belarus, the choice of criteria was substantiated and for the first time a point scale for assessing the complex index of the ecological state of urban reservoirs was developed, taking into account the current conditions of anthropogenic influence. The criteria for the scoring of the complex index are based on hydrobiological, hydrochemical, and hydromorphological indicators of the ecological state of reservoirs, their recreational significance, anthropogenic transformation, trophic state, and environmental degradation.

The results of the developed point assessment of the complex index of the ecological state of reservoirs in the urbanized territories of the south-west of Belarus for 2020 are presented. It has been established that the overwhelming majority of urban water bodies in the south-west of Belarus (3/5 of the total) are characterized by a satisfactory ecological status, 1/5 of the studied reservoirs are in poor condition, and 1/5 of the total are in good condition. The research results can be used to develop recommendations for measures to improve and rehabilitate reservoirs in satisfactory and poor ecological condition.

**Keywords:** urban reservoirs, comprehensive index of ecological state, recreational potential, environmental degradation.

## КОМПЛЕКСНАЯ ОЦЕНКА ЭКОЛОГИЧЕСКОГО СОСТОЯНИЯ ВОДОЕМОВ УРБАНИЗИРОВАННЫХ ТЕРРИТОРИЙ ЮГО-ЗАПАДА БЕЛАРУСИ

Л. А. Кириченко, А. А. Волчек

### Реферат

Современное состояние водных объектов городских территорий является одной из характеристик экологии урбосистемы и её социальной привлекательности. Поэтому разработка критериев комплексной оценки водных объектов урбанизированных территорий с целью разработки рекомендаций по реабилитации и поддержанию в хорошем экологическом состоянии представляет собой достаточно актуальную задачу.

Цель исследования – разработка критериев комплексной бальной оценки общего состояния водоемов урбанизированных территорий на примере водоемов юго-запада Беларуси. Объекты исследования – типичные водоемы городских территорий юго-запада Беларуси.

На основании анализа результатов собственных экспедиционных и лабораторных исследований и существующей информации по водоемам урбанизированных территорий юго-запада Беларуси обоснован выбор критериев и впервые разработана бальная шкала оценки комплексного индекса экологического состояния городских водоемов с учетом сложившихся условий антропогенного влияния. В основу критериев бальной оценки комплексного индекса положены гидробиологические, гидрохимические, гидроморфологические показатели экологического состояния водоемов, их рекреационная значимость, антропогенная трансформация, трофическое состояние и экологическая деградация.

Приводятся результаты разработанной бальной оценки комплексного индекса экологического состояния водоемов урбанизированных территорий юго-запада Беларуси за 2020 г. Установлено, что для подавляющего большинства городских водоемов юго-запада Беларуси (3/5 части) характерен удовлетворительный экологический статус, в плохом состоянии находится 1/5 часть из исследуемых водоемов, в хорошем – 1/5 часть. Результаты исследований могут быть использованы для разработки рекомендаций мероприятий по улучшению и реабилитации водных объектов, находящихся в удовлетворительном и плохом экологическом состоянии.

**Ключевые слова:** городские водоёмы, комплексный индекс экологического состояния, рекреационный потенциал, экологическая деградация.

### Introduction

Most of the reservoirs of the city are the least studied water resources in Belarus due to their shallow depth and small water area, since they are not included in the NEMS. Water bodies of urbanized areas are subject to the influence of many factors, both abiotic and anthropogenic. This affects the ecological state of such reservoirs in such a way that water protection measures alone are sufficient, environmental measures in the form of a water protection zone are not quite effective. The self-cleaning ability of most of these reservoirs deteriorates due to the inflow

of various pollutants into the water from the catchment area, with groundwater, precipitation, etc. In this case, there is a need to apply measures to improve the ecological condition and recreational opportunities of urbanized reservoirs.

The use of only a technical approach in solving these problems most often turns out to be impossible, inexpedient or ineffective. Therefore, an integrated approach is needed to solve technical and environmental problems to maintain a good ecological condition of urbanized reservoirs or restore (rehabilitate) them to a good condition.

It follows from this that the assessment of the ecological state of urban reservoirs should include a variety of criteria, not only hydrochemical, hydrobiological and hydromorphological, but also cultural, historical, social, recreational, etc.

For this purpose, we have developed a point assessment of the criteria for determining the ecological state and recreational opportunities of urban reservoirs.

Thus, the purpose of the work is to develop criteria for assessing the comprehensive index of the ecological state of reservoirs in urbanized territories, taking into account the recreational and aesthetic load on the example of water bodies in the south-west of Belarus.

**Materials and methods**

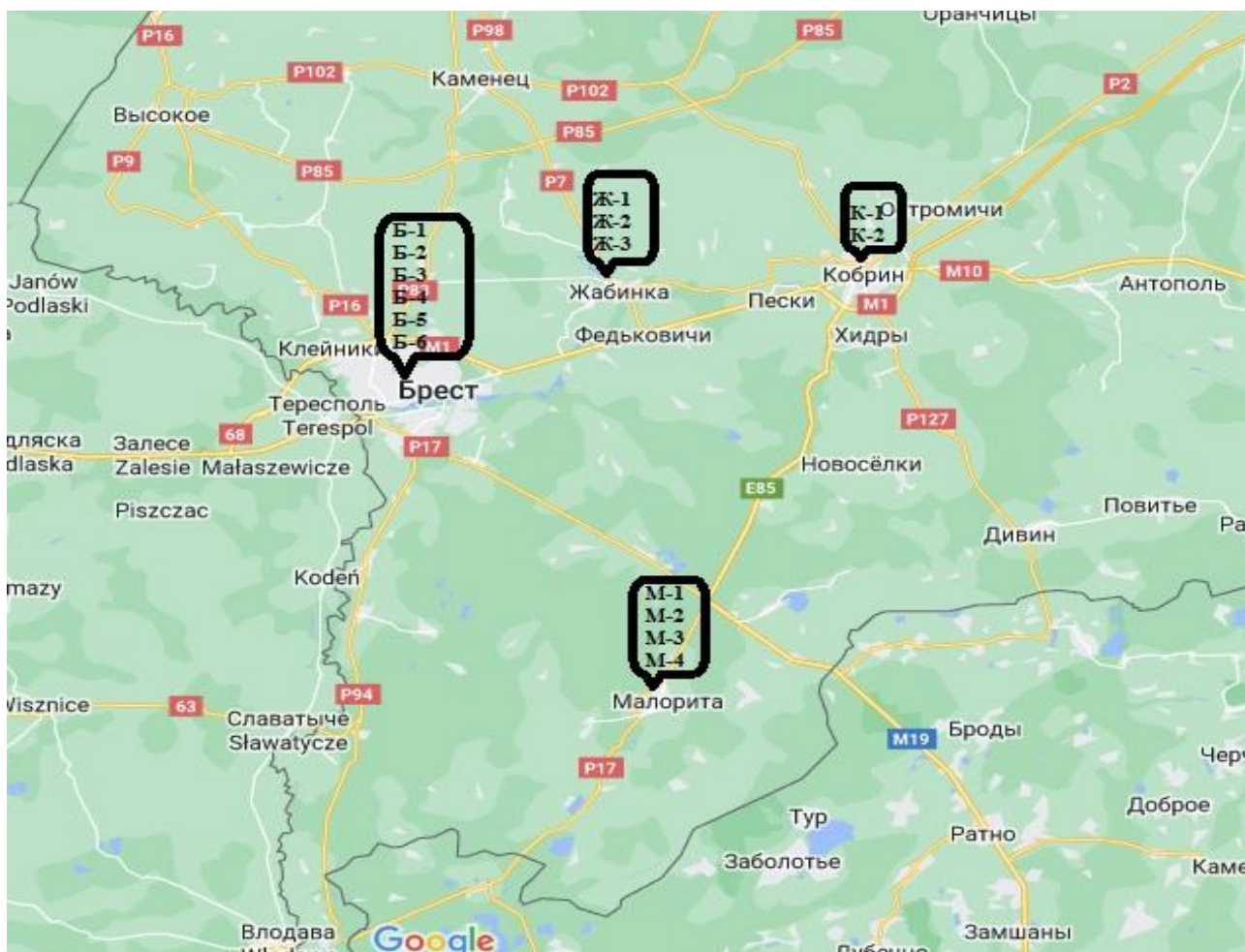
The objects of the study are typical representative water bodies of the urbanized territories of the south-west of Belarus, characterized by different recreational load and different degrees of anthropogenic impact (Figure 1).

To determine the criteria for assessing the comprehensive index of the ecological state (CIES) of urban reservoirs, the indicators of the eco-

logical state (hydromorphological, hydrochemical, hydrobiological), as well as recreational and aesthetic potential, anthropogenic transformation, etc., are used.

To determine the estimated state of reservoirs in urbanized areas subject to various anthropogenic impacts, a system of criteria (levels) is proposed.

The ecological state of urban reservoirs was assessed on the basis of hydrochemical and hydrobiological indicators by known methods. The ecological state of urbanized reservoirs in terms of hydrochemical indicators was determined based on the multiplicity of exceeding the MPC by comparing the studied indicators with the lowest (most stringent) indicators of permissible concentrations of chemical indicators from the combined lists of information documents of the Republic of Belarus on the quality of surface waters: within the boundaries of settlements, recreational areas, MPC of pollutants of fishery water bodies and MPC of drinking water [1–4]. The ecological state according to hydrobiological indicators was assessed by the indicator of the saprobity index of reservoirs by macrophytes [5, 6].



**Figure 1** – Sampling sites: Kobryn – K-1 park pond, K-2 pond w/n on Polesskaya Street; Zhabinka – Zh-1 park pond, Zh-2 pond "Mukhina Yama", Zh-3 pond "Vdkhr Vizhar"; Malorita – M-1 park pond, M-2 pond w/n on Dzerzhinskaya Street, M-3 pond "Voennoye Ozero", M-4 pond "Torfboloto"; Brest – B-1 pond "Vychulki", B-2 pond "Zodchikh", B-3 park pond "Nizhny", B-4 pond "Gershonsky", B-5 pond w/n on Kirpichnaya Street, B-6 pond "Zerkalka"

The assessment of the recreational potential and anthropogenic impact on urban reservoirs is considered using the indicators introduced by us: the level of recreational significance, the level of anthropogenic transformation (Tables 1, 2) [4, 7–10].

The level of environmental degradation of water bodies in urbanized areas was assessed based on their trophic state according to the indicators of the trophic state index TSI, the nitrification index  $I_{nitr}$  and the modified aggregation index  $I_{m-agr}$  according to the methods [11–17].

**Results and discussion**

On the basis of the ecological state according to hydrochemical, hydrobiological and hydromorphological indicators, as well as with the help of such indicators of recreational potential and the magnitude of anthropogenic impact on water bodies as the level of recreational significance, the level of anthropogenic transformation and the level of environmental degradation, we propose a point assessment of the integrated index of the ecological state of reservoirs of the CIES of urbanized territories, specified in the Table 3.

**Table 1** – Indicators of the level of recreational significance of reservoirs in urbanized areas [7]

Level of recreational significance, score	Characteristics of the level of recreational significance
High	<i>Recreational-safe</i> water bodies are reservoirs that are in good and satisfactory ecological and sanitary-hygienic condition, used by the population in various types of recreation, and have recreational, cultural and historical potential
Average	<i>Recreationally significant</i> – reservoirs that are in a satisfactory ecological and sanitary-hygienic condition, have a high aesthetic load and are used by the population in contact types of recreation
Low	<i>Recreationally insignificant</i> – reservoirs that are in a satisfactory ecological condition, the banks of which are used for non-contact types of recreation and have an insignificant recreational potential (or in a poor ecological condition with a significant recreational potential), which cannot be used for the organization of active recreation zones, but for them it is possible to develop projects to increase the recreational potential or environmental protection or rehabilitation to a satisfactory environmental condition
"Zero"	<i>Recreationally insignificant</i> – reservoirs that are in a poor ecological condition (or in a state of degradation) and do not have a recreational potential (or with an insignificant recreational potential), which are not used by the population for recreational purposes, for which rehabilitation to a satisfactory ecological condition is impossible or inexpedient

**Table 2** – Indicators of the level of anthropogenic transformation of reservoirs [7]

Level of anthropogenic transformation	Characteristics of anthropogenic transformation
"Zero" transformation	A favorable indicator of safety for recreation, characterized by insignificant anthropogenic interference (up to 5 %), as well as in the case when the reservoir has retained its original appearance
Minor Transformation	A favorable or relatively favorable indicator of safety for recreation, characterized by the engineering arrangement of a part of the coastline or a change in the lithological composition of the bottom of the reservoir by up to 30 %
Partial Transformation	A relatively favorable indicator of safety for recreation, characterized by a complete (or partial) change of the coastline, transformation from 30 to 60 %
Significant transformation	An unfavorable indicator of safety for recreation characterizes reservoirs, part of the area of which (more than 60 %) has been lost (filled up or drained)
Complete Transformation	An unfavorable indicator of safety for recreation characterizes completely lost reservoirs, or transformed into underground water bodies, or technological water bodies

The ecological state of reservoirs is assessed by comparing the results of research on hydrochemical and hydrobiological indicators. If the status of the water body of the reservoirs of urbanized territories in terms of hydrobiological indicators is higher than in terms of hydrochemical indicators, then the ecological state in terms of hydrochemical indicators is considered a priority. In our opinion, such a priority determination of the ecological state by hydrochemical indicators is associated with the effect of anthropogenic factors on the reservoirs: water pollution with chemicals has already occurred, and living organisms have not yet had time to adapt to the changed conditions of existence.

**Table 3** – Score assessment of the Complex Index of the Ecological State of reservoirs of urbanized territories

No p/n	Criteria for the CIES of the reservoir	Point
<b>Ecological state</b>		
<b>Hydrochemical indicators</b>		
1	Excellent condition / low contamination water (no indicators of exceeding the MPC)	1
2	Good (favorable) / low (MPC multiplicity 1–2)	2
3	Satisfactory (relatively favorable) / medium (MPC multiplicity 2–10)	3
4	Bad (unfavorable) / high (MPC multiplicity 10–50)	4
5	Very poor ecological condition (degradation) / extremely high (MPC multiplicity >50)	5
<b>Hydrobiological indicators</b>		
1	Excellent environmental condition	1
2	Good (favorable) environmental condition	2
3	Satisfactory (relatively favorable) environmental condition	3
4	Poor (unfavorable) environmental condition	4
5	Very poor environmental condition	5
<b>Recreational potential</b>		
<b>Level of recreational significance</b>		
1	High	1
2	Average	2
3	Low	3
4	"Zero"	4
5	Missing	5
<b>Level of anthropogenic transformation</b>		
1	"Zero" transformation	1
2	Minor Transformation	2
3	Partial Transformation	3
4	Significant transformation	4
5	Complete Transformation	5
<b>Degradation of a water body</b>		
<b>Level of environmental degradation</b>		
1	A reservoir with a natural ecosystem	1
2	A reservoirs in an anthropogenically stressed trophic state	2
3	A reservoirs in a crisis trophic state	3
4	A reservoirs in a catastrophic trophic state	4
5	The reservoir is completely lost	5

When assessing the CIES of an urbanized reservoirs, a higher score of the ecological state indicator in terms of hydrochemical and hydrobiological indicators is taken into account, taking into account the predominance of the hydrochemical indicator.

The points of recreational potential and environmental degradation are summed up.

The CIES, like existing methods, classifies the ecological status of water bodies as *excellent*, *good*, *satisfactory*, *bad* and *very bad*. It is calculated according to the following formula

$$CIES = \sum UES/n,$$

where UES is the level (criterion) of the status of a reservoirs, *n* is the number of criteria.

The values of the CIES are characterized by the following:

- Excellent condition – 1–1.49 points;
- Good condition – 1.5–2.5 points;
- Satisfactory condition – 2.51–3.0 points;
- Poor condition – 3.01–4.0 points;
- Very poor condition – 4.01–5 points.

Thus, when calculating the CIES of water bodies, all factors affecting the reservoirs of urbanized areas are taken into account. At the same time, the following trend can be traced – the higher the score for a particular indicator, the worse the general condition of the reservoirs.

However, if:

- the general condition of reservoirs in urbanized areas is excellent, but isolated cases of water blooms have been recorded, then their condition is assessed as good;

- the general condition of the water body of the reservoirs of urbanized areas is good, but the cases of water blooming are frequent, the condition is assessed as satisfactory;

- the general condition of the reservoirs of urbanized areas is satisfactory, but the cases of water blooms are annual and its condition is assessed as poor.

According to the developed point assessment, the ecological state of urbanized reservoirs in the south-west of Belarus was studied, the results of the research are shown in Table 4.

Based on the results obtained, it was established that most of the water bodies in the south-west of Belarus are in good and satisfactory condition, except for the pond "Vychulki" of the pond "Voennoye Ozero" and the "Nizhny" park pond, for which a poor ecological condition has been established (Table 4) [18–20].

Thus, the results of the CIES show the true ecological state of reservoirs in urbanized areas, taking into account the recreational potential and the level of environmental degradation.

### Conclusion

Almost all urban reservoirs are natural-anthropogenic or anthropogenic water bodies, the intensity of self-purification processes in which is slowed down. Therefore, a more accurate determination of the ecological state of reservoirs in urbanized areas requires an integrated approach based on the ranking of mutually related biotic, abiotic and anthropogenic factors.

**Table 4** – The state of urbanized reservoirs in the south-west of Belarus in the summer period of 2020

Indicators/ Basin	Hydrochemical	Hydrobiological	Level of recreational significance	Level of environmental degradation	Level of anthropogenic transformation	CIES	Condition
K-1	4	4	2	2	3	2,75	Satisfactory
K-2	5	5	4	3	2	3,5	Bad
Zh-1	3	2	2	1	2	2	Good
Zh-2	<u>2</u>	3	3	1	1	1,75	Good
Zh-3	4	4	2	2	3	2,75	Satisfactory
M-1	3	2	2	1	3	9	Good
M-2	4	4	3	2	2	2,75	Satisfactory
M-3	<u>4</u>	5	3	4	2	3,25	Bad
M-4	<u>3</u>	4	3	2	1	2,75	Satisfactory
B-1	5	5	3	3	3	3,5	Bad
B-2	4	4	2	2	2	2,5	Satisfactory
B-3	5	5	2	4	3	3,5	Bad
B-4	2	2	2	1	1	1,5	Good
B-5	3	3	3	2	1	2,25	Satisfactory
B-6	4	4	2	1	2	2,25	Satisfactory

\* the underlining indicates the score of the ecological state for the assessment of the CIES of the reservoirs of urbanized areas

The proposed system for assessing the comprehensive index of the ecological state of urbanized reservoirs, taking into account the ecological state in terms of hydrochemical, hydrobiological and hydromorphological indicators, environmental degradation, social and recreational attractiveness of urban reservoirs, quite objectively reflects the changes occurring with them in the current conditions of external influences.

A comprehensive assessment of the ecological state of water bodies in urbanized areas showed that the vast majority of urban reservoirs in the southwest of Belarus (3/5) are characterized by a satisfactory ecological status, 1/5 of the studied reservoirs are in poor condition, and 1/5 are in good condition. For these water bodies, it is necessary to develop measures to improve and (or) rehabilitate the ecological state.

It has been tested in the development of measures to maintain a good ecological condition of water bodies and (or) the need to rehabilitate reservoirs in the urbanized territories of the south-west of Belarus, as well as in the development of measures for restoration and reclamation and restoration of the hydraulic system of the park of the State Institution of Culture "Historical and Memorial Museum "Nemtsevich Estate".

The work was carried out with the partial support of the Grant of the Ministry of Education of the Republic of Belarus No for state registration of 20200621.

### References

1. Ob utverzhdenii Sanitarnykh norm i pravil «Trebovaniya k soderzhaniyu poverhnostnykh vodnykh ob'ektov pri ih rekreacionnom ispol'zovanii» : postanovlenie Ministerstva zdavoohraneniya Respubliki Belarus' ot 5 dekabrya 2016 g. Ne 122 // Nacional'nyj pravovoj Internet-portal Respubliki Belarus'. – URL: <https://pravo.by/document/?guid=12551&p0=W21631536p> (data obrashcheniya: 23.10.2024).
2. Ohrana okruzhayushchej sredy i prirodopol'zovanie. Gidrosfera. Kompleksnaya ocenka ekologicheskogo riska i raschet normativov dopustimyh rekreacionnykh nagruzok na vodnye ob'ekty v rekreacionnykh zonah Belarusi : TKP 17.06-17-2018 (33140), BY. – Vveden 01.06.19. – Minsk : Minprirody, 2019. – III, 19 s.
3. Pit'evaya voda. Gigenicheskie trebovaniya k kachestvu vody centralizovannykh sistem pit'evogo vodosnabzheniya. Kontrol' kachestva. Sanitarnye pravila i normy : SanPiN 10-124 RB 99. – Minsk : Minzdrav, 2000. – 48 s.
4. Ohrana okruzhayushchej sredy i prirodopol'zovanie. Gidrosfera. Trebovaniya k soderzhaniyu poverhnostnykh vodnykh ob'ektov v nadlezhashchem sostoyanii i ih blagoustrojstvu: EkoNiP 17.06.08-003-2022. – Vveden 15.05.2022. – Minsk : Minprirody, 2022. – 28 s.

5. Volkova, I. V. Ocenka kachestva vody vodoemov rybohozyajstvennogo naznacheniya : uchebnoe posobie dlya vuzov / I. V. Volkova, T. S. Ershova, S. V. SHipulin. – 2-e izd., ispr. i dop. – Moskva : Izdatel'stvo YUrajt, 2018. – 353 s.
6. Vysshaya rastitel'nost' ozera Nozhnicy / L. M. Merzhvinskij, V. P. Martynenko, YU. I. Vysockij, YU. L. Stanovaya // Vesnik Vicebskaga dzyarzhaj'naga y'niversiteta. – 2013. – № 2 (74). – S. 60–66.
7. Ocenka rekreacionnoj privilekatel'nosti vodoemov urbanizirovannyh territorij yugo-zapada Belarusi po gidromorfologicheskim pokazatelyam / L. A. Kirichenko, A. A. Volchek // Prirodopol'zovanie : sbornik nauchnyh trudov. – 2024. – № 1. – S. 54–67.
8. Ovcharova, E. P. Geoekologicheskie kriterii dlya celej rehabilitacii vodnyh ob'ektov na urbanizirovannyh territoriyah / E. P. Ovcharova, O. V. Kadackaya // Prirodopol'zovanie : sbornik nauchnyh trudov / Nacional'naya akademiya nauk Belarusi, Gosudarstvennoe nauchnoe uchrezhdenie "Institut prirodopol'zovaniya". – Minsk, 1996. – S. 25–30.
9. Kirichenko, L. A. Issledovanie ekologo-rekreacionnoj znachimosti nekotoryh vodoemov g. Bresta / L. A. Kirichenko // Perspektivnye metody ochistki prirodnyh i stochnyh vod : sbornik statej regional'noj nauchno-tekhnicheskoy konferencii, Brest, 26 sentyabrya 2019 g. / Ministerstvo obrazovaniya Respubliki Belarus', Brestskij gosudarstvennyj tekhnicheskij universitet, Kafedra vodosnabzheniya, vodootvedeniya i ohrany vodnyh resursov ; redkol.: S. G. Belov [i dr.]. – Brest : BrGTU, 2019. – S. 68–71.
10. Tomash, M. S. Rekreacionnyj potencial limnosistem g. Gomelya / M. S. Tomash // Vesnik Brestskaga y'niversiteta. Seryya 5. Himiya. Biyologiya. Navuki ab zyamli. – 2020. – № 2. – S. 148–156.
11. Zlyvko, A. S. Antropogennaya transformaciya i samoochishchayushchaya sposobnost' maloj reki / A. S. Zlyvko, S. M. CHesnokova, I. A. Borodina // Teoreticheskaya i prikladnaya ekologiya. – 2012. – № 3 – S. 44–49.
12. Neverova-Dziopak, E. Ocenka troficheskogo sostoyaniya poverhnostnyh vod : monografiya / E. Neverova-Dziopak, L. I. Cvetkova ; SPbGASU. – SPb., 2020. – 176 s.
13. Kirichenko, L. A. Troficheskoe sostoyanie i sposobnost' k samoochishcheniyu vodoemov urbanizirovannyh territorij YUgo-Zapada Belarusi v 2020 g. / L. A. Kirichenko, A. A. Volchek // Vesnik Grodzenskaga dzyarzhaj'naga y'niversiteta imya YAnki Kupaly : navukovy chasopis. – 2024. – T. 14, № 1. – S. 177–186.
14. Hrisanov, N. I. Upravlenie evtrofirovaniem vodoemov / N. I. Hrisanov, G. V. Osipov. – SPb., 1993. – 279 s.
15. Bulgakov, N. G. Biogennyye elementy v srede i fitoplankton: sootnoshenie azota i fosfora kak samostoyatel'nyj faktor regulirovaniya struktury al'gocenoza / N. G. Bulgakov, A. P. Levich // Uspekhi sovremennoj biologii. – 1995. – T. 115. № 1. – S. 13.
16. Kratzer, C. R. A Carlson-type trophic state index for nitrogen in Florida Lakes / C. R. Kratzer, P. L. Brezonik // Water Resources Bulletin. – 1981. – Vol. 17. – P. 713–715.
17. Dunalska, J. Total organic carbon as a new index for monitoring trophic states in lakes / J. Dunalska // Oceanography and Hydrobiology. – 2011. – Vol. 20. – P. 112–115.
18. Kirichenko, L. A. Ekologicheskoe sostoyanie gorodskih vodoemov yugo-zapada Belarusi v vesennij period 2020 g. / L. A. Kirichenko, A. A. Volchek // Pryrodnae asyaroedze Palesyya: asablivasci i perspektyvy razvicya : zbornik navukovyh prac / Nacyanal'naya akademiya navuk Belarusi, Paleski agrarna-ekalagichny instytut, redkal. M. V. Mihal'chuk (gal. red.) [i insh.]. – Minsk : Belaruskaya navuka, 2022. – Vyp. 13. – S. 117–120.
19. Ekologo-gidrohimicheskoe sostoyanie vodoemov urboterritorij yugo-zapada Belarusi v zimnij period / L. A. Kirichenko [i dr.] // Vestnik Brestskogo gosudarstvennogo tekhnicheskogo universiteta. Seryya: Vodohozyajstvennoe stroitel'stvo, teploenergetika i geoekologiya. – 2020. – № 2. – S. 80–82.
20. Kirichenko, L. Ecological condition of water bodies of the south-west of Belarus in spring 2020 / L. Kirichenko, A. Volchak, A. Golovach // 2020 International Conference on Building Energy Conservation, Thermal Safety and Environmental Pollution Control (ICBTE 2020). – 2020. – Volume 212. – 11 p. – DOI: 10.1051/e3sconf/202021201007.

*Material received 29/10/2024, approved 25/11/2024, accepted for publication 03/12/2024*