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Breus D. S. [1; ORCID ID: 0000-0001-7238-518X],
Candidate of Agricultural Sciences (Ph.D.), Associate Professor

[1]*Kherson State Agricultural and Economic University, Kherson*

ECOSYSTEM-BASED ASSESSMENT OF WATER QUALITY AND ANTHROPOGENIC PRESSURE IN THE INHULETS RIVER BASIN

The increasing anthropogenic and technogenic pressure on river basins requires the implementation of integrated approaches for assessing the ecological condition and environmental safety of aquatic ecosystems. The Inhulets River basin is one of the most environmentally stressed hydrographic systems in southern Ukraine due to intensive mining activity, industrial wastewater discharge, agricultural runoff, urbanization, and hydrological regulation. Long-term technogenic impact has caused significant transformation of hydrochemical regimes.

The article presents an integrated hydroecological assessment of the ecological state of the Inhulets River basin based on the analysis of hydrochemical, hydrobiological, and ecological indicators. The methodological framework combines traditional resource-based approaches with ecosystem-oriented principles of environmental assessment. Particular attention is devoted to the application of integrated water quality indices, including the Water Pollution Index (WPI), saprobity index, ecological index, and hydrochemical quality indicators, allowing for a comprehensive evaluation of anthropogenic transformation processes within the basin.

The study identifies the major sources of environmental pressure affecting the river ecosystem and determines the role of industrial and municipal discharges in the formation of hydroecological instability.

The results confirm that the existing resource-based assessment system does not fully reflect structural and functional transformations occurring within aquatic ecosystems under conditions of long-term technogenic impact. The proposed integrated approach improves the objectivity of environmental monitoring and provides a scientific basis for sustainable river basin management, ecological rehabilitation measures, and optimization of water protection policy under conditions of increasing anthropogenic pressure.

Keywords: anthropogenic transformation; water quality; hydrochemical indicators; saprobity index; aquatic ecosystems; technogenic pressure;

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ecological monitoring.

Problem statement. The ecological condition of river basins is one of the key indicators of environmental safety and sustainable regional development. River ecosystems perform essential hydrological, ecological, economic, and social functions; however, under conditions of intensive anthropogenic pressure, their natural capacity for self-regulation and self-purification gradually decreases. This problem is especially relevant for rivers located within industrially developed regions, where long-term technogenic impact significantly transforms the natural hydroecological regime.

One of the most environmentally vulnerable hydrographic systems in Ukraine is the Inhulets River basin, which has been subjected to prolonged industrial and anthropogenic influence for decades. The ecological state of the basin is largely determined by the combined impact of mining and metallurgical enterprises, discharge of highly mineralized mine waters, municipal wastewater inflow, agricultural runoff, hydrotechnical regulation of river flow, and increasing urbanization within the catchment area. Such conditions have caused significant hydrochemical transformation of the river system and deterioration of surface water quality [1].

Long-term technogenic pressure within the basin has resulted in increased mineralization, changes in ionic composition, accumulation of pollutants, disturbance of the oxygen regime, intensification of eutrophication processes, and degradation of aquatic ecosystems. In addition, the river's ability to maintain ecological stability and natural recovery has substantially weakened, which negatively affects both environmental safety and the suitability of water resources for domestic, agricultural, industrial, and fishery use.

A characteristic feature of the Inhulets River basin is the complex and cumulative nature of anthropogenic impact. Unlike local pollution events, the hydroecological condition of the river is formed under the simultaneous influence of multiple sources of contamination and hydrological disturbances. Under such conditions, assessment of water quality based solely on individual hydrochemical parameters becomes insufficient, since it does not fully reflect the overall ecological state of the aquatic ecosystem or the scale of anthropogenic transformation processes.

Modern approaches to environmental assessment increasingly emphasize the importance of integrated hydroecological analysis

combining hydrochemical, hydrobiological, and ecological indicators within a unified assessment system. The application of integral indices allows the transformation of heterogeneous monitoring data into generalized ecological characteristics reflecting the degree of pollution, ecological stability, and level of anthropogenic disturbance within river systems [2].

Particular importance in this context belongs to the use of ecological classification systems and water quality indices, including the Water Pollution Index, saprobity index, ecological index, and hydrochemical assessment indicators. These approaches provide an opportunity not only to evaluate the current ecological condition of surface waters but also to identify dominant degradation factors, determine environmentally critical sections of the basin, and substantiate measures aimed at improving the hydroecological state of the river system.

Therefore, the necessity of conducting an integrated hydroecological assessment of the Inhulets River basin under conditions of long-term anthropogenic pressure represents an important scientific and practical task. Such assessment is essential for improving environmental monitoring systems, increasing the objectivity of water quality evaluation, and developing scientifically grounded recommendations for sustainable river basin management and reduction of technogenic impact on aquatic ecosystems [3].

Analysis of recent research. In recent decades, the problem of deterioration of river water quality under conditions of intensive anthropogenic pressure has become one of the central directions of hydroecological research. Modern studies increasingly focus on integrated assessment of river basin ecosystems, considering hydrochemical, hydrobiological, and ecological indicators as interconnected components of a unified environmental system. This approach is associated with the transition from traditional resource-oriented water assessment toward ecosystem-based principles of river basin management.

A significant number of contemporary studies emphasize that long-term industrial activity, urbanization, agricultural runoff, and hydrotechnical regulation are the main drivers of hydroecological transformation of river systems. Researchers note that under conditions

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of constant technogenic pressure, river ecosystems gradually lose their natural self-purification capacity, while the cumulative effect of pollutants causes structural and functional degradation of aquatic environments. Particular attention is devoted to the impact of highly mineralized mine waters and industrial wastewater on hydrochemical regimes of rivers located within mining regions [4].

Recent hydroecological studies demonstrate that assessment of water quality based exclusively on hydrochemical parameters is insufficient for determining the actual ecological state of aquatic ecosystems. Modern environmental monitoring increasingly incorporates biological quality elements, including phytoplankton, benthic organisms, macrophytes, and bioindication indices, which provide more objective information regarding ecological stability and long-term anthropogenic transformation [5].

Contemporary scientific approaches are also closely connected with the implementation of the European Union Water Framework Directive (WFD), which establishes river basin management as the primary principle of water policy. According to WFD requirements, ecological assessment of surface waters should combine hydrochemical, hydromorphological, and biological indicators in order to achieve a comprehensive understanding of ecosystem condition and environmental risks.

A number of Ukrainian and international studies are devoted to the ecological assessment of transformed river basins under anthropogenic pressure. Considerable attention is paid to the use of integrated ecological indices, such as the Water Pollution Index, saprobity index, and ecological classification systems, which allow heterogeneous monitoring data to be generalized into unified indicators reflecting the degree of pollution and ecological degradation. Recent investigations confirm that the use of integrated hydroecological indices significantly improves the objectivity of environmental assessment and enables identification of environmentally critical sections within river basins.

Special attention in recent publications is devoted to the ecological consequences of technogenic transformation of aquatic ecosystems in Ukraine. Researchers emphasize that industrial regions characterized by mining and metallurgical activity demonstrate the highest levels of hydrochemical disturbance, increased mineralization, oxygen deficiency, and accumulation of toxic substances within river systems. These processes are accompanied by changes in aquatic biocenoses, reduction

of biodiversity, intensification of eutrophication, and destabilization of hydroecosystem functioning [6].

At the same time, despite the considerable number of studies devoted to water quality assessment, the problem of integrated hydroecological evaluation of river basins subjected to prolonged technogenic pressure remains insufficiently systematized. Existing studies are often focused either on separate hydrochemical indicators or on local environmental characteristics without comprehensive analysis of the interaction between anthropogenic factors and ecological state of river ecosystems.

In particular, the Inhulets River basin remains one of the most environmentally transformed hydrographic systems in Ukraine, where the combined influence of mining enterprises, municipal wastewater discharge, agricultural activity, and hydrological regulation forms a complex pattern of anthropogenic pressure. Under such conditions, there is a need for a comprehensive hydroecological assessment based on integrated analysis of hydrochemical indicators, ecological indices, and biological characteristics in order to determine the current ecological condition of the basin and identify the dominant factors of environmental degradation [7].

Therefore, modern scientific trends confirm the necessity of applying integrated ecosystem-based approaches for assessing river basin condition, which forms the methodological basis of the present study.

Aim, objectives and methodology. The aim of this study is to conduct an integrated hydroecological assessment of the ecological condition and water quality of the Inhulets River basin under conditions of long-term anthropogenic and technogenic pressure using hydrochemical, ecological, and index-based assessment approaches.

To achieve the stated aim, the following objectives were defined:

- to analyze the current ecological condition of the Inhulets River basin and determine the main anthropogenic factors affecting the hydroecosystem;

- to assess hydrochemical characteristics of surface waters within different sections of the basin;

- to evaluate the degree of anthropogenic transformation of the aquatic environment using integrated ecological indicators and water

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quality indices;

- to determine the level of organic pollution and ecological stability of the river ecosystem;

- to identify environmentally critical sections of the basin characterized by increased technogenic pressure;

- to generalize the obtained results in order to substantiate measures aimed at improving water quality and optimizing river basin management.

The methodological framework of the study is based on an integrated hydroecological approach combining hydrochemical analysis, ecological assessment methods, water quality indices, and comparative analysis of monitoring data. The research was conducted using environmental monitoring materials and analytical data characterizing the ecological state of the Inhulets River basin under conditions of intensive industrial and anthropogenic influence [8].

Assessment of water quality was carried out using hydrochemical indicators reflecting the degree of transformation of the aquatic environment. Particular attention was devoted to indicators characterizing mineralization processes, oxygen regime, nutrient content, organic pollution, and concentrations of priority pollutants. The obtained values were compared with environmental quality standards and maximum permissible concentrations established for surface waters.

To determine the general level of anthropogenic pollution within the river basin, the Water Pollution Index (WPI) was applied:

$$\mathrm{WPI} = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{MPC_i}, \quad (1)$$

where MPC_i – maximum permissible concentration of the chemical component; C_i – the actual concentration of the analyzed parameter; n – the number of analyzed indicators [9].

The Water Pollution Index allows the transformation of separate hydrochemical indicators into an integrated characteristic reflecting the overall degree of contamination of surface waters and the level of anthropogenic pressure within the river ecosystem.

An important component of the study was the assessment of water quality using the hydrochemical water quality index, which provides an integral evaluation of ecological condition based on the combined

influence of hydrochemical parameters:

$$\mathrm{I}_{\omega} = \frac{1}{n}\sum_{i=1}^{n} K_i, \quad (2)$$

where I_ω – the hydrochemical water quality index; K_i – the ecological coefficient of the corresponding hydrochemical parameter; *n* – the number of analyzed indicators [10].

The application of the hydrochemical water quality index makes it possible to classify surface waters according to ecological quality categories and identify sections of the basin exposed to the highest level of anthropogenic transformation.

The ecological condition of the aquatic environment was additionally assessed using saprobity analysis, which reflects the degree of organic pollution and intensity of decomposition processes within the river ecosystem. The Pantle–Buck saprobity index was determined according to the following equation:

$$S = \frac{\sum(s \cdot h)}{\sum h}, \quad (3)$$

where *s* – the saprobic value of the indicator organism; *h* – the quantitative characteristic of species occurrence [11].

The saprobity approach allows evaluation of ecological condition through biological responses of aquatic organisms to changes in environmental quality and oxygen regime. This method is widely used in hydroecological studies of river systems subjected to prolonged anthropogenic impact.

Integrated ecological assessment of surface waters was carried out using ecological classification approaches that combine hydrochemical and biological indicators into generalized categories of environmental quality. Such methods allow determination of ecological condition, degree of anthropogenic transformation, and spatial variability of pollution processes within the river basin.

The methodological approach used in the study is based on the basin principle of environmental assessment, according to which the river basin is considered as an integrated hydroecological system formed

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under the interaction of natural and anthropogenic factors. This approach provides an opportunity to identify relationships between anthropogenic load and ecological condition of surface waters, evaluate the hydroecological stability of different sections of the basin, and determine environmentally critical areas characterized by increased technogenic pressure [12].

The obtained results were systematized using comparative, analytical, and ecological assessment methods in order to determine the current hydroecological condition of the Inhulets River basin and identify the dominant processes influencing the ecological transformation of the river ecosystem.

Results and discussion. The conducted hydroecological assessment demonstrates that the ecological condition of the Inhulets River basin has been significantly transformed under conditions of long-term anthropogenic and technogenic pressure. The obtained results confirm that the hydroecosystem of the river is characterized by unstable hydrochemical conditions, increased mineralization, deterioration of oxygen balance, and a high level of organic pollution caused primarily by mining activity, industrial wastewater discharge, agricultural runoff, and municipal effluents.

One of the most important factors influencing the ecological state of the basin is the long-term inflow of highly mineralized mine waters originating from mining enterprises within the Kryvyi Rih industrial region. Under these conditions, the natural hydrochemical regime of the river has undergone substantial transformation, resulting in deterioration of ecological stability and reduction of the self-purification capacity of the aquatic ecosystem.

Hydrochemical monitoring data indicate that the Inhulets River is characterized by naturally elevated mineralization combined with additional anthropogenic contamination. According to the obtained results, the concentration of magnesium in the river water reached 75.39 mg/dm^3, while organic pollution indicators demonstrated systematic exceedances of maximum permissible concentrations.

Particular attention should be devoted to indicators characterizing organic pollution of surface waters. Analysis of hydrochemical monitoring results revealed that exceedances of maximum permissible concentrations for chemical oxygen demand (COD) and biochemical oxygen demand (BOD_5) were observed in 100% of analyzed samples. The recorded exceedances reached 1.8 times for COD and 1.3 times for BOD_5

compared to standards established for waters of domestic and drinking use. The hydrochemical indicators are presented in Table 1.

Table 1

Selected hydrochemical indicators of the Inhulets River

Indicator	Measured Value	Environmental Characteristic
Magnesium concentration	75.39 mg/dm^3	Increased mineralization
COD exceedance	1.8 MPC	Significant organic pollution
BOD_5 exceedance	1.3 MPC	Disturbance of oxygen regime
Number of measurements (2021)	232	Environmental monitoring basis
Number of water samplings	8	Seasonal hydrochemical assessment

The obtained results indicate the presence of a persistent anthropogenic load affecting the hydrochemical state of the river ecosystem. Elevated concentrations of organic substances contribute to increased oxygen consumption during decomposition processes, which negatively affects aquatic organisms and destabilizes ecological functioning of the river system.

Comparative analysis of hydrochemical indicators between 2020 and 2021 additionally revealed deterioration of several ecological parameters. In particular, alkalinity increased from 4.22 to 4.26 mg-eq/dm^3, while BOD values increased from 4.02 to 4.08 mgO_2/dm^3. At the same time, slight improvement was observed for COD and water hardness indicators. These fluctuations demonstrate the unstable nature of hydrochemical processes within the basin and confirm the strong dependence of river water quality on anthropogenic and hydrological factors.

An important feature of the ecological state of the Inhulets River basin is the significant spatial variability of pollution processes. Hydrochemical conditions vary depending on the proximity to industrial discharge sources, hydrotechnical structures, and sections influenced by periodic flushing using Dnipro water supplied through the “Dnipro-Inhulets” canal system. According to monitoring observations, seasonal changes in water quality indicators within the Iskrivske Reservoir were

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directly associated with the flushing of the river channel performed during April-August through additional Dnipro water inflow.

These measures partially improve the ecological condition of the river system by reducing mineralization and increasing water exchange intensity; however, they do not completely eliminate the consequences of long-term anthropogenic transformation. Previous hydroecological investigations of the Inhulets River basin also confirm that periodic flushing of the river channel improves environmental conditions only temporarily and cannot fully restore ecological balance under conditions of continuous technogenic pressure.

Assessment of surface water quality using integrated ecological indicators demonstrated that the Inhulets River belongs predominantly to the 4^{th}-6^{th} water quality categories and corresponds to III-IV classes of ecological quality. Such classification characterizes the ecological condition of the river as satisfactory to polluted. The generalized results of ecological assessment are presented in Table 2.

The obtained ecological classification confirms that the river basin experiences substantial anthropogenic transformation associated with prolonged industrial exploitation of the territory. The ecological condition of surface waters is formed under the cumulative influence of multiple pollution sources, resulting in degradation of hydrochemical and ecological characteristics of the aquatic environment.

Table 2

Integrated ecological assessment of surface water quality

Assessment Indicator	Ecological Characteristic
Water quality category	4–6
Ecological quality class	III–IV
General ecological condition	Satisfactory / Polluted
Dominant ecological problem	Organic and technogenic pollution
Main transformation factor	Industrial and mining impact

An important aspect of the conducted research is the use of integrated ecological assessment approaches rather than analysis of isolated hydrochemical indicators only. The study confirms that individual hydrochemical parameters do not fully reflect the overall ecological condition of the river system. Under conditions of prolonged technogenic impact, ecological transformation occurs simultaneously at chemical, hydrological, and biological levels, which necessitates the application of integrated hydroecological assessment methods.

The conducted analysis also demonstrates the limitations of the traditional resource-based approach commonly applied in water quality assessment. Although such an approach allows determination of pollution classes and exceedances of maximum permissible concentrations, it does not fully account for ecosystem-level responses and structural-functional changes occurring within aquatic environments under anthropogenic stress.

From an ecological perspective, deterioration of hydrochemical conditions within the Inhulets River basin contributes to destabilization of aquatic ecosystems, intensification of eutrophication processes, reduction of oxygen availability, and gradual degradation of biological communities. These processes collectively reduce ecological resilience of the river system and increase risks associated with further anthropogenic pressure.

The obtained results confirm that the hydroecological condition of the Inhulets River basin remains environmentally unstable and requires implementation of integrated environmental protection measures aimed at reducing technogenic impact, improving wastewater treatment efficiency, optimizing basin water management, and strengthening ecological monitoring systems.

Conclusions. 1. The conducted study allowed a comprehensive assessment of the ecological condition of the Inhulets River basin under conditions of prolonged anthropogenic and technogenic impact. The analysis demonstrated that the hydroecological state of the river system is determined by the combined influence of industrial activity, discharge of highly mineralized mine waters, municipal wastewater inflow, agricultural runoff, and hydrological regulation within the basin.

2. Assessment of hydrochemical indicators revealed deterioration of surface water quality associated with increased mineralization, disturbance of oxygen balance, and elevated levels of organic pollution. The obtained results indicate the formation of a stable anthropogenic load affecting the ecological functioning of the river ecosystem.

3. Application of integrated ecological assessment methods and water quality indices made it possible to characterize the degree of anthropogenic transformation within different sections of the basin and identify environmentally stressed areas exposed to the highest technogenic pressure. The study demonstrated that integrated

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hydroecological approaches provide a more objective evaluation of ecological condition compared to assessment based solely on individual hydrochemical parameters.

4. The conducted analysis also showed that periodic river flushing through the “Dnipro-Inhulets” canal contributes to temporary improvement of hydrochemical conditions; however, such measures do not eliminate the primary causes of ecological degradation within the basin.

5. The obtained results substantiate the necessity of implementing basin-oriented environmental management measures aimed at reducing technogenic impact, improving wastewater treatment efficiency, strengthening ecological monitoring systems, and restoring hydroecological stability of the Inhulets River basin.

6. The proposed methodological approach may be used in further hydroecological investigations of transformed river systems and can serve as a scientific basis for sustainable water resource management under conditions of increasing anthropogenic pressure.

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Бреус Д. С. [1; ORCID ID: 0000-0001-7238-518X],
к.с.-г.н., доцент

[1]Херсонський державний аграрно-економічний університет, м. Херсон

ЕКОСИСТЕМНО-ОРІЄНТОВАНА ОЦІНКА ЯКОСТІ ВОДИ ТА АНТРОПОГЕННОГО НАВАНТАЖЕННЯ В БАСЕЙНІ РІЧКИ ІНГУЛЕЦЬ

Зростання антропогенного та техногенного навантаження на річкові басейни зумовлює необхідність упровадження комплексних підходів до оцінювання екологічного стану та екологічної безпеки водних екосистем. Басейн річки Інгулець є однією з найбільш екологічно напружених гідрографічних систем півдня України внаслідок інтенсивної гірничодобувної діяльності, скидання промислових стічних вод, сільськогосподарського стоку, урбанізації та гідрологічного регулювання. Тривалий техногенний вплив спричинив суттєву трансформацію гідрохімічних режимів.

У статті представлено комплексну гідроекологічну оцінку екологічного стану басейну річки Інгулець на основі аналізу гідрохімічних, гідробіологічних та екологічних показників. Методологічна основа дослідження поєднує традиційні ресурсні підходи з екосистемно орієнтованими принципами екологічного оцінювання. Особливу увагу приділено застосуванню інтегральних індексів якості води, зокрема індексу забруднення води (ІЗВ), індексу сапробності, екологічного індексу та гідрохімічних показників якості, що дає змогу комплексно оцінити процеси антропогенної трансформації в межах басейну.

У дослідженні визначено основні джерела екологічного навантаження, які впливають на річкову екосистему, а також встановлено роль промислових і комунальних скидів у формуванні гідроекологічної нестабільності.

Результати підтверджують, що існуюча ресурсна система оцінювання не повною мірою відображає структурно-функціональні трансформації, які відбуваються у водних екосистемах в умовах тривалого техногенного впливу. Запропонований комплексний підхід підвищує

об'єктивність екологічного моніторингу та формує наукове підґрунтя для сталого управління річковими басейнами, реалізації природоохоронних і відновлювальних заходів, а також оптимізації водоохоронної політики в умовах зростання антропогенного навантаження.

Ключові слова: антропогенна трансформація; якість води; гідрохімічні показники; індекс сапробності; водні екосистеми; техногенне навантаження; екологічний моніторинг.

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