Досліджено зміни кліматичних показників у Харківській області і гідрологічних показників української частини р. Оскіл за допомогою побудови прогнозних моделей. На основі кореляційних зв'язків визначено фактори, що мають найбільший вплив на гідрохімічні показники обраного басейну, оцінено інтенсивність деградаційних процесів. Результати дослідження можуть бути використані при визначенні пріоритетних проблем і науковому обґрунтуванні водоохоронних заходів

Ключові слова: якісний стан, деградаційні процеси, кліматичні зміни, гідрологічні показники, кореляція

Исследованы изменения климатических показателей в Харьковской области и гидрологических показателей украинской части р. Оскол с помощью построения прогнозных моделей. На основе корреляционных связей определены факторы, имеющие наибольшее влияние на гидрохимические показатели в выбранном бассейне, оценена интенсивность деградационных процессов. Результаты исследований могут быть использованы при определении приоритетных проблем и научном обосновании водоохранных мероприятий

Ключевые слова: качественное состояние, деградационные процессы, климатические изменения, гидрологические показатели, корреляция

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A STUDY OF SIGNIFICANT FACTORS AFFECTING THE QUALITY OF WATER IN THE OSKIL RIVER (UKRAINE)

A. Vasenko
Candidate of biological science, Associate Professor*
E-mail: alexandr.vasenko@gmail.com
O. Rybalova
PhD, Associate Professor
Department of Labour Protection
and technogenic and ecological safety
National University of Civil Defense of Ukraine
Chernishevskaya str., 94, Kharkiv, Ukraine, 61023
E-mail: olga.rybalova@mail.ru
O. Kozlovskaya
Postgraduate Student*
E-mail: xsenia.ka@gmail.com
*Laboratory of research of ecological sustainability
of the objects of the environment
and natural areas of special protection
Ukrainian Scientific Research Institute
of Ecological Problems
Bakulina str., 6, Kharkiv, Ukraine, 61166

1. Introduction

An intensive use of surface water and an excessive anthropogenic impact predetermine the fact that most of the Siverskyi Donets basin rivers belong to class III (polluted) (by the average performance levels) [1] and category 4 (slightly contaminated) (by the environmental assessment of surface water quality for the respective categories) [2]. Changes in the water quality depend on the anthropogenic impact, climatic conditions, landscape and ecological features, as well as physical and geographical peculiarities of the river basin.

The authors of [3] state that a multivariate nature of water quality determines the complexity of its investigation. The research problem is aggravated by an insufficient justification of the theoretical and methodological bases and an ambiguous use of instrumental methods, which complicates the attempts of disclosing the mechanisms of water quality formation that are aimed at improving the control over water protection activities.

Obvious climatic changes due to an increase in average air temperatures and an increased variability of precipitation significantly affect the formation of water quality. Numerous studies predict that climate change may have considerable effects on water quality [4, 5] and on the biotic component of aquatic ecosystems [6, 7].

Miscellaneous conditions and factors influencing the formation of groundwater quality predetermine the need to study the factors that have the biggest impact. Studies in this area are topical due the fact that contemporary climate changes and an intensive use of water resources require identifying the largest sources of pollution of surface waters for further development of a complex of environment protection measures.

2. An analysis of previous studies and formulation of the problem

The Oskil river is the largest (left) tributary of the Siverskyi Donets and is important for the whole river basin in Ukraine. The Oskil waters are used in the agricultural and industrial sectors and support the hydraulic system of the Siverskyi Donets-Donbas canal. The Oskil river basin has cross-border significance as it is located both in Russia and Ukraine.

The vast majority of rivers and reservoirs of the Kharkiv region degrades through an excessive human pressure that dominates over the ability of self-cleaning and self-healing. Significant river changes have been caused by failure of legislation and rules for the use of land in water protection zones and coastal strips.

The authors of [8] assessed the ecological state of the Oskil in 2014 and showed that the overall environmental index (by the maximum value) proved that the water quality had degraded to "satisfactory" for the environmental condition and to "slightly contaminated" for the degree of purity. It was found that the main limiting parameters that determine the deterioration of the water quality were nutrients such as phosphates, nitrates, and nitrites.

When planning water protection activities and identifying priority issues, it is important to assess the actual ecological state of a selected aquatic site and obligatorily consider pool features and factors that have the greatest influence on the formation of aquatic ecosystems.

Particularly important is research on climate changes, because the analysis of long-term observations on climate changes in the Kharkiv region have showed that in recent years, namely since 1992, there has been a tendency of the average air temperature to increase. Such changes may further provoke uncontrollable effects on aquatic sites since they have significant direct and indirect impacts, especially on such important characteristics as precipitation, water consumption, as well as hydrochemical and hydrobiological indicators.

Modern concepts of water management increasingly emphasize the preventive character of the necessary measures and recognize the importance of acting now to adapt to the effects of global warming in the future [9, 10].

Analysis of the previous studies shows that many of them are devoted to the impact of climate changes on the quantitative and qualitative characteristics of water resources [10, 11]. Examples of such studies indicate heterogeneity of climate changes and ambiguity of their effects on different aquatic sites, so when planning water protection measures it is necessary to study the natural conditions of the formation of a selected aquatic site.

The effect of a climate change on biodiversity is of great concern. In particular, in [12], the authors identify the main factors of biodiversity loss under the effect of interaction between the four determining factors: climate, land-use change, invasive species, and N/C cycle changes. The research results are shown in Fig. 1, adapted from [13].

Natural environment disturbance as a result of the climate change facilitates naturalization of alien species. The authors of [14] found that, in warmer years, groups of three common alien ascidian species usually tended to adapt to substrates earlier than any local species. Tests have been carried out on the relationship of water temperature with the annual total number of each species (both alien and indigenous) on the water surface. The total annual settlement exponent positively correlates with the average winter temperature suitable for alien species although it negatively correlates with that for local species, which suggests that sea groups of New England can become inferior to the alien species if the minimum annual water temperature in winter has a further tendency to increase [15].

Changes in the conditions of natural environments also accelerate the progress of tropical infestations, such as occurrence of *Pistia stratiotes* around the village of Eskhar [16]. This plant can cause a number of negative economic, social and environmental problems, and its invasive spread becomes biologically contaminating. Fig. 2 and Fig. 3 show a mass development of pistia in 2014. An increase in the average air temperatures is likely to raise the risk of a further intensive and extensive spread of pistia.

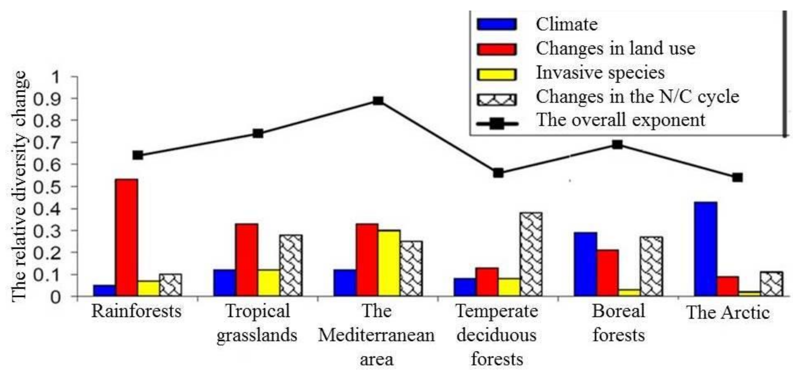

Fig. 1. Expected biodiversity changes in ecoregions by 2100 under the effect of the four dominant factors [12]

Fig. 2. The extensive spread of *Pistia stratiotes* in the Siverskyi Donets (2014, spring)

Fig. 3. The extensive spread of *Pistia stratiotes* in the Siverskyi Donets (2014, autumn)

The formation of water quality is significantly affected by the physical and geographical river basin conditions (in particular, the landscape, soil, geological structure, and vegetation). Identification of the priority problems requires considering both the intensity of degradation processes and the contribution of "positive" stabilization factors and improvement of river basin ecosystems.

Studying the effect of natural and anthropogenic factors on hydrochemical characteristics of the quality of an aquatic site allows a more reliable prediction of the occurrence of dangerous situations such as a mass extinction of fish, a spread of infestation, and a spread of infectious diseases.

3. The purpose and objectives of the study

The research is aimed at determining the factors that significantly affect the quality of the Oskil surface waters under conditions of climate change and intensive human activities.

To achieve this goal, it is necessary to solve the following problems:

– to analyse long-term climate changes in the Kharkiv region by the factors that have the greatest effect on the quality of the aquatic sites and the changes in the hydrological characteristics of the Oskil, and to construct predictive models;

– to determine the significance of the impact of the selected anthropogenic and natural factors on the quality of the Oskil waters on the basis of a correlation and regression analysis;

– to assess the intensity of the degradation processes in the selected aquatic site and to determine the extent of the positive impacts and the negative anthropogenic load.

4. Materials and methods of studying the effect of significant natural and anthropogenic factors on the quality of the Oskil river

4. 1. The Holt-Winters method in studying changes in the climatic and hydrological factors affecting the quality of water

The long-term dynamics of climate change have been studied by means of the following parameters: an average air temperature and precipitation from 1969 to 2012; a predictive model was built by the Holt-Winters method. We have studied the Oskil hydrological parameters such as the runoff volume and water consumption for 61 years, from 1953 to 2014, and constructed predictive models.

Models built by the Holt-Winters method are widely used to develop long-term prognoses. The chosen method has advantages as it takes into account seasonality and the general tendency and uses a three-parameter exponential smoothing.

4. 2. The correlation and regression analysis in determining the effect of the selected anthropogenic and natural factors

Regression analysis is a major statistical method in building mathematical models of objects or phenomena on the basis of experimental data [17].

The analysis of previous studies shows that regressive dependence is most frequently determined by the method of least squares and with the help of nonparametric methods of data processing [18].

A multivariate correlation and regression analysis based on the method of least squares allows assessing to what extent each model factor affects the resultant exponents if the positions of other factors are fixed at the average level. An important condition is the absence of a functional link between the factors.

Mathematically, the problem is reduced to finding an analytical expression that would reflect in the best way the link between the factor characteristics X_i and the resultant Y, which requires determining the function:

$$Y = f(X_1, X_2, X_3, \ldots, X_p). \quad (1)$$

Factors that significantly affect the Oskil quality were determined by the method of multivariate correlation and regression analysis on the basis of parameters such as the average temperature, annual precipitation, water flow in the river, discharges of waste water, and hydrochemical exponents; an example is shown in Fig. 4.

The findings show that the resultant exponent is significantly affected by two parameters such as the discharge of wastewater (density dependence) and temperature (average dependence).

Thus, the content of soluble oxygen in the Oskil is most affected by wastewater discharges from industrial enterprises and utilities, as well as an average annual air temperature. It is known that the content of soluble oxygen is an important indicator of the viability of aquatic organisms, and its reduction often causes fish mortality, which predetermines the relevance of studying the impact of natural and anthropogenic factors on the quality of the Oskil river basin.

Regression Summary for Dependent Variable: Solution, O_2^* (Spreadsheet29)
R= ,68030185 R?= ,46281060 Adjusted R?= ,36513980
F(4,22)=4,7385 p<,00655 Std.Error of estimate: 1,3075

N=27	Beta	Std.Err. of Beta	B	Std.Err. of B	t(22)	p-level
Intercept			-0.731730	3.962902	-0.184645	0.855199
The total water discharges, mln m^3	0.766411	0.186417	0.274490	0.066765	4.111279	0.000460
An average annual temperature	0.419231	0.192068	0.613275	0.280968	2.182722	0.040014
Annual precipitation, mm	0.113769	0.164712	0.002315	0.003351	0.690713	0.496969
Consumption Q, m^3/s	0.076786	0.181592	0.013993	0.033093	0.422846	0.676512

Fig. 4. Determining the impact of natural and anthropogenic factors on the soluble oxygen content in the Oskil: Intercept is soluble oxygen

4. 3. Assessment of the intensity of degradation processes in the Oskil river basin

The methodology of [19] was applied to determine the rationality of using a river basin in evaluating the intensity of degradation processes and assessing the impact of positive and negative factors on the formation of aquatic ecosystems.

The intensity exponent of the degradation processes that occur in the basin is calculated by the following parameters: the ravine formation (R), land erodibility (E), silting (S), and waterlogging (L), and it is calculated by the following formula [19]:

$$I_{pr} = \frac{1}{2}(R+L)\times(E+S). \quad (2)$$

The methodology of [19] is used to calculate separately the degree of the negative effect of the anthropogenic factors on the development of degradation processes in river basins in terms of tillage, urbanization, water intake, and wastewater discharge.

The favourable factors of stabilization and improvement of river basin ecosystems include: forest cover, meadow cover, lake cover, and a change in the river flow.

The factor of orientation of the processes in river basins (F_o) can be calculated as the ratio of the value of negative influence of anthropogenic factors on the development of degradation processes (S_a^-) and the value of positive influence of natural factors (S_{es}^+) [19]:

$$F_o = \frac{S_a^-}{S_{ec}^+}. \quad (3)$$

The index of development (I_D) of processes that occur in river basins under the influence of natural and anthropogenic factors is calculated as follows [19]:

$$I_D = F_o \times I_{pr}. \quad (4)$$

An assessment of the orientation of the processes in aquatic ecosystems is essential to identify problematic situations and to develop a set of environmental protection measures by analysing the significance of affecting factors and negative consequences.

The intensity of the degradation processes in the Oskil river basin was evaluated according to the statistical reports of 1990 and 2012.

We have assessed the negative influence of anthropogenic factors on the development of degradation processes in the Oskil basin streams and the impact of positive factors, as well as calculated the orientation factor of 2012.

5. The research findings on the significant factors that affect the Oskil river water quality

While monitoring the average temperature in the Kharkiv region according to the State Committee for Hydrometeorology from 1969 to 2012 and building a predictive model, we have revealed an expected global warming by 1.9 °C – from 7.8 °C to 9.7 °C – in 2020 (Fig. 5). The blue colour in Fig. 5 marks the observation data on the average temperatures from 1969 to 2012, the red colour indicates the forecast for the period until 2020 by the Holt-Winters method, and the green colour marks errors. Similar designations are found in Fig. 6–8.

The monitoring of the average annual precipitation in the Kharkiv region, according to the State Committee for Hydrometeorology from 1969 to 2012, and the building of a predictive model have disclosed that there is an expected slight decrease in the amount of precipitation from 523 mm in 1969 to 504.8 mm in 2022 (Fig. 6).

Studying the volume of the Oskil flow from 1924 to 2014 showed its considerable variability, and, according to the forecast model by the Holt-Winters method (Fig. 7), in 2024, there is an expectation of 613.8 mln m^3, which is well below the average volume for the years studied (1159.7 mln m^3).

The study of the fluctuations in the Oskil water flow within 61 years – from 1953 to 2014 – showed that from 1994 to 2014 the average annual water consumption significantly decreased from 56.9 m^3/s in 1994 to 25.4 m^3/s in 2014, and its further decrease is predicted for the future (Fig. 8).

The significance of the impact of the selected anthropogenic and natural factors has been assessed by means of the models constructed with the help of a multivariate regression and correlation analysis. The findings show that soluble oxygen is most affected by wastewater discharges (the density dependence is 0.76) and temperature (the average dependence is 0.42); oil content – by wastewater discharges (the average dependence is 0.49); manganese content – by wastewater discharges (the density dependence is 0.7); BOD_5 content – by wastewater discharges (the average dependence is 0.62); zinc content – by wastewater discharges (the average dependence is 0.43) and temperature (the average dependence is 0.53); and total chromium content – by annual precipitation (the average dependence is 0.46). The impact of natural and anthropogenic factors on other hydrochemical indices of the Oskil water quality has not been detected because of weak dependence.

The study has shown that the Oskil water quality is most affected by wastewater discharges and the increase in the average temperature, which means that, when setting targets for the quality of the Oskol river basin, it is necessary to consider the need for reducing wastewater discharges and pay attention to the landscape and ecological characteristics of the river basin.

Thus, it is necessary to study the basin processes that have a direct impact on the formation of water quality. The chosen methodology [19] was used to assess the intensity of the degradation processes in the Oskil river basin and to determine the extent of impact of the positive factors and the negative anthropogenic load.

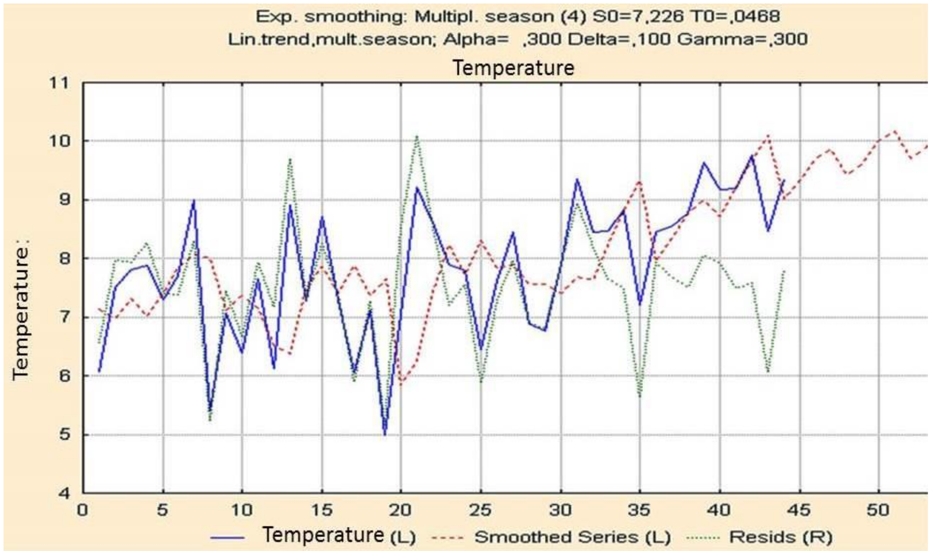

Fig. 5. The forecast of an increase in the average temperature in the Kharkiv region

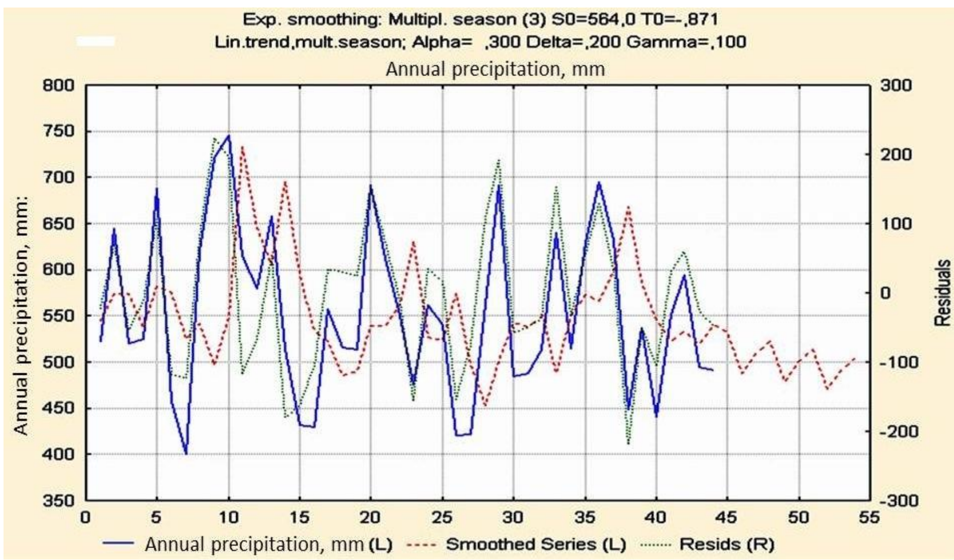

Fig. 6. The forecast of a decrease in the average precipitation in the Kharkiv region

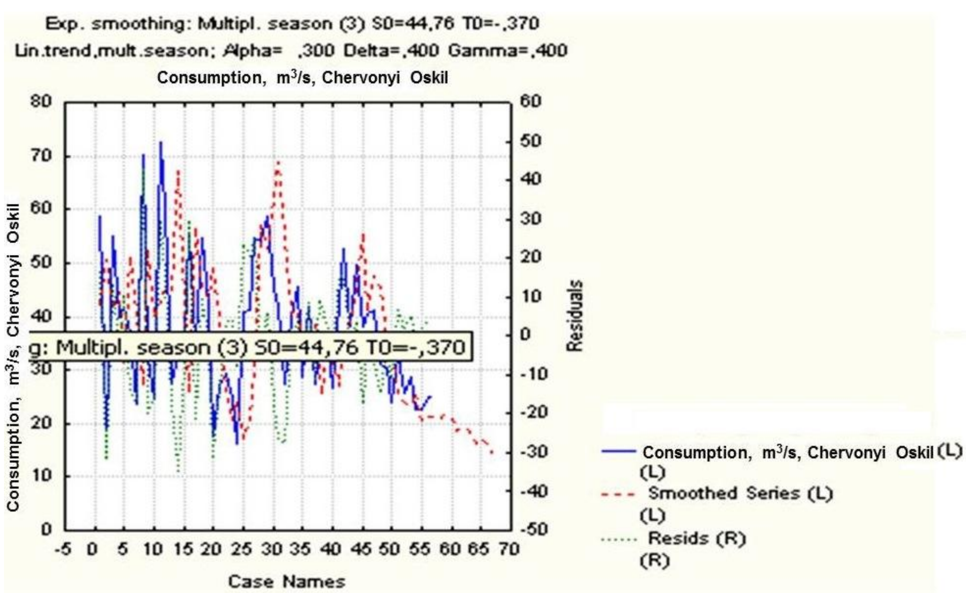

Fig. 7. The forecast of changes in the average water consumption from the Oskil river

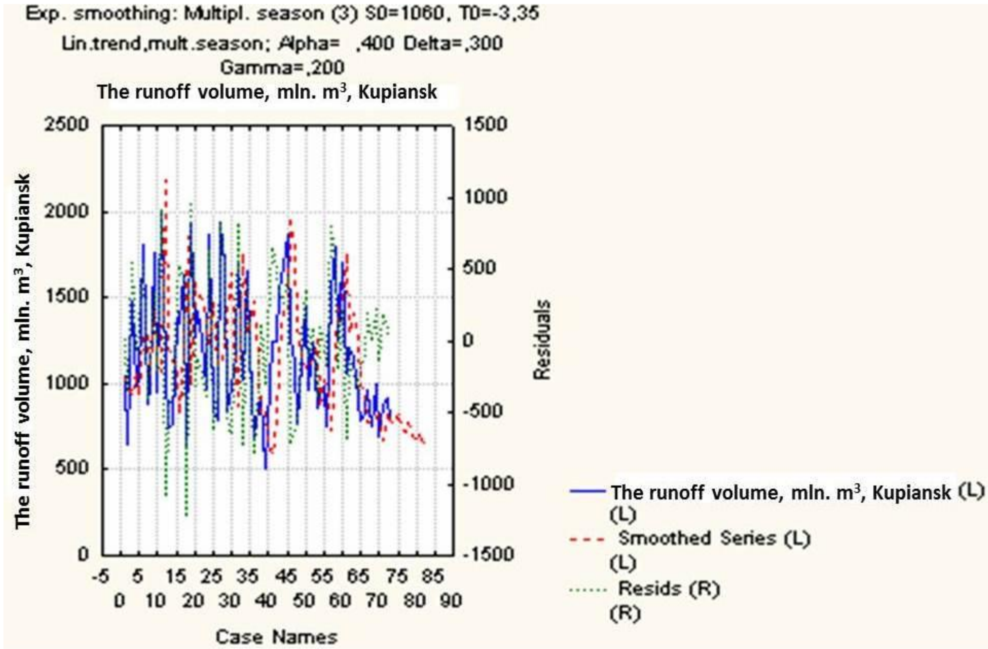

Fig. 8. The forecast of reduction in the Oskil runoff volume

The assessment of the degradation intensity in the Oskil river basin according to the data of 1990 and 2012 indicates a tendency to a significant increase in the intensity of degradation processes in rivers such as the Nyzhnia Dvorichna (17.9 times), the Bakhtyn (5.49 times), and the Hnylytsia (4.35 times). The ranking of these rivers by magnification of the intensity of the degradation processes from 1990 to 2012 is presented in Fig. 9.

The analysis of the impact of negative factors on the ecological state of the Oskil river basin shows that the most influential negative factor is tillage, which has the following indices for the rivers: the Solona – 86.0 %, the Hnylytsia – 72.4 %, and the Borova – 74.9 %. Evaluation of the degradation processes shows that the most contaminated rivers are the Solona and the Hnylytsia (Fig. 10).

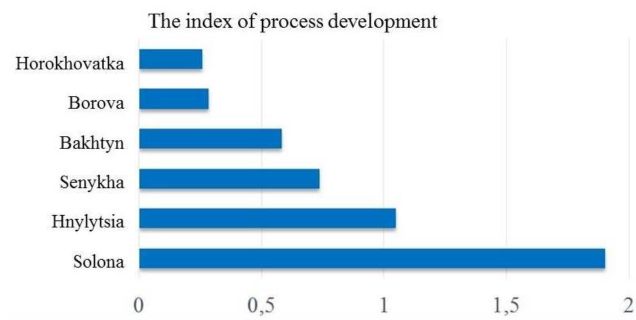

Fig. 10. The ranking of the small rivers in the Oskil river basin (in the Kharkiv region) by the index of process development in 2012

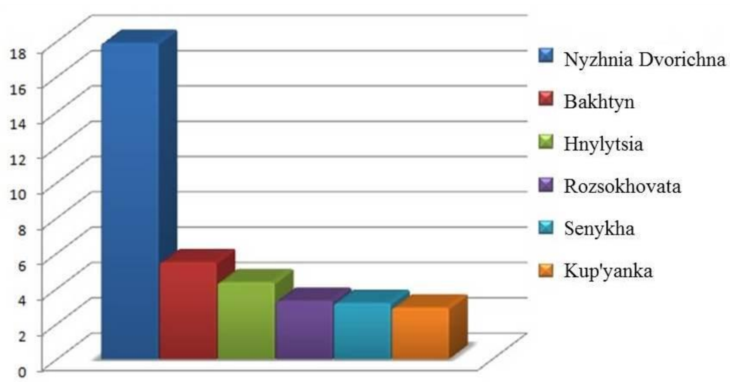

Fig. 9. The ranking of the Oskil basin watercourses (in the Kharkiv region) by magnification of the intensity of the degradation processes from 1990 to 2010

The biggest problems of the basins of these rivers include the following: high rates of erosion, excessive tillage of the catchment areas, and low percentages of forest cover, i. e. the above problems are priorities in the development of environmental protection measures for the region.

6. Discussion of the research results on the impact of significant factors on the qualitative state of the Oskil river

Taking into account long-term observations, we have analysed the climatic and hydrological changes that have had a decisive influence on shaping the water quality; the expedient detailed consideration entailed construction of predictive models by the Holt-Winters method. The employed method is widely used for building long-term predictions, having advantages over other methods due to the three-parameter exponential smoothing and taking into account the general trend.

According to the developed predictions, there is an expectation of a projected decrease of the average annual precipitation and an increase in the temperatures, which will have a direct impact on the deterioration of the water quality.

To determine the significance of the impact of anthropogenic and natural factors on the hydrochemical content in the qualitative parameter of the Oskil river water, a statistical analysis was used to select the determinants of water quality formation such as the average annual temperature, annual precipitation, water flow in the river, and wastewater discharges. A multivariate correlation and regression analysis was applied to identify the significant factors of the surface water quality in the Oskil river basin.

The multivariate correlation and regression analysis has revealed that the most significant impacts on the water quality have been produced by wastewater discharges and the average temperatures. Moreover, the analysis of the Oskil river water basin shows that during the period from 1986 to 2014 the discharge of wastewater decreased more than 6 times, but many indicators of the river water quality do not comply with the maximum admissible concentrations for fishery operation, according to the monitoring data for 2015 and the modal parameters for the period from 1977 to 2015.

The exponent of the wastewater discharge was used due to the fact that it has been the parameter annually reported by companies in the form 2TP-water industry. The calculations did not include such indicators of the economic use of the Oskil river basin as the forest cover, tillage, and meadow cover, due to lack of long-term data on their quantitative values. The need to take into account the indicators of the economic use was confirmed as a result of assessing the intensity of the degradation processes.

In further research, for a more detailed analysis, we intend to consider more factors of influence and explore the effects of these factors on the hydrobiological component of water ecosystems as an important element in the formation of water quality and the development of invasive species.

The causes of the worsened ecological condition of the Oskil river were identified by evaluating the processes occurring in small river basins, and the rationality of the use of a basin was analysed by the method suggested in [19].

The downside of the methodology for assessing the intensity of the degradation processes is that the calculations involve ambiguous and miscellaneous impacts on the basin produced by characteristics such as lake cover and swamps, which requires a further improvement of this technique. Another significant problem is created by disadvantages of monitoring observations, including a large amount of data required for calculation and contained only in the ecological passports of small rivers; they are outdated and a source of incorrect results.

The finding of the evaluation indicate that the priority environmental protection measures should be implemented for basins of such rivers as the Nyzhnia Dvorichna, the Solona, the Hnylytsia Senykha, the Bakhtyn, the Borova, the Horokhovatka, and the Kup'yanka. The high rates of the degradation processes can be explained by the sensitivity of the small rivers to decay as a result of excessive anthropogenic impacts and unsustainable use of the aquatic sites.

Currently, to determine changes in the ecosystems, it is necessary to use geographic information systems (GIS), despite the fact that working with them requires additional involvement of experts in the field, and the results are difficult to compare with historical data.

According to [20], in the case of man-made causes of problems, their solution is likely to depend on the choice of the directions and ways of doing business, developing and applying new technologies, engineering and technical support of sustainable development of anthropogenically-altered ecosystems, with the greatest possible approximation of their development to natural conditions. If a problem arises for natural evolutionary reasons, it is imperative to bring economic activities into line with the direction of the occurring natural changes. If an ecological problem is caused by a complex of natural and anthropogenic factors (for example, floods in the Carpathian Mountains or mass extinction of fish in a river basin, their solution will be of integrated nature.

7. Conclusion

1. The study has specified the long-term dynamics of the climatic factors and hydrological parameters of building predictive models by the Holt-Winters method. The results indicate that the climate change tends to increase the average temperatures. Another consequence is a decrease in the average amount of precipitation. The model, which was built with using the hydrological parameters of the runoff volume and water consumption, predicts their significant reduction in the future. These trends can have negative consequences for the environmental state, create risks, and increase infestations.

2. The correlation and regression analysis has helped determine the dependence of the hydrochemical parameters of the surface water quality in the Oskil river on natural and anthropogenic factors. The results show that the greatest dependence of these parameters is associated with discharges of wastewater. This creates a further need to study the general condition of the aquatic site.

3. The assessment of the intensity of the degradation processes indicates the need to restore and maintain the optimal regime of the small rivers in the Oskil river basin, which can be achieved by addressing the causes of their degradation and by implementing a set of special institutional, farming, agroforestry and other regenerative water conservation measures based on a rational economic analysis of using the water resources and the catchment land area.

The results of the study can be used in planning water protection measures and identifying priority problems of surface water; the constructed regression and correlation dependencies provide an opportunity to assess objectively the state of the surface water and identify the time periods of different degrees of influence.

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