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Vasyl V. Leta, Candidate of Geographical Sciences, Associate Professor, Department of Geography and Social Sciences, Faculty of Management and Hospitality Industry, Mukachevo State University. Mukachevo, Ukraine.
ORCID: 0000-0001-9111-7121, Scopus: 57219013995

Statistical analysis of water quality indicators in the Tisa River's transboundary section

Abstract: In today's conditions, when river basin systems are undergoing anthropogenic transformation and considering the multifactorial impact of economic activity on the environment, there is a need for a comprehensive analysis of surface water quality. Since river waters are closely connected with the catchment area, they serve as indicators of the geo-environmental state of the entire basin system. When selecting the research object – a transboundary section of the Tisa in Zakarpattia Oblast (Dilove – Tyachiv) – not only natural factors that shape river water quality but also various anthropogenic pressures were considered. The Tisa basin in the Rakhiv district is of great ecological, economic and transboundary significance. The study aims to assess the water quality of the Tisa's transboundary section from Dilove to Tyachiv. The objectives are to substantiate the scientific basis for environmental studies of surface waters, analyse the hydrochemical parameters of water quality in the transboundary section of the Tisa, based on the stock materials of the Tisa Basin's water resources management, determine the quality of river waters in the section of the Tisa, using the methodology for assessing water quality by a complex indicator – the hydrochemical water pollution index; identifying natural and anthropogenic factors that affect the physical and chemical indicators of water quality; developing recommendations for improving water quality within the study area. The study applies a systematic approach to analysing the water quality of the Tisa, which aims to optimise nature management and increase the effectiveness of water protection measures. General scientific methods, such as retrospective analysis, systematic and structural approach, and evaluation methods, like special methods, such as mathematical and statistical analysis, semi-stationary observations, and cartographic studies, were used. The main tool used in the study is the methodology for assessing water quality based on the hydrochemical water pollution index.

Keywords: hydrochemical indicators, anthropogenic impact, water quality, water monitoring, transboundary section of the Tisa River.

Василь Васильович Лета, кандидат географічних наук, доцент кафедри, кафедра географії та суспільних дисциплін, факультет менеджменту та індустрії гостинності, Мукачівський державний університет. Мукачево, Україна.
ORCID: 0000-0001-9111-7121, Scopus: 57219013995

Статистичний аналіз показників якості вод транскордонної ділянки річки Тиса

Анотація: У сучасних умовах, коли річково-басейнові системи зазнають антропогенної трансформації та з урахуванням багатофакторного впливу господарської діяльності на навколишнє природне середовище, постає необхідність комплексного аналізу якості поверхневих вод. Оскільки річкові води тісно пов'язані з водозбірною територією, вони слугують індикаторами геоекологічного стану всієї басейнової системи. При виборі об'єкта дослідження - транскордонна ділянка річки Тиса в Закарпатській області (с. Ділове – м. Тячів), враховано не лише природні фактори, що формують якість річкових вод, але й різноманітні антропогенні навантаження. Басейн річки Тиса в Рахівському районі має велике екологічне, господарське і транскордонне значення. Метою дослідження є визначення оцінки якості вод транскордонної ділянки річки Тиса від с. Ділове до м. Тячів. Завданнями є: обґрунтування наукових основ екологічних досліджень поверхневих вод; аналіз гідрохімічних параметрів якості вод на транскордонній ділянці р. Тиса, спираючись на фондові матеріали Басейнового управління водними ресурсами річки Тиса; визначення якості річкових вод ділянки р. Тиса, використовуючи методику оцінки якості вод за комплексним показником – гідрохімічним індексом забрудненості вод; виявлення природних і антропогенних чинників, що впливають на фізико-хімічні показники якості вод; розробка рекомендацій для покращення якості вод у межах досліджуваної ділянки. У дослідженні застосовано системний підхід до аналізу якості вод річки Тиса, що має на меті оптимізацію природокористування та підвищення ефективності водоохоронних заходів. Використані загальнонаукові методи, такі як ретроспективний аналіз, системно-структурний підхід та методи оцінювання, а також спеціальні методи, зокрема математико-статистичний аналіз, напівстаціонарні спостереження та картографічні дослідження. Основним інструментом у дослідженні є методика оцінки якості вод на основі гідрохімічного індексу забрудненості вод.

Ключові слова: гідрохімічні показники, антропогенний вплив, якість вод, моніторинг вод, транскордонна ділянка річки Тиса.

Abbreviations:

BOC_5 is five-day biochemical oxygen consumption

COC is chemical oxygen consumption

HWP is hydrochemical water pollution

MPC is maximum permissible concentrations

Tisa or Tysa, or Tisza are similar names of the river of Central and Eastern Europe

Introduction

The territory's mountainous natural conditions have unique features that affect the formation and dynamics of hydrological and physicochemical parameters of water resources. These parameters are subject to changes under various anthropogenic factors, such as deforestation, intensive land use, and industrial and agricultural waste pollution, directly affecting surface water quality. Such a diverse impact of natural and human factors requires a comprehensive and detailed study since the effectiveness of water resources management depends on it (*Dubis, 1994*).

In particular, for the transboundary Basin of the Tisa, where water resources are of great economic and environmental significance, it is significant to ensure an effective water quality monitoring system (*Khilchevsky et al., 2023*; *Leta, 2017*). This will allow the timely detection of negative changes in hydrological conditions and the chemical composition of water to minimise the impact of harmful factors on the ecosystem. Such a study will help improve existing monitoring methods, such as contributing to the development of an optimal environmental management strategy that considers the ecological sustainability of the region and ensures the rational use of water resources within the basin.

This study aims to assess water quality in the transboundary section of the Tisa extending from the village of Dilove to the city of Tyachev. Several tasks were set to achieve this goal. First, a scientific justification of environmental studies of surface waters was performed. Secondly, the analysis of hydrochemical parameters of water quality in the specified section of the Tisa was performed using stock materials for the basin management of Tisa's water resources. The next step was to determine water quality using a complex indicator – the HWP index. Special attention was paid to identifying natural and anthropogenic factors that affect water's physical and chemical characteristics. In conclusion, recommendations were developed to improve the water quality within the studied section of the Tisa.

Water quality assessment methodology

The study uses a comprehensive, systematic approach to analysing Tisa's water quality, aiming to optimise nature management and improve the efficiency of water protection measures in the region. The main focus is on integrating various methodological approaches to obtain a comprehensive assessment of the state of water resources and develop practical recommendations for their protection (*Obodovsky, 2001*).

General scientific methods such as retrospective analysis, system-structural approach, and assessment methods are used to in-depth analyse changes in water quality over time and structure data. Special methods include mathematical and statistical analysis, which allows the identification of relationships between different indicators, semi-stationary observations to assess the dynamics of water quality, and cartographic studies, providing visualisation of spatial aspects of the problem.

The key tool in the study is the method of water quality assessment based on the HWP index, allowing quantifying the level of water pollution based on the integration of many physical and chemical indicators. This approach ensures the objectivity of the assessment and forms the scientific basis for making managerial decisions on water resources' protection (*Levchak et al., 2013*).

The HWP index is a water quality assessment method, considering parameters such as dissolved oxygen content, BOC_5, chemical oxygen consumption, concentrations of ammonium ions, nitrite ions, and petroleum products (*Snezhko, 2001*). The obtained values of these indicators are compared with the MPC for waters used in fisheries (MPC_f), after which the arithmetic mean is calculated.

$$HWP = \frac{1}{6}\sum_{i=1}^{6}\frac{C_i}{MPC_i}, \quad (1.1)$$

where:

C_i is concentration of the i-th indicator;

MPC_i is maximum permissible concentration for the i-th indicator.

Indicators of BOC_5 and dissolved oxygen content (O_2) are calculated according to the relevant standards, depending on their values. The resulting HWP value is compared with ranges corresponding to some water quality classes, based on which the level of its contamination is determined (*Table 1*).

The information base for this study was a variety of sources that provided a comprehensive and objective understanding of the quality of water resources. In particular, we used the reporting materials of the Boris Sreznevsky Central Geophysical Observatory, which contain significant hydrometeorological data. In addition, the materials on the basin management of Tisa's water resources played a significant role, providing information on the condition of Tisa Basin's water resources and the results of monitoring the water quality of the transboundary section of the river.

Materials from periodicals covering topical issues of ecology and water resources, like scientific works of domestic scientists, allowing us to consider modern approaches and experience in the study of water geosystems, added to the official reporting. A significant element of the information base was the results of our field studies conducted for a detailed study of physical and chemical indicators of water quality. These data provided a real picture of the state of water resources within the study area and made drawing reasonable conclusions and recommendations possible.

The results of the study

Natural conditions for forming the ecological state of Tisa's surface waters

The study area includes the entire Rakhiv district and most of the Tyachiv District of Ukraine's Transcarpathian region. The complex morphometry of the territory includes the mountain ranges of Chernogora and Svidovets, like part of the Marmaros Massif, Yasinyansk and Solotvyno basins. The complexity of the mountainous terrain of the territory also affects the density of the river network, represented by the Chernaya Tisa and Belaya Tisa, the confluence of which near the town of Rakhov (at an altitude of 460 m above sea level) gives rise to the Tisa. There are also numerous tributaries of the Tisa, the largest of which are the Kosovskaya, the Shopurka, Apshitsa, Teresva, etc. The dismemberment of the topography decreases from the sources of the Chernaya Tisa downstream. The study area is approximately 3,420 sq. km, and the length of the Tisa section from Rakhov to Tyachev is 80 km, of which approximately 60 km is the state border between Ukraine and Romania.

The map showing the location of water monitoring points in the upper reaches of the Tisa was developed using ArcGIS 10.4.1 software and appropriate tools (*Figure 1*).

The climatic conditions of the studied territory are formed mainly under the influence of topography since this is one of the highest areas in Ukraine, except for its southwestern part. The mountain ranges of Svidovets, Chernogora, Rakhiv and Marmaros mountains serve as natural barriers that prevent the penetration of various air masses. This affects the level of moisture, which, in turn, regulates watercourses, particularly flood and low-water regimes, like the level of groundwater and the processes of erosion and mudflows. Thus, the climate of this area is characterised by high humidity, which is significant for developing local ecosystems.

Air masses entering the territory of the Tisa catchment area within Transcarpathia have different origins: temperate, arctic, and tropical. They determine key climatic characteristics such as temperature, humidity, and precipitation. However, their movement is limited by narrow river valleys and mountain ranges, which contribute to specific air circulation. The exception is heights of more than 1200 meters, where the terrain has less influence on the movement of air masses.

The Tisa Basin's temperature regime is related to the height of the terrain. In the valley, the average annual temperatures range from +5°C to +7°C, while at higher elevations, they drop to +3°C. the coldest month is January, with a temperature from -5°C to -6°C and the warmest is June, with an average temperature from +15°C to +16°C, while is about +11°C at higher elevations. This temperature pattern gives the region a temperate continental climate, where the difference between winter and summer temperatures remains insignificant.

The annual humidity in this area is approximately 80%, contributing to the moistening of forests and affecting the vegetation cover. The moisture coefficient varies between 1.32 and 1.43, and the amount of precipitation per year varies depending on altitude. In the Lowlands, it falls from 900 to 1,400 mm, and altitude areas are more than 1,600 mm high. This distribution of precipitation significantly affects water resources and flood phenomena, which are most pronounced in spring and summer, when up to 53% of the annual precipitation rate falls. During this period, rivers become full-flowing, especially during snowmelt, increasing the water table.

Snow cover in the mountains is formed in early November and lasts about five months. The highest snow heights are observed in late January and early February. In high-altitude areas (800-1,000 m), the snow height reaches 150-200 cm, while valleys range from 70-80 cm. Snowmelt and rainwater significantly impact the chemical composition of watercourses, increasing the content of oxygen, iron, manganese, zinc and lead washed out of soils and rocks. In addition, agricultural runoff in the valleys adds nitrogen-containing compounds and phosphates to the water, especially during spring floods.

In the mountainous conditions of the Rakhiv and Tyachiv districts, the river flow of the Tisa and its tributaries is most affected by precipitation, geological features, terrain dismemberment, steep slopes, and the limited ability of catchments to accumulate water. Research shows that the average annual runoff over the past decades has tended to increase.

Changes in rivers' hydrological characteristics, such as water level, flow rate, seasonal and annual flow distribution, and food sources, affect water's chemical composition. Such fluctuations are reflected in water mineralisation, the concentration of basic ions, heavy metals, and biogenic substances.

Like many other Carpathian watercourses, the Tisa has a flood regime. Frequent floods occur due to heavy precipitation during the warm period of the year (from May to October), snowmelt during winter thaws, and spring snowmelt, often accompanied by rain.

Spring floods on the Yew and its tributaries usually begin in late March or early April due to snowmelt and rain. They can occur in several waves, raising the water level by 150-200 cm per day during large floods and 5-15 cm during small ones. According to hydrological data for 1950-2016 at the hydropost in Rakhiv, the maximum water level was recorded on March 5, 2001, and it was 575 cm. In years with a large amount of precipitation, up to 10-14 floods can occur, most of which occur in summer and autumn due to heavy rains. Winter floods are less predictable, but due to thaws, the water level can rise sharply to 2.2 m per day. Summer and autumn downpours and spring floods usually cause the most significant water rises.

The annual flow regime of rivers in part of the Tisa Basin is mainly characterised by floods observed from March to August. However, floods also often occur in autumn and winter, making it difficult to distinguish between seasons and hydrological periods clearly.

The soils of the Rakhovsky district were formed during the Holocene under the influence of biological processes on rocks in conditions of diverse moisture and relief. In mountainous areas, brown-earth soil formation dominates, characterised by high-altitude zoning, a thin layer of soil, and significant erosion processes.

The most common are brown or brown mountain forest soils, which occur up to an altitude of 1500 m and were formed on diluvial fish rocks. Under forest cover, the humus content can reach 10-15%, and on cultivated land – 3-5%.

Sod-brown soils, forming on slopes and river terraces in the Yasinya Basin and the southwest, are similar to brown mountain forest soils but characterised by a higher humus content (up to 5%).

In the subalpine and alpine zones of Svidovets and Montenegro, mountain-meadow-Brown-Earth soils are common, characterised by a high humus content (7-15%).

Thus, it can be argued that the annual flow regime of rivers in the Tisa Basin is characterised by a predominance of floods, which most often occur from spring to summer. However, they can also be observed in autumn and winter, making it difficult to distinguish between seasonal hydrological periods. The soil cover of the Rakhovsky and Tyachevsky districts was formed under difficult mountain conditions and varying degrees of moisture for a long time. The dominant type is brown-earth or brown mountain-forest soils, occurring up to an altitude of 1500 m. These soils are formed on fish rocks and contain much humus, especially under Woodlands. Sod-Brown soils are found in basins and river terraces, with a similar composition but higher humus content. Subalpine and alpine zones are dominated by mountain-meadow-Brown soils, also characterised by a high organic matter content. This soil structure affects the region's local ecosystem and water resources.

Anthropogenic factors affecting the ecological condition of Tisa's surface waters

Natural conditions, topography, and historical features of the territory contributed to the development of the economy, which intensively used the limited resources of agricultural land. As the height decreases, the area of hayfields and pastures in the land funds of administrative divisions decreases. The most valuable category of agricultural land is arable land (arable land). The area of arable land depends on natural conditions, such as orography, forest cover, climate, and population. The share of arable land in the Land Fund is growing downstream of the Tisa, which is natural; as the river valleys expand, the number of suitable lands for cultivation increases, the average height of the territory decreases, and the area of hayfields and pastures decreases, while the population increases.

Analysing the ploughing of agricultural land, it can be seen that mountainous terrain plays a key role in determining the specialisation of Agriculture, the nature of land use and the size of areas allocated for arable land, hayfields and pastures. Arable land is often located on the slopes of narrow river valleys and coastal areas, creating risks of organic contamination of surface waters due to the introduction of fertilisers, pesticides and increased solid runoff during floods and floods. Regarding the distribution of protected land, the main factor is the presence of protected areas, nature reserves, natural monuments and other objects of the nature reserve fund within administrative divisions.

When analysing the impact of recreational activities on the water resources of the Tisa within the Rakhiv district, you should also highlight the area of land intended for recreational purposes in various administrative entities (village, town and city councils). Land use in the context of recreation covers small areas. However, this industry's significant natural resource potential explains some differentiation in the distribution of such land.

Managing solid household waste and its disposal in landfills and landfills is problematic. Due to the relief features of the mountainous area, which limit the possibility of placing landfills, many of them are located near rivers, particularly the Tisa. The situation with the landfill in Rakhov, located on Tisa's left bank, is especially alarming. In some areas, the height of garbage layers reaches ten meters, causing water pollution from household waste, chemicals and other pollutants, especially during floods, when hundreds of waste units per minute enter the river.

A significant aspect of the economy of the Rakhiv and Tyachiv districts is water use, affecting the hydroecological condition of the rivers of the Tisa Basin (*Boyko et al., 2008*). Water intake is performed from municipal wells and the Tisa's surface waters. In urban settlements of the Rakhiv District, 40% of the housing stock is equipped with water supply, including private water supply systems, and in rural areas, this figure is 35.7%. Sewerage covers 30% of residential buildings in urban settlements and 25.6% in rural areas. At the same time, a significant part of the rural population uses water from wells, about 20% of which do not meet environmental standards due to violations of sanitary protection zones.

Among the main pollutants of water resources of the Tisa and its tributaries, water users dominate, including public utilities, mining and woodworking industries, recreational facilities, environmental institutions and educational institutions. The largest volumes of wastewater fall on the woodworking enterprise LLC "Karpaty" in the village of Veliky Bychkov and municipal enterprises "Rakhivvodokanal" and "Rakhivteplo" in the city of Rakhov. The sewer infrastructure of the Rakhovsky district is in unsatisfactory technical condition. Expanding the water supply network in Rakhiv is an extremely costly process that has remained unresolved over the past 20 years due to financial difficulties.

The Tisa collects Rakhov's sewage and drainage water, one of the area's main sources of modern pollution. The treatment facilities of Rakhov and Tyachev, like the water intake system of the village of Bolshoy Bychkov, have been in operation since Soviet times, are not being upgraded, and no longer meet modern needs.

One key cause of water pollution is insufficiently treated or untreated wastewater containing organic substances from municipal, industrial, and agricultural sources, such as livestock complexes and manure storage facilities. These pollutants violate the oxygen balance in the water, which can negatively affect the ecological state of water bodies and the number of aquatic organisms.

During route surveys of the Chernaya Tisa, Belaya Tisa, and Tisa along the Ukrainian-Romanian border, fertilisers, household waste, spontaneous landfills, manure storage facilities, and summer animal sites located in coastal protective zones and floodplains were found to affect water quality.

The impact of agriculture on the quality of water in rivers is mainly due to the following factors:

- the use of organic and mineral fertilisers on cultivated land plots;
- the use of coastal zones and floodplains for agricultural needs;
- the placement of manure storage facilities and summer livestock sites near rivers;
- the discharge of water from fish ponds into rivers;
- the lack of sewage treatment plants and centralised drainage at livestock facilities.

The field of recreation and tourism in the upper reaches of the Tisa has a rich potential due to natural historical and architectural resources. However, unsystematic development of territories suitable for tourist and recreational use, low level of developing transport infrastructure, poor water supply, lack of regular removal of household waste and the need to create centralised sewage systems, in particular in the Dragobrat Valley hinder the development of the tourism industry.

As a result, we can see that economic activity in the Rakhiv and Tyachiv districts significantly affects the hydrochemical regime of rivers, manifested in an increase in the content of biogenic substances and heavy metals, such as copper, zinc and lead. The anthropogenic impact is manifested through small areas of arable land, which occupy less than 1% of the territory, and a significant decrease in water-intensive industries led to a 20-fold reduction in the volume of water used from 1990 to 2018. The main pollutants of rivers are municipal enterprises, of which only 10% of wastewater undergoes mechanical and biological treatment. In addition, the widespread spontaneous landfills along rivers, particularly in Rakhov, significantly worsen the water quality. Economic activity in small river basins can potentially transform natural ecosystems into natural economic ones, threatening aquatic ecosystems (*Afanasyev, 2006*). This highlights the significance of conducting studies of rivers used for fishing and recreation to predict hydro-ecological conditions. It is necessary to analyse structural changes and seasonal fluctuations in hydrochemical indicators to improve water management and solve water quality problems.

Hydrochemical regime and water quality assessment of the Tisa section

The study of the hydrochemical regime and water quality assessment of the transboundary section of the Tisa in the Rakhiv district were performed based on data collected by the basin management of water resources of the Tisa. The analysis of chemical and physicochemical indicators of the composition of surface waters and the corresponding environmental assessment was carried out on the materials of monitoring points along the transboundary section of the Tisa – Dilove, Solotvino and Tyachev – according to the results of laboratory tests for 2021 and 2022.

The hydrochemical regime of surface waters of the transboundary section of the Tisa from the village of Dilove to the city of Tyachev within the Rakhiv and Tyachiv districts of the Transcarpathian region is considered based on the available stock materials of the basin management of water resources of the Tisa. Monitoring of the chemical composition of water is carried out monthly to ensure high data quality and the ability to track the intra-annual distribution and regime characteristics of indicators. The hydrological regime also plays a significant role because some chemical indicators (ionic composition, nitrogen-containing compounds, trace elements, and heavy metals) change at different river water content phases.

The selected chemical parameters allow us to analyse the oxygen regime, the content of biogenic substances, and specific pollutants, particularly petroleum products. This, in turn, allows us to analyse both natural conditions for forming water quality and trace anthropogenic factors of influence.

The high content of dissolved oxygen, in the average annual values of the range of 10.9-11.85 mg O_2/dm^3, is due to the mountainous nature of the Tisa, and therefore, the rapid turbulent flow, the presence of rapids and a large number of tributaries. High indicators indicate a favourable habitat for living organisms. However, the increase in the average annual values of BOC_5 and COC downstream of the Tisa from the village of Dilove to the city of Tyachev indicates an increasing anthropogenic impact, in particular, due to the discharge of water by municipal enterprises, private households, tourist and recreational facilities, and industrial enterprises. Thus, the entry of organic substances into surface waters causes a deterioration in water quality, which is reflected in the appendix (*Table 2*).

The high total iron content (0,14-0,27 mg O_2/dm^3) corresponds to a multiple of exceeding the maximum permissible norms, even for average annual values. Such indicators are due to both natural conditions (the presence of heavy metals in the geological foundation, soils, and underground waters) and anthropogenic sources (transboundary transfer and runoff from industrial enterprises) (*Skobley et al., 2014*; *Skoyley et al., 2017*).

Considering the impact of surface runoff from agricultural areas is also significant. In particular, river floodplains are used under arable land in the mountainous part of the study area, which, in the conditions of heavy rains, causes organic contamination of surface waters, including pesticides and nitrogen-containing compounds ($N–NH_4^+$).

The low content of petroleum products in surface waters indicates the absence of natural and anthropogenic sources of pollution due to the absence of the mining industry, oil pipelines and oil refining enterprises. Indicators of the content of petroleum products are on the verge of determination (0.01 mg/dm^3).

The arithmetic determines the HWP index mean excess of the maximum permissible concentrations of some group of indicators. According to the analysed data downstream, a consistent increase in HWP values is observed in the transboundary section of the Tisa (*Figure 2*). The calculated indices range from 0.9 to 1.4, which, in turn, corresponds to the second and third water quality classes (clean water and moderately polluted water, respectively). The increase in HWP downstream indicates an increasing anthropogenic impact. This is due to an increase in the number of people living in the coastal zone, like an increase in quantitative indicators of anthropogenic impact, particularly recreational facilities within the village of Solotvino. Consistently increased HWP values in the city of Tyachev due to a slight increase in the values of BOC_5, COC and a corresponding decrease in the content of dissolved oxygen indicate the presence of sources of organic contamination of surface waters.

Thus, studies of the hydrochemical regime and water quality of the transboundary section of the Tisa in the Rakhovsky district have shown that surface waters have a high content of dissolved oxygen, contributing to organisms' vital activity. However, there is an increase in anthropogenic impact downstream, manifested in the biochemical and chemical consumption of oxygen, iron content, and organic substances. This is caused by both natural conditions and the activities of the local population, like agricultural and industrial runoff, particularly in the area of Tyachev.

Discussion

The study showed that municipal industrial and private farms significantly degrade Tisa's water quality, confirmed by an increase in BOC_5 and COC indicators downstream from the village of Dilove to the city of Tyachev.

Changes in the river's water content phases affect the concentration of chemical parameters, particularly ions, nitrogen-containing compounds, and trace elements, which are worth considering during monitoring.

The gradual increase in the downstream water pollution index is associated with more intense anthropogenic impact, especially in coastal areas with high population densities and recreational activities.

The increased iron content in water caused by natural and anthropogenic factors exceeds the maximum permissible standards, although the level of petroleum products remains low.

Agriculture, especially in floodplain lands, contributes to water pollution with pesticides and nitrogen-containing compounds, which are noticeable after heavy rains.

Strengthening cross-border cooperation and developing joint water management strategies for the Tisa are necessary to reduce pollution.

Conclusion

Based on the analysis of chemical and physicochemical parameters of the surface waters of the Tisa in the transboundary area within the Rakhiv and Tyachiv districts, it was found that the mountain nature of the river contributes to a high content of dissolved oxygen, creating favourable conditions for aquatic organisms. However, an increase in BOC_5 and COC downstream indicates an increase in anthropogenic load, which negatively affects the ecological state of the river.

Increased concentrations of iron, nitrogen-containing compounds and organic substances indicate a mixed impact of natural and anthropogenic factors, including wastewater discharge and agricultural activities. At the same time, the low level of petroleum products confirms the absence of significant sources of petrochemical pollution.

Water pollution indices are rising from the village of Dilove to the city of Tyachev, indicating the growing impact of human activities, particularly wastewater discharge and recreational load in coastal areas.

It is necessary to develop and implement a more detailed and frequent programme for monitoring the chemical composition of waters to consider seasonal fluctuations and quickly respond to changes in the river's hydrochemical regime (*Leta et al., 2022*).

Expanding research on the impact of specific sources of pollution, such as municipal runoff, agricultural surface runoff, and recreational facilities, is advisable to develop effective measures to reduce their negative impact.

Strengthening international cooperation in water resources management is a significant step that will improve the ecological state of the Tisa in cross-border areas.

Prospective studies should examine the impact of climate change on the river's hydrochemical regime and predict possible long-term consequences for water quality.

Conflict of interests

The author states that there was no conflict of interest.

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Appendix

Table 1. Classification of water quality by HWP

Water quality class	Water pollution level	HWP range
I	very clean water	$HWP < 0{,}3$
II	clean water	$0{,}3 < HWP < 1$
III	moderately polluted water	$1 < HWP < 2{,}5$
IV	contaminated water	$2{,}5 < HWP < 4$
V	dirty water	$4 < HWP < 6$
VI	very dirty water	$6 < HWP < 10$
VII	extremely dirty water	$HWP > 10$

Compiled by the author based on materials (*Snezhko, 2001*)

Table 2. Average annual values of chemical indicators of surface water composition of the transboundary section of the Tisa

Year / Item / Indicator		Biochemical oxygen consumption for 5 days, mg O_2/dm^3	Oxygen dissolved, mg O_2/dm^3	Ammonium nitrogen, mg/dm^3	General iron, mg/dm^3	Chemical oxygen consumption, mg O/dm^3	Petroleum products, mg/dm^3
2021	Dilove	1,71	11,85	0,080	0,17	5,1	0,01
	Solotvino	2,15	11,4	0,090	0,24	5,8	0,01
	Tyachev	2,44	11,3	0,080	0,27	6,6	0,01
2022	Dilove	1,93	11,2	0,086	0,14	6,1	0,01
	Solotvino	2,10	11,0	0,100	0,20	7,5	0,01
	Tyachev	2,30	10,9	0,110	0,21	7,2	0,01

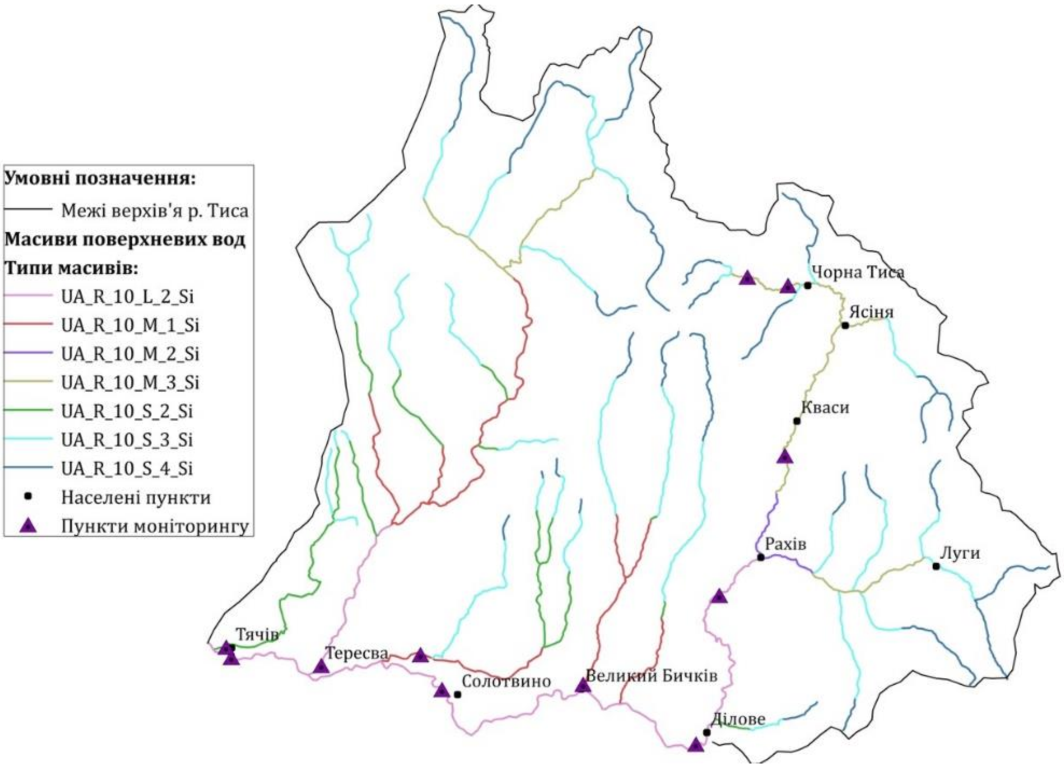

Figure 1. Map layout of water monitoring points within the upper reaches of the Tisa Basin
(Leta et al., 2022)

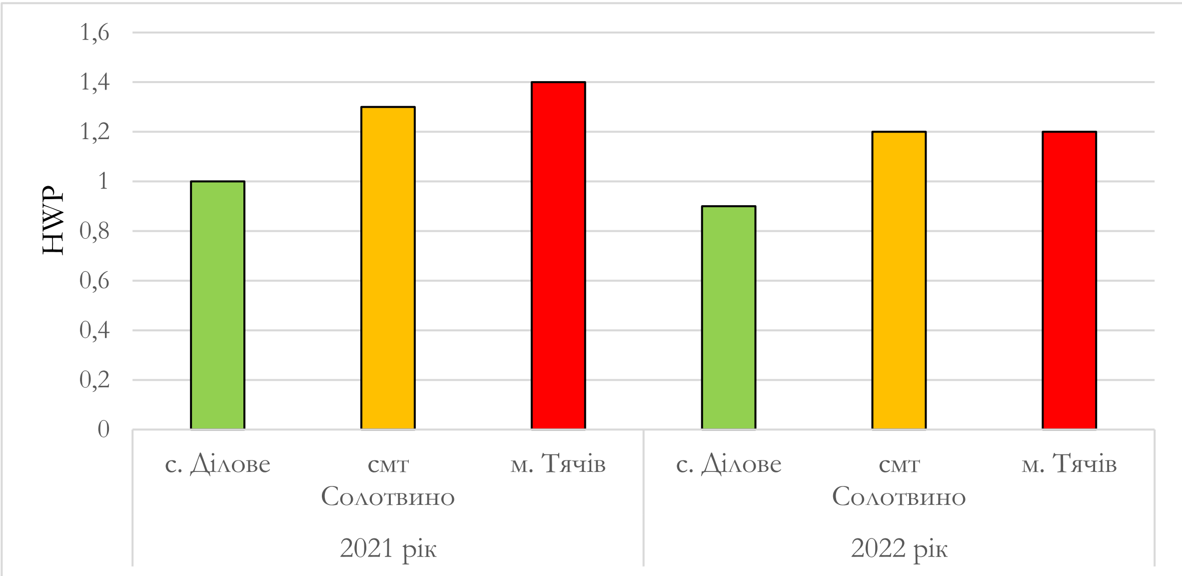

Figure 2. Dynamics of downstream HWP values in the transboundary section of the Tisa