Розроблено методику оцінки рівня екологічної безпеки водних об'єктів на основі співставлення впливу окремих точкових джерел скиду стічних вод. Використання такої методики дозволяє розв'язати проблему виявлення екологічно небезпечних об'єктів та визначення пріоритетних напрямків захисту водних об'єктів у регіоні. Сутність методу полягає у оцінці екологічної небезпеки конкретних об'єктів народного господарства з урахуванням рівня небезпечності, ступеня впливу на якість води водного об'єкту, ефективності моніторингу та величини антропогенного навантаження.

Запропоновано логіко-математичну модель оцінки впливу джерел забруднення водного середовища, що базується на визначенні коефіцієнтів умов скиду стічних вод, забрудненості стічних вод та навантаження на водний об'єкт. Визначення ступеня екологічної небезпеки джерел забруднення водних об'єктів здійснюється за значенням коефіцієнту шкідливого впливу джерела забруднення на водні об'єкти за п'ятирівневою шкалою від «безпечного» до «надзвичайно небезпечного». Розроблена шкала відповідає екологічній класифікації Водної Рамкової Директиви ЄС 2000/60/ЕС.

Апробація розробленої методики проводилася на прикладі типової для територіальних виробничих комплексів ділянки басейну річки, де розташовані об'єкти атомної енергетики, промислового виробництва та комунального господарства. На основі визначення блокових та загального коефіцієнту шкідливого впливу джерел забруднення водних об'єктів було розроблено карту екологічної небезпеки джерел забруднення басейну річки. Проведено класифікацію джерел забруднення водних об'єктів за розробленою шкалою. Встановлено, що найбільший ступінь екологічної небезпеки мають великі підприємства житлово-комунального господарства та виробничі об'єкти машинобудівної галузі. Ці об'єкти належать до другого класу і характеризуються як «небезпечні». Підприємства атомної енергетики та гідроелектростанції належать до третього класу небезпеки – «помірно небезпечні».

Результати аналізу можуть бути використані при розробці стратегії управляння водними ресурсами та заходів щодо зниження рівня впливу джерел забруднення на водні об'єкти

Ключові слова: екологічна небезпека, джерело забруднення, шкідливий вплив, навантаження на водний об'єкт

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DEVELOPMENT OF PROCEDURE FOR ASSESSING THE DEGREE OF ENVIROMENTAL HAZARD FROM THE SOURCES OF AQUATIC ENVIRONMENT POLLUTION

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1. Introduction

Intensification of the activity of industrial, municipal, and agricultural enterprises located near water bodies results in a significant deterioration of quantitative and qualitative indicators of the state of aquatic environment and an increase in the level of anthropogenic load on the environment. The main reasons for this are not ordered wastewater draining from residential settlements, economic facilities and agricultural lands, as well as the constant discharge of insufficiently purified water from water treatment facilities.

Such a situation requires reaction and orderly operative control of water quality of aquatic facilities. This is only possible if we identify hazardous sources of the water pollution and give actual assessment of the level of their impact and load on the river basin.

That is why the system of ecological monitoring and assessment of the impact on the water environment has been recently designed and implemented in developed countries [1]. However, the two proposed systems today have a number of unresolved issues when it comes to the procedure of assessment of the ecological quality of surface water. Such questions include, in particular, the improvement of the methods for assessment of the negative influence of discharge sources on the state of the hydrosphere. Therefore, the most urgent area of research in this area is the development of generalizing indicators that characterize organizational and technological aspects of environmental hazard of water supply facilities.

2. Literature review and problem statement

Assessment of the ecological state of hydro-ecosystems is based on the results of hydro-chemical, biological, sanitary-hygienic and other types of water quality monitoring. In addition, the data of special research into chemical, hydro-chemical, microbiological pollution of water, bottom sediments, and the state of fauna and flora of water are used [1].

The results of monitoring enable the identification of aquatic sites with deteriorated environmental characteristics of hydrobionts, an increased risk of population morbidity, associated with the use of poor-quality water [2].

At present, there are different methodological approaches to assessment of the state of aquatic sites by the separate individual hydrological, hydro-biological, and hydro-chemical indicators or by comprehensive or integrated criteria.

The method for environmental evaluation of aquatic ecosystems by higher water plants (HWP) [3] implies determining the index of phyto-indication of the ecological state of aquatic ecosystems. This approach is based on an analysis of the species diversity of the HWP cenoses, the number of species that are sensitive to water pollution, the degree of vegetation development facilitation by a river ecosystem. In paper [4], it was offered to conduct the evaluation of the qualitative state of hydro-ecosystems taking into consideration the processes of the transformation of pollutants, self-cleaning and biogenic load in the aquatic environment. The designed procedure takes into account the dynamics of changes and the ratio of biogenic elements to the rate of self-purification processes in the aquatic site. However, an essential drawback of the mentioned procedures is the insufficient consideration of the extent of the influence of anthropogenic load and the ecological state of littoral areas.

To resolve this problem, it was proposed in [5] to perform assessment by the value of a comprehensive indicator of anthropogenic load (CIAL). The method is based on assessment of the blocks: "use of water resources", "use of land resources", "technogenic load". This procedure was subsequently developed in paper [6]. Given a significant impact of the area of a water body and flood plains on the ecosystems of small river basins, it was proposed to determine additionally the indicators, grouped into the blocks of "flood plain" and "water body area". However, this approach does not take into consideration the negative impact of hydrosphere state deterioration on the population.

There are no such shortcomings in the approach, based on determining the level of the environmental hazard of aquatic sites with the help of the indicators of development of degradation processes, the impact of positive and negative factors of the aquatic ecosystem formation [7]. The criteria of the comprehensive assessment of surface water quality also include a degree of the potential risk to the health of the population in the recreational use of reservoirs and environmental-hygienic indicators of the quality condition of water sites [8, 9]. However, this criterion does not make it possible to make a comparative assessment of the negative impact of the separate sources of hydrosphere pollution.

The basic principles adopted of the Water Framework Directive of the EU 2000/60/EU, adopted in 2000 are the identification of the biological indicators of aquatic ecosystems that have the greatest influence on the reproduction of water resources [10]. The requirements of this document were applied to the conditions of Germany in paper [11], which was the basis for the analysis of the modern ecological state of water sites of the country [12]. At the same time, as it is noted in article [13], these methods need further improvement, specifically, taking into account the synergic effect of natural and anthropogenic load on aquatic communities.

Many researchers propose to evaluate the state of surface water by a limited number of indicators. In particular, the approach with consideration of general chemical, toxicological and biological indicators of the water quality of rivers is proposed in [14], and that of lakes in [15]. The use and analysis of the data of observation of the state of species of bioindicators to determine the water quality in rivers was proposed in [16], and in paper [17], it was proposed to use them to determine the state of hydrosphere genotoxicity. The general shortcomings of these methods include the inability to establish the degree and sources of anthropogenic influence.

Paper [18] proposes the method for water quality evaluation based on the visual analysis of the state of an aquatic site and of the littoral territory. This method makes it possible to establish the main sources of hydrosphere pollution; however, it is based only on qualitative assessment of unsafety of such sites.

Based on the comparison of actual values and ecologically safe concentrations, major pollutants were ranked according to the degree of risk for surface waters [19, 20]. The approach to determining the environmental risk to water sites, taking into consideration spatial and temporal factors, is more common [21]. However, application of this approach makes it possible to assess the water quality only in the water body and does not make it possible to establish the contribution of separate sources to the general level of the environmental hazard.

As can seen from this review, the approaches to integrated assessment of qualitative condition of the aquatic environment are characterized by diversity. Different authors proposed a significant number of criteria for assessment of the quality of aquatic ecosystems. However, none of the proposed methods can be considered universal. The reason for this is the need for simultaneous determining and comparison of a large number of indicators of state that have a different character. The problem of assessing the impact of one-point sources of wastewater discharge on the surface water bodies remains unresolved.

The extent of the problem is proved by the fact that today there is no commonly acceptable legal document that legally approves of a certain method for water quality assessment, the evaluation and characteristic of the impact of littoral point sources of pollution on water sites and recommends it to be widely used.

The attempts to introduce the methods for comprehensive assessment of the ecological condition of water sites have been repeatedly made. In particular, the Hydrochemical institute of the State committee of hydrometeorology designed the Technique for evaluation of water quality of aquatic sites by hydrochemical indicators, according to which water is given a certain category of quality, depending on magnitude of conditional coefficient of complexity and combinatory index of water pollution [22]. A significant drawback of this procedure is a small number of indicators used in assessing the state of the surface waters.

The procedure of comprehensive evaluation of the state of surface waters by the indicators of salt composition, tropho-saprobiological criteria, the content of specific toxic and radiation substances was implemented in the comprehensive regulatory document "Environmental assessment of the quality of surface waters of land and estuaries of Ukraine" [23]. However, it is impossible to determine the influence of the ecological state of water environment on living organisms and humans using this procedure. The draft of "The Methodology of ecological assessment of surface water quality by appropriate categories" was developed in order to eliminate these drawbacks [24]. The proposed procedure includes additional blocks of characteristics of biotic communities and bioindicative indexes, biochemical, as well as bacteriological criteria, the data of biological testing water and bottom sediments.

The Ukrainian scientific-research institute of hydro-economic and environmental problems (Kyiv) developed the Procedure for calculation of anthropogenic load and classification of the ecological state of basins of small rivers of Ukraine, where in addition to the mentioned indicators of water quality evaluation, the indicators of radioactive contamination of territories, land management and river runoff management are taken into account. The inductive coefficient of anthropogenic load (ICAL), which characterizes the level of anthropogenic load on a river basin, is determined based of these indicators [25].

Thus, the existing procedures make it possible to assess either the ecological state of certain water supply sites, or that of territories. At the same time, the problem of detection of hazardous sites and determining priority directions of protection of water bodies in the region remains challenging in the practice of environmental control authorities. To do this, it is necessary to determine the level of environmental hazard of specific facilities of national economy. At present, it is assessed by the compliance of wastewater drains to the values of maximum acceptable discharges. This approach does not take into consideration the organizational and technological issues, and therefore it does not make it possible to plan the water protection activity of enterprises in the long-term prospects.

A promising way of solving this problem is to develop a fundamentally new approach to integrated planning of the measures aimed at making the rivers of the region healthier. The basis of the approach should be the estimation of probability of adverse effects of economic activity of industrial, agricultural, municipal enterprises, heat and atomic power plants for the natural environment and humans.

A comprehensive assessment of the influence of point pollution sources on the ecological state of the basins of rivers should be conducted based on the identification of the most significant pollution sources and depletion of river ecosystems. Such assessment will make it possible to take scientifically substantiated managerial decisions on the priority of the implementation of nature protection measures and to develop a strategy for the rational water management.

3. The aim and objectives of the study

The aim of this research is to develop the new procedure for evaluation of the level of ecological safety of aquatic sites based on the comparison of the influence of separate point sewage discharge sources.

To achieve the set goal, the following tasks were set:

– to develop the criterion of assessment of the degree of environmental hazard of the sources of pollution of aquatic sites based on analysis of essential factors of the negative impact;

– to develop a logical-mathematical model for evaluation of the influence of sources of water environment pollution taking into consideration the specified factors;

– to conduct testing of the developed model by studying the influence of littoral sources of sewage waters discharge on the state of aquatic sites.

4. Materials and methods of research into the influence and assessment of the level of environmental hazard of sources of aquatic environment pollution

According to the analysis of data in literature, there has not been developed a comprehensive criterion of assessment of the level of environmental hazard that would take into consideration the system of various indicators of the impact of separate pollution sources on an aquatic site.

That is why in this paper it is proposed to determine the level of the environmental hazard of surface water pollutants by the value of the total coefficient of harmful influence of the pollution source on aquatic sites *P*. The developed criterion takes into account the most significant indicators of the level of anthropogenic load on the river basin, technological risk and harmful influence of discharges on ecosystems.

In this study, it is proposed to calculate the coefficient from formula:

$$P = \lambda_1 \cdot r_{\text{mean}} + \lambda_2 \cdot c_{\text{mean}} + \lambda_3 \cdot m_{\text{mean}}, \quad (1)$$

where r_{mean}, c_{mean}, m_{mean} are the mean value of coefficient of influence of a pollution source by the indicators of conditions of wastewater discharge, characteristics of the wastewater discharged by the pollution source into the water environment, the pollution load on an aquatic site; λ_1=0.15...0.25, λ_2=0.25...0.35, λ_3=0.45...0.55 are the weight coefficients by each block.

To determine the coefficient of harmful influence of a pollution source on aquatic sites, the authors developed the logical-mathematical model by three blocks of indicators (Fig. 1).

The authors proposed to form the evaluation indices of blocks 2 and 3 based on the regulations existing on the given territory. When characterizing the sewage discharge conditions and effectiveness of monitoring, the authors were the first to propose to take into account additionally the technical state of wastewater treatment facilities, the type of discharge, the way of sewage discharge, the location of a pollution source.

The authors recommend performing the qualitative assessment of the indicators for all the blocks by the 5-point scale that corresponds to the generally accepted scale of evaluation of surface waters quality.

Mathematical formalization of the estimation for the respective blocks is based on finding the mean magnitude of the indicators, by which the category of hazard, harmfulness and load is established.

The authors propose to represent every *i*-th indicator of the three blocks (i=1, 2, 3,..., *n*, where *n* (*u*=1, 2, 3,..., *n*, where n is the number of indicators of the units) as a vector of values of coefficients:

$$\overline{y}_i \left\{ y_1^i,\ y_2^i,\ y_3^i,\ y_4^i,\ y_5^i,\ y_6^i \right\}. \quad (2)$$

The components of vectors $\overline{r_i}$ for each i-th indicator, which can be expressed in a qualitative form, are found from the logical function:

$$Y^i\left(x_k^i\right) = \begin{Bmatrix} y_1^i = 0,\ if\ \ x^i \le x_1^i \\ y_2^i = 1,\ if\ \ x_1^i < x^i \le x_2^i \\ y_3^i = 2,\ if\ \ x_2^i < x^i \le x_3^i \\ y_4^i = 3,\ if\ \ x_3^i < x^i \le x_4^i \\ y_5^i = 4,\ if\ \ x_4^i < x^i \le x_5^i \\ y_6^i = 5,\ if\ \ x_5^i < x^i \end{Bmatrix}, \quad (3)$$

where x^i is the value of the i-th indicator (for block 1 – p_i, for block 2 – k_i, for block 3 – s_i); x_k^i is the maximum magnitudes of the i-th indicator (Fig. 1).

If the indicator cannot be expressed in a quantitative form, value $\overline{r_i}$ is derived from function:

$$Y^i\left(x_k^i\right)=\begin{Bmatrix} y_1^i=0,\ if\ \ x^i=x_1^i \\ y_2^i=1,\ if\ \ x^i=x_2^i \\ y_3^i=2\ if\ \ x^i=x_3^i \\ y_4^i=3,\ if\ \ x^i=x_4^i \\ y_5^i=4,\ if\ \ x^i=x_5^i \\ y_6^i=5,\ if\ \ x^i=x_6^i \end{Bmatrix}. \quad (4)$$

After determining arithmetic mean values of the indicators for each block (r_{mean}, c_{mean}, m_{mean}), the influence of a pollution source on aquatic sites is assessed.

The estimation scale that is shown in Table 1 is proposed in order to characterize the influence of littoral sources of pollution of water environment by the indicators of the general state and the level of hazard (unreliability, failures, threats) for a water basin.

Table 1

Classification of sources of aquatic environment pollution by the level of hazard (unreliability, failures, threats) for a river basin

Category (class) of hazard	Coefficient of influence of pollution sources by indicators of conditions of sewage discharge and monitoring, rmean	Level of hazard (unreliability, failures, threats) for a river basin
I	more than 4.0	very high
II	3.1–4.0	high
III	2.1–3.0	above normal
IV	1.1–2.0	close to normal
V	0–1.0	low

It is advisable to determine the characteristic of the influence of littoral sources of water environment pollution by the indicators of sewage pollution and the class of harmfulness of a pollution source by the value of calculated coefficient c_{mean} from Table 2.

Table 2

Classification of sources of aquatic environment pollution by the degree of their impact on water quality in the basin of a river

Category (class) of hazard	Coefficient of influence of a point pollution source by the indicators of sewage pollution, cmean	Characteristics of the influence of a point pollution source on an aquatic site	
		Level of influence on the water quality of an aquatic site	Class of hazard
I	more than 3.0	catastrophic	extremely harmful
II	1.6–3.0	critical	very harmful
III	0.6–1.5	permissible	moderately harmful
IV	0–0.5	low	slightly harmful
V	0	no influence	not harmful

It is proposed to determine the level of load of a pollution source on an aquatic site by the value of the calculated coefficient m_{mean} from Table 3.

Table 3

Classification of sources of aquatic environment pollution by the load on an aquatic site

Category (class) of hazard	Coefficient of load on an aquatic site by pollution source, mmean	Level of load on an aquatic site
I	more than 4.0	unsafe
II	3.1–4.0	considerable
III	2.1–3.0	moderate
IV	1.1–2.0	insignificant
V	0–1.0	absent

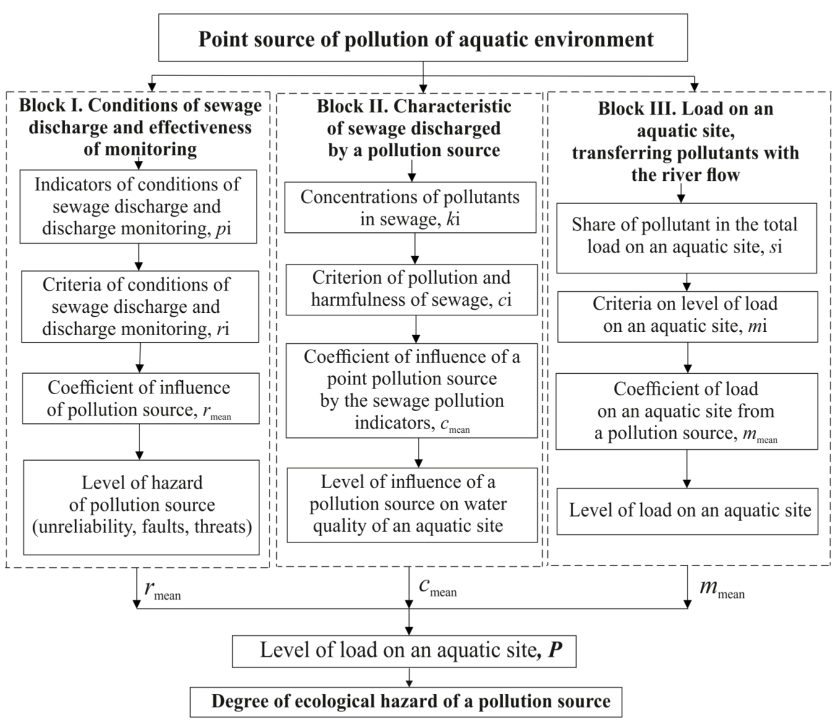


Fig. 1. Block diagram of the logical-mathematical model for evaluating the influence of pollution sources on water sites

The next step is the calculation of total coefficient of harmful influence of pollution sources on aquatic sites from formula (1). The following classification is proposed to assess the level of the environmental hazard of the sources of water environment pollution (Table 4).

Table 4

Classification of sources of aquatic environment pollution by the degree of environmental hazard

Class of hazard	Total coefficient of hazardous influence of a pollution source on aquatic sites, P	Characteristic of the level of environmental hazard
I	more than 3.5	extremely hazardous
II	2.1–3.5	hazardous
III	1.1–2.0	moderately hazardous
IV	0.1–1.0	slightly hazardous
V	0	safe

The developed classification of sources of water environment pollution is fully consistent with the requirements and the classification of quality state of surface water, presented in "The Water Framework Directive of the European Union" (2000/60 EU) [10].

In this paper, it is proposed to carry out the pre-selection of the biggest sources of pollution of water bodies that are sewage receivers by the value of effective mass of pollutants, taking into consideration toxicity of polluting substance in the sewage relatively to ammonium sulfate. The value of effective mass (M_x) is derived from formula:

$$M_x = \sum_{i=1}^{n} \frac{MPC_{(NH_4)_2SO_4}}{MPC} \cdot m_i, \qquad (5)$$

where $MPC_{(NH_4)_2SO_4}$ is the maximum permissible concentration of ammonium sulfate, mg/l; MPC_i is the maximum permissible concentration of a pollutant, mg/l; m_i is the weight of a pollutant, discharged in aquatic environment, t/year; i is the pollutant, the discharge of which into aquatic sites is standardized and controlled in the given country; n is the total number of standardized pollutants.

In particular, in Ukraine, it is necessary to take into consideration the characteristic of the discharge by 20 indicators, when determining the effective mass. For subsequent analysis, the pollution sources, in which the value of effective mass of pollutants exceeds 1 ton/year are selected.

To assess the influence of littoral sources of water environment pollution, the official materials of the state bodies on the regulation of water resources were used.

The database of the state statistical reporting in Ukraine was used initial quantitative data on the existing volumes of pollutants discharge and their concentration in refluent waters, used in the research.

5. Results of assessment of the degree of environmental hazard of the sources of pollution of aquatic sites

Testing of the developed procedure was carried out on the example of the section of the South Buh river basin on the territory of Mykolaiv Oblast in Ukraine. The selection of this section is explained by the existence of facilities of atomic power industry (E), sites of industrial production (B) and municipal economy (C). This structure of water supply facilities is typical of territorial production complexes of European countries.

According to the procedure (chapter 4), we selected the largest sources of pollution of aquatic sites, which are sewage receivers and received the code (Table 5).

At the next stage, a detailed estimation of the influence of the selected point source of pollution on aquatic sites and the environmental safety on the territory of Mykolaiv Oblast was carried out based of the logical-mathematical model.

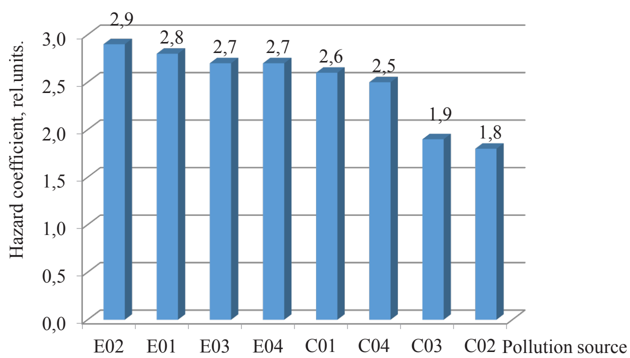
The results of the estimation of the influence of point sources of pollution and ranking by the level of hazard (unreliability, failures, threats) for aquatic sites are shown in Fig. 2.

For the purpose of establishing the level of hazard of sewage discharges, the classes of harmfulness were determined and ranking of sources of pollution of aquatic sites was performed (Fig. 3).

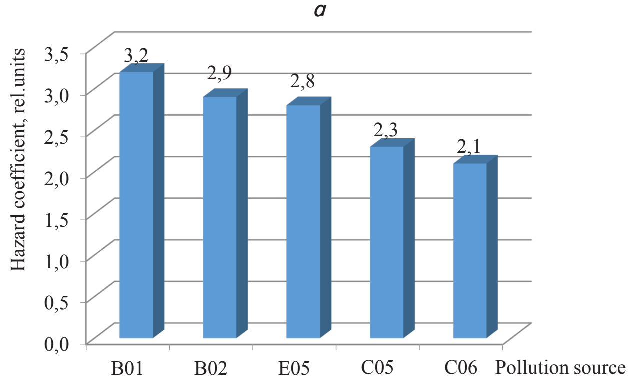
Table 5

Pollution sources that are subject to a detailed analysis of their impact on aquatic sites of Mykolaiv Oblast

No. by order	Name of a point source of pollution of aquatic environment	Effective mass, t/year	Code of pollution source
1	ME «Pervomaisk gorvodokanal»	201.7	C01
2	Pervomaisk HEP	11,843.2	E02
3	Myhiiv HEP	3,445.3	E04
4	Konstantynivka HEP	4,948.6	E03
5	Treatment facilities PE «South Ukraine APS»	15.5	C02
6	PE «South Ukraine APS»	37,735.7	E01
7	Ltd «Biological treatment facilities», the town of Voznesensk	556.9	C03
8	ME «City vodokanal», Bashtanka	73.1	C04
9	OJSV «Mykolaiv thermoelectrocentral»	50.9	E05
10	RE Scientific-productive complex of pipeturboconstruction «Zoria» – «Mashproject»	292.4	B01
11	PJSV Mykolaiv ship building plant «Ocean»	26.8	B02
12	CME «Mykolaiv vodokanal»	71.9	C06
13	CME «Mykolaiv vodokanal», Galytsynove	1,655.9	C05



a



b

Fig. 2. Influence of pollution sources by indicators of their general state and level of hazard: *a* – basin of the South Buh river; *b* – the Buh estuary

The results of the evaluation of the load of pollution sources on aquatic sites and ranking are shown in Fig. 4.

Based on determining the block coefficients and the total coefficient of harmful influence of sources of pollution of aquatic sites pollution, we designed the map of the environmental hazard of pollution sources in the basin of the South Buh River on the territory of Mykolaiv region (Fig. 5).

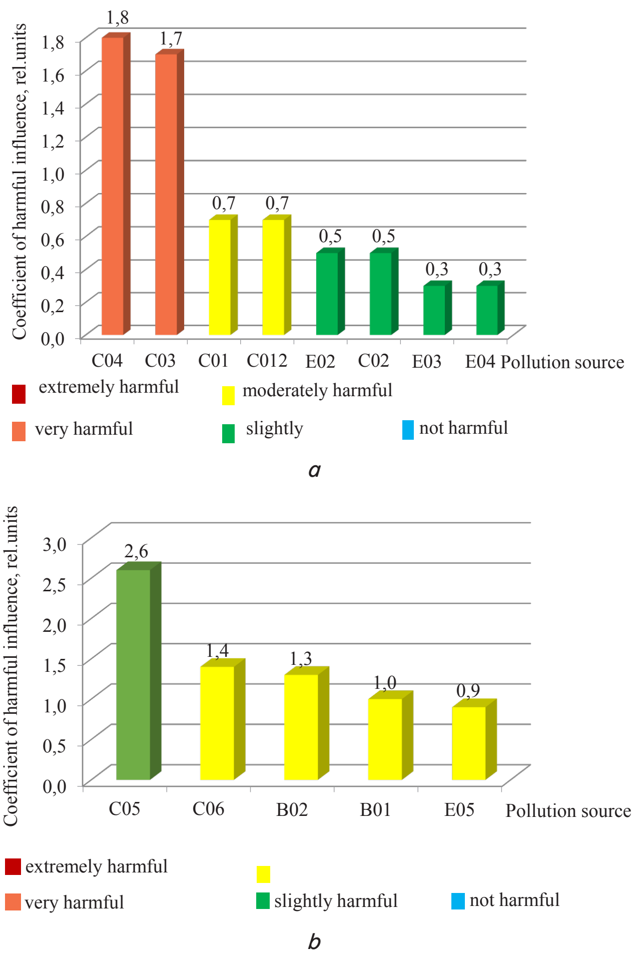


Fig. 3. Influence of pollution sources on water quality of an aquatic site by indicators of their harmful influence in: *a* — basin of the South Buh river; *b* — the Buh estuary

Such maps can be used as the basis for the development plans that are designed by territorial communities and authorities of the basin water management. Based on the obtained data, we selected the priority measures to improve water management in the regions.

The research results revealed that by the degree of environmental hazard on the territory of Mykolayiv Oblast, 4 enterprises belong to the most dangerous sites (Fig. 6). All these enterprises discharge sewage to the Buh estuary water.

From the general list of the pollution sources that were pre-selected for detailed analysis and studying their impact on aquatic sites of the oblast, the dangerous ones include:

1) Treatment facilities of the sewerage of CME "Mykolaivvodokanal" are the main source of hydrosphere pollution in the Oblast. These drains make up 89 % of the total volume and contain a significant amount of harmful substances in concentrations far exceeding the maximum permissible. Wastewater of the enterprise causes the greatest harm to the hydroecosystem of the Buh estuary and significantly worsens the sanitary-epidemiological situation in the region.

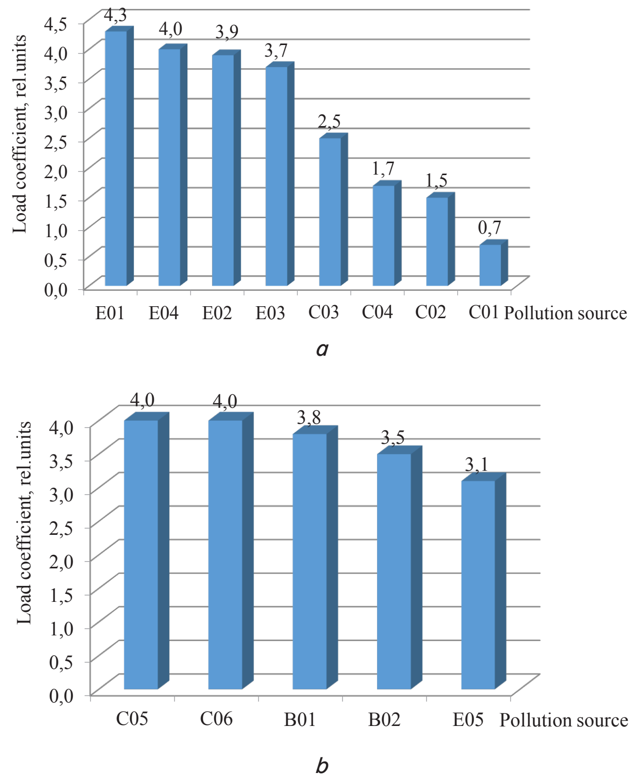


Fig. 4. Influence of pollution sources by indicators of the load on an aquatic site in: *a* — basin of the South Buh; *b* — the Buh estuary

The ecological efficiency of this enterprise can be significantly enhanced through the introduction of a complex of water protection measures. The negative impact of the site on the water may be decreased due to the installation of plants of deep biological treatment, construction of local treatment facilities at the enterprises of the city, increasing the power of the watercourse scattering discharge, reconstruction of secondary settling reservoirs.

2) Treatment facilities of the water pipeline of CME "Mykolaivvodokanal", sewage discharges also adversely affect the state of the Buh estuary. According to the general classification, the sewage of this enterprise is characterized as moderately hazardous (class III). However, too high content of heavy metals in sewage of this enterprise creates a high level of anthropogenic load and hazardous influence on the waters of the Buh estuary (Fig. 5).

3) RE Scientific-production complex of gasturbineconstruction "Zoria" – "Mashproject" has the worst indicators that characterize the conditions of sewage discharge, the general state and a high level of hazard. Wastewater of the enterprise can be characterized as moderately harmful. However, the level of harmful influence and load on the Buh estuary because of the large amount of pollutants, discharged annually, is rated as high.

4) PSC Mykilaiv shipbuilding plant "Ocean", discharge 9, has a high level of hazard that is above the standards and unsatisfactory conditions of discharge. Although the sewage quality can be characterized as moderately harmful, a high content of heavy metals in discharge increases the total level of load and adverse effects on the water site.

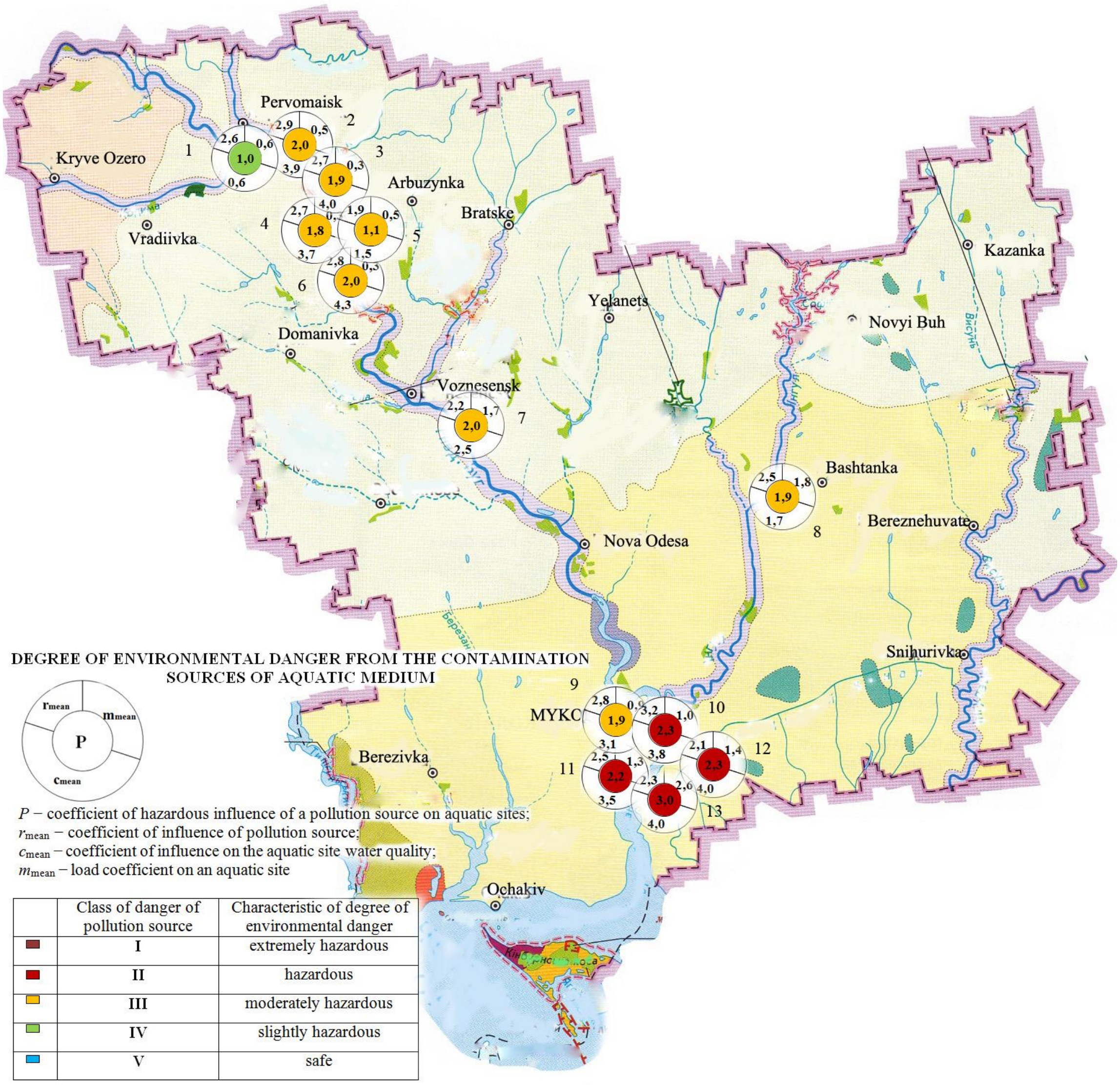


Fig. 5. The map of environmental hazard of sources of pollution of the South Buh basin in Mykolaiv Oblast

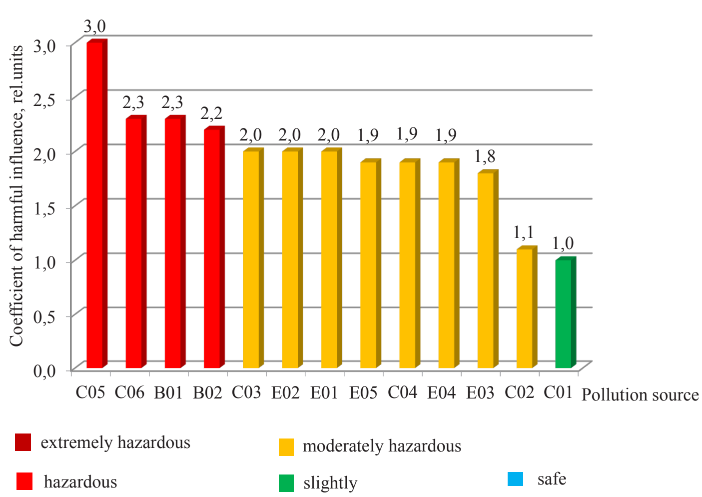


Fig. 6. Ranking of the sources of pollution of aquatic sites on the territory of Mykolaiv Oblast according to the degree of environmental hazard

The moderately hazardous include:

1) enterprises of housing and communal services – LLC "Biological treatment facilities" in Voznesensk, ME "Mìsk-vodokanal" in Bashtanka, CVKG and TM SE "Yuzhnoukrainsk NPP";

2) production enterprises – PSC Mykolayiv shipbuilding plant "Ocean", discharge 7;

3) enterprises of electric power industry – Pervomaisk HES, PE "Yuzhnoukrainsk NPP", Mygiiv HPS, Konstantinìvka HPS, OJSC "Mikolaiv teploelectrocentral, discharge 1.

The slightly hazardous enterprises include "Pervomaisk city vodokanal" and OJSC "Mykolaiv teploelectrocentral", discharge 2.

6. Discussion of results of evaluation of environmental hazard of sewage discharge sources on the territory of Mykolaiv region

The developed criterion of assessment of the level of environmental hazards of pollution sources of water sites has a comprehensive character. Different researchers propose the criteria that take into consideration either only indices of sewage harmfulness, or indicators of load on an aquatic site. In this work, it was proposed to make the estimation by the entire totality of the mentioned values, together with the indicators of environmental risk. The criterion developed in the study for the first time includes such indicators as the characteristics of the technical condition of water treatment equipment, location of discharge, the way of sewage discharge. Thus, virtually the entire range of possible negative effects of pollution sources on the state of aquatic environment is taken into account.

The developed logical-mathematical model makes it possible to estimate with high accuracy the level of dangerous environmental impact of the sites of different sectors of the economy. The use of the proposed model enables us with high reliability to conduct a comparative analysis of the negative effects of separate discharges of large enterprises on the state of the hydrosphere. Another direction is to evaluate block-by-block the hazard, the degree of influence on water quality of a water site, the effectiveness of monitoring and the magnitude of anthropogenic load. The results, obtained using this model, significantly increase the efficiency of the procedure of selecting priority directions of water protection activity of this enterprise which are included to the program of development.

The joint use of the developed procedure with the traditional methods of water quality evaluation enable us to determine the ecological state of territories with greater accuracy and information. A comprehensive assessment in this case, in addition to identifying the biological, hydro-morphological and physical-chemical indicators according to the Water Framework Directive of the EU 2000/60/EU, will be supplemented by an analysis of the degree of hazard of potentially dangerous sites. Identification of the most significant pollution sources, taking into consideration the probability of adverse effects of economic activity will make it possible not only to determine the places, but also to establish the causes of emerging the zones of increased level of pollution of an aquatic site.

The obtained results of testing well correlate with the results of monitoring the state of the South Bug river basin of the state environmental control authorities.

The cause of the described situation is the modern economic state in the region. Under conditions of decreasing volumes of industrial production, large enterprises of housing and communal services have the greatest degree of environmental hazard. The main reason for the negative impact is inefficient functioning of these structures. Insufficient capacity of the treatment facilities causes too high content of heavy metals in wastewater. Unsatisfactory state of deep-sea sewage discharges creates the zones of unacceptably high concentrations of such substances.

At the same time, enterprises of the machine-building industry that continue functioning, are characterized by a considerable volume of untreated sewage discharges with low multiplicity of dilution, and in some cases have incorrect organization of location places. That is why, very often, it is impossible to control the actual quantity and quality of sewage coming to an aquatic site. It should be noted that even sewage discharges of such enterprises contain dangerous and toxic substances. Thus, the named sites can be attributed to class II and described as "hazardous". The following pollution sources create a high level of threat to the life and health of the population and hydrobionts. Sewage discharges of such sources significantly alter hydrological or hydro-chemical characteristics of wastewater receivers. This leads to significant pollution of an aquatic site and the impossibility of its using as a source of economic-drinking water supply. The suitability of the aquatic site for other types of water supply of the population also decreases substantially. These changes lead to a decrease in the indicators of water quality of the water body – receiver to the level "bad", according to "The Water Framework Directive of the European Union" (2000/60 EU).

The enterprises of nuclear power and hydro power plants can be characterized as "moderately hazardous" (class III). The negative environmental impact of such enterprises is caused by the high amount of discharges and, therefore, the total amount of pollutants in the water. At the same time, the concentration of pollutants in the discharge corresponds to the low level of harm, which reduces the general level of hazard. Sewage discharges of such sources change the hydrological or hydro-chemical characteristics of an aquatic site – sewage receiver to the "satisfactory" level. These changes decrease the suitability of an aquatic site for all types of water supply of the population. That is, its environmental potential corresponds to the "satisfactory" level [10].

The same result was obtained in this study when assessing the impact of municipal enterprises of the cities with the population from 20 to 100 thousand people. However, the causes of this situation are opposite: high concentrations of polluting substances at an insignificant amount of sewage.

It should be noted that the reconstruction of wastewater treatment facilities of municipal enterprises, introduction of highly effective methods of treatment makes it possible to decrease the level of hazard to "slightly hazardous". As an example, we can specify the source C 01, where modern water treatment facilities have been mounted in recent years (Fig. 5). Sewage discharges of such sources to a minor extent change the hydrological, hydro-chemical characteristics of an aquatic site, which corresponds to the "good" state of water quality according to [10]. Such changes will not reduce the suitability of an aquatic site for all types of water supply of the population. However, under such circumstances, the natural attractiveness of an aquatic site as a place of rest can worsen as a result of steady unpleasant smell, toxic or irritating actions that may prevent the use of beaches. Therefore, these water bodies belong to the sites with "good" potential.

Thus, the developed procedure for assessment of the level of environmental hazard of point sources of pollution of aquatic sites can be considered adequate. The results of the study showed a high enough level of sensitivity of the developed procedure to a change in technological indicators of wastewater treatment facilities and sewage discharges. That is why the assessment of the degree of ecological hazard by the total coefficient of harmful influence of a pollution source on aquatic sites can be used for a wide range of river basins. Such territories may differ by the character of current, the average annual volume of water body area, water consumption intensity, the regional structure of the economy, population density, etc. For example, a significantly higher number of industrial enterprises – surface water pollutants is characteristic of the EU countries. On the other hand, the effectiveness of functioning of treatment facilities of such sites is higher in comparison with Ukraine. That is why the assessment results for these territories can differ from those obtained in this study. However, the structure of the proposed indicators of environmental hazard is universal because it is based on the regulatory requirements, accepted in developed countries.

Possible directions of improvement of this procedure are consideration of quantitative indicators of operation reliability of the water treatment systems and facilities and the adaptation to the sources of pollution of marine environment.

7. Conclusions

1. We developed the new methodological approach to the evaluation of the degree of environmental safety of aquatic sites based on the comparison of levels of hazard, influence on water quality of an aquatic site, effectiveness of monitoring and anthropogenic load of separate point sources. It was proposed to carry out the assessment of the degree of environmental hazard of sources of pollution of aquatic sites by the value of coefficient of harmful influence of a pollution source on aquatic sites by the five-level scale from "safe" to "extremely hazardous". The designed scale corresponds to the ecological classification of the Water Framework Directive of the EU 2000/60/EU.

2. The logical-mathematical model of evaluating the impact of pollution sources, based on determining the coefficients of conditions of wastewater discharge, wastewater pollution and the load on an aquatic site, was developed.

3. The developed model was tested on the example of the section of the South Buh river basin. It was established that large enterprises of housing and municipal services and production facilities of machine-building industry pose the highest environmental danger. Sewage discharges of such facilities lead to a decrease in indicators of the water quality of a water body-receiver to the "bad" level and are characterized as "hazardous". Results of the analysis can be used in the development of water resources management strategies and the measures for reducing the impact of pollution sources on aquatic sites.

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CURRENT DISTRIBUTION OF ^{137}Cs IN SOD-PODZOLIC SOILS OF DIFFERENT TYPES OF FOREST CONDITIONS

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Досліджено сучасний розподіл ^{137}Cs у дерново-підзолистих лісових ґрунтах різних типів лісорослинних умов. Аналіз перерозподілу ^{137}Cs у ґрунті через 30 років після аварії на ЧАЕС є необхідним для оцінки надходження радіонукліда у різні компоненти лісових екосистем та обґрунтування реабілітації лісових територій. Виявлено переміщення значної кількості ^{137}Cs до мінеральної частини ґрунту у всіх типах лісорослинних умов, у яких проводились дослідження. Встановлено максимальні величини питомої активності ^{137}Cs у лісовій підстилці, а також зменшення даного показника від верхньої її частини (сучасного опаду) до нижньої (розкладеної). У свіжих борах дане зменшення складає 3,1 разів, свіжих суборах – 1,2 разів, вологих суборах – 1,5 разів. За величиною питомої активності ^{137}Cs шари лісової підстилки у досліджуваних типах лісорослинних умов можна розмістити у порядку зменшення: розкладений шар > напіврозкладений шар > сучасний опад. У гумусово-елювіальному горизонті ґрунту потужністю 12 см сконцентровано у свіжих борах – 54,0 %, свіжих суборах – 40,0 % і вологих суборах – 52,8 % від загальної активності радіонукліду у ґрунті, а разом з вмістом ^{137}Cs у лісовій підстилці – 75,0 %; 65,8 % і 71,5 % (відповідно до типів лісорослинних умов). Відмічене поступове зменшення питомої активності ^{137}Cs по профілю до материнської породи. Так, до нижніх шарів ґрунтового розрізу (12–88 см) мігрувало відповідно 26,4 %, 35,7 % та 28,5 % від загального запасу радіонукліду у ґрунті. Отримані матеріали підтверджені за допомогою однофакторного аналізу на 95 %-му довірчому рівні. На основі отриманих результатів можна спрогнозувати майбутні рівні радіоактивного забруднення продукції лісового господарства

Ключові слова: ^{137}Cs, радіоактивне забруднення, питома активність, лісові насадження, дерново-підзолисті ґрунти

1. Introduction

It is known that the radionuclides, upon entering the components of forest ecosystems, gradually moved from the upper to the lower tiers of vegetation and the soil surface. Over time, the main volume of radioactive elements moved to the forest litter and, depending on the type of forest conditions and the composition of tree tier, the migration of radionuclides of different intensity into the mineral part of forest soils started. The result of the accident at the Chernobyl nuclear power plant (CHNPP) is the fixation of the radionuclides in soil and their penetration to the numerous components of forest biocenoses. These components of the forest ecosystems have been widely used in the practice of forest management, as well as by the local population for their own use. Traditionally, the local population uses the non-tree products of the forest: wild berries, mushrooms, and medicinal plants. The dosage of internal irradiation due to the consumption of the specified forest products varies from 12 to 40 % for the total population, and from 50 to 95 % for the critical groups of population [1]. Thus, along with the "forest gifts", the population receives a significant dosing load. Radioactive contamination of certain components of forest ecosystems, which are subsequently utilized as raw materials for the manufacture of food products, depends on the generic features and the type of forest conditions. For the time being, studies into the redistribution of radionuclides in forest soils have almost stopped; existing publications are based on the fragmented materials while data on the current distribution of ^{137}Cs in the turf-podzolic soils are lacking.