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Hydrochemical regime of rivers in the Borzhava River basin

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✓ **Abstract.** The aim of the study was to analyse the hydrochemical parameters of surface water quality in the Borzhava River basin in Zakarpattia Region. Based on the collected data, a detailed analysis of the hydrochemical indicators of water quality in the Bozhava, Irshava, Salva and other rivers was carried out. This study was preceded by a detailed analysis of the natural conditions of the Borzhava catchment area and anthropogenic factors affecting the physical and chemical parameters, main ions and mineralisation of water, content of biogenic substances, heavy metals and specific pollutants. The ratio of calculated hydrochemical concentrations to maximum permissible concentrations for water used in fisheries was considered. The content of dissolved oxygen was found to be below the maximum permissible concentration, while the content of ammonium, phosphate, total iron, manganese, copper and zinc exceeded the normative values. The role of natural conditions in the formation of the chemical composition of surface waters in the Borzhava River basin was studied: the hydrological regime of waters, changes in water sources, the geological structure of the catchment area, and the main sources of anthropogenic impact along the river course were identified – unauthorised landfills, systematic discharges of domestic wastewater, insufficient treatment of municipal wastewater, agricultural development of floodplains and coastal lands, application of fertilisers during the farming season, and slowing of the flow in the canal system in the lower reaches of the Borzhava River, the Salva River, and the Balva Canal.

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It has been determined that the waters of the upper Borzhava River are hydrocarbonate calcium, moderately fresh with average mineralisation and clear seasonal variability. The results obtained are of significant practical importance and can be used in the preparation of the Tisza River Basin Management Plan, in the justification and implementation of environmental control measures for economic entities in the upper reaches of the Tisza, as well as in the development and implementation of environmental programmes aimed at improving water quality in the river basin

✔ **Keywords:** anthropogenic load; water mineralisation; biogenic substances; seasonal variability; environmental planning

✔ Introduction

Changes in river water quality can occur as a result of various types of anthropogenic intervention: industry, municipal services, agriculture, land reclamation, fishing, recreation, forestry, etc. Being closely linked to the catchment area, the surface water bodies of the Borzhava River reflect the ecological state of the entire geosystem. Thus, determining the physical, chemical and chemical indicators of river water and studying their seasonal and long-term dynamics will allow to identify the factors that shape and influence water quality within individual sections of the river. One of the largest tributaries of the Tisza River in the Zakarpattia Region, the Borzhava River, is of great importance. The Borzhava River basin is of great ecological, economic, tourist and recreational importance. Natural conditions and anthropogenic influences within this territory determine the main features of the chemical composition of water in the basin, particularly in its lower reaches.

V. Stokral (2021) analysed the problems of pollution of Ukraine's transboundary rivers and outlined five prospects for sustainable development to achieve SDG 6. The proposed approaches were aimed at integrating EU water legislation and forming an effective water management policy. Z. Odnorih *et al.* (2020) examined the organisation of environmental monitoring of surface waters with a view to bringing them closer to European standards, analysed water sample data from 2018 in the Western Bug basin, and outlined ways to improve environmental water management. A study by P.S. Lozovitsky (2025) found that despite significant financial expenditure on water protection in Ukraine, the environmental condition of water resources remains critical. The identified imbalance between the volume of investments and actual results indicates the inefficiency of existing management mechanisms. This highlights the need to transition to an integrated water management model that combines economic instruments with environmental priorities and a transparent assessment of the impact of environmental protection measures.

The article by M. Vovkunovych *et al.* (2024) presents a geoinformation analysis of the hydrographic network of the Borzhava River basin, which identified more than 3,000 km of watercourses of various types, including permanent, temporary, canals and reclamation areas. The structure of permanent watercourses has been established, allowing for the assessment of the internal organisation of the river system, the identification of areas of erosion and flooding, and the creation of a cartographic basis for

environmental monitoring and risk management. O.I. Symkanych *et al.* (2024) presented the results of mapping the spatial and seasonal distribution of natural (^{40}K , ^{238}U , ^{232}Th) and technogenic (^{137}Cs) gamma-active nuclides in the bottom sediments of the Borzhava River, which made it possible to identify areas of their accumulation and migration depending on the season. The data obtained are of practical importance for forecasting the ecological state of the territory, developing regulatory and legal acts, and managing radiation safety in mountainous regions.

Scientists L.Yu. Roman & S.Yu. Chundak (2019) carried out background monitoring of the ecological state of surface waters of the Bronka and Synyavka rivers. The aim of the study by L.Yu. Roman & S.Yu. Chundak was to identify or refute the dynamics of changes in the water quality of the Synyavka and Bronka rivers due to anthropogenic impact, which, according to the results of the study, was determined to be insignificant and legitimate. The work of V. Leta & M. Karabiniuk (2025) revealed a decrease in water intake and discharge in the Borzhava River basin in 2010-2023 and established the impact of anthropogenic factors (agriculture, lack of sewage systems, industrial discharges) on water quality. A set of measures to optimise water use and reduce environmental impact was proposed. At the same time, there is no systematic analysis of hydrochemical indicators of water quality that would provide a spatial-temporal distribution in the Borzhava River basin. Thus, the aim of this study was to conduct a comprehensive analysis of the hydrochemical regime of surface waters in the Borzhava River basin, taking into account the natural features of the territory and the impact of economic activity.

✔ Materials and Methods

The analysis of the hydrological regime of waters and a brief hydrographic description are based on data from the Central Geophysical Observatory Named After Boris Sreznevsky (n.d.). To study the chemical composition of surface waters in the Borzhava River basin, monitoring data from four monitoring stations operated by the Tisza River Basin Water Resources Management Authority were used: Borzhava River – Velyki Komyaty Village, Borzhava River – Bene Village, Irshava River – Loza Village, Salva River – Bukove Village, as well as data from hydrochemical surveys conducted by the authors in September 2024 at 23 points (Table 1). Publicly available hydrochemical data from the Tisza River Basin Water Resources Management

Authority for a period of many years (2007-2023), as well as the results of own field studies, the correlation of which was ensured by comparing a set of water quality assessment

parameters and conducting hydrochemical surveys after coordination with the Tisza River Basin Water Resources Management (n.d.) surface water monitoring programme.

Table 1. List of water sampling locations

No.	Sampling location	Geographical coordinates
1	Borzhava River – Koretsky Village	48°28'23" N; 23°13'34" E
2	Prokhidnyi Stream – Koretsky Village	48°28'20.7" N; 23°13'28.1" E
3	Borzhava River – upstream of Bereznyky Village	48°27'58.7" N; 23°13'55.8" E
4	Kushnytsia River – mouth	48°26'14" N; 23°15'14.1" E
5	Bronka River – mouth	48°24'30.1" N; 23°16'05.5" E
6	Borzhava River – downstream of Bronka Village	48°23'25.5" N; 23°17'27.1" E
7	Borzhava River – downstream of Dovhe Village	48°21'21.4" N; 23°16'24.6" E
8	Borzhava River – Lukove Village	48°19'26.5" N; 23°11'57.2" E
9	Kryvulia River – Zahattia Village	48°22'15.5" N; 22°58'32.6" E
10	Irshava River – Zahattia Village	48°22'21.7" N; 22°58'35.5" E
11	Irshava River – Dovzhnytsia Village	48°22'14.3" N; 22°59'02.1" E
12	Ilnytsia River – mouth	48°19'32.2" N; 23°02'17.4" E
13	Synyavka River – mouth	48°19'32.2" N; 23°02'17.4" E
14	Borzhava River – Velyki Komyaty Village	48°14'44.1" N; 22°54'48" E
15	Irshava River – Kamyanske Village	48°15'20.5" N; 22°55'46.8" E
16	Borzhava River – Nyzhni Remety Village	48°15'04.3" N; 22°49'52.2" E
17	Borzhava River – Kvasovo Village	48°11'21.4" N; 22°46'34.9" E
18	Borzhava River – downstream of Velyka Roztoka Village	48°16'49.1" N; 29°03'58.6" E
19	Borzhava River – upstream of Velyki Komyaty Village	48°14'45.7" N; 22°59'35.2" E
20	Borzhava River – Nyzhni Remety Village	48°15'04.4" N; 22°49'48.3" E
21	Balva Canal	48°11'31.7" N; 22°57'12.9" E
22	Salva River – downstream of Balva Canal	48°11'32.7" N; 22°57'11.9" E
23	Salva River – mouth	48°11'09.2" N; 22°47'41.1" E

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

The chemical composition of surface waters in the Borzhava River basin was analysed according to the following groups of components: physical and chemical indicators (suspended solids, pH, dissolved oxygen content, permanganate oxidisability (PO), chemical oxygen demand (COD) and BOD₅); main ions (HCO₃⁻, Ca²⁺, Mg²⁺, SO₄²⁻, Cl⁻) and water mineralisation (dry residue); nitrogen compounds (NH₄⁺); heavy metals (Cu, Cr, Zn); specific pollutants (anionic surfactants – AS). The quality of surface waters in the upper reaches of the Tisza River was assessed according to hygienic standards for water quality in water bodies for drinking, domestic and other needs of the population, as well as requirements for fishery water bodies – maximum permissible concentrations (Order of the Ministry of Agrarian Policy of Ukraine No. 471, 2012; Order of the Ministry of Health of Ukraine No. 721, 2022).

The analysis of hydrochemical parameters was carried out in a logical sequence of actions: identification of maximum values of indicators; comparison of indicators with each other; comparison of indicators in the context of spatial and temporal variability; comparison of the results obtained with the MPC regulatory indicators; comparison of measurement results with retrospective data. Water sampling during the field stage of the study was carried out in compliance with regulatory documents, in particular DSTU ISO 5667-6:2009 (2009) and DSTU EN ISO 5667-6:2022 (2022)

and the principles of representativeness, isokinetics, stratification, and traceability. The programming of surface water sampling in the Borzhava River basin included the definition of objectives (water quality control, assessment of anthropogenic impact, identification and study of trends), and the selection of sampling sites and points was carried out taking into account hydrography, accessibility, safety and mixing of flows, and the availability of an existing network of water monitoring points (Tisza River Basin..., n.d.).

During sampling, sampling devices with a rope and rod were used, as well as special containers equipped with mechanisms for opening at a specified depth and refrigeration equipment. The samples were stabilised in accordance with DSTU EN ISO 5667-3:2022 (2022), taking into account the characteristics of the components under study (dissolved gases, metals, organic substances). The samples were stored at a temperature of 1-5 °C and transported in conditions that prevented any change in their composition (no light, airtightness, cooling), and all actions were recorded in the relevant protocols. Chemical analysis of the selected water samples was carried out at the Uzhhorod Border State Control and Toxicology Laboratory (n.d.) using the following methods: spectrometric, photometric, titration, thin-layer chromatography in accordance with DSTU ISO 6332:2003 (2003), DSTU 7260:2012 (2012), DSTU 7811:2015 (2015), and DSTU ISO 18412:2017 (2017).

The results of spatial analysis were visualised using a graphical method of data representation in the form of bar charts with the help of the ArcGIS 10.8.2 software package. This method allowed for a clear comparison of quantitative indicators along the course of the studied rivers of the Borzhava basin, while maintaining spatial reference.

Results

The Borzhava River flows within the modern Khust and Berehove districts of Zakarpattia Region, covering territories that previously belonged to the Svaliava, Irshava, Vynohradiv, and Berehove districts. It is a right tributary of the Tisza and is part of the Danube drainage basin. The total length of the Borzhava is 106 km, and the area of its basin is 1,360 km². The source of the river is located on the slopes of Mount Stiy, which is part of the Borzhava mountain range. In its upper reaches, the Borzhava is mountainous, with a V-shaped valley ranging from 40 to 900 m in width. Further on, the river crosses the Zakarpattia lowlands. Its course is characterised by considerable sinuosity, with numerous islands and oxbow lakes in the floodplain. The width of the riverbed varies from 0.6 to 53 m, and the average slope is 13 m/km. The main tributaries of the river are the Irshava (right) and Salva (left). The hydrological regime of the Borzhava is determined by frequent floods, which provide approximately 70% of the annual runoff from March to August. Summer-autumn and winter low water levels are unstable, and flooding is possible in spring. The average water flow is 10 m³/s, and its turbidity varies from 50 to 500 g/m³ according to data from the Zakarpattia Regional Centre for Hydrometeorology (n.d.).

The long-term dynamics and seasonal variability of the chemical composition of river waters in the Borzhava basin have been analysed in detail, and regime characteristics have been identified for individual parameters. The hydrochemical analysis of water covered a number of parameters, among which physicochemical parameters, in particular the content of suspended solids, are of key importance. Suspended solids include sand, clay, iron hydroxides, as well as organic components: silt, microorganisms, petroleum products. In the Borzhava River basin, an increase in the concentration of suspended solids downstream from 0.58 to 29.58 mg/dm³ was recorded, which is associated with active agriculture and increased organic content in the water. At the same time, the level of suspended solids in the upper reaches of the river also reaches 29.58 mg/dm³, but this is due to natural processes. The concentration of suspended solids correlates with water transparency, which indicates the influence of erosion processes in the upper part of the basin and anthropogenic load in the lower part.

Among the hydrochemical indicators important for assessing the state of the environment of hydrobionts, the pH level is key. In all the rivers studied, there are slight seasonal fluctuations caused by changes in food sources, soil type and, to some extent, economic impact (Fig. 1). Summer and autumn floods contribute to water alkalisation and an increase in pH. The lowest values were recorded in the Borzhava River (6.8 units in the Velyki Komyaty Village, Bene Village) and the Salva River (6.7 units in the Bukove Village), which are close to the lower limit of the MPC for fishery waters.

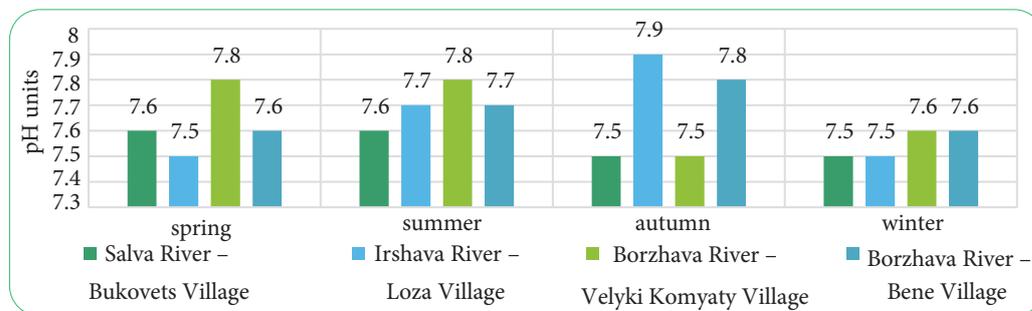


Figure 1. Seasonal fluctuations in average annual pH values

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

The dissolved oxygen (O₂) content is a key indicator of water quality, as it ensures the mineralisation of organic matter in surface waters. Its level has clear seasonal fluctuations, with minimum values in the summer-autumn period. In the Borzhava basin, the average long-term seasonal values range from 7.8 to 12.2 mg/dm³. At the same time, a decrease was recorded in Salva and the Balva Canal: in September 2021 – 5.5 mg/dm³ (Salva), in September 2024 – 5.91 mg/dm³ (Balva) and 3.76 mg/dm³ (Salva mouth). This indicates water pollution and an excess of organic substances, which is environmentally hazardous at low flow rates.

A comparison of the monitoring data with the MPC of 5 mg/dm³ revealed that the PO levels were exceeded. In particular, in September 2024, a value of 9.67 mg/dm³ was recorded in the waters of the Salva River (mouth) and 6.7 mg/dm³ in the Balva Canal, indicating a significant presence of hard-to-oxidise organic substances and pollutants that can accumulate in the aquatic environment downstream (Fig. 2). At the same time, the average long-term PO indicators in the waters of the Borzhava River (control point in the Bene Village) show insignificant fluctuations within the range of 2.7-2.9 mg/dm³, which do not exceed the established MPC.

Table 2. Continued

Monitoring point	Season	Values, mgO/dm ³
Irshava River – Loza Village	spring	0.9
	summer	2.4
	autumn	2
	winter	1.5

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

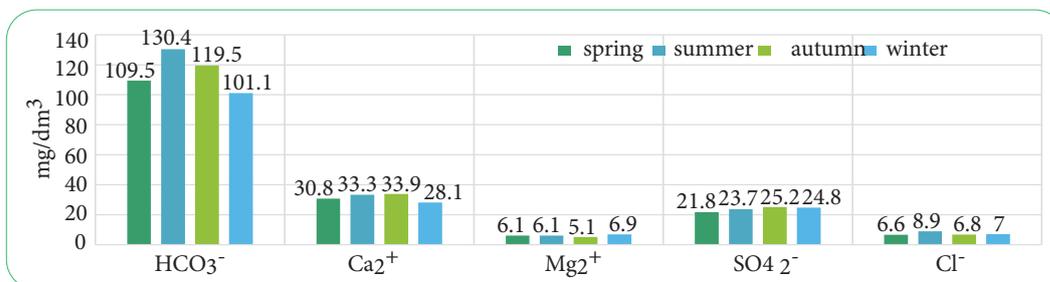


Figure 3. Seasonal fluctuations in the multi-year average values of major ion content (Borzhava River – Bene Village)
Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

The presence of biogenic substances in surface waters is caused by biological processes such as the metabolism of aquatic organisms, the decomposition of organic matter, and inputs from agricultural land and wastewater. Analysis of ammonium in the waters of the Borzhava basin showed seasonal variability with peak concentrations in summer (Fig. 4). The average long-term values were 0.4 mg/dm³ (Salva River – Bukovets Village) and 0.47 mg/dm³ (Borzhava River – Velyki Komyaty Village). During the summer-autumn low water period, concentrations approached the

fishery MPC due to anthropogenic influences: farms, manure storage facilities, wastewater and recreational facilities. Exceedances of the MPC were recorded: on the Borzhava River – Velyki Komyaty Village – from 0.84 to 2.53 mg/dm³, on the Salva River – Bukovets Village – 0.58-0.65 mg/dm³. The data obtained during the field stage of the study indicate a growing anthropogenic impact downstream of the Borzhava and Salva rivers due to the expansion of the network of settlements, as well as an increase in the volume of wastewater and irrigation systems.

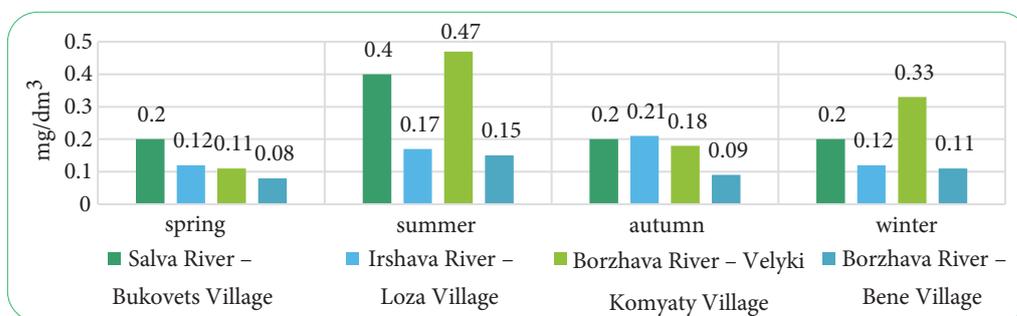


Figure 4. Seasonal fluctuations in average annual ammonium content
Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

During the same observation period, the nitrate content reached 8.3 mg/dm³ in 2010 on the Borzhava River in the Bene Village. Of particular interest from the perspective of assessing anthropogenic pressures are the nitrate levels recorded in the Prokhidnyi Stream in the Keretsky Village. Although the values did not exceed the maximum permissible concentration for fisheries waters, the concentration reached 6.02 mg/dm³. Phosphates (PO₄³⁻) serve as an indicator of the intensity of biological activity in aquatic ecosystems. For fishery waters, the MPC for phosphates in surface waters is 0.17 mg/dm³. Long-term monitoring data indicate a single exceedance of the MPC in the Borzhava River – Velyki Komyaty Village in December 2021 at a level

of 0.37 mg/dm³. Analysis of the results of field sampling indicates that the phosphate content is high in the waters of the Borzhava River above the Bereznyky Village (0.26 mg/dm³), the Kushnytsia River at its mouth (0.26 mg/dm³), the Bronka River – at the mouth (0.22 mg/dm³) and the Borzhava River – below the Bronka Village (0.28 mg/dm³), the Borzhava River – below the Dovhe Village (0.19 mg/dm³), Borzhava River – Lukova Village (0.2 mg/dm³), Kryvulia River – Zahattia Village (0.24 mg/dm³) and Salva River – mouth (0.23 mg/dm³).

Iron is usually present in both groundwater and surface water. Its content is determined by the geological features of the territory, the hydrological conditions of water

bodies and the level of anthropogenic impact, in particular pollution by wastewater. The chronological series of monitoring the total iron content in the waters of the Borzhava basin rivers is limited to the period 2007-2018 according to data from a single point on the Borzhava River – Bene Village. Considering that this is the final monitoring point in the river basin, its data can be indicative for the entire Borzhava River. The MPC for fisheries is 0.05 mg/dm³, and

the MPC for domestic and drinking water is 0.3 mg/dm³. The absolute values of iron content in the waters of the Borzhava range from 0.12 mg/dm³ to 1.05 mg/dm³, which significantly exceeds environmental standards. It has been recorded that the average long-term values for the study period are quite high and reflect dependence on natural conditions, in particular changes in water sources during the summer-autumn and winter low-water periods (Fig. 5).

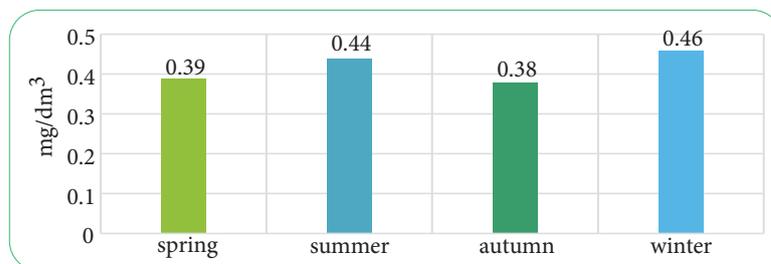


Figure 5. Seasonal fluctuations in the multi-year average values of major iron content (Borzhava River – Bene Village)

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

The level of iron in water changes and reaches its highest levels during floods, when iron-containing compounds are actively washed out of the soil. In winter, when water levels are low, vegetation stops consuming iron, and due to the lack of aeration, ferrous iron is not oxidised to ferric iron, which leads to its significant accumulation in the aquatic environment. The results of the hydrochemical survey confirm a high iron content of 0.061 and 0.066 mg/dm³ in the Borzhava River in the villages of Nyzhni Remety and Kvasovo. Spatial analysis shows a relatively uniform iron content downstream of the Borzhava, with some exceptions in the lower reaches, which may be associated with an increase in anthropogenic load, an increase in the volume of wastewater discharged into the Borzhava river system, in particular from recreational facilities.

Manganese appears in surface waters as a result of leaching of iron-manganese ores and minerals, as well as in the process of decomposition of aquatic plants. MPC for fisheries. At a level of 0.1 mg/dm³. Absolute values of iron content range from 0.01 to 0.46 mg/dm³, which indicates a high dependence on the hydrological regime of waters and economic use of coastal lands in the Borzhava basin. According to average annual data for 2007-2018 in the lower reaches of the Borzhava River (Bene Village), constant exceedances of the norms were recorded in the spring and summer periods, which is associated with the melting of snow and the passage of floods, resulting in increased surface runoff and, consequently, manganese content in rivers (Fig. 6).

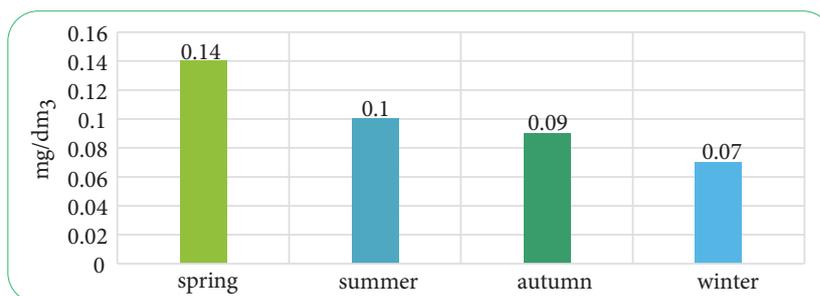


Figure 6. Seasonal fluctuations in the multi-year average values of manganese content (Borzhava River – Bene Village)

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

Copper – a heavy metal that occurs naturally in rocks in the form of compounds with sulphur, silicates, carbonates and oxides. The main source of its entry into surface waters is the weathering of minerals, and among anthropogenic sources are industrial effluents from chemical and metallurgical enterprises and agricultural effluents using copper sulphate. The MPC for fishery waters is 0.001 mg/dm³, for domestic and drinking waters – 1 mg/dm³. According to

Tisza River Basin Water Resources Management (n.d.), the concentration of copper in the summer period consistently exceeds the fishery norm by 4-5 times (Fig. 7).

Hydrochemical surveys confirmed even higher values – from 0.04 to 0.58 mg/dm³ (Fig. 8). The reasons for this are natural weathering, ore mineralisation (the section between the villages of Bereznyky and Dovhe) and the use of copper sulphate in the middle and lower reaches.

Samples taken during economic activities showed an increase in copper concentration downstream. The

exceptions are the Salva and Borzhava rivers in the Nyzhni Remety Village – 0.58 and 0.5 mg/dm³ respectively.

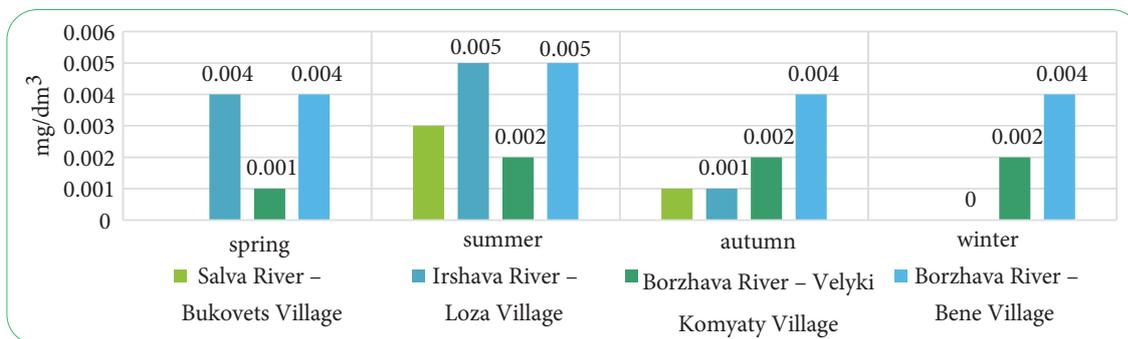


Figure 7. Seasonal fluctuations in average annual copper content

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

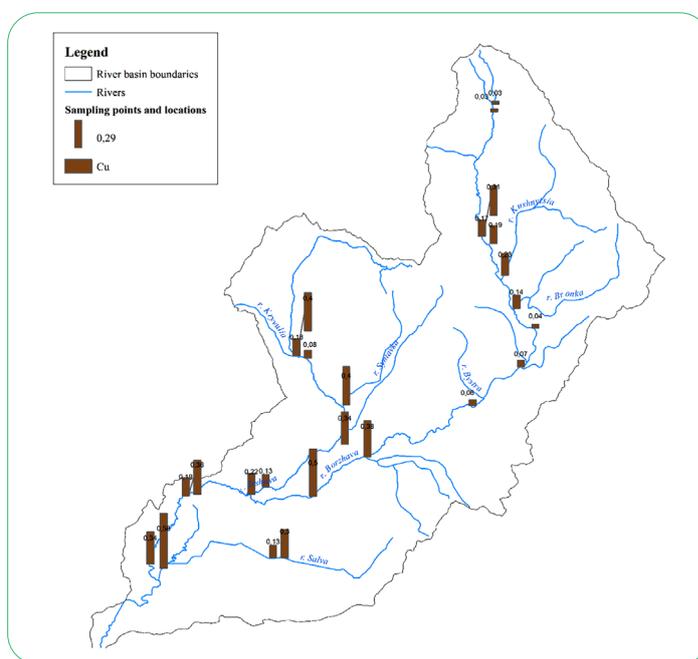


Figure 8. Cartogram of spatial distribution of copper, mg/dm³

Source: compiled by the authors based on field research materials

Chromium belongs to the group of heavy metals, and its compounds are highly toxic and have a harmful effect on surface waters. The main sources of chromium in the environment are minerals and rocks containing this element, surface runoff from mineral extraction sites, and wastewater.

For waters intended for fisheries, the MPC for chromium is 0.001 mg/dm³. The increase in chromium content in surface waters is seasonal, which is explained in particular by the increase in surface runoff during periods of intense flooding in the warm season (Fig. 9).

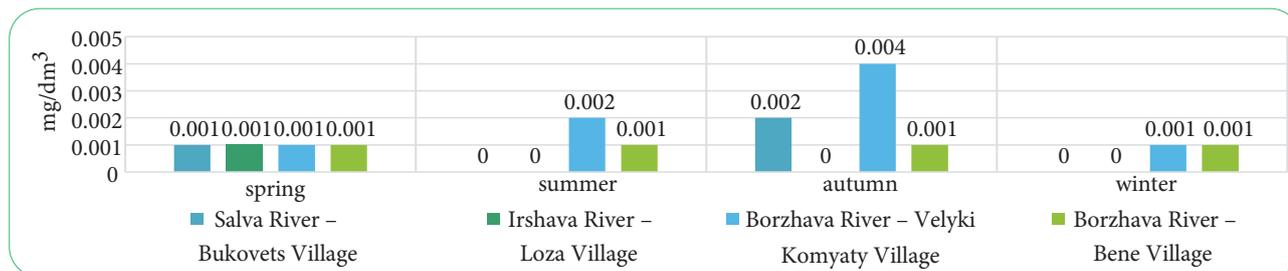


Figure 9. Seasonal fluctuations in average annual chromium content

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

Zinc – a heavy metal commonly found in water and soil due to the dissolution of sphalerite. Its concentration in water varies from thousandths to tenths of a milligram per decimetre cubed, depending on the hydrological regime. The maximum permissible concentration in surface waters is 0.001 mg/dm^3 . In the Borzhava basin, exceedances of

fishery standards are consistently recorded, mainly due to natural factors: geological structure and weathering of ore deposits (Fig. 10). Anthropogenic impact is less significant. The absence of clear seasonal dynamics confirms the dominance of natural processes in the formation of the hydrochemical regime.

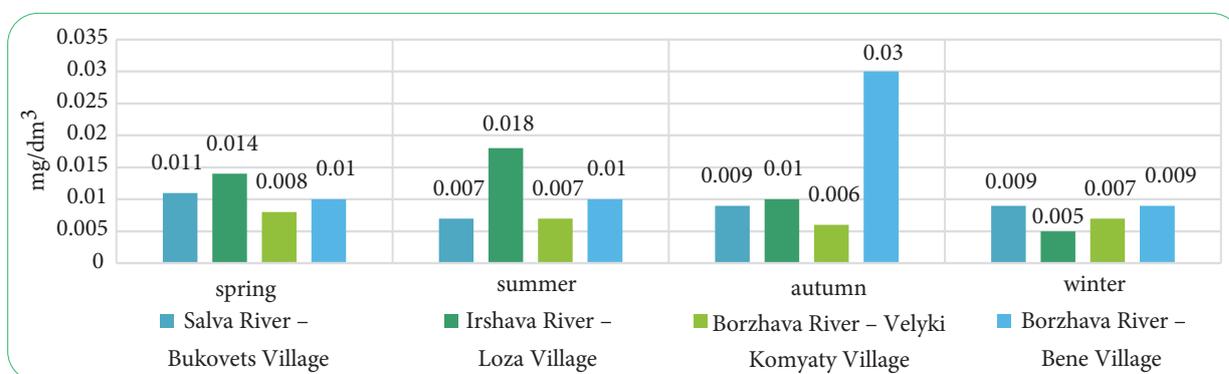


Figure 10. Seasonal fluctuations in average annual zinc content

Source: compiled by the authors based on materials from Tisza River Basin Water Resources Management (n.d.)

AS are synthetic pollutants that affect the quality of surface water. They contain organic and inorganic components and are used in cleaning agents, disinfectants, emulsifiers, and metallurgical processes. They enter the environment through wastewater and industrial emissions. The MPC for fishery waters is 0.2 mg/dm^3 . The results of hydrochemical surveys show insignificant fluctuations in the content of synthetic surfactants (SS) in the waters of the Borzhava basin: from 0.02 mg/dm^3 to 0.11 mg/dm^3 . Nevertheless, spatial analysis indicates a greater load on surface waters from SS in the upper reaches of the Borzhava River from the Bereznyky Village to the Dovhe Village, which, in the absence of industrial facilities, indicates a load on the Borzhava ecosystem from municipal and domestic sewage. The absence of sewage treatment facilities in the upper reaches of the Borzhava has a negative impact on the quality of surface waters.

Discussion

As a result of a broad analysis of the literature, it should be noted that the quality of water resources is deteriorating as a result of both natural and anthropogenic factors, which complicates the identification of sources of pollution and requires interdisciplinary management. Effective environmental management of water resources requires the integration of environmental, economic and regulatory approaches. The article by N. Akhtar *et al.* (2021) summarises a wide range of natural and anthropogenic factors causing water quality degradation, with an emphasis on the complexity of identifying sources of pollution and their pathways, which is consistent with the unauthorised discharges and diffuse pollution identified in the Borzhava basin. The authors emphasise the need for an interdisciplinary approach and cross-border cooperation to ensure sustainable water management in the context of global environmental challenges.

The article by E. Lucas *et al.* (2023) reviews the impact of climate change on phosphorus losses from agricultural land as a key factor in increasing water pollution. The article by P. Ebeling *et al.* (2021) examines the seasonal dynamics of nitrate concentrations in the surface waters of 290 catchment basins in Western Europe, using a new approach to analyse long-term changes, which also correlates with the seasonal variability of hydrochemical indicators recorded in the upper reaches of the Borzhava River basin. The study revealed a complex response of water systems to nitrogen inputs and high spatial variability of seasonal patterns, highlighting the importance of hydrochemical monitoring for effective water quality management. The article by H. Huan *et al.* (2020) proposes a comprehensive approach to assessing the risk of groundwater pollution, which allows combining water flow and nitrate transport modelling in the aeration zone and aquifers. J. Liu *et al.* (2023) analysed the dynamics of nitrogen compounds in the Jiangnan Plain in the context of their impact on total nitrogen (TN) export, using an empirical model to predict future scenarios. The study highlighted the critical role of accumulated nitrogen in soils and the need for integrated management strategies to effectively control pollution in agricultural regions, which is somewhat analogous to studies where phosphorus losses and nitrogen accumulation in soils are identified as key factors in surface water pollution and confirms the relevance of integrated management strategies aimed at controlling the impact of agriculture on surface water quality.

The article by Y. Gao *et al.* (2023) examines the long-term impact of nitrogen compounds on pollution in the Songhua River, with an emphasis on seasonal time lags between the reduction of nitrogen inputs and improvements in water quality. The results of the study by A. Sultana (2025) indicate seasonal variability in surface and groundwater quality parameters, highlighting the

importance of long-term monitoring to assess the risks associated with the formation of disinfection by-products in conditions of variable water quality. A.B. Laniyan *et al.* (2025) investigated the seasonal influence of climatic factors on the physicochemical and microbial indicators of water quality in the Osun River basin, which revealed a significant deterioration in indicators during the wet season due to the influence of surface runoff. These studies confirm the importance of implementing and maintaining long-term monitoring, as exemplified by the Borzhava River basin, which is one of the key recommendations based on the results of the study. The article by A.O. Adeyefa (2024) assesses the physical and chemical parameters of the Ogun River water in the Abeokuta area, which is an important source of water supply for densely populated communities. Although most indicators comply with World Health Organisation standards, the calculated water quality index showed that it is unsuitable for domestic use. The study emphasises the need for regular monitoring and tighter control of sources of pollution.

The article by K.A. Bawa-Allah (2023) provides a meta-analysis of data on heavy metal pollution in Nigeria's surface freshwaters. The results showed critically high concentrations of Cd, Cr, Mn, Ni and Pb, exceeding international drinking water quality standards. The study by G. Singh *et al.* (2023) analysed the water quality of the Hindon River and found significant exceedances of MPCs for organic pollutants and heavy metals, especially in the middle reaches, where industrial and domestic effluents have an impact. The results indicate a global problem of anthropogenic pressure on aquatic ecosystems, especially in regions with insufficient control over sources of pollution, and confirm the need for urgent measures by regional authorities to restore the aquatic environment and ensure sustainable resource management. The study by A. Kadir *et al.* (2022) found that changes in land use and land cover in the coastal zone of the Surma River significantly affect water quality, especially in terms of BOD₅, electrical conductivity, TDS and TSS. In contrast, the study by M.E. Akiner *et al.* (2024) investigated the water quality of the Betwa River basin and found that the main sources of pollution are point discharges of industrial and domestic wastewater, as well as diffuse pollution from agricultural land.

The study by R. Mansour *et al.* (2024) conducted a comprehensive assessment of the water quality of the Rachine River in an urban environment, using WHO standards and multidimensional statistical analysis, which revealed seasonal fluctuations, microbial contamination and the spatial structure of sources of impact. A study by N.H. Duc *et al.* (2023) found that surface water quality in the city of Can Tho has deteriorated significantly due to intensive urbanisation, the expansion of industrial zones and agricultural impact. The results obtained are an important tool for the development of integrated water resource management strategies in the context of sustainable development. In the article by H. Allafra & C. Opp (2020), the authors studied the spatial distribution of sources of heavy

metal pollution in the Shatt al-Arab River. The use of pollution indices revealed the dominance of anthropogenic factors and high levels of pollution within the studied sections of the river. W. Zhang *et al.* (2021) assessed the pollution of the Liujiang River with heavy metals using multidimensional statistical analysis, which revealed seasonal fluctuations, spatial differentiation and sources of water pollution. The above-analysed works demonstrated the effectiveness of this approach for identifying the spatial structure of pollution sources, which can be applied for further analysis of the Borzhava River basin, particularly in the context of developing a management plan for the Tisza River basin.

The article by G. Busico *et al.* (2024) implements an integrated approach to assessing water quality in the Aspio River basin. The study combines SWAT modelling, time series and statistical analysis to identify sources of pollution, which ultimately showed the dominance of urban wastewater in the formation of nitrogen load on water, and also indicates the priority of controlling urbanised areas in water protection planning. The study by V.K. Khilchevskiy *et al.* (2023) confirms that the hydrochemical regime of the upper Tisza River is formed under the influence of both natural factors (geological structure, seasonal fluctuations in water content) and anthropogenic load, and indicates the relevance of this study for regional planning, since the Borzhava is part of the Tisza catchment system. The results obtained demonstrate the need for an integrated approach to water quality management that takes into account seasonal variability of indicators and sources of anthropogenic impact. The study by K. Matiyiv *et al.* (2022) analyses the water quality of the Prut River in the Yaremche tourist cluster and its dependence on the intensity of tourist flow. The selected samples included analysis of physicochemical indicators and heavy metal concentrations determined by Sensafe membrane tests.

The article by R.L. Kravchynskiy *et al.* (2021) analysed landslides in the upper reaches of the Prut River and, based on data from Google Earth, Landsat and field observations, established a link between the spread of exogenous processes and the characteristics of the river network. The article by O. Dzham *et al.* (2021) provides an ecological assessment of the quality of surface waters of the Prudnyk River based on hydrochemical indicators and an integral pollution index. The results of the study confirm the need for regular monitoring and implementation of environmental protection measures to stabilise the ecological state of the watercourse. In a similar study on this topic, X. Zhao *et al.* (2024) found that the hydrochemical composition of the Minyong River water is formed mainly as a result of the weathering of carbonate rocks, which is confirmed by the dominance of Ca^{2+} , Mg^{2+} and ions, which echoes the conclusions of the present study and confirms the need for a systematic study of the factors that shape and influence the ecological condition of surface waters, in particular under the influence of the geological structure of the river basin.

It has been determined that the main sources of surface water pollution are industrial effluents, urbanisation,

irrational or improper land use, and agriculture within floodplains. Hydrochemical studies of river basins also show the influence of geology, tourism and exogenous processes on the chemical composition of water, which requires local monitoring and adaptive management. On the other hand, analysis of hydrological processes indicates a link with nitrogen, phosphorus and nitrate content, which in turn also justifies the need for their long-term monitoring and modelling.

✔ Conclusions

In summary of the conducted research, a wide spatio-temporal overview of the surface water quality in the Borzhava River basin was obtained, based on a set of hydrochemical indicators sourced from both the archival materials of the Tisza River Basin Water Resources Management and the results of the conducted field investigations. The river waters of the Borzhava basin are characterised by a hydrocarbonate-calcium type with average mineralisation, corresponding to moderately fresh conditions. A clear seasonal variability in chemical composition, in particular dry residue, was found, which correlates with the hydrological regime. The spring-summer period is accompanied by an increase in the concentration of nitrogen-containing compounds caused by the active decomposition of organic matter coming from domestic wastewater and surface runoff from agricultural land. Significant exceedances of MPCs for a number of indicators have been recorded. In particular, the concentration of total iron reached 1.05 mg/dm³ with a standard of 0.3 mg/dm³, which is 3.5 times higher than the standard. The copper content ranged from 0.04 to 0.58 mg/dm³ with a standard of 0.01 mg/dm³, i.e. the excess reached 58 times. Excessive levels of manganese (up to 0.46 mg/dm³), chromium (up to 0.004 mg/dm³) and zinc (up to 0.03 mg/dm³) were also detected. The main factors

that shape or influence the ecological state of surface waters in the Borzhava basin are the geological structure of the territory, which causes the natural entry of iron, copper, chromium and zinc metals into the aquatic environment, and the discharge of spent mineral waters from balneological resorts, in particular “Borzhava” in the Dovhe Village. It is also worth noting the impact of a significant number of existing unauthorised landfills (the villages of Keretsky, Dunkovytsia, Velyki Komyaty, and Nyzhni Remety) and insufficiently treated municipal wastewater within the Kamianske, Bilky, Dovhe, Irshava, and Keretsky territorial communities, as well as agricultural activities, in particular through the application of mineral fertilisers and the economic development of floodplains, particularly in the Salva River sub-basin. Prospects for further research are related to the expansion of spatial and temporal monitoring of the hydroecological state, the improvement of methods for assessing the impact of anthropogenic factors on water resources, and the development of innovative approaches to rational nature management and the restoration of the ecological balance of aquatic ecosystems.

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✔ Conflict of Interest

None.

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✔ **Анотація.** Мета дослідження полягала в аналізі гідрохімічних параметрів якості поверхневих вод басейну річки Боржава в Закарпатській області. На основі зібраних матеріалів здійснено детальний аналіз гідрохімічних показників якості вод річок Божава, Іршава, Сальва та інших. Даному дослідженню передувало детальний аналіз природних умов водозбору Боржави та факторів антропогенного впливу на значення фізико-хімічних параметрів, головних йонів та мінералізацію води, вмісту біогенних речовин, важких металів та специфічних забруднювальних речовин. Розглянуто співвідношення розрахункових концентрацій гідрохімічних до гранично допустимих концентрацій для вод рибогосподарського використання. Зафіксовано менший за норму гранично допустимої концентрації вміст розчиненого кисню, перевищення нормативних значень за вмістом амонію, фосфату, заліза загального, марганцю, міді та цинку. Вивчено роль природних умов формування хімічного складу поверхневих вод у басейні річки Боржава: гідрологічний режим вод, зміна джерел живлення, геологічна будова водозбірної території, а також вказано основні джерела антропогенного впливу вздовж течії – несанкціоновані сміттєзвалища, систематичні скиди побутових стічних вод, недостатній рівень очистки комунальних стічних вод, сільськогосподарське освоєння заплави та прибережних земель, внесення добрив у період ведення господарства, уповільнення течії в системі каналів у нижній течії річки Боржава, річки Сальва, каналу Бальва. Визначено, що води верхів'я річки Боржава є гідрокарбонатними кальцієвими, помірно прісними з середньою мінералізацією та чіткою сезонною мінливістю. Отримані результати мають вагомий прикладний характер та можуть бути використані під час підготовки Плану управління басейном річки Тиса, обґрунтуванні та реалізації заходів екологічного контролю діяльності суб'єктів господарювання у верхів'ях Тиси, а також у процесі розроблення та впровадження екологічних програм, спрямованих на покращення якості вод у басейні річки

✔ **Ключові слова:** антропогенне навантаження; мінералізація води; біогенні речовини; сезонна мінливість; екологічне планування