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Regularities of changes in the recreation ecosystems' quality parameters in space

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SUMMARY

Our study of the Danube hydro-ecosystems of the Carpathian region using of the integrated natural water quality assessment resulted in obtaining the functional dependencies between quality indicator and altitude. For the first time, the regularities of changes in the ecosystems' quality parameters in space were established by means of developing functional dependences among the ecological standard values of the composite quality indicators of natural waters and the river length and terrain altitude, and performing the statistical processing of the database containing the results of the quality monitoring observations of the upper reaches of the Danube ecosystems in the Ukrainian Carpathians for the period from begin 21 st. The obtained dependencie and map can be used for the Carpathian region as the territorial background standard values of the ecological state indicators of basin ecosystems, which will help to scientifically substantiate the ecologically safe values of the anthropogenic pressure.

Introduction

According to the European environmental legislation (*Guidance on Scoping, 2017*), the environmental quality assessment is carried out to set the maximum permissible levels to guarantee population`s environmental safety, its genetic conservation and ensure natural resource management amid economy`s sustainable development (*Mandryk et al., 2020*). The most water resources in the studied region are river flows. Understanding the consequences of anthropogenic impacts on aquatic environment, we believe that finding ways to solve the optimization problem of correlation between society and nature is one of the hot button current problems (*Kravchynskyi et al., 2021*). Water use being an anthropogenic process, consisting of successive human actions aimed at using natural resources to ensure its livelihoods, was and still remains extensive and irrational (*Mandryk et al., 2020*). Thus, study and modelling of the qualitative component of fresh water resources is one of the most important tasks. The article objectives are to establish the background values of water quality indicators for river ecosystems applying the case of the Ukrainian Carpathians area and to determine ecological standards of its natural waters` basic components. General and specific patterns of the studied natural waters, their spatial distribution based on statistical processing of hydro-chemical observation results provided by the national network of water quality monitoring have been revealed and analyzed in the article.

Methods

The following research methods were used in the study: analytical method, cartographic modelling, monitoring information processing; statistical and mathematical methods based on Microsoft EXCEL and TableCurve 2D software packages (*Khaylov, 2010*). The Composite Potential Quality Indicator (CPQI) (*Arkhypova, 2022*) was used to determine natural regularities. The CPQI is calculated by adding so-called coefficients of indicators reserves (relative reserve capacity), which are calculated as the excess of permissible values over the actual ones (concentrations, units, points, quantity, etc.), and subtracting the coefficients of indicators reserves shortage (relative reserve shortage), which are calculated as the excess of concentrations (or other measurements) over the permissible values (in the same units). The result is divided by the number of indicators used:

$$CPQI = \frac{1}{n}\sum_{i=1}^{n} x_i; \quad x_i = \begin{cases} \frac{QS_i}{C_i}, if \frac{QS_i}{C_i} > 1 \\ -\frac{C_i}{QS_i}, if \frac{QS_i}{C_i} < 1 \end{cases}, \tag{1}$$

where QSi – water quality standard for the i^{th} indicator – limit (permissible) values of the indicators of water conditions and their properties, which meet the requirements of different consumers; Ci – actual value of water quality for the i^{th} indicator; n – number of indicators.

The proposed methodology makes it possible to apply simple prioritization method, that is, certain aquatic ecosystem areas meeting the environmental quality standards could be considered a point of reference without further adjustments, while other aquatic ecosystem areas can be ranked and assessed by the CPQI index and value.

Results

The state water resources monitoring system supports four or more times per year (different hydrological seasons) water sampling for Physicochemical analysis in accordance with the procedure established by regulatory document KND 211.1.1.106-2003 *(Klymchuk et al., 2022*).

Statistical processing of the obtained monitoring results (average annual values were calculated, and data for the 2001-2021 period were summarized) allows to conclude that the water quality of river ecosystems at altitude more than 500 m above sea level in the Ukrainian Carpathians generally corresponds to standard (reference) conditions (*Kravchynskyi et al., 2021*). Based on the fact that the long-term monitoring results of the surface waters in mountain areas, the beds of which are located at altitude above 500 m, show that for many years the water belongs to the quality class "clean" or "fairly clean", "good" or "very good", and considering the fact that due to the discharge of sewage water from mountain settlements the diffuse pollution in 99% of cases does not cause exceeding quality standards, we set the task to determine the environmental standard of the natural water quality components and investigate the functional regularities of their spatial changes within the studied territory.

Mathematical modelling based on statistical processing of surface water analyses results have been used in the study. The analyses were carried out within the state water monitoring in Ukraine by the certified laboratories of basin directorates. Each numerical result characterizing water body`s monitoring area is an integrated indicator of more than 50 observations. Samples were taken four times annually. The database of hydro-chemical monitoring was processed by the geometric mean method:

$$F(x) = \ln x, \qquad (2)$$

Scholars consider that in a ratio scale among all means only generalized mean and geometric mean are firm being compared. (*Khaylov, 2010*).
Thus, for each sampling point, taking into account all sampling dates, we obtained geometric mean for 2001-2021 referring to each group of components:

- general and total hydro-chemical indicators: mineralization, total hardness, hydrogen index (pH), dissolved oxygen, permanganate and dichromate oxidation, biochemical oxygen demand (BOD_5);
- concentrations of inorganic substances: nitrite, nitrate, and ammonium nitrogen, total phosphorus, mineral phosphates, sulfates, chlorides, calcium, magnesium, zinc, iron, copper, chromium, cadmium, cobalt, manganese;
- concentrations of organic substances: petroleum products, phenols, pesticides, formaldehyde, synthetic surface active agents;
- hydro-physical and organoleptic indicators: water temperature at the bottom layer, organoleptic observations (smell, turbidity, color, and transparency).

TableCurve 2D was used to obtain linear functional dependencies and regression equations for statistical series of observations. Functional dependency equation, equation coefficients, and calculated statistics parameters are represented in the description above the dependencies curve developed by the TableCurve 2D programme. TableCurve 2D uses four goodness-of-fit statistics. The dependency between data sets will be closer, if r^2 values approach 1.0 (0 is total lack of correlation), the standard error decreases to zero, and the F-statistics goes to infinity *(Klymchuk et al., 2022*). We used the TableCurve 2D programme to obtain the following regression close functional dependency of the reservoirs` quality standard (mean persistent value) of the Tysa river ecosystem within the Carpathian region and the area`s altitude (Fig. 1).

$$y=8,129-39,334/x^{0,5} \qquad (3)$$

In this case, $Fstat=33.837$ *(calculated)*$>Fstat=F_m(\alpha=0,05)=4,41$ (table value). Thus, the correlation between the properties is not accidental, it is significant.
The spatial distribution model of the Composite Potential Quality Indicator within the Prut and Syret rivers hydro-ecosystem at the Carpathian region was built as a cartographic map (Fig. 2). Six shades of the main colour show the spatial change in real quality of the Prut and Syret rivers hydro-ecosystem. It was calculated using mean persistent Composite Potential Quality Indicator, which varies in this case from – 0.2 CPQI to +2.1 CPQI.

The spatial distribution model of the current mean persistent CPQI within the Danube water ecosystem at the Carpathian region is a three-dimensional one (Fig. 3) within geographic coordinate system.

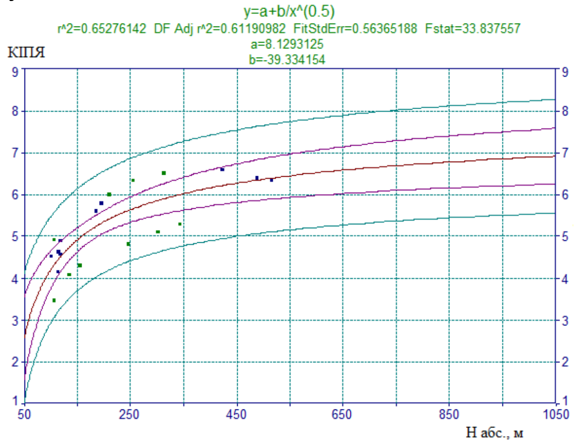

Figure 1 Functional dependency between water quality standard of the Tysa river ecosystem and terrain altitude

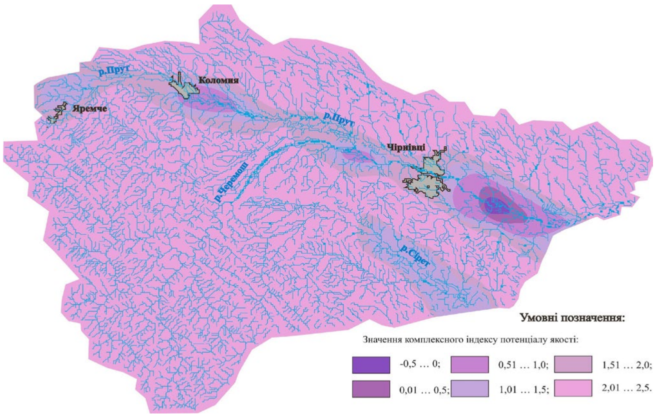

***Figure 2** Map-scheme of the regional spatial distribution of the Composite Potential Quality Indicator within the Prut-Syret hydro-ecosystem*

The model clearly demonstrates the variation of hydro-ecosystem`s quality potential. For the given model: the abscissa is presented by area`s latitude, the ordinate – area`s longitude, six main colour gradations illustrate sites` distribution for the hydro-ecosystems` quality indicator of natural and man-made safety, which changes referred to CPQI`s change amplitude. That is, pessimum of the Prut-Syret hydro-ecosystem is marked with red, yellow and green colours with corresponding gradations from -0.5 to + 0 – red, from 0 to +0.5 – yellow, from +0.5 to +1 – green. The other colours like light blue, blue, and pink characterize the gradations of adaptation stress zone by the quality component of environmental security for the Prut-Syret hydro-ecosystem.

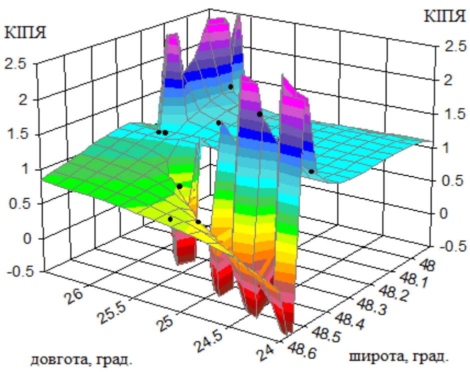

Figure 3 Spatial distribution model of the real quality of surface water bodies within the Danube aquatic ecosystem of the Ukrainian Carpathians north-eastern slopes

The model includes ecological control methods for various surface water uses, detection and assessment of the pollution impact`s on aquatic ecosystems, quality of water resources and conditions of their reproduction. It also can be used to assess the quality of polluted and clean waters, and to determine the ecological status of water bodies.

The proposed method can be used in environmental regulatory actions, environmental expertise, environmental audit, hazard assessment and pollutant action forecasting, and development of water protection measures. Pollution reveals the task to find out a critical level of pollutant concentration, which unbalances the hydro-ecosystem (homeostasis). At present, there is no such system. Therefore it is a complex multidisciplinary task *(Water Framework Directive 2000/60/EC)*. It has been proposed to measure hydro-ecosystems` ecological stability by hydro-ecological potential. We think that hydro-ecological potential is part of water resources, which can be used by the national economic complex in case of ecological safety and balanced water use (that is, human activity ensures sustainable development while minimizing hydro-ecosystems` disturbance to the limits of homeostasis).

Conclusions

Our study of the Danube Rivers hydro-ecosystem of the Carpathian region of Ukraine using methodologies of the integrated natural water quality assessment resulted in obtaining the functional dependencies between quality indicator and altitude. On the one hand, this correlation is logical: as the altitude increases, the level of anthropogenic load decreases, and the quality of natural waters improves. On the other hand, the Ukrainian Carpathians are low mountains, they are quite populated, and in small settlements there is no centralized water supply and sewage treatment. This is a tourist region. The following conclusions were made as the results of the study: the proposed methodology allows to provide quantitative assessment of aquatic ecosystems` buffer capacity and to apply simple prioritization method. Determined ecosystem areas meeting environment reference conditions can be accepted as reference points (conditionally without anthropogenic pressure), and other areas of aquatic ecosystems can be ranked and evaluated depending on the quantitative index and CPQI. We believe that this approach makes it possible to normalize the level of anthropogenic load on water bodies. For the sustainable development of the Carpathian region, the resulting dependencies and map can be used as territorial background standards for the ecological status of Danube basin ecosystems. These studies are important to justify and improve the Ukrainian monitoring programmes, which must be adapted to the EU legislation.

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