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DEVELOPMENT OF METHODS FOR ESTIMATING THE ENVIRONMENTAL RISK OF DEGRADATION OF THE SURFACE WATER STATE

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Пропонуються методи визначення екологічного ризику погіршення стану річкових басейнів на державному, регіональному та місцевому рівні. Для розробки комплексу природоохоронних заходів передбачається визначення впливу природних і антропогенних чинників з урахуванням ландшафтних і географічних особливостей річкових басейнів. Застосування запропонованого підходу дасть змогу справедливо оптимізувати фінансові ресурси на оздоровлення водних екосистем

Ключові слова: водоохоронна стратегія, екологічний ризик, кліматичні зміни, раціональність водокористування, річковий басейн

Предлагаются методы определение экологического риска ухудшения состояния речных бассейнов на государственном, региональном и местном уровнях. Для разработки комплекса природоохранных мероприятий предусматривается определение влияния природных и антропогенных факторов с учетом ландшафтных и географических особенностей речных бассейнов. Применение предложенного подхода позволит справедливо оптимизировать финансовые ресурсы на оздоровление водных екосистем

Ключевые слова: водоохранная стратегия, экологический риск, климатические изменения, рациональность водопользования, речной бассейн

1. Introduction

Modern trends in climate change affect the state of quality and hydrological regime of water bodies in all countries of the world, which requires development of new approaches to the scientific substantiation of water protection strategy. Adaptation to new climatic conditions, a growth of anthropogenic pressure, emergencies related to an increase in the number of floods and droughts requires a new concept of water protection policy.

An achievement of target characteristics of the ecological state of surface water taking into consideration landscape and geographical features of river basins and a gradual reduction of ecological risk should be a base of the water resources management program.

The regional strategy for achievement of target characteristics of the ecological state of water bodies should be based on a forecast of climate changes with definition of a risk to health of the population and natural ecosystems, as well as technological and socio-economic opportunities of the society.

Decentralization of water resources management implies the necessity of scientific substantiation of a complex of environmental protection measures at state, regional and local levels. That is why the hierarchical approach to determining environmental risk of deterioration of a state of water bodies presented by this study is very important.

2. Literature review and problem statement

Environmental legislation is one of those tools that combine a rational use of natural resources with prevention and control of environmental pollution. The aim of the environmental policy of the European Union is to ensure environmental sustainability through the inclusion of the development of prevention measures following the basic principles of sustainable development and adoption of common commitments in sectoral EU policies. The mentioned laws are trying to ban or limit effects of environmental degradation. Environmental legislation should be flexible in the first place in order to make the implementation of current and future goals possible in order to stimulate a concept of sustainable development and a solution of complex environmental problems. Despite significant improvements in the environment, especially in reducing air and water pollution, European legislation needs to evolve further. The process of implementation and adoption of new normative legal acts on environmental protection is ongoing in the European Union to eliminate causes of deterioration of a quality of the environment and a quality of life [1].

Paper [2] analyzes the Protocol on Problems of Water and Health to the Convention on the Protection and Use of Transboundary Watercourses and International Lakes. The main objective of the protocol is to protect human health and well-being with improved water management, including protection of aquatic ecosystems, prevention, limitation and reduction of the spread of water-related diseases. The protocol takes into consideration differences in health, environmental and economic conditions in the region and gives states-participants a freedom to determinate priorities taking into consideration specific situations. In addition, the protocol reflects innovative functions of modern environmental law and includes regulations related to international cooperation and international support for national actions in support of its implementation. It is necessary to identify transboundary watercourses that are in the worst state according to the general methodology for implementation of international cooperation. This would make possible to determine the priority of implementation of water protection measures. The aim of methods of assessment of the environmental risk related to deterioration of a state of surface waters proposed in this study is a solution of the mentioned problem.

Improvement of the current state of aquatic ecosystems involves integration of key principles of the ecosystem approach to water policy. A work [3] presents an innovative approach to monitoring of a quality of water and assessment of the ecological state of water bodies for the achievement of a good ecological state for all Romanian reservoirs. The approach considers a river system as a set of ecosystems, which includes not only rivers, but also coastal zones with species of plants and animals that inhabit a space. Work [3] presents hydromorphological characteristics determined in accordance with the requirements of the Water Framework Directive [4] and the hydromorphological classification of rivers in five classes of quality. The aim of improved monitoring systems is improvement of the quality of water in Romania. But the work does not consider an impact of a use of a water catchment area of river basins on the ecological state of water bodies. A base of the methodology for assessing the environmental risk of development of degradation processes in river basins at the local level, which this study presents, is determining the rationality of economic use of a water catchment area.

Papers [5, 6] present proposals for improvement of a surface water monitoring system in Ukraine. It is necessary to add proposals for improvement of hydrobiological monitoring of surface water to the proposals presented in the mentioned works. This is important for the assessment of the ecological state of water bodies and meets the requirements of the Water Framework Directive.

Paper [7] presents a single transnational assessment of ecological characteristics in the Tisza river basin aimed at preservation of aquatic ecosystems. Authors applied a complex cross-sectoral approach to assess the current state of the Tisza basin. They analyzed the following characteristics: sources of surface water, water supply resources, a risk of failure to achieve environmental objectives, significant sources of water pollution, a water quality, sources of pollution of the air, soil, waste management. The paper does not show how authors defined environmental objectives, nor methods for assessment of an impact of negative factors on the ecological state of water bodies. The assessment of rationality of the economic use of a water catchment area involves determination of an impact of natural and anthropogenic factors on a state of aquatic ecosystems.

Economic efficiency of water preservation measures is an important component of integrated water resources management. The integrated water resources management system stipulates achievement of target characteristics of a state of water bodies taking into consideration economic tools and technological capacities of water users [8]. In Ukraine, developers of programs for rehabilitation of river basins do not take into consideration technological and financial capabilities of water users for the implementation of environmental measures. It is necessary to implement an iterative approach to water resources management. The paper proposes an algorithm for improvement of a water protection strategy taking into consideration the environmental risk, economic and technological capabilities of enterprises and financial resources.

Articles [9, 10] consider issues of increasing of environmental safety and reducing a load on the environment. But the mentioned works do not consider economic and environmental effectiveness of reducing an impact of industrial enterprises on a state of water bodies. We believe that it is necessary to determine a degree of reduction of the environmental risk of deterioration of surface water at development of environmental measures.

There are scenarios developed for future emissions of greenhouse gases and aerosols, which will further increase the air temperature by 2 °C by 2100, based on the scientific assessment of the Intergovernmental Panel on Climate Change (IPCC). An impact of climate change on water resources necessitates focusing on flood control and protection of aquatic ecosystems, as global warming has an impact on all aspects of water management. An increase in temperature, a loss of snow cover, increasing sizes and frequency of floods and rising sea levels are just some of effects of climate change, which are important for water resources management. The aim of paper [11] is to highlight environmental risks caused by climatic abnormalities for water resources to study negative effects of the greenhouse effect on demand and supply on water and socio-economic implications. Climate change has an impact on increasing of the environmental risk of deterioration of surface water. Therefore, the study presents a forecast of a temperature increase and precipitation reduction in Kharkiv region.

A number of floods and droughts increased due to climate change, so integrated water resources management became increasingly important in recent times. Korea's experts are working to prevent flood and drought-related disasters based on coordinated water management work [12]. Measures to reduce the ecological risk of well-being violation of a water ecosystem at the regional level taking into consideration climate change will help to prevent emergencies.

Challenges and threats currently facing water management and growing uncertainty about climate change evidence a clear need for a flexible system of environmental regulation. A correct balance between implementation flexibility and reliable standards compliance is critical to strengthening of the adaptive capacity in water resources management. But the achievement of the mentioned objectives creates particular difficulties at the same time. The EU's approach to water resources management is aimed at strengthening of a local governance at the appropriate levels [13]. The article proposes definition of target and permissible environmental standards of a state of surface water in order to introduce a flexible system of ecological regulation. This study proposes a method for assessment of a risk of degradation processes in river basins at the local level. The method is a part of a hierarchical approach to assessment of the environmental risk of deterioration of a surface water state. In order to solve the problem of strengthening of local water resources management, the article proposes definition of a complex of environmental protection measures on the basis of assessment of rationality of the economic use of a water catchment area.

Many studies investigate an influence of forest and climate variability on hydrological parameters. Study [14] applies a comprehensive approach to isolate an influence of changes in forestry, climate variability and other factors on hydrological fluctuations of flow in two major rivers in China. Studies showed that deforestation led to a significant reduction in flow during a dry season, while fluctuations in the climate had a positive effect in the studied water catchments. The impact of deforestation on hydrological parameters varies over time because of changes in infiltration and evaporation in the soil. Changes in sub-alpine natural forests have a greater impact on the dry season's flow. These data are useful for water resources management and forestry management under climate change conditions. Paper [14] considers an influence of the percentage of forestland of a water catchment and climate changes on hydrological parameters, but it does not present an assessment of an influence on a state of aquatic ecosystems. The influence of reducing a percentage of a woodland, especially under conditions of an increase in average annual temperature and a decrease in the amount of precipitation, as proven by forecast characteristics in the article, leads to an increase in the ecological risk of deterioration of a surface water state.

Water resources management with taking into consideration the analysis of a state of agricultural water catchments with a use of geographic information systems (GIS) becomes essential for solution of environmental problems in South Texas [15]. There are many land-use conflicts in this area and they contributed to degradation of water ecosystems greatly. The obtained results indicate the growing degradation of ecosystems over time and the geographical cluster of countries experiencing environmental stress. There are the following stress factors identified: a population growth, an increased use of fertilizers, a growing area of agricultural land, emissions of atmospheric pollutants, a presence of a large number of domestic and industrial wastewater treatment plants. An inflow of pathogenic microorganisms and pesticides directly from agricultural water catchments poses a serious threat to a quality of aquatic ecosystems [15]. The work determines significant factors of negative influence on a state of water bodies, but it does not present methods for assessment of the influence. Therefore, it is important to assess rationality of the economic use of a water catchment area, which is the basis for determination of a risk of degradation processes in river basins.

About a half of the world's population lives in urban areas today, and in the next 20 years, urbanization will increase steadily, especially in the developing world. Large cities face the problem of providing good quality water. In addition, flooding is a threat to city dwellers during a rainy season in tropical urban areas. Paper [16] identifies the main problems of water resources management: insufficient water resources, pollution of underground and surface waters, loss of biodiversity, overcoming of administrative and financial difficulties, as well as operational failures. In order to solve the mentioned problems, it is necessary to implement the following measures gradually: an optimal use of surface and ground water, protection against pollution, management of water catchment basins, flood prevention, technological innovations, economic tools [16]. The paper shows an influence of urbanization on a state of the environment and highlights general directions of improvement of water resources management. But it does not show how the mentioned negative factors affect an increase of the environmental risk of deterioration of surface water state. Therefore, it is relevant to continue research [16] into determining specific ways to solve the problems presented in the work.

Paper [17] analyzes the legislation on water management in Sao Paulo. It shows that the basic importance of protection of water sources is integration of water resources management and a land use. The new Water Protection Act No. 9.866/97 stipulates decentralization and integrated management. However, harmonization of public policy in this sector, broad coordination and cooperation between municipalities are necessary for the effective implementation of the law [17].

The solution to the problem of water quality improvement requires integrated water resources management. Environmental policy includes economic and socio-ecological models, as well as decentralization and transition to a new system of basin management. The analysis of water quality management in Georgia showed that transition countries need institutional development and a change in the regulatory framework [18]. Ukraine also refers to countries with transitional economies and needs integrated water management to improve aquatic ecosystems and to reduce a risk of deterioration of surface water.

The above studies elucidate certain issues of water resources management: legal, institutional, technological, economic, and social ones. A state of surface water shows an influence of various negative factors (increasing urbanization and plowed land areas, reducing forest covering, climate change, etc.). The studies prove a need to implement integrated water resources management. Therefore, it is promising to improve the management of a quality of water resources on the basis of a hierarchical approach to definition of the environmental risk of deterioration of surface water state. Each stage of environmental risk assessment at state, regional and local levels has its own objective and tasks aimed at the improvement of water ecosystems.

3. The aim and objectives of the study

The aim of present study is to develop methods for determining the environmental risk of deterioration of surface water at the state, regional and local levels.

It is necessary to solve the following tasks to achieve the objective:

– to improve a method for assessment of the environmental risk of deterioration of surface water at the state level;

– to improve a method for assessment of the risk of water ecosystem well-being disruption at the regional level;

– development of a method for assessment of the risk of development of degradation processes in river basins at the local level;

– development of an algorithm for improvement of water protection strategy based on defining the ecological risk of deterioration of surface water state at the state, regional and local levels.

4. Methods for determining the environmental risk of deterioration of a surface water state at state, regional and local levels

4. 1. Method for assessment of the environmental risk of deterioration of surface water at the state level

We propose to determine a level of danger of the present state of a water use and identification of basins of the major rivers in the worst ecological state through an assessment of the ecological risk of deterioration of a surface water state.

Environmental risk (P_w) as a probability of disturbance of water ecosystem stability depends on the existing state of surface water and an influence of anthropogenic loading and can be expressed by function:

$$P_w = f\left(I_w, AP_w\right), \quad (1)$$

where I_w is the integral parameter of a surface water state, a dimensionless value; AP_w is the integral parameter of anthropogenic loading on the state of surface waters, a dimensionless value.

Achieving a critical state of surface water can occur in several scenarios. First, when the current state of surface water is very poor, then even a small anthropogenic pressure can lead to an intensive development of degradation processes, and secondly, when anthropogenic pressure exceeds acceptable volumes (Table 1).

We performed an analysis of the state of water bodies based on official monitoring data of surface waters of Ukraine.

Table 1

Characteristics of the ecological risk of deterioration of a surface water state by values of an integral parameter of surface water state (I_w) and values of an integral parameter of anthropogenic loading (AP_w)

State of surface water by a value of an integral parameter of a state of surface water (I_w)	Parameter of anthropogenic loading (AP_w)				
	Insignificant pressure	Increased pressure	SIGNIFICANT PRESSURE	HIGH PRESSURE	DANGEROUS PRESSURE
	Environmental risk of deterioration of surface water (P_w)				
very poor	**significant**	**significant**	***HIGH***	**CRITICAL**	**CRITICAL**
poor	***increased***	**significant**	**significant**	***HIGH***	**CRITICAL**
satisfactory	***increased***	***increased***	**significant**	***HIGH***	***HIGH***
good	*insignificant*	***increased***	**significant**	**significant**	***HIGH***
excellent	*insignificant*	*insignificant*	***increased***	**significant**	**significant**

We determined the parameter of an ecological state of surface waters by a value of an ecological index (Ie) according to the "Methodology for establishment and use of environmental quality standards for surface waters and estuaries in Ukraine" [19]. According to the above method, water bodies are assigned to one of 7 categories of water qualities and one of 5 classes of qualities according to the value of the ecological index (Ie).

The following formula determines a value of the ecological index of water quality [19]:

$$I_e = \frac{(I_1 + I_2 + I_3)}{3}, \quad (2)$$

where I_1 is the index of contamination with components of saline composition; I_2 is the index of trophic-saprobiological (ecological-and-sanitary) parameters; I_3 is the index of specific parameters of toxic and radiation action.

We carried out the overall environmental assessment of a water state according to the basin principle. For this purpose, we obtained block indices of environmental assessment for each item in two ways: by averaging categories of parameters in a block and by selection of the worst one in a category block. The general ecological assessment index is an average block index for each item. After that, we averaged the obtained indices by all points of a basin. The estimate is based on average values and on an average of the worst variables by points of a basin.

We propose to determine the integral parameter of a surface water state (I_w) by values of the ecological index (*Ie*) by the formula:

$$I_w = 1 - \left(\frac{n - K_{ie}}{n}\right), \quad (3)$$

where K_{ie} is the corresponding class according to values of the ecological index (*Ie*); n is the total number of classes according to the "Methodology for establishment and use of environmental quality standards for surface waters of land and estuaries of Ukraine" (5 classes) [19].

We used official data from the National Report on the state of the natural environment of Ukraine to calculate an anthropogenic load on a surface water state.

We analyzed data regarding a volume of discharged return water and a volume of polluted substances released to determine a generalized parameter of an anthropogenic load on a state of surface waters.

It is important to know a level of pollution of wastewater that is thrown into surface water bodies by industrial enterprises, housing-communal and agriculture facilities. Therefore, in order to determine a level of an anthropogenic loading on surface water, it is necessary to use a parameter of average pollution of wastewater (IP):

$$IP = \frac{VP}{VS}, \quad (4)$$

where VP is the volume of pollutants discharged into water bodies, thousand tons; VS is the volume of wastewater discharged into water bodies, thousand m^3.

We propose to calculate the parameter of an influence of contaminated wastewater on river flow (IW) by formula:

$$IW = \frac{1000 \times VCS}{RM}, \quad (5)$$

where VCS is the volume of contaminated wastewater discharged into water bodies, million m^3; RM is the river flow in average for water year, thousand m^3.

All parameters are dimensionless, because they are reduced to an average in the country, and they are assigned to a class in accordance with Table 2 by their value.

Table 2

Characteristics of anthropogenic loading on aquatic ecosystems

Class	Value of anthropogenic pressure parameter	Level of danger of anthropogenic pressure on aquatic ecosystems
1	0.01–0.40	Insignificant pressure
2	0.41–0.80	Increased pressure
3	0.81–1.00	Significant pressure
4	1.01–1.80	High pressure
5	>1.80	Dangerous pressure

Then we average classes and determine a level of danger of the current state of water use by the formula:

$$AP_w = 1 - \left(\frac{m - K_m}{m} \right), \quad (6)$$

where AP_w is the integral parameter of anthropogenic load on a state of surface waters, dimensionless value; K_m is the generalized class of danger of current anthropogenic pressure on aquatic ecosystems; m is the total number of classes according to the characteristics of anthropogenic loading on aquatic ecosystems (Table 2).

We used a rank scale to determine a level of danger of anthropogenic load on aquatic ecosystems (Table 2).

We suggest to determine the ecological risk of deterioration of a state of aquatic ecosystems (P_w) by formula:

$$P_w = I_w \times AP_w. \quad (7)$$

Table 3 presents characteristics of the environmental risk by its value.

There is a generalized assessment of the environmental risk as a “macroecological indicator” in studies in the scale of a domain, a region, or for making of pre-planned generalized management decisions.

Table 3

Characteristics of the ecological risk of deterioration of a state of aquatic ecosystems

Class	Value of environmental risk parameter	Qualitative assessment of environmental risk
1	0.01–0.19	Insignificant risk
2	0.20–0.39	Increased risk
3	0.40–0.59	Significant risk
4	0.60–0.79	High risk
5	0.80–1.00	Critical risk

An assessment of the environmental risk of deterioration of a surface water state is necessary to perform to identify a level of danger of anthropogenic stress. Such an approach is aimed at determination of the priority of introduction and financing of environmental measures in river basins (the first stage of management of water protection activities).

A need to determine levels of the environmental risk in the regions of Ukraine in order to make managerial decisions on the priority of implementation of environmental measures and attraction of financial support, is primarily due to the state environmental policy on a regional principle, which is carried out in the field by regional departments of environmental protection.

Fig. 1 shows a schematic map of Ukraine with a designation of different colors of the regions of the country by determining the ecological risk of deterioration of a surface water state at preservation of the existing trends of anthropogenic loading.

According to Fig. 1, we can observe the greatest value of the ecological risk of deterioration of a surface water state in industrially developed regions – in Donetsk and Luhansk regions, where water flows from the Siversky Donets River basin.

The Seversky Donets River has a transboundary importance, because it flows through the territory of Russia and Ukraine. In Ukraine, water bodies of the Siversky Donets River basin are located in Kharkiv, Donetsk, and Luhansk regions.

There is no information on the current state of surface water and anthropogenic pressure on them in Donetsk and Luhansk regions due to military operations. Therefore, it makes sense to carry out further research for watercourses of the Siversky Donets River Basin located in Kharkiv region.

4. 2. Method for assessment of the risk of water ecosystem well-being disruption at the regional level

Paper [20] proposes a methodology for assessment of the environmental risk of degradation of a state of an aquatic ecosystem based on determination of ecological standards taking into consideration landscape and geographical features of river basins.

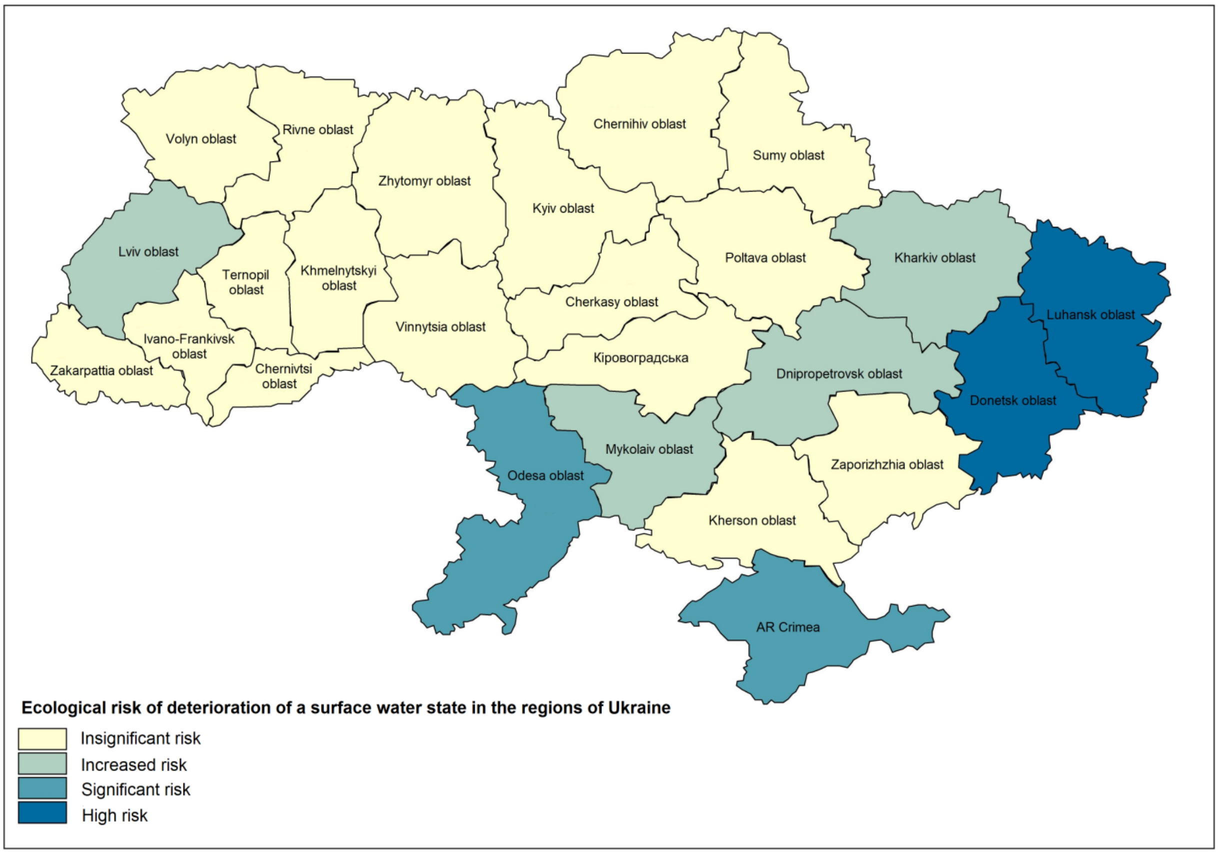

Fig. 1. Ecological risk of deterioration of the surface water state in the regions of Ukraine

There are two types of environmental standards developed according to the methodology [21]: acceptable ecological standards (ESa) and target environmental standards (ESt). Environmental standards are determined on the basis of processing of long-term (at least 30 years old) data of monitoring of hydrological, hydrochemical and hydrobiological parameters of a state of surface water and construction of forecasting models. The purpose of establishing acceptable ecological standards (ESa) is to justify an obligatory level of water quality for specific water bodies provided that a water ecosystem remains in a good state [20]. Target ecological standards (ESt) are developed for a multi-year period taking into consideration social, economic and technological opportunities of achievement provided implementation of an iterative approach to the management of a surface water quality.

Determining an ecological index using a new method of environmental assessment of a quality of surface water in the relevant categories [22] is a base for the development of environmental standards.

At present, there are environmental standards for only some rivers in the country developed by the methodology [21]. This study should continue, and definition of the environmental risk of deterioration of an aquatic ecosystem by the methodology [20] at the regional level will become a further prospect.

Paper [20] proposes a methodology for assessment of the risk of water ecosystem well-being disruption based on determination of the ecological index (Ie) according to the "Methodology for establishment and use of environmental quality standards for surface waters of land and estuaries in Ukraine" [19].

There is a proposition to use the upper limit of category 3 of the classification of a surface water quality, which corresponds to class II with a good state according to the methodology, as a threshold value [19].

We can accept only those parameters that exceed the upper limit of category 3 of classification [19] to determine the environmental risk, because it is considered that if an ecological norm is exceeded, there is a probability of water ecosystem well-being disruption.

But paper [20] proposes to limit a number of parameters to five. We consider such a restriction as incorrect, because the analysis of the ecological state of the Siversky Donets River in Kharkiv region showed an exceeding of the ecological norm by 8–10 parameters. Thus, the methodology for assessment of the risk of water ecosystem well-being disruption presented in [20] needs a serious improvement.

Probit-regression models are often useful to determine a "dose-effect" dependence in order to assess probability of negative consequences. We propose to assess a risk of water ecosystem well-being disruption (ER) by defining a probit using Table 4 based on equation:

$$\text{Prob} = -2{,}3 + 2{,}2\lg\sum\left(\frac{C_i}{C_{es}}\right), \quad (8)$$

where C_i is the concentration of i-th substance in a water body, mg/dm^3; C_{es} is the environmental standard for water bodies, which is defined as an upper limit of category 3 of the classification of surface water quality, which corresponds to class 2 of a good state, mg/dm^3.

Table 4

Normal-probabilistic distribution with interconnection of probits and risk

Prob	ER	Prob	ER
–3.0	0.001	0.1	0.540
–2.5	0.006	0.2	0.579
–2.0	0.023	0.3	0.618
–1.9	0.029	0.4	0.655
–1.8	0.036	0.5	0.692
–1.7	0.045	0.6	0.726
–1.6	0.055	0.7	0.758
–1.5	0.067	0.8	0.788
–1.4	0.081	0.9	0.816
–1.3	0.097	1.0	0.841
–1.2	0.115	1.1	0.864
–1.1	0.136	1.2	0.885
–1.0	0.157	1.3	0.903
–0.9	0.184	1.4	0.919
–0.8	0.212	1.5	0.933
–0.7	0.242	1.6	0.945
–0.6	0.274	1.7	0.955
–0.5	0.309	1.8	0.964
–0.4	0.345	1.9	0.971
–0.3	0.382	2.0	0.977
–0.2	0.421	2.5	0.994
–0.1	0.460	3.0	0.999
0.0	0.50	–	–

Table 3 gives the classification of ecological risk of water ecosystem well-being disruption by its value.

The presented methodology provides an assessment of the ecological risk of water ecosystem well-being disruption for watercourses of basins of the Siversky Donets River in Kharkiv region (Fig. 2).

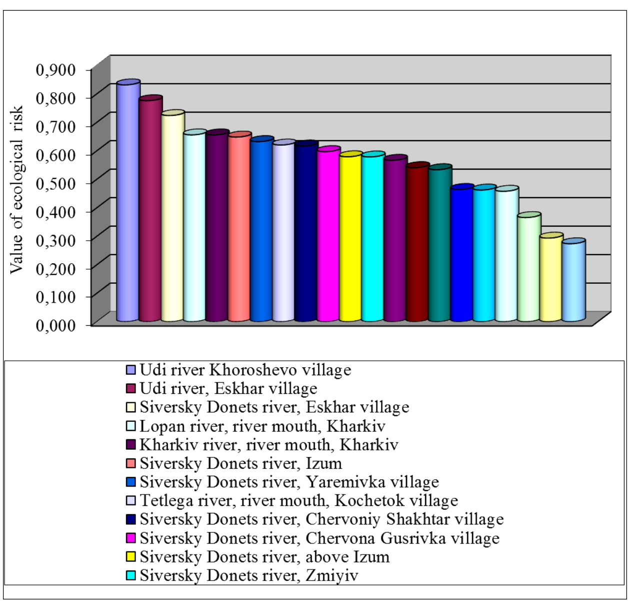

Fig. 2. Ranking of water cources of the Siversky Donets river basin in Kharkiv region by the environmental risk of water ecosystem well-being disruption

As shown in Fig. 2, there is the Udi river in the area below the city of Kharkiv in the worst state. Therefore, it is necessary to determine an influence of natural and anthropogenic factors on the ecological state of the river and to analyze rationality of the economic use of a water catchment area of the river basin to define a complex of environmental protection measures.

4. 3. Method for risk assessment of development of degradation processes in river basins

We need a comprehensive analysis of interconnections of all components of a landscape-geographical system in general, consideration for genesis and properties, patterns of formation and changes under an influence of natural and anthropogenic factors for rational use of water resources. At the local level, when managing a surface water quality, we should pay a particular attention to the improvement of small rivers, as they are the main elements of the geographical environment.

Small rivers form water resources, hydrological regime and water quality of medium and large rivers, they create natural landscapes of large territories, and, on the other hand, a state of regional landscape complexes determine functioning of basins of small rivers [23].

An important feature of small rivers is the dependence of water content, hydrological regime and water quality on parameters, which characterize a surface of a water catchment (percentage of forestland, bogginess, erosion, cultivation, overregulation, etc.) [24].

Many studies investigate influence of percentage of forestland, cultivation, meadow formation on a state of aquatic ecosystems, especially small rivers [14, 15, 23–25].

Forest plantations affect a quality of surface water, they absorb cations and anions from a solution, improve bacteriological properties of water, purify it from suspended solid particles and affect a temperature mode of water bodies. Forest contributes to transition of surface flow to an internal one and an increase of flow due to underground nutrition, and it also reduces a peak load of a surface flow [25].

Thus, we can state that forest has the following functions in formation of a river flow:

– forest arrays intercept atmospheric precipitation using moisture partially to support their livelihoods (transpiration, feeding of root systems, etc.), and partially to replenish groundwater, and reduce a surface flow;

– forests evaporate much more moisture than a grassy surface. Forest floor absorbs water from melted snow, infiltrates it into the soil and replenishes ground water providing underground food;

– rivers with water catchment areas covered with forest have, in comparison with forestless ones (located in the same zone), a flow, which is more steady in time.

Meadow formation of a catchment area also affects the ecological state of a river greatly:

– a meadow is a natural surface flow filter, it provides solid flow sedimentation processes;

– a meadow intercepts a surface flow partially;

– a meadow is a mechanical protection against erosion and destruction of floodplain soils and silting of rivers.

Paper [26] analyzes rationality of a use of a water catchment area of small rivers in the Oshkil basin by the methodology [24]. The paper gives estimation of an influence of positive and negative factors on the intensity parameter of degradation processes occurring in a river basin (formation of ravines, erosion of land, silting, bogginess).

The method [24] proposes to identify “negative” factors that cause or can accelerate a process of degradation of ecosystems and “positive” factors that can stabilize a state of aquatic ecosystems. We can consider the ratio of a value of a negative impact of anthropogenic factors to a value of positive effects of natural factors as a measure value for the risk of degradation processes.

Anthropogenic factors, which are a cause of degradation processes in river basins, include:

– percentage of plowed land (P);

– diffuse sources of surface water pollution (DS);

– water intake by industrial, communal and agricultural enterprises (WI);

– sewage of industrial, communal and agricultural enterprises (WS).

Large percentage of plowed land intensifies processes of erosion and formation of ravines and leads to silting of rivers. Percentage of plowed land (P) is one of the main negative factors in development of degradation processes in river basins. The ratio of an area of plowed land to an area of a river basin determines it by the formula:

$$P = \frac{S_p}{S_{RB}}, \quad (9)$$

where S_p is the area of plowed land in a river basin, ha; S_{RB} is the area of a river basin, Ha.

Diffuse sources of surface water pollution (surface flow from urbanized areas and agricultural land) affect a quality of water bodi e s, increase erosion processes, formation of ravines and silting of rivers. A monograph [27] describes a calculation of an inflow of pollutants to water bodies from diffuse sources of pollution described in detail.

The following formula calculates a parameter of an influence of di ffuse sources of pollution of surface water on development of degradation processes (DS):

$$DS = \frac{V_{DS}}{V_{RF95\%}}, \quad (10)$$

where V_{DS} is the volume of a surface flow from urbanized areas and agricultural lands to water bodies, thousand m^3; $V_{RF95\%}$ is the volume of a flow of a river of 95 % of provision, thousand m^3.

Water intake by industrial, communal and agricultural enterprises affects desiccation of water resources and reduction of natural flow of rivers. We can calculate a parameter of an influence of water intake (WI) as a ratio of a volume of water intake by enterprises-water users to a volume of a river flow of 95 % of provision by formula:

$$WI = \frac{V_{WI}}{V_{RF95\%}}, \quad (11)$$

where V_{WI} is the volume of water intake by enterprises-water users, thousand m^3.

Discharges of wastewater from industrial enterprises, communal and agricultural industries pollute water bodies with harmful substances, inhibit processes of self-purification and significantly degrade a state of aquatic ecosystems.

We can determine a parameter of an influence of wastewater discharges on development of degradation processes (WS) by formula:

$$WS = \frac{V_{WS}}{V_{RF95\%}}, \quad (12)$$

where V_{WS} is the volume of wastewater discharged by enterprises-water users, thousand m^3.

All of the above parameters are dimensionless and have a value of less than 1.

In order to determine a degree of a negative influence of anthropogenic factors on development of degradation processes in river basins, we propose to apply the above indicators to a coordinate grid in the percentage ratio. Then we can calculate a parameter of a negative influence of anthropogenic factors on development of degradation processes in river basins (AF) as a square of a quadrilateral by formula:

$$AF = 1/2(DS + P)(WI + WS). \quad (13)$$

Positive factors of stabilization and improvement of the state of aquatic ecosystems include:

– forestland (*F*);

– meadow formation (*G*);

– presence of lakes (*L*);

– river change flow rate (*RF*).

Forestland (*F*) is a ratio of an area covered by forest (S_F) to a total area of a river basin (S_{RB}), we can determine it by formula:

$$F = \frac{S_F}{S_{RB}}. \quad (14)$$

Meadow formation (*G*) is the ratio of a basin area covered by meadows (S_G) to a total area of a river basin (S_{RB}), we can determine it by formula:

$$G = \frac{S_G}{S_{RB}}. \quad (15)$$

Presence of lakes affects even distribution of a flow in a river. A parameter of presence of lakes (*L*) is a ratio of a total area of reservoirs (S_L) to a total area of a river basin (S_{RB}), we can determine it by formula:

$$L = \frac{S_L}{S_{RB}}. \quad (16)$$

A silting process depends on a hydrological regime of a river. A rate of change in a hydrological flow of a river (*RF*) is a ratio of flow norm (V_{RFR}) to an annual average river flow discharge (V_{RFM}), we can determine it by formula:

$$RF = \frac{V_{RFR}}{V_{RFM}}. \quad (17)$$

All the above parameters are also dimensionless and have a value less than 1. We propose to plot percentage ratio parameters of meadow formation (*G*), presence of lakes (*L*), a rate of river flow change (*RF*) and forestland (*F*) in a coordinate grid. Then we can calculate a parameter of an influence of positive factors on development of processes in river basins (*NF*) as a square of a quadrilateral by formula:

$$NF = 1/2(F + G)(L + RF). \quad (18)$$

We can determine a coefficient of direction of development of processes in river basins (*Kp*) by a ratio of a value of a negative influence of anthropogenic factors on development of degradation processes (AF) to a value of positive effects of natural factors (NF) by formula:

$$K_P = \frac{AF}{NF}. \tag{19}$$

If $AF>NF$, then $K_p>1$, then there is a probability of development of degradation processes in river basins as a result of excessive influence of anthropogenic factors.

It is necessary to determine watercourses with a value $K_p>1$ and apply the probit-regression method to assess a risk of development of degradation processes in river basins at the local level.

We can assess a risk of degradation processes in river basins by determining a probit using Table 4 based on equation:

$$\text{Prob} = -1{,}3 + 2{,}2\lg K_P. \tag{20}$$

Table 3 presents characteristics of the environmental risk by its value.

Fig. 3 shows ranking of small rivers in the Siversky Donets river basin in Kharkiv region by the value of a risk of development of degradation processes in river basins.

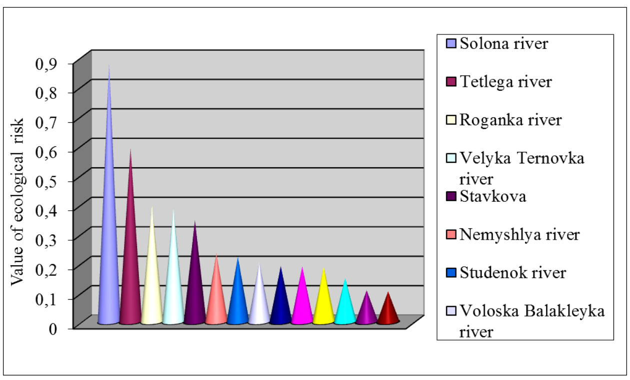

Fig. 3. Ranking of watercourses of the Siversky Donets river basin in Kharkiv region by a value of a risk of development of degradation processes in river basins

It is necessary to hold the following terms to stabilize formation of hydrological and hydrochemical regimes of a river:

$$(DS+P)(WI+WS)\angle(F+G)(L+RF). \tag{21}$$

We can achieve renewal of rivers through introduction of a complex of special organizational, agrotechnical, forest-melioration and other rehabilitation water protection measures.

The development of a complex of water protection measures requires an analysis of causes of degradation processes in aquatic ecosystems and factors that have a positive effect on the ecological state of rivers. It is also necessary to analyze rationality of economic activity in river basins and the existing state of environmental activity.

4. 4. Proposals for improvement of water protection strategy based on the determining of ecological risk

The following scheme can represent the algorithm for improvement of the water protection strategy based on the determining of the ecological risk of deterioration of a surface water state at the state, regional and local levels:

Stage 1 of the water protection strategy based on determining the ecological risk at the state level:

1) determination of the environmental risk of deterioration of a surface water state at the state level based on information on the ecological state of large rivers of the country and anthropogenic pressure on them;

2) identification of river basins with high ecological risk;

3) determination of the priority of financing of state programs for improvement of river basins with high environmental risk.

Stage 2 of the water protection strategy based on definition of the ecological risk at the regional level:

1) determination of the ecological risk of water ecosystem well-being disruption at the regional level based on information on exceeding the ecological standards in certain water bodies using the probit regression-model;

2) identification of a list of rivers with a high environmental risk;

3) research of an influence of anthropogenic and natural factors on the increase of a risk of water ecosystem well-being disruption;

4) determination of significant factors of influence on a qualitative state of water bodies in order to develop measures to minimize the environmental risk.

Stage 3 of the water protection strategy based on definition of the ecological risk at the local level:

1) determining a coefficient of direction of development of processes in river basins based on information on landscape and geographical features of rivers and the economic use of a water catchment area;

2) determining a list of rivers with a coefficient of direction for the development of degradation processes of more than 1;

3) assessment of a risk of degradation processes in river basins at the local level;

4) analysis of rationality of the economic use of river basins and their catchment area;

5) determining the most significant anthropogenic factors of influence on development of degradation processes in river basins based on ranking;

6) ranking of positive factors, which influence development of stabilization processes in river basins, in order to identify the most significant ones;

7) restructuring of the economic use of a catchment area based on determining the optimal parameters for forestlands, meadow formation and plowing for a separate river basin;

8) development of a complex of environmental protection measures based on determination of significant factors of influence on increasing the ecological risk and analysis of rationality of the economic use of a catchment area of a river basin;

9) analysis of technological opportunities for implementation of measures to improve the ecological state of water bodies;

10) development of an economic mechanism for attractiveness of implementation of environmental measures.

The water protection strategy should include monitoring of implementation of measures to reduce the environmental risk of deterioration of surface water at state, regional and local levels. Integrated management of water protection activities stipulates phased achievement of target ecological standards taking into consideration social, technological, and economic opportunities.

5. Results of assessment of environmental risk of deterioration of a surface water state

The results of assessment of the environmental risk of deterioration of surface water at the state level showed that there are water bodies of the Siversky Donets River basin, which flows in Ukraine through the industrial regions – Kharkiv, Donetsk, and Luhansk oblasts (Fig. 1), in the most dangerous state. There are no monitoring data on a state of water bodies and conditions of water use due to military operations in Donetsk and Luhansk region. Therefore, we conducted the study of the ecological state of watercourses of the Siversky Donets river basin in Kharkiv region.

The assessment of risk of water ecosystem well-being disruption of watercourses of the Siversky Donets basin in Kharkiv region showed that the Udi river is in the most dangerous state (Fig. 2, Table 5).

Table 5

Ranking of watercources of the Siversky Donets river basin in Kharkiv region by the risk of water ecosystem well-being disruption

Name of a river and post of observation	Ecolog-ical risk (ER)	Class	Characteristics of risk
Udi river, Khoroshevo village, below Kharkiv	0.831	5	Critical risk
Ud river, Yeskhar village, 3 km, river mouth	0.776	4	High risk
Siversky Donets river, Yeskhar village	0.724	4	High risk
Lopan river, Kharkiv	0.656	4	High risk
Kharkiv river, river mouth, Kharkiv	0.656	4	High risk
Siversky Donets river, below Izum	0.648	4	High risk
Siversky Donets river, Yaremivka village	0.632	4	High risk
Tetlega river, river mouth, Kochetok village	0.620	4	High risk
Siversky Donets river, Chervoniy Shakhtar village	0.617	4	High risk
Siversky Donets river, Chervona Gusarivka village	0.597	3	Significant risk
Siversky Donets river, above Izum	0.579	3	Significant risk
Siversky Donets river, Zmiyiv	0.578	3	Significant risk
Udi river, Peresechne village, above Kharkiv	0.567	3	Significant risk
Oskil river, Chervoniy Oskil village	0.541	3	Significant risk
Lopan river, Kazacha Lopan village	0.534	3	Significant risk
Siversky Donets river, Petrivske village	0.464	3	Significant risk
Vovcha river, Gatische village	0.462	3	Significant risk
Oskil river, below Kupyanska	0.458	3	Significant risk
Siversky Donets river, Ogirtseve village	0.366	2	Increased risk
Udi river, Okop village, Russia border	0.293	2	Increased risk
Oskil river, Topoli village, Russia border	0.274	2	Increased risk

We can observe in Table 5 that the greatest values of ecological risk demonstrated by the rivers after the course of the urbanized area and after an impact are of the industrial city of Kharkiv on the ecological state of the rivers.

Thus, a characteristic of the environmental risk of well-being violation in the Udi river ecosystem in Okop village at the border with the Russian Federation (RF) corresponds to class 2 (high risk), and below the city of Kharkov in the village Khoroshevo – to class 5 (critical risk). A value of the ecological risk of water ecosystem well-being disruption of the Lopan river increased from 0.534 in Kazacha Lopan at the border with the Russian Federation to 0.656 in the city of Kharkiv. This fact indicates a significant influence of wastewater discharges from industrial enterprises and utilities in the city of Kharkiv on the ecological state of watercourses of the Siversky Donets river basin.

Work [26] gives definition of significant factors, which influence the ecological state of the Oskil river. It is necessary to analyze an influence of natural and anthropogenic factors on the ecological state of the Udi river in order to substantiate a complex of measures to reduce environmental risk scientifically.

The forecast of temperature change in Kharkiv region based on observations from 1969 to 2016 shows an increase in the average annual temperature of 1.7 °C from 9.9 °C in 2016 to 11.6 °C in 2025 (Fig. 4).

There is a forecast based on observations of precipitation volumes in Kharkiv region for the period from 1969 to 2016, which shows a decrease in rainfall from 536.5 mm in 2016 to 504.78 mm in 2022.

We should note that a volume of wastewater discharged to the Udy river for the period from 1992 to 2016 decreased by 1.87 times from 368.4 million m^3 in 1992 to 197.2 million m^3 in 2016 (Fig. 5).

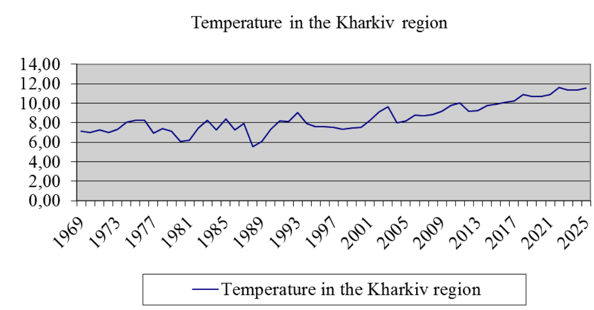

Fig. 4. Forecast of temperature changes in Kharkiv region until 2025

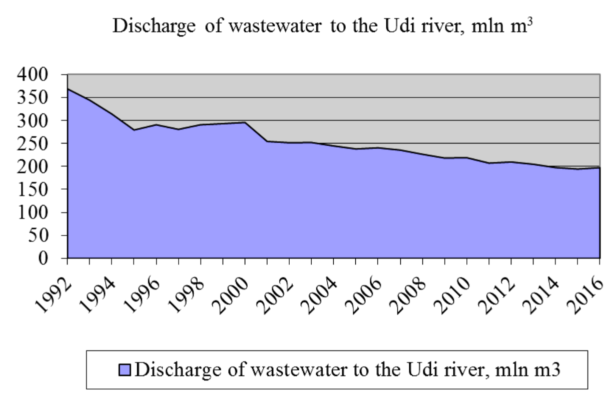

Fig. 5. Dynamics of wastewater discharge into the Udi river in Kharkiv region

The study into influence of wastewater discharge in the Udi river, an increase of temperature and a decrease of sediments in Kharkiv region on the ecological state of a water ecosystem by a value of the ecological index in the STATISTICA program showed that in wastewater discharge with a correlation coefficient of 0.747 is a significant factor.

It is necessary to carry out a research on landscape and geographical features of functioning of aquatic ecosystems and to analyze the economic use of a catchment area to develop a complex of environmental measures.

The assessment of the risk of degradation processes in river basins showed a dangerous level of economic water use (Fig. 3, Table 6).

Table 6

Ranking of small rivers of the Siversky Donets river basin in Kharkiv region by the importance of a risk of degradation processes

River name	Ecological risk	Class	Characteristic of a risk
Solona river	0.88	5	Critical risk
Tetlega river	0.59	3	Significant risk
Roganka river	0.40	3	Significant risk
Velyka Ternovka river	0.39	2	Increased risk
Stavkova basin	0.35	2	Increased risk
Nemyshlya river	0.23	2	Increased risk
Studenok river	0.22	2	Increased risk
Voloska Balakleyka river	0.20	2	Increased risk
Sukhiy Troets river	0.19	1	Insignificant risk
Lebyazha river	0.19	1	Insignificant risk
Balakleyka river	0.19	1	Insignificant risk
Lozovenka river	0.15	1	Insignificant risk
Kutziy tream	0.11	1	Insignificant risk
Britay river	0.10	1	Insignificant risk

To reduce the environmental risk, we propose to analyze an influence of anthropogenic factors on development of degradation processes in river basins and to identify measures to soften a negative impact.

We determine the complex of measures for the rational use of water resources for each small river based on landscape, hydrological and hydrochemical features, as well as technological and economic opportunities of water users.

6. Discussion of application of methods for assessment of the environmental risk of deterioration of the surface water state

A constant increase in anthropogenic loading under conditions of climate change leads to further pollution of water bodies of the country.

The study presents three methods of assessment of the environmental risk of deterioration of surface water state at regional, state and local levels. Each of the methods has a different degree of detail and needs information from official sources to calculate risks. This is the advantage of the methods, because it enables easy calculation with a use of modern programs and without additional measurements and surveys.

Only official monitoring data and regional reports and the National Report on the state of the natural environment of Ukraine are used at the state level to assess the environmental risk of deterioration of a surface water state.

The purpose of assessing the environmental risk of deterioration of surface water at the state level is the identification of the most polluted large rivers and areas of the country that require priority financing for implementation of environmental protection measures. This is the first stage of a water preservation strategy.

Determination of the ecological risk of deterioration of surface water at the state level will enable the Cabinet of Ministers of Ukraine to justify allocation of the necessary funds for state programs for improvement of river basins scientifically. Such solution is considerably relevant in a context of limited financial resources.

The industrial area of Ukraine – Donetsk and Luhansk regions relate to class 4 (high risk, Table 3) by the value of the environmental risk of deterioration of the surface water state. There are ecologically dangerous industrial enterprises, which exert an extremely large anthropogenic pressure on the environment, in the mentioned region. The ecological state of watercourses of the Siverskyi Donets river basin relates to class 5 according to the classification [19] by the value of the average annual ecological index (Ie), which corresponds to unsatisfactory quality.

The Siversky Donets river basin has transboundary importance and flows through the territory of Russia (Bilogorodskiy and Rostov regions) and Ukraine (Kharkiv, Donetsk and Luhansk regions). The total area of the river basin is 98.9 thousand km^2, 54.54 thousand km^2 or 55 % of which is located within Ukraine, with 40 % or 22.03 thousand km^2 located in Kharkiv region, respectively, – Donetsk 15 % and 7.95 thousand km^2, Luhansk – 45 % and 24.56 thousand km^2.

After the start of military operations in these areas, the situation deteriorated significantly, but there is no information on a state of surface water and conditions of water use. Therefore, we selected the Siversky Donets river basin in Kharkiv region for assessment of the ecological risk of deterioration of a surface water state at the regional level.

Paper [20] proposes a methodology for assessment of the risk of water ecosystem well-being disruption based on statistical processing of acceptable ecological standards for surface water quality. But the methodology for determination of environmental quality standards for surface water is not approved and applies only to certain rivers.

We proposed a methodology based on determination of exceeding the upper limit of category 3 of the ecological classification of surface water quality by the methodology to simplify assessment of the risk of water ecosystem well-being disruption [19]. We consider water bodies, which relate to category 3 according to the classification, as of "good" quality. Exceeding the limit means violation of the well-being of an aquatic ecosystem. The probit-regression method is for estimation of the risk of water ecosystem well-being disruption with definition for each contaminating substance of multiplicities of exceeding the upper limit of category 3 of ecological classification of surface water quality. The practical application of the method for watercourses of the Siversky Donets river basin in Kharkiv region made it possible to improve it. The method became easy to apply and showed good results.

The purpose for determining the risk of water ecosystem well-being disruption at the regional level is identification of a list of water bodies that require immediate implementation of environmental measures based on the analysis of the causes of surface water pollution. This is the second stage of a water preservation strategy.

The ranking of watercources of the Siversky Donets river basin in Kharkiv Oblast in terms of the environmental risk showed that the Udi river is in the worst state (Fig. 2, Table 5). In the village of Khoroshevo, which is located below the city of Kharkiv, the ecological risk value corresponds to class 5 (critical risk). Below, in the village of Eshara, the ecological risk value corresponds to class 4 (high risk).

We analyzed an influence of natural and anthropogenic factors on a qualitative state of a watercourse to determine causes of pollution of the Udi river. We fulfilled the forecast of climate change in the Kharkiv region by the Holt-Winters method. We expect that the average annual air temperature is going to increase by 1.7 °C by 2025 and precipitation is going to decrease to 504.78 mm in 2022. This circumstance indicates a need to adapt the water protection policy to changing climatic conditions.

The volume of discharge of wastewater to the Udi river for the period from 1992 to 2016 decreased by 1.87 times. However, determining significant factors of influence on a quality state of the Udi river showed that it is human-induced factors that determine the high risk of water ecosystem well-being disruption. In order to develop effective water protection measures, it is necessary to analyze rationality of the economic use of a water catchment area in more detail.

At the local level, surface water quality management requires special attention to small rivers that are most vulnerable to anthropogenic pressures.

A base of the proposed methodology for assessment of the risk of development of degradation processes in river basins at the local level is the study of landscape and geographical features of a water catchment area and water use conditions. The methodology is based on determining the stabilizing and negative factors of development of degradation processes, which is the basis for development of a required complex of environmental protection measures. This is the third stage of the water preservation strategy.

The ranking of small rivers in the Siversky Donets basin in Kharkiv region in terms of ecological risk showed that the Solon river is in the critical state (class 5) (Fig. 3, Table 6). The main reason is large-scale plowing of a water catchment area – 86 %, as well as wastewater discharges. For the rivers Tetleg, Roganka, Velyka Ternovka, Nemyshl, Studenok and Voloska Balaklejka, it is necessary to restructure the use of a catchment area in order to increase an influence of stabilizing factors. A prerequisite for development of a complex of environmental measures is a comprehensive study of causes of deterioration of a state of water ecosystems.

The proposed algorithm for improvement of the water protection strategy based on definition of the ecological risk of deterioration of surface water at the state, regional and local levels is aimed at introduction of a new integrated approach to surface water quality management.

We carried out approbation of methods for assessment of the environmental risk of deterioration of a surface water state for watercourses in Ukraine. We should note that application of the methods is possible for plain rivers of European countries.

The introduction of the proposed hierarchical approach to assessment of the environmental risk of deterioration of watercourses in European countries needs to be adapted to a monitoring system for surface water and the use of water resources.

A generalized assessment of the ecological risk of deterioration of a surface water state at the state level takes place during research at the scale of the region and area or for adoption of pre-planned generalized management decisions. A more detailed assessment of the environmental risk can be made provided sufficient data on ability of an ecosystem to self-heal from anthropogenic pressure based on the analysis of negative effects and factors of forecasted negative effects, levels of possible impacts of harmful substances and radiation, duration of exposure, scale of pollution distribution, taking into consideration landscape and meteorological conditions.

For a more detailed assessment of the environmental risk it is necessary to consider capability of an aquatic ecosystem to self-healing, remoteness of an ecosystem from a source of a pressure, duration of an influence of factors of anthropogenic pressure, etc.

In the future, we plan to improve the method of risk assessment of development of degradation processes in river basins taking into consideration processes of self-cleaning of rivers, features of a hydrological regime, landscape, and geographic characteristics of a water catchment area (including a soil cover), an impact of pollutant emissions into the atmosphere, waste placement and other negative factors.

7. Conclusions

1. The study proposes the method of assessment of the ecological risk of deterioration of a state of surface water at the state level. The application of the proposed methodology showed that there are watercourses of the Siversky Donets river basin in Luhansk and Donetsk regions in the dangerous state (class 4, high risk). Due to the lack of up-to-date information on the ecological state of water bodies and conditions of water use, we conducted further research for water courses of the Siversky Donets river basin in Kharkiv region.

2. We improved the method for assessment of the risk of water ecosystem well-being disruption. The ranking of watercourses of the Siversky Donets river basin in Kharkiv region showed that the Udi river is the most polluted by the values of critical (class 5) and high (class 4) risk of well-being violation of aquatic ecosystems. We fulfilled the forecast of climate change in Kharkiv region by the Holt-Winters method. There is a forecast about an increase in the air temperature of 1.7 degrees by Celsius by 2025 and a decrease in precipitation to 504.78 mm in 2022. The analysis of an influence of natural and anthropogenic factors on a qualitative state of the Udi river showed that discharge of wastewater with a correlation coefficient of 0.747 is a significant factor.

3. A base of the new method for assessment of the risk of degradation processes in river basins is a study of landscape and geographical features and analysis of the economic use of a water catchment area. Ranking of small rivers in the Siversky Donets river basin in Kharkiv region showed that Solon, Tetleg and Rogan rivers require restructuring of the water catchment area. Reducing negative factors in the development of degradation processes and increasing stabilization factors make it possible to develop really effective measures for the improvement of aquatic ecosystems.

4. We proposed an algorithm for the improvement of water protection strategy based on determining the eco-

logical risk of deterioration of a surface water state. The algorithm consists of three stages of surface water quality management at the state, regional and local levels. We should determine the environmental risk of deterioration of surface water by new methods at each stage of the strategy. We developed a complex of measures to preserve the ecological water ecosystem well-being based on determining an influence of natural and anthropogenic factors on a state of water bodies, analysis of rationality of economic water use.

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Проведено аналіз основних принципів і методів утилізації токсичних промислових відходів, що містять важкі кольорові метали. Наведено результати експериментів по обробці донних опадів хвостосховищ в сірчанокислому середовищі. Запропоновано схеми їх переробки, що дозволяє досягти максимальних показників вилучення основних цінних компонентів. Запропоновані технологічні рішення дозволять підвищити ефективність переробки зазначених видів техногенних відходів

Ключові слова: техногенні відходи, важкі кольорові метали, очищення стічних вод, відходи гальваноцехів

Проведен анализ основных принципов и методов утилизации токсичных промышленных отходов, содержащих тяжелые цветные металлы. Приведены результаты экспериментов по определению состава осадков городских сточных вод и гальванических кеков. Предложены схемы их переработки, позволяющие достичь максимальных показателей извлечения тяжелых цветных металлов. Предложенные технологические решения позволят повысить эффективность переработки указанных видов техногенных отходов

Ключевые слова: техногенные отходы, тяжелые цветные металлы, очистка сточных вод, отходы гальваноцехов

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DEVELOPMENT OF NEW TECHNOLOGICAL SOLUTIONS FOR RECOVERY OF HEAVY NON-FERROUS METALS FROM TECHNOGENIC WASTE OF ELECTROPLATING PLANTS AND SLUDGE OF WATER TREATMENT SYSTEMS

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1. Introduction

During the operation of industrial and municipal facilities, a significant amount of multi-component waste is formed. The analysis of the situation in the regions of mineral extraction and processing shows that the intensification of production leads to a large-scale damage and pollution of the environment. At the same time, artificial sources of environmental pollution arise and function for a long time.

The negative impact of disintegrated mineral waste is not so obvious as that of toxic dust and gas emissions or discharges. The analysis of mineral waste storage processes showed that under the influence of natural and technogenic factors they undergo weathering and transformation into new crystallochemical phases. This contributes to their destruction and spreading with groundwater and atmospheric flows. The processes of geochemical transformation most actively occur on the day surface of tailing ponds when exposed to low-mineralized atmospheric precipitation and air components, UV irradiation. This is accompanied by intense wind erosion of soils and dispersion of toxic components. At the same time, there is a significant contamination of surface and ground water and lands for various purposes. The solution of this problem became especially important in the