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DEVELOPMENT OF A PROCEDURE FOR ASSESSING THE ENVIRONMENTAL RISK OF THE SURFACE WATER STATUS DETERIORATION

Пропонується новий підхід до визначення екологічного ризику погіршення statusу поверхневих вод. Нова методика ґрунтується на визначенні екологічних нормативів якості поверхневих вод з урахуванням ландшафтних і географічних особливостей річкових басейнів. Застосування запропонованої методики дасть змогу прийняти науково обґрунтовані управлінські рішення в галузі водоохоронної діяльності. Визначення ризику порушення благополуччя водної екосистеми дасть змогу удосконалити водоохоронну стратегію

Ключові слова: екологічний ризик, водна екосистема, екологічний норматив, річковий басейн, водоохоронна стратегія

Предлагается новый подход к определению экологического риска ухудшения состояния поверхностных вод. Новая методика основывается на определении экологических нормативов качества поверхностных вод с учетом ландшафтных и географических особенностей речных бассейнов. Применение предложенной методики даст возможность принять научно обоснованные управленческие решения в области водоохранной деятельности. Определение риска нарушения благополучия водной экосистемы даст возможность усовершенствовать водоохранную стратегию

Ключевые слова: экологический риск, водная экосистема, экологический норматив, речной бассейн, водоохранная стратегия

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1. Introduction

The current state of surface waters requires development of a new tools for managing the water protection activities. In most European countries and the United States, environmental risk assessment is an indispensable step in development of environmental policy. Environmental risk determines probability of violation of ecological wellbeing, ecosystem degradation, reduction of biological diversity and simplification of trophic structure.

Assessment of the environmental risk of surface water deterioration has the purpose of identifying the water bodies requiring an immediate implementation of water protection measures. This task is very relevant in development of a water protection strategy, especially in industrially developed regions with low water availability. That is why application of the new procedure for environmental risk assessment was carried out for the most contaminated rivers in Kharkiv region, Ukraine, namely Udy River and Oskil River.

2. Literature review and problem statement

Environmental regulation of anthropogenic impact on the environment requires consideration of sustainability and regenerative capacity of ecosystems on the basis of analysis of interconnection of all components of the landscape-geographical system.

The landscape-ecological approach to determining the quality state of surface waters in northern Mongolia and analysis of the causes of pollution are presented in [1]. The study of monitoring data on hydrology, hydromorphology, climatology, physical-chemical characteristics of soils, landscape geography, and fish diversity in the Khara River basin has made it possible to obtain for the first time a detailed description of aquatic landscapes. In the course of assessment, the background status of various aquatic ecosystems was identified and its indicators were used to establish environmental standards.

Comprehensive study of causes of surface water pollution is the basis for development of a water protection policy [2].

Analysis of changes in land use has shown presence of a risk of degradation of water ecosystems in Australian subtropics because of the growing load on biogenic substances. Eutrophication of surface water caused by contamination from diffuse sources is a serious problem for water quality worldwide which leads to the loss of ecosystem functions in respective reservoirs. Climate change exacerbates this problem [3].

Study of the regularities of formation, functioning and sustainability of aquatic ecosystems under the influence of natural and anthropogenic factors is very important.

It has been shown in [4] that climate change will significantly change river runoff regimes in Europe and throughout the world. Based on SWIM forecasting models, estimation of future changes in river runoff throughout the Danube River basin was made using environmentally relevant river flow indicators under different climate change scenarios.

According to the forecasts, changes in climatological conditions will increase hypoxia risk, and oxygen concentration in deep water will decrease by 11.5 % by 2100 [5].

If global average temperatures will rise by more than two degrees, this will be a serious threat to both natural environment and human health [6].

Investigation of the negative effects of warming on the state of surface waters makes it possible to assess environmental risks caused by climate anomalies and identify future socio-economic problems [7].

Many scientific stUdyes are devoted to this complex problem, in particular in the field of environmental risk assessment [8–12]. In a generalized form, environmental risk is reduced to two types:

– risk of violation of ecosystem stability as a result of actual or potential environment pollution;

– risk to the health of population which means a probability of unfavorable health effects [13].

At present, there are a large number of known procedures for assessing risk to the population health but in most cases they are based on sanitary and hygiene standards, boundary (safe) values [14–16].

Approaches to the assessment of quality of water bodies based on determination of the limits of maximum permissible concentrations (MPC) do not adequately reflect the ecological status. Therefore, the use of such limit values in calculations of environmental risk is incorrect. And although units of measurement of the level of environmental safety may be indicators characterizing people's health, there is a problem of determining namely the risk of deterioration of the aquatic ecosystem status.

The method for assessing the environmental risks arising from the influence of pollution sources on water bodies [17] is based on processing of data collected by a specially designed express scheme of field research based primarily on biological data. At the level of detailed risk assessment, an expert analysis of characteristics of receptors and indicators of risk, levels of anthropogenic pressure and possible threats to the aquatic ecosystem is used.

Methods for assessing the environmental risk for water bodies based on biological sensitivity and response of certain organisms [18] as well as the methods for probabilistic species sensitivity distribution (SSD) are known [19].

Assessment of the environmental risk using SSD reflects the probability that the observed concentrations will exceed critical values for organisms. StUdyes [19] have shown that probabilistic results well reflect empirical information, so this method is valuable as an addition to more traditional approaches to risk calculation.

Disadvantage of the aforementioned methodological approaches include complexity, ambiguity of conditions in aquatic ecosystems and the reaction of organisms, the need for additional hydrobiological stUdyes with an involvement of leading specialists.

In Directive 2000/60/EC [20], in accordance with Article 16, it was proposed to carry out assessments of risk from priority substances identified in accordance with Article 16 (2) and listed in Annex X. At present, not all substances, in particular those listed in Annex X, are monitored and can be provided with official monitoring data. This indicates the need to implement the risk assessment systems that will be provided with an existing monitoring system and statistical reporting.

3. The aim and objectives of the study

This study objective was to develop a method for assessing the environmental risk of deterioration of surface water status and its testing for Udy River and Oskil River.

To achieve this goal, the following tasks have been accomplished:

– develop a procedure for assessing the risk of the aquatic ecosystem well-being;

– determine ecological standards for Udy River and Oskil River, Kharkiv region;

– assess environmental risk of deterioration of status Udy River and Oskil River and determine a list of priority pollutants for them;

– substantiate necessity of introduction of the European iterative approach to formation of a water protection strategy.

4. Methodological approach to the definition of environmental risk of surface water deterioration

4. 1. Procedure for assessing the risk of violation of the water ecosystem stability

The complexity of ecosystem properties causes ambiguity of reactions to the action of external and internal factors, so when establishing priority issues, it is expedient to use a probabilistic approach.

Assessment of the environmental risk involves determining the probability of violations of the aquatic ecosystem well-being under the influence of anthropogenic and natural factors. That is why the procedure for assessing the risk of deterioration of surface water is based on the definition of environmental standards. The procedure for determining the environmental standards of the surface water state is given in [21]. Establishment of the values of ecological standards for surface water quality conisists in a substantiation of the obligatory level of water quality for specific water bodies under the condition of maintaining well-being of the aquatic ecosystem. Ecological standards are characterized by certain values of hydrophysical, hydrochemical, hydrobiological and bacteriological indicators of water quality as well as the content of priority substances of toxic and radiation action [21].

Environmental standards (ES) are established on the basis of processing long-term observation data with definition of the ecological index by an improved procedure of environmental assessment of the surface water quality according to corresponding categories [22].

It is necessary to establish the years with the minimum values of the environmental index (I_E) among all data of the observation results taking into account the water content factor ($Kw\leq 1$) based on construction of a diagram of the trends of changes in ecological indices and water content factors. ES corresponds to the minimum value among the average and modal values for each index of ecological status of the water body, the minimum values of the ecological index taking into account the water content factor and predicted values.

The environmental water quality index (I_E) is calculated as an arithmetic mean of chemical (I_{ch}) and biological (I_b) indices [22]:

$$I_E = \frac{\left(I_{ch} + I_b\right)}{2}. \quad (1)$$

The ecological index of water quality like the block indices, is calculated for the average values of the categories $I_{E\,av}$. The assessment should be made using the same list of indices.

To select representative years for a certain period of observations, it is necessary to use the value of the water content coefficient C_w [21]:

$$C_w = \frac{Q_{av}}{Q_{alt}}, \tag{2}$$

where Q_{av} is average water consumption during the period for which assessment is made; Q_{alt} is the average long-term water consumption during the same period (season) [21].

To construct a forecasting model of the ecological status of surface waters, the Holt-Winters method was used which solves the task of predicting the time series with allowance for seasonality [23].

Analysis of the long-term observations of surface water quality status has shown that the hydrochemical and hydrological parameters can change dramatically over the years. The Holt-Winters method is capable of finding micro-trends at the time moments directly preceding the predicted ones and extrapolating these trends for the future. The method of triple exponential smoothing of the time series enables both mid-term and long-term prediction. Therefore, the Holt-Winters method was chosen to predict ecological status of water bodies.

If environmental standards are not established for an individual water body, it is proposed to use the upper limit of the third category of classification of surface water quality [22] as the limit value which corresponds to class II with a good status.

It is proposed to determine the environmental risk of violation of well-being of water ecosystems for each i-th pollutant in the j-th range of observation of the surface water quality state using the formula:

$$R_{ij} = 1 - ((1 - P_{ij}) \times (1 - S_{ij})), \tag{3}$$

where P_{ij} is probability of violation of the ecological standard for the i-th indicator in the j-th range, dimensionless quantity; S_{ij} is the indicator of consequences of violation of ecological well-being for the water ecosystem for the i-th indicator in the j-th range, dimensionless value.

The probability of violating the ecological standard is determined by the formula:

$$P_{ij} = \frac{n^i_{EHj}}{N^i_{EHj}}, \tag{4}$$

where n^i_{EHj} is the number of observations of the ecological status of the water body for each i-th pollutant in the j-th range with a violation of the environmental standard; N^i_{EHj} is the total number of observations of the ecological status of the water body for each i-th pollutant in the j-th range with definition of the ecological standard.

In accordance with the Concept of environmental standardization [24], violation of the environmental standard will mean negative consequences for the aquatic ecosystem. Therefore, the indicator of the consequences of violation of the environmental standard (S) is proposed to be determined on the basis of an estimation of the average concentration of the i-th pollutant among the concentrations exceeding the ES ($C^i_{\text{српEH}}$).

Then, according to the value of this concentration and the value of the ecological index (I_E), one of the five classes of quality is assigned according to the procedure [22]. The indicator of the consequences of violation of the environmental norm (S) is determined by interpolation using data from Table 1.

Table 1

Characteristics of the status of watercourses by the values of the indicator of the consequences of violation of the environmental standard (S) and the values of the ecological index (I_E)

Indicator name	Class 1, good status	Class 2, satisfactory status	Class 3, fair status	Class 4, bad status	Class 5, very bad status
Values of the indicator of the consequences of violation of well-being for water ecosystem (S)	0–0.19	0.2–0.39	0.4–0.59	0.6–0.79	0.8–1.0
Values of the ecological index (I_E)	0–1.0	1.1–3.0	3.1–5.0	5.1–6.0	6.1–7.0

The total environmental risk of deterioration of the status of water ecosystems in the j-th range of observation of the quality state of surface waters (R_{evj}) is defined as the average geometric of individual risks for each i-th contaminant (R_{ij}) by the formula:

$$R_{evj} = \sqrt[m]{\prod_{i=1}^{m} R_{ij}}, \tag{5}$$

where m is the number of stUdyed indicators of the qualitative state of the aquatic ecosystem.

Environmental risk for large or medium-sized rivers is determined proceeding from a sufficient information provision (monitoring information available for 30 years or more).

In the case when the available hydrochemical, hydrobiological and hydrological information does not cover the entire list of the indicator blocks, calculation is carried out according to the following scheme.

The calculation is based on five indicators that exceed the environmental standards most of all.

At the first stage of assessment of the environmental risk of deterioration of the status of water bodies, a list of the pollutants that exceed the ecological standard value is determined. It is believed that these substances contribute to the development of degradation processes in the aquatic ecosystem.

At the second stage of assessment of the environmental risk of deterioration of the status of water bodies, probit analyses (Prob) are determined by the following formula [25]:

$$\mathrm{Pr}\,ob = -2 + 3{,}32 \times \lg \frac{C_i}{C_{EHi}}, \tag{6}$$

where C_i is concentration of the i-th substance in the water body, mg/dm^3; C_{EHi} is the value of the ecological norm for the i-th substance in the water body, mg/dm^3.

At the third stage, a corresponding value of environmental risk of status deterioration of the water bodies is determined by the value of Prob in accordance with the law of normal-probabilistic distribution.

At the fourth stage, the total environmental risk of deterioration of water bodies determines is found by the formula [25]:

$$ER = 1-(1-ER_1)\times(1-ER_2)\times...(1-ER_n), \qquad (7)$$

where ER is the total environmental risk of deterioration of the status of water bodies; ER_1,..., ER_n is environmental risk for each pollutant.

At the fifth stage, characteristic of the environmental risk of deterioration of the status of water bodies is given. When interpreting the resulting values of the environmental risk, it is proposed to use the next rank scale (Table 2).

Table 2

Characteristics of surface water quality in terms of environmental risk

Class of water quality	Water body quality characteristics	Environmental risk value (ER)	Trophicity
I, excellent	Water bodies in the natural state are usually oligotrophic, water is transparent or with a small amount of humus. Water objects are suitable for all types of uses	<0.1	Oligothropic
II, good	Water bodies are close to the natural status or slightly eutrophied. Water is suitable for all types of uses	0.1–0.19	Mezothropic
III, satisfactory	Water bodies are under a weak effect of sewage, plane pollution sources or other types of influence. Quality usually meets the requirements of most types of water use	0.2–0.59	Euthrophic
IV, unsatisfactory	Water of water bodies is significantly polluted as a result of sewage, surface runoff, and other factors. Water bodies are only suitable for those types of use which have less stringent requirements to water quality	0.6–0.89	Polythropic
V, bad	Water bodies are heavily polluted with sewage, surface runoff or as a result of the influence of other factors	0.9–1.0	Hyperthropic

Classification of water bodies according to the environmental risk (Table 2) makes it possible to determine their suitability for water use. This is important for introduction of an iterative approach to managing water protection activities.

4. 2. Assessment of environmental risk of deterioration of the status of Udy River and Oskil River, Kharkiv region

Kharkiv region is a large industrial center of Ukraine with a diversified agriculture and numerous settlements requiring a large number of high-quality water resources. But the Kharkiv region is one of the last cities in the country as to water provision. However, the highly developed industrial complex exerts a large anthropogenic load on the water bodies of the Kharkiv region. Therefore, establishment of environmental standards and identification of the most polluted watercourses on the basis of environmental risk assessment is an important task. There are 867 rivers and temporary watercourses on the territory of the Kharkiv region inclUdyng 1 large river (Siversky Donets River), 6 medium rivers (Udy, Lopan, Oskil, Merla, Orel, Samara) and the rest are small rivers.

The total length of all rivers in the region is 6,405 km of which 172 rivers have a length of more than 10 km, and their total length is 4,655 km. All rivers and temporary watercourses belong to Don River and Dnieper River basins covering respectively 3/4 and 1/4 of the region area.

The territory of Kharkiv region includes forest-steppe and steppe geographic zones which causes difference in the features of formation and functioning of aquatic ecosystems. When developing ecological standards, it is important to take into account geographical location as well as the specific features of hydrological, hydrochemical and hydrobiological regimes which clearly differ between individual river basins.

Siversky Donets River is the main water artery of the Kharkiv region, the largest tributaries are Udy River in the forest-steppe zone and Oskil River which flows on the border of the forest-steppe and steppe zones.

Udy River basin is one of the largest inflows of the Siversky Donets River and has a transboundary character. The total length of the river is 164 km of which 127 km pass through the territory of Kharkiv region. The total catchment area is 3894 km^2 of which 3,460 km^2 are in the Kharkiv region.

Basin of Udy River, the right tributary of Siversky Donets, is located in the south-western spurs of the Central Russian Upland within the Dnieper-Don watershed. The territory is a flat-wavy plain dissected by a dense network of gullies and ravines. Udy River is mainly fed with snow while rain and ground feed plays a smaller role.

The rivers of the Udy basin are the most full-flowing. They originate in the Belgorod region of Russia and flow in the southern direction. Due to the fact that they flow through densely populated areas of the region, the rivers are highly regulated and polluted.

Assessment of the ecological condition of the Udy river basin in the Chuguivsky district of the Kharkiv region for the period from 1969 to 2015 basically corresponds to four categories according to the ecological classification [22] (Fig. 1).

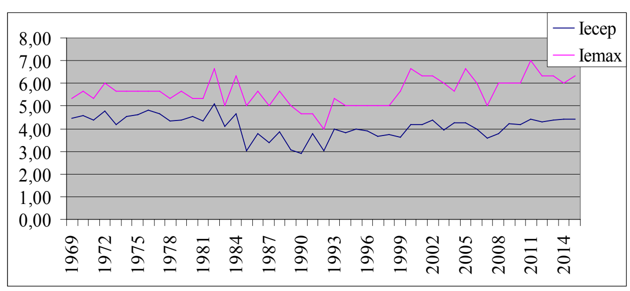

Fig. 1. Dynamics of changes in the average ecological index (I_{Ecep}) and the maximum ecological index (I_{Emax}) in Udy River in the Chuguivsky district of the Kharkiv region for the period from 1969 to 2015

Establishment of the values of the target ecological standard (ES_t) for individual water quality indicators is done in a similar manner to the permissible one (ES_p). The value of the target ecological standard corresponds to the minimum value among indicators for the selected years with the lowest values of the ecological index taking into account the coefficient of water content, the current state, the average and predicted quantities.

In order to calculate the environmental risk of surface water deterioration, an acceptable ecological norm (ES_a) is adopted.

Table 3 presents calculation of priority substances of environmental risk of well-being violation of Udy River water ecosystem in Chuguivsky district, Kharkiv region in accordance with the procedure presented above.

Similarly, environmental risk of well-being of the water ecosystem of Oskil River in the Kharkiv region is determined.

Oskil River is the largest left tributary of Siversky Donets River. The basin of Oskil River also has a transboundary importance because it flows through two countries: Russia and Ukraine. The total length of the river is 472 km of which 290 km pass through the territory of the Kharkiv region. The total catchment area is 14800 km^2 of which 3830 km^2 are in the Kharkiv region.

Oskil River flows into Siversky Donets River at 580 km from the mouth. The peculiarity of Oskil River before its regulation was a significant variation in its runoff. After a brief flood, the water content of the river was usually small for most of the year. At the moment, the runoff has somewhat levelled.

A point upstream the city of Kupyansk on Oskil River was selected for the study.

A general procedure was presented and environmental standards for Oskil River at the observation point above the city of Kupyansk were defined in [21].

According to the analytical quality control of surface waters of the Kharkiv region, ecological index and the water content coefficient were calculated proceeding from the average indicators for the period from 1977 to 2014.

The dynamics of changes in the ecological status of Oskil River according to the determined ecological index taking into account the change in hydrological parameters (Iey) is presented in Fig. 2.

Analysis of the ecological index dynamics taking into account the water content coefficient in Oskil River for the period from 1977 to 2014 has shown that its lowest value was observed in 1984, 1992 and 2001 (Fig. 2). This means that the quality of surface water in Oskil River in these years should be taken as a basis for determination of environmental standards (Table 4).

Table 4 presents acceptable ecological standards (ESa) and target ecological standards (ESt). Target values for water quality indicators are such their threshold values that can be achieved by water consumers over a certain period of time taking into account technological and economic opportunities. The target ecological standards are established on the basis of forecasting models of the ecological status of a separate water body taking into account long-term observations of the surface water quality status.

Determination of the environmental risk of well-being violation in the water ecosystem of Oskil River in Kharkiv region for the most common pollutants is presented in Table 5.

Table 3

Environmental risk of well-being violation in Udy River water ecosystem in Chuguivsky district, Kharkiv region

Substance name	ES, mg/dm^3	n	N	P	C_{avexES}, mg/dm^3	S	R
Solid residue	745	16	54	0.30	786.74	0.39	0.57
Sulphates	216	17	54	0.31	233.19	0.79	0.86
Chlorides	80	28	51	0.55	130.03	0.49	0.77
Ammonium nitrogen	1.10	36	52	0.69	3.24	0.98	0.99
Nitrite nitrogen	0.309	8	51	0.16	0.402	0.98	0.98
Nitrate nitrogen	4.93	6	52	0.12	5.49	0.98	0.98
Suspended matters	11.20	37	45	0.82	24.10	0.49	0.91
Dissolved oxygen	7,30	26	52	0.50	6.49	0.49	0.75
BOD_5	4.77	35	55	0.64	6.84	0.59	0.85
pH	7.80	25	54	0.46	7.99	0.39	0.67
SSAS	0.039	22	41	0,54	0.273	0.98	0.99
Oil products	0.182	27	37	0.73	0.655	0.98	0.99
Iron, total	0.21	24	51	0.47	0.32	0.49	0.73
Manganese	0.027	4	14	0.29	0.0377	0.39	0.56
Copper	0.0060	7	22	0.32	0.0069	0.49	0.65
Zinc	0.016	3	37	0.08	0.0472	0.49	0.53
Average environmental risk							0.78

Assessment of the environmental risk of well-being violation in the water ecosystems of Udy River and Oskil River has shown that the risk values correspond to the class IV of quality (unsatisfactory) according to Table 2. Water bodies are not suitable for fishery water use.

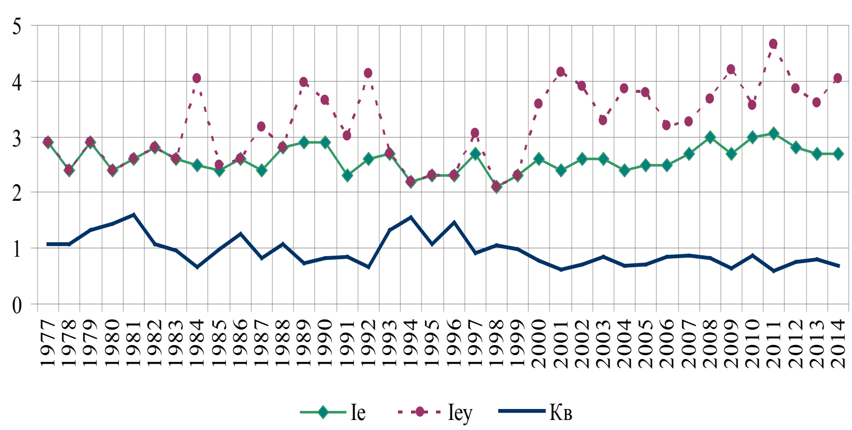

Fig. 2. Dynamics of changes of the ecological index (I_E), coefficient of water content (K_B) and the ecological index taking into account the change of hydrological indicators (Iey) in Oskil River for the period from 1977 to 2014

Table 4

Ecological standards of surface water quality of Oskil River basin

Ingredient name	Concentration of pollutants						
	1984	1992	2001	2014	2025	ESa	ESt
	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³	mg/dm³
Solid residue	467.6	513.5	503.5	553.8	609.8	529.64	503.5
Sulphates	107.5	127.3	111.7	113.4	131.9	118.36	107.5
Chlorides	88	46.97	41.57	43.,5	44.6	52.928	41.57
Ammonium nitrogen	0.176	0.241	0.095	0.303	0.36	0.235	0.095
Nitrite nitrogen	0.03	0.008	0.02	0.01	0.008	0.0152	0.008
Nitrate nitrogen	0.07	0.23	1.22	0.77	0.16	0.49	0.07
Phosphate phosphorus	0.047	0.12	0.25	0.3	0.403	0.224	0.047
BOD_5	3.174	4.298	2.013	2.573	2.24	2.859	2.013
Dissolved oxygen	9.48	9.94	9.06	7.72	9.39	9.12	9.94
pH	7.64	7.08	8.13	7.9	7.88	7.73	7.08
COD	–	–	12.325	19.75	17.3	16.458	12.325
Copper	0.0068	0.0007	0.0068	0.0038	0.007	0.005	0.0007
Petroleum products	0.1	0.15	0.0167	0.1125	0.105	0.0968	0.0167
Iron, total	0.165	0.0943	–	0.0133	0.043	0.0789	0.0133
Manganese	0.185	0.21	0.005	0.14	0.059	0.1198	0.005
$Zinc^{2+}$	0.0055	0.012	0.0068	0.01	0/007	0.0083	0.0055
SSAS	0.03	0.0114	0.0233	0.0133	0.014	0.0184	0.0114

Table 5

Environmental risk of water ecosystem well-being violation in Oskil River, Kharkiv region

Substance name	*ES*, mg/dm³	*n*	*N*	*P*	C_{avexES}	*S*	*R*
Solid residue	529.64	19	38	0.50	593.046	0.29	0.65
Sulphates	118.36	10	38	0.26	137.236	0.49	0.62
Chlorides	52.93	10	38	0.26	73.280	0.39	0.55
Ammonium nitrogen	0.235	13	38	0.34	0.310	0.98	0.99
Nitrite nitrogen	0.0152	24	38	0.63	0.027	0.59	0.85
Nitrate nitrogen	0.49	22	38	0.58	1.238	0.79	0.91
Phosphate phosphorus	0.224	13	36	0.36	0.285	0.79	0.87
BOD_5	2.859	22	38	0.58	3.449	0.49	0.79
PH pH	7.73	26	38	0.68	8.036	0.39	0.81
Copper	0.005	10	38	0.26	0.019	0.59	0.70
Petroleum products	0.0968	22	38	0.58	0.225	0.79	0.91
Iron, total	0.0789	21	38	055	0.189	0.49	0.77
Manganese	0.1198	17	32	0,53	0.176	0.59	0.81
$Zinc^{2+}$	0.0083	17	38	0.45	0.020	0.39	0.66
SSAS	0.0184	23	38	0.61	0.043	0.49	0.80
Dissolved oxygen	9.12	24	38	0.63	7.904	0.29	0.74
Average environmental risk							0.77

5. Analysis of the results obtained in assessing the risk of deterioration of the ecological status of Udy River and Oskil River

Determination of the magnitude of environmental risk allows one to rank individual indicators to identify priority pollutants for which implementation of measures to restore sustainability of the water ecosystem should be undertaken in the first place. Ranking of pollutants for the Udy River is shown in Fig. 3, 4 shows respective data for Oskil River.

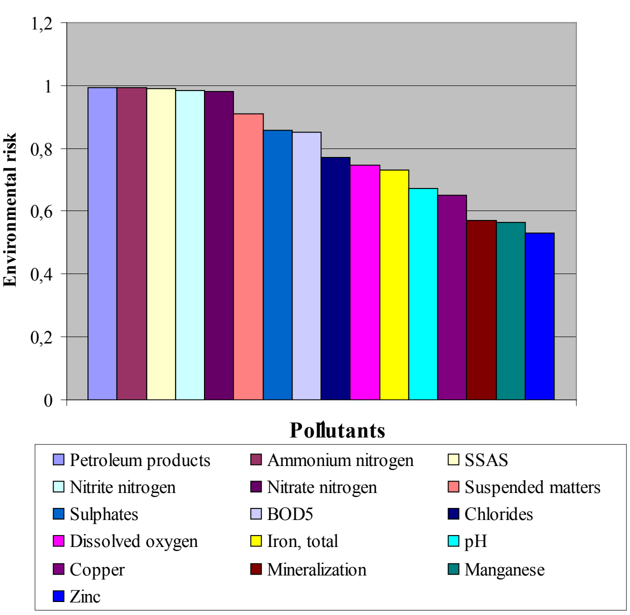

Fig. 3. Classification of pollutants in Udy River in terms of environmental risk

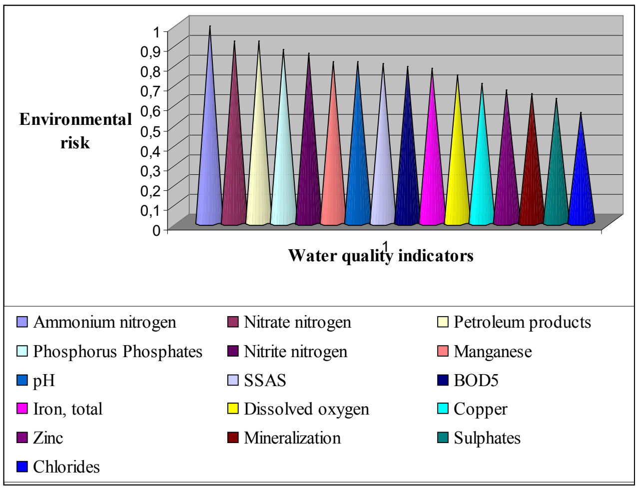

Fig. 4. Classification of pollutants in Udy Oskil River in terms of environmental risk

The results of ranking of pollutants of the highest environmental risk for both Udy River and Oskil River show that the list of priority pollutants for both rivers includes nitrogen group, petroleum products, SSAS, phosphate phosphorus, suspended matter and organic matter by the indicator BOD_5. This list is explained by the impact of discharges of sewage of the communal services and industrial enterprises.

The environmental risk of violation of the aquatic ecosystem well-being shows likelihood of achieving environmental standards. Table 6 shows multiplicity of the excessive average concentration of pollutants among the concentrations exceeding the *ES* (C_{avexES}) to the value of the ecological standard.

Table 6

Multiplicity of excess of the average concentration of pollutants among the concentrations exceeding the *ES* (C_{avexES}) to the ecological norm for Udy River and Oskil River

Substance name	$(C_{avexES})/ES$ for Udy River	$(C_{avexES})/ES$ for Oskil River
Solid residue	1.06	1.12
Sulphates	1.08	1.16
Chlorides	1.63	1.38
Ammonium nitrogen	2.95	1.32
Nitrite nitrogen	1,30	1,76
Nitrate nitrogen	1.11	2.53
Dissolved oxygen	1.12	0.87
BOD_5	1.43	1.21
pH	1.02	1.04
SSAS	7.00	2.33
Petroleum products	3.60	2.33
Iron, total	1.50	2.39
Manganese	1.40	1.47
Copper	1.15	3.72
Zinc	2.95	2.40

Analysis of the data in Table 6 shows that in Udy River, the highest excess of the ecological standard was for SSAS (7-fold), petroleum products (3.6-fold), zinc (2.95-fold) and ammonium nitrogen (2.95-fold). In Oskil River, the highest ecological norm was exceeded by copper (3.72-fold), nitrate nitrogen (2.53-fold), zinc (2.4-fold, total iron (2.39-fold), petroleum products and СПАР (2.33-fold). This fact confirms the hypothesis that the unsatisfactory quality of the surface waters of Udy River and Oskil River results from wastewater discharges from industrial enterprises for the most part.

6. Proposals of implementation of the iterative approach to the management of surface water quality

In the conditions of the current unsatisfactory quality status of the watercourses of the Siversky Donets River basin and the lack of a single concerted approach to the development and implementation of environmental protection measures, the problem of developing an effective water management system becomes crucial.

Based on the analysis of the long-term dynamics of climatic and hydrological changes, it was shown in work [26] that warming of climate in the Kharkiv region is expected to be 1.9 °C (from 7.8 °C to 9.7 °C) in 2020 and a decreased average annual rainfall number, runoff volume and water consumption are predicted. Such trends will have negative consequences for the ecological status of water bodies and require development of a new water protection strategy in conditions of climate change and anthropogenic pressure growth through creation of a flexible system of water quality regulation.

For the purpose of assessing the surface water quality status, the maximum permissible concentrations (MPC) inherited from the normative legal acts of the Soviet era are used currently in the countries of Eastern Europe, the Caucasus and Central Asia. In accordance with the resolution of the Council of Ministers of the USSR No. 1045 of 1958, all reservoirs were considered as water bodies of fishery destination. In the Soviet Union, sanitary-and-hygienic MPCs were set for more than 1300 parameters, and the MPC for fishery waters had almost 1100 parameters. Such long lists serve as useful sources of information but they were ineffective in practice. The requirements of the Ukrainian environmental legislation for compliance with the MPC for fishery water use inherited from the water protection policy of the former Soviet Union are contrary to the iterative approach to the management of surface water quality in the European Union.

At present, when our country seeks to join the EU, it is necessary to adapt the Ukrainian environmental legislation to the legislation of the member states of the European Union. The current practice of using MPC for assessment of surface water quality and development of maximum allowable discharges (MAD) for point sources of contamination contravenes the basic principles of the Water Framework Directive [20].

A number of fishery and sanitary-and-hygienic MPCs of the Soviet era correspond to practically untouched water quality with very low levels of violation as a result of anthropogenic activity. Although achievement of the surface water quality close to their natural status is an extremely ambitious goal, the MPC, in essence, requires their immediate observance since the terms of their implementation are not defined.

Acceptable environmental standards should be introduced as environmental quality standards for surface water instead of MPC. Target ecological standards constitute an environmental component of development of a water conservation strategy taking into account technological and financial capabilities, social needs, climate change and prediction of human-induced impacts.

Table 7 shows possibility of reaching fishery and household MPCs for Udy River and Table 8 for Oskil River.

Table 7

Compliance of ecological standards and prediction indicators of surface water quality in Udy River with fishery and household maximum permissible concentrations (MPC)

Indicator name	*ESa*, mg/dm³	ESa/MP, MPC_f	ESa/ MPC_h	Predicted concentration for 2025, Cpr mg/dm³	Cpr/ MPC_f	Cpr/ MPC_h
Solid residue	745	0.75	0.75	813	0.81	0.81
Sulphates	216	2.16	0.43	211	2.11	0.42
Chlorides	80	0.27	0.23	83,4	0.28	0.24
Ammonium nitrogen	1.10	2.82	0.55	1.66	4.26	0.83
Nitrite nitrogen	0309	15.45	0.31	0.26	13.00	0.26
Nitrate nitrogen	4.93	0.54	0.48	3.64	0.40	0.36
Phosphates	0.47	2.76	0.13	1.03	6.06	0.29
BOD_5	4.77	2.13	1.06	3.69	1.65	0.82
COD	28.3	1.89	0.94	30.1	2.01	1.00
Copper	0.006	6.00	0.01	0.007	7.00	0.01
Petroleum products	0.182	3.64	0.61	0.22	4.40	0.73
Iron, total	0.21	2.10	0.70	0.27	2.70	0.90
Manganese	0.027	2.70	0.27	0.035	3.50	0.35
$Zinc^{2+}$	0.016	1.60	0.02	0.012	1.20	0.01
SSAS	0.039	0.39	0.08	0.07	0.70	0.14

Analysis of multiplicity of exceeding the maximum permissible concentrations for fishery water use (MPC_f) by the values of permissible ecological standard (ESa) and the predicted concentrations of pollutants (Cpr) shows impossibility of using Udy River for fish breeding. The value of ESa for nitrate nitrogen exceeds (MPC_f) by 15.45 times and its prognostic concentration by 13 times. Significant excess of (MPC_f) by environmental standards is also observed for copper (6-fold), petroleum products (3.64-fold), ammonium nitrogen (2.82-fold) and other pollutants.

As calculations show, it is impossible to achieve quality of surface water required for fishery for most substances but the qualitative composition of Udy River and Oskil River corresponds to the household use.

Acceptable ecological standards for Oskil River exceed the maximum permissible concentrations for the fishery water use for the following substances: manganese (11.98-fold), copper (5-fold), petroleum products (1.94-fold), phosphates (1.32-fold), BOD_5 (1,28-fold), chlorides (1,18-fold). Prediction of the ecological status of Oskil River for 2025 has also shown significant excess concentrations of pollutants MPC_f This analysis suggests that the use of Oskil River water for fishery is also a very ambitious goal.

Surface water quality management should reflect general objectives, specific targets, agreed and desirable types of water use taking into account available financial resources and technical capabilities.

An iterative approach to surface water quality management implemented in EU countries provides for the gradual achievement of targets. Each stage (5–10 years) represents a feasible and financially acceptable program for achievement of the medium-term targets for water quality.

Table 8

Compliance of ecological standards and predicted indicators of surface water quality in Oskil River with fishery and household maximum permissible concentrations (MPC)

Indicator name	*ESa*, mg/dm³	ESa/ MPC_f	ESa/ MPC_h	Predicted concentration for 2025 (Cpr), mg/dm³	Cpr/ MPC_f	Cpr/ MPC_h
Solid residue	529	0.53	0.53	609.8	0.61	0.61
Sulphates	118.36	1.18	0.24	139.2	1.39	0.28
Chlorides	52.93	0.18	0.15	44.57	0.15	0.13
Ammonium nitrogen	0.235	0,60	0,12	0,376	0,96	0,19
Nitrite nitrogen	0.0152	0.76	0.02	3.00E-04	0.02	0.00
Nitrate nitrogen	0.49	0.05	0.05	0.26	0.03	0.03
Phosphates	0.224	1.32	0.06	1.215	7.15	0.35
BOD_5	2.859	1.28	0.64	2.24	1.00	0.50
COD	12.3	0.82	0.41	17.29	1.15	0.58
Copper	0.005	5.00	0.01	0.007	7.00	0.01
Petroleum products	0.0968	1.94	0.32	0.096	1.92	0.32
Iron, total	0.0789	0.79	0.26	0.012	0.12	0.04
Manganese	0.1198	11.98	1.20	0.059	5.90	0.59
$Zinc^{2+}$	0.0083	0.83	0.01	0.007	0.70	0.01
$Chromium^{+6}$	0.004	0.67	0.08	6.00E-04	0.10	0.01
SSAS	0.0184	0.18	0.04	0.014	0.14	0.03

The regulatory base of such multi-stage planning and management should include an iterative process of water quality planning and a system of surface water quality standards with its values matching the relevant medium-term targets. In order to regulate surface water quality in transboundary basins, it is necessary, at a minimum, that neighboring countries agree on common criteria of assessing the quality of surface waters. Common criteria are necessary to make countries' assessments comparable and enable countries to draw a conclusion on water quality. The next stage is defining common targets for surface water quality that have to be met at both sides of the border and coordination of measures for water resource management [27].

7. Discussion of expediency of application of the procedure for assessing the environmental risk of deterioration of surface water

To ensure environmental safety, it is important to use tools for assessing outcomes of the environmental risks of surface water pollution.

Advantage of the proposed method of assessing the environmental risk of deterioration of the water body status consists in the fact that the environmental standard of surface water quality is used as the limit value but not the sanitary-hygienic norm (MPC). Environmental risk reflects probability of violations of conditions of aquatic ecosystem functioning. The modern system of surface water monitoring in Ukraine fully provides for the initial data necessary for calculating the environmental risk values. The environmental risk of deterioration of the water body status is determined on the basis of exceeding the ecological standards which makes it possible not to smooth out the assessment results.

Assessment of the environmental risk of deterioration of water bodies involves analysis and statistical processing of long-term monitoring data which complicates application of this procedure and can be considered a disadvantage. But a simplified procedure for assessing environmental risk is proposed.

It should be noted that the procedure of environmental risk assessment is based on determination of environmental standards, but there is no approved procedure of this determination in Ukraine. This is the problem of implementation of the proposed procedure of environmental risk assessment in the modern practice of management of water protection activities.

The necessity of scientific substantiation of the permissible limit of anthropogenic influence on the status of surface waters determines urgency of implementation of the system of environmental standards and approval of the procedure for their calculation.

For the future, it is planned to improve the procedure of environmental risk assessment by taking into account sustainability and vulnerability of the aquatic ecosystem to anthropogenic load and climate change. It is possible to improve the forecast models with definition of factors having the strongest influence on the status of the water ecosystem.

The proposed procedure for assessing environmental risks of the well-being of the water ecosystem should become the basis for improving the water protection strategy. The method of assessing the environmental risk of deterioration of water bodies can be used to improve effectiveness of environmental protection measures and provide scientific substantiation of their priority along with development of state and regional programs for protection of surface water and preparation of normative and methodological documents in the field of water protection activities.

8. Conclusions

1. A procedure for determining the environmental risk of deterioration of surface water was proposed. It is intended to establish the degree of probability of violation of the aquatic ecosystem well-being in conditions of anthropogenic load and influence of natural factors. Assessment of the environmental risk of deterioration of surface water can be used for effective management of water protection activities.

2. Assessment of the environmental risk of deterioration of surface water is based on determination of permissible environmental norms. Ecological norms are determined on the basis of statistical processing of data on monitoring hydrochemical, hydrobiological and hydrological parameters for Udy River for the period from 1969 to 2015, and for Oskil River from 1977 to 2014. Forecast models were constructed by the Holt-Winters method up to 2025. Calculations have shown that the qualitative composition of Udy River and Oskil river does not meet the fishery standards.

3. Ecological norms were worked out on the basis of analysis and statistical processing of long-term monitoring data on the surface water quality status taking into account the forecast models. Environmental risk indicates probability of violation of the aquatic ecosystem well-being, that is, the probability of violation of environmental standards. Assessment and analysis of the environmental risk of deterioration of surface water is an important stage in the water protection strategy. Assessment of the environmental risk for Udy River and Oskil River has shown that the status of these rivers is unsatisfactory and belongs to grade IV of quality. Ranking of pollutants according to the environmental risk value makes it possible to make a list of priority pollutants which is necessary for analysis of the causes of pollution of water bodies. The list of priority pollutants for Udy River and Oskil River includes nitrogen group, phosphates, petroleum products, SSAS, suspended matter and organic matter according to the $БСК_5$ indicator. This list of pollutants indicates that the unsatisfactory state of rivers is caused by sewage discharges from industrial enterprises and utilities.

4. Assessment of the environmental risk of deterioration of the quality status of Udy River and Oskil River has shown necessity of implementing an iterative approach to the management of water protection activities. The iterative process of water quality planning is intended to find a balance between the desired types of water use and the target indicators of water quality on the one hand and the available financial and technical resources and social conditions, on the other hand.

Application of the proposed procedure is aimed at adapting the methodological approaches in the field of surface water protection to European standards.

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