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## PROSPECTS OF UKRAINE'S WATER RESOURCES UNDER THE DEVELOPMENT OF THE MINING INDUSTRY

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The article examines current trends in the transformation of Ukraine's water resources under the influence of mining industry development, using the Inhulets River basin as one of the most technogenically impacted water systems in the country. It has been established that the long-term discharge of highly mineralized mine waters from enterprises of the Kryvyi Rih basin causes a persistent exceedance of the maximum permissible concentrations for chlorides, sulfates, and total mineralization. Analysis of the data provided by the Basin Water Resources Administration and the State Water Resources Agency of Ukraine for 2021–2025 indicates that even after scheduled flushing operations from the Karachunivske Reservoir, the parameters rapidly return to critical levels: mineralization exceeds  $2.0 \text{ g/dm}^3$  and chloride concentrations reach  $1200\text{--}1500 \text{ mg/dm}^3$ , which is 2–4 times higher than the standards defined in DSTU 2730:2015 “Water quality for irrigation”. It was revealed that in the lower reaches of the river (Andriivka and Lativka areas) during the summer period of 2024–2025, the highest level of hydrochemical load is observed, accompanied by a decrease in dissolved oxygen content to  $2.3\text{--}2.5 \text{ mg/L}$ , indicating a reduced self-purification capacity of the aquatic system.

A comparative analysis of international experience from countries with developed mining sectors—Chile, Canada, and Australia—demonstrates that the efficiency of water resource management is ensured through the implementation of closed water-use cycles, desalination technologies, real-time digital monitoring, and contractual fixation of investors' environmental obligations. Based on this, two development scenarios are identified: an inertial one, which maintains the current practice of episodic flushing and increases the risks of aquatic ecosystem degradation, and an innovative one, which envisages the transition to adaptive management based on digital platforms, automated monitoring, and the implementation of water quality KPIs. Implementation of the second scenario will contribute to reducing technogenic pressure, stabilizing the hydrochemical regime of the Inhulets River, restoring the ecological potential of water bodies, and harmonizing Ukraine's water policy with European environmental standards in the context of post-war recovery.

**Key words:** water resources, Inhulets River, mining industry, mineralization, sulfates, chlorides, flushing operations, irrigation, adaptive management, environmental safety, DSTU 2730:2015.

### **Коваленко Р. Ю. Перспективи водних ресурсів України в умовах розвитку гірничодобувної промисловості**

У статті розглянуто сучасні тенденції трансформації водних ресурсів України під впливом розвитку гірничодобувної промисловості, зокрема на прикладі басейну річки Інгулець як одного з найбільш техногенно навантажених водних об'єктів країни. Встановлено, що тривалі скиди високомінералізованих шахтних вод із підприємств Криворізького басейну зумовлюють стійке перевищення гранично допустимих концентрацій за хлоридом, сульфатом та загальною мінералізацією. Аналіз даних Басейнового управління водних ресурсів та Державного агентства водних ресурсів України за 2021–2025 рр. свідчить, що навіть після проведення регламентних промивок із Карачунівського водосховища показники швидко повертаються до критичних рівнів: мінералізація перевищує  $2,0 \text{ г/дм}^3$ , а концентрація хлоридів сягає  $1200\text{--}1500 \text{ мг/дм}^3$ , що у 2–4 рази вище нормативів, установлених ДСТУ 2730:2015 «Якість води для зрошення». Виявлено, що у нижній течії річки

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(райони Андріївки, Латівки) в літній період 2024–2025 рр. спостерігається найвищий рівень гідрохімічного навантаження із одночасним зниженням вмісту розчиненого кисню до 2,3–2,5 мг/л, що свідчить про зменшення самоочисної здатності водної системи.

Проведено порівняльний аналіз міжнародного досвіду країн із розвинутою гірничодобувною галуззю — Чилі, Канади та Австралії, де ефективність управління водними ресурсами забезпечується шляхом впровадження замкнутих циклів водокористування, опріснення, цифрового моніторингу в реальному часі та контрактного закріплення екологічних зобов'язань інвесторів. На основі цього визначено два сценарії розвитку: інерційний, за якого зберігається практика фрагментарних промивок і зростають ризики деградації водних екосистем, та інноваційний, що передбачає перехід до адаптивного управління на основі цифрових платформ, автоматизованого моніторингу й впровадження КРІ якості води. Реалізація другого сценарію сприятиме зменшенню техногенного навантаження, стабілізації гідрохімічного режиму Інгульця, відновленню екологічного потенціалу водних об'єктів та гармонізації водної політики України з європейськими стандартами в контексті післявоєнної відбудови.

**Ключові слова:** водні ресурси, річка Інгулець, гірничодобувна промисловість, мінералізація, сульфати, хлориди, промивки, зрошення, адаптивне управління, екологічна безпека, ДСТУ 2730:2015.

**Introduction.** Water is a strategic resource that determines the environmental security and socio-economic development of a state. For Ukraine, with its complex economic structure and extensive water management system, the rational management of water resources is of particular importance. Under conditions of warfare and post-war reconstruction, ensuring water security becomes a priority of state policy [1].

One of the main factors contributing to the deterioration of surface water quality is mining activity, accompanied by discharges of highly mineralised mine and drainage waters. These cause the degradation of the hydrochemical regime and a reduction in the self-purification capacity of rivers [2; 3]. The most illustrative example is the Inhulets River basin, which has long been affected by mine waters from the Kryvyi Rih basin. Regulated flushes from the Karachunivske Reservoir provide only a temporary effect — within a few weeks, salt concentrations exceed permissible limits [3; 4].

The situation in the Inhulets demonstrates the limitations of traditional approaches to mine water management. Further expansion of mineral extraction, particularly of critical minerals such as lithium, uranium, titanium, and graphite, may lead to large-scale degradation of aquatic ecosystems [5; 6]. Pollution from the Inhulets, transmitted through the Dnipro River system, reaches the Black Sea, giving the problem a trans-boundary dimension [7].

Therefore, assessing the impact of mining activities on Ukraine's water resources and developing effective management solutions is an essential task of contemporary environmental policy. The analysis of the Inhulets basin as a typical technogenic system makes it possible to develop scientifically grounded approaches to improving water management and adapting to international environmental standards.

**Analysis of recent research and publications on the topic.** The problem of the impact of mining activities on water resources has been well studied; however, most research focuses on local aspects. Ukrainian scholars have paid the greatest attention to the Inhulets basin as an example of chronic technogenic load and long-term practice of regulated flushes [2–4].

Studies by V. Mokin, I. Zhuravel, L. Havrylenko and others show that the main source of water quality deterioration is the discharge of highly mineralised mine waters from Kryvbas enterprises. High concentrations of sulphates and chlorides consistently exceed irrigation standards, and even after flushes, the indicators quickly return to critical levels [2–4].

According to the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine, the use of Inhulets water for irrigation causes

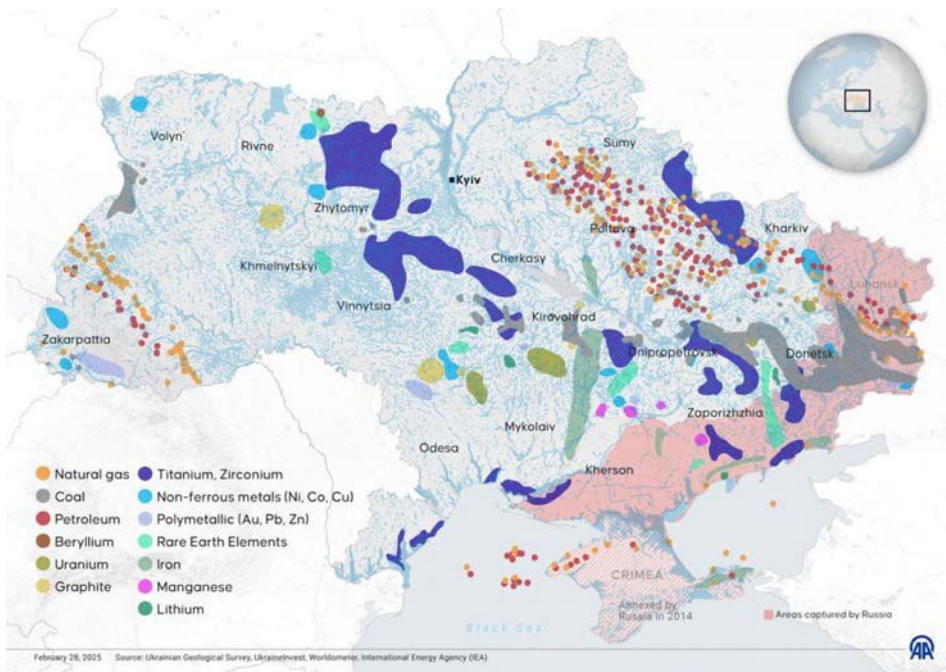
salt accumulation in soils and a reduction in their fertility, posing a threat to the stability of agricultural production in steppe regions [8].

Similar processes are observed in the Siverskyi Donets basin, where mine flooding and the discharge of contaminated waters result in increased mineralisation of surface waters and potential pollution of underground horizons [9]. Analogous problems are recorded in small rivers such as the Samara and Vovcha (Dnipropetrovsk region), which are characterised by the accumulation of heavy metals and reduced self-purification capacity [10].

In international practice (Chile, Canada, Australia), key approaches include the transition to closed water-use cycles, seawater desalination, multistage treatment of mine effluents, and the establishment of guarantee reclamation funds [4; 6; 11].

**The aim of the study** is to assess the impact of mining activities on the condition of river ecosystems in Ukraine, using the Inhulets River basin and similar watercourses subjected to technogenic load as examples, as well as to analyse the potential environmental consequences of expanding mineral extraction within the framework of international cooperation. Particular attention is devoted to comparing national and foreign approaches to mine water management and identifying promising directions for improving water management policy.

**Materials and methods.** The study is based on official data from the Basin Water Resources Departments and the State Agency of Water Resources of Ukraine regarding the condition of surface waters in the Inhulets, Siverskyi Donets, Samara, and Vovcha river basins [1] (Fig. 1).



*Fig. 1. Map of Ukraine showing the hydrographic network and principal mineral extraction zones (lithium, uranium, titanium, iron, graphite, manganese, etc.). Compiled by the author based on data from the Ukrainian Geological Survey, UkraineInvest, and IEA (2025)*

Additional materials include the regulations on the Inhulets channel flushes and normative legal documents, in particular DSTU 2730:2015 “Water quality for irrigation. Classification” [2]. The source base also comprises works by Ukrainian and foreign authors, as well as analytical materials on current and prospective projects in the mining sector [3].

The methodological framework combines analytical, comparative, and systemic approaches:

- the analytical approach was applied to summarise hydrochemical indicators and monitoring results;
- the comparative approach was used to contrast the condition of water resources in basins with varying levels of mineral extraction;
- the systemic approach was employed to formulate coherent conclusions and recommendations;
- in addition, elements of scenario forecasting were used to assess medium-term trends in water quality change.

**Current situation in Ukraine.** The analysis confirms the systemic nature of technogenic load on river ecosystems in the mining-industrial regions of Ukraine. The most illustrative case is the Inhulets River basin, where prolonged discharges of highly mineralised mine and drainage waters cause elevated mineralisation and persistent exceedances of chloride and sulphate concentrations in the lower reaches. This directly affects the suitability of water for irrigation and creates risks of secondary soil salinisation [1; 5–7].

To illustrate this, the results of public water quality measurements in the Inhulets over recent years are compared with the standards of DSTU 2730:2015 “Water quality for irrigation. Agroecological criteria” (Table 1) [2].

As shown in the table, during 2021–2025, water quality in the Inhulets remained unstable and seasonally stressed. In the lower reaches (Andriivka, Lativka areas), systematic exceedances of chloride concentrations by 2–4 times above the standard were recorded. At the end of the 2024 irrigation period, chloride levels reached the upper permissible limit, while mineralisation was about 2.0 g/dm<sup>3</sup> — the threshold value for irrigation. In July 2025, despite moderate mineralisation, low dissolved oxygen (~2.35 mg/L) indicated a reduced self-purification capacity of the river system [1; 2].

Regulated flushes from the Karachunivske Reservoir provide only short-term improvements in water quality without addressing pollution sources. After their completion, salt concentrations rapidly return to critical levels, causing biotic degradation and secondary salinisation of irrigated lands [5–7].

Polluted waters from the Inhulets are transported to the Dnipro basin and subsequently to the Black Sea, intensifying regional environmental stress [11]. Similar processes occur in the Siverskyi Donetsk basin (Donbas), where the combination of mine drainage and flooding increases the mineralisation of surface and groundwater [9], as well as in small rivers of the Dnipropetrovsk region (Samara, Vovcha), which are highly sensitive even to minor technogenic discharges [10]. Collectively, this confirms the nationwide scale of the mining industry’s impact on Ukraine’s water resources [1; 8].

Table 1

**Verified Water Quality Indicators of the Inhulets River  
(Selected Data, 2021–2025) and Comparison with DSTU 2730:2015**

Year / Date	Monitoring Site	Indicator	Measured Value	Reference Standard for Irrigation (DSTU 2730:2015)	Assessment Relative to Standard
2021 (Sep.–Dec.)	Lower reach, Andriivka village	Chlorides	up to 1365 mg/dm <sup>3</sup>	300–500 mg/dm <sup>3</sup>	Exceedance 2.7–4.6×
		Sulfates	672–842 mg/dm <sup>3</sup>	500–1000 mg/dm <sup>3</sup>	Within / above lower limit (salinization risk)
2022 (16–17 Sep.)	Kryvyi Rih; Andriivka station	Chlorides	1180–220 mg/dm <sup>3</sup> (per day)	300–500 mg/dm <sup>3</sup>	Short-term normalization after emergency actions
		Hardness	19 → 6 mg-eq/L	≤ 7 mg-eq/L	Normalized to permissible level
2024 (25 Sep.)	Near Inhulets Pump Station	Mineralization	2.018 g/dm <sup>3</sup>	≤ 2000 mg/dm <sup>3</sup>	At the permissible limit
		Chlorides	553 mg/dm <sup>3</sup>	300–500 mg/dm <sup>3</sup>	At / slightly above upper limit
		pH	8.82	6.5–8.4 (recommended)	Above recommended interval
2025 (30 Jul.)	Kryvyi Rih (urban section)	Mineralization	861 mg/L	≤ 2000 mg/dm <sup>3</sup>	Within range, but elevated salt background
		Dissolved oxygen	2.35 mg/L	(not standardized by DSTU for irrigation)	Very low self-purification capacity

**International context.** Comparative analysis indicates that in countries with developed mining industries (Chile, Canada, Australia), the reduction of water load is achieved through a combination of technological innovations and effective mechanisms of state regulation [3; 4; 12].

In Chile, where most deposits are located in the arid regions of the Atacama Desert, closed water-use cycles and seawater desalination technologies for industrial purposes have been implemented, significantly reducing anthropogenic pressure on natural water systems [3].

In Canada, water-use policy is based on strict licensing of water abstraction and discharge, multistage treatment of mine and process effluents, and the establishment of guarantee reclamation funds financed by the enterprises themselves [4].

In Australia, an integrated environmental monitoring system operates on the principles of transparency and precaution. Water quality data are publicly available, and the trigger points mechanism requires enterprises to temporarily suspend operations when established standards are exceeded. At the national level, standards for the gradual reduction of the “water footprint” have been introduced [12].

Thus, international practice confirms the effectiveness of transitioning from reactive to adaptive water resource management, based on digital monitoring, prompt response,

and contractually established environmental standards [3; 11; 12]. Such approaches ensure the long-term resilience of water management systems even under conditions of intensive industrial load.

**Prospects and development scenarios.** Ukraine's transition to the large-scale extraction of critical minerals within international projects simultaneously creates significant economic opportunities and new water–environmental challenges [3; 11].

Under the inertial (“business-as-usual”) scenario, maintaining the practice of episodic flushes without technological modernisation will reproduce the “Inhulets scenario” in other river basins [1; 5]. This will lead to further increases in water treatment costs, deterioration of irrigation water quality, accumulation of environmental losses, and heightened social tension in water-deficient regions [7; 8].

The innovative scenario envisions the implementation of closed water-use systems at mining enterprises, the application of adaptive dilution regimes (including pulse flushes based on actual hydrochemical data), and the development of digital water quality monitoring systems [4; 10; 12]. An essential condition is the inclusion of transparent environmental commitments regarding water use, reclamation, and monitoring within international investment agreements [12; 13].

The implementation of the innovative scenario will contribute to reducing technogenic load on water systems, increasing the efficiency of water resource management, and ensuring environmental security during post-war reconstruction. This approach aligns with the principles of the European Green Deal and will promote Ukraine's integration into the European environmental space [3; 11].

**Conclusions.** The study confirmed the systemic nature of the technogenic impact of mining activities on Ukraine's river ecosystems. The most illustrative example is the Inhulets River basin, where discharges of highly mineralised mine waters cause prolonged exceedances of mineralisation, chloride, and sulphate levels. Regulated flushes from the Karachunivske Reservoir provide only short-term improvements in water quality without addressing the primary sources of pollution.

A similar situation is characteristic of the Siverskyi Donets basin and small rivers of the Dnipropetrovsk region, indicating the nationwide scale of the problem. Under conditions of limited natural runoff, even minor discharges lead to the degradation of aquatic ecosystems and disruption of their equilibrium.

International experience from Chile, Canada, and Australia demonstrates the effectiveness of combining technological and managerial solutions. These include closed water-use cycles, desalination and reuse of wastewater, as well as digital monitoring and strict regulation of water use. Guarantee reclamation funds also play an important role, ensuring environmental restoration after the completion of extraction activities.

Two development paths are possible for Ukraine. The first involves maintaining existing approaches, which fail to deliver sustainable results and lead to further deterioration of water resources. The second is based on the implementation of closed water-use systems, adaptive management of flushes, and digital water quality control. The realisation of this approach, complemented by the inclusion of water protection standards in international agreements, will enhance the ecological resilience of water systems and strengthen the state's water security during the post-war reconstruction period.

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