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Ecological assessment of surface water quality in the upper Pripyat river basin based on hydrochemical indicators

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Absrtact. The article presents the results of the ecological assessment of the surface water quality of the upper Pripyat River basin based on hydrochemical indicators, using the integral ecological index I_E. The study covers the period from 2019 to 2023 and includes the analysis of water mineralization, physicochemical indicators, biogenic substances, trace elements and toxic pollutants in the Turia, the Vyzhivka, the Styr, the Stokhid, the Tsyr and the Pripyat rivers. Of the three analyzed components of water quality indicators (salt composition, tropho-saprobiological composition, and specific toxic substances), the tropho-saprobiological section which reflects the degree of organic pollution had relatively worse values. It was found that the main factors affecting the water quality of the studied rivers are discharges of untreated and poorly treated wastewater, agricultural pollution, as well as changes in the agricultural landscape.

Key words: surface waters, ecological quality, pollutants, right-bank tributaries of the Pripyat

Introduction

The European integration processes of Ukraine and its obligations to implement the guiding provisions of the Water Framework Directive of the European Union make maintaining good ecological status of surface waters one of the key priorities of the state's environmental policy. That is why the use of effective methods of monitoring and assessing water quality is a necessary condition for ensuring sustainable management of water resources, planning environmental measures and preventing negative impacts of anthropogenic activities. Such an approach allows not only to fulfill international obligations but also contributes to the preservation of biodiversity, improving the quality of life and ensuring the rational use of water resources in the long term.

Accurate quantification of changes in river water quality is essential for the development of environmental protection measures and resource management policies (Del Mar Sanchez-Montoya M. et al., 2012; Behmel S. et al., 2016). Methods for assessing water quality that are suitable for widespread use, easy to calculate, and provide reliable results are thus becoming increasingly necessary.

Research worldwide identified effective methods for assessing water quality, including the single-factor index method (Debels P. et al,, 2005); a method based on target indicators and needs of the water body (Shamshirband S. et al., 2018; Tiyasha T.M. and Yaseen Z.M., et al., 2020). A widely used assessment method is the water pollution index (Haribowo R. et al., 2024; Marselina M. et al., 2025) in which the value of the strongest pollution indicator, i.e. the determinant of the water quality assessment result, is considered to be the most important. Nevertheless, none of the approaches can be considered universal, at least given the fact that it is impossible to isolate the impact of different pollutants on water quality (Li R. et al., 2016).

Numerical indices are often used as convenient parameters for assessing the quality of river water. This relatively simple method reduces a large amount of data to a single value which provides a qualitative characteristic of the ecological state of surface waters. Among the huge number of similar approaches, the calculation of the Water Quality Index (WQI) has become widespread in recent decades.

WQI is a mathematical approach in which several water quality parameters (variables) are linked together, forming a single whole value that reflects the overall health of a water body (Mohammed I. et al., 2021; Das A., 2025).

This approach simplifies not only data interpretation, but also understanding of the space-time variability of water quality parameters (Noori R. et al., 2019). WQI is mainly divided into two types, pollutant index and quality index. WQI values in the pollutant index increase with increasing pollution levels, and vice versa in the quality index (Misaghi F. et al., 2017). Furthermore, the WQI approach is divided into four categories depending on the ultimate purpose of surface water use (Satish N. et al., 2024):

1) without taking into account the final purpose of water use: gives an integral view of WQI;

2) precisely defined target orientation: largely depends on water use, such as drinking water, irrigation, industrial discharges and assessment of heavy metal pollution, etc.;

3) planning and management: usually used in cases where the focus is on effective management and planning of water resources allocation;

4) use of mathematical tools: statistical and other mathematical models are used to determine the overall condition of a water body.

The main limiting factor in water quality indexing is the subjective approach to establishing auxiliary levers which can be biased and in some cases misleading. This is primarily because the use of expert opinions is often considered unscientific, as they can vary from one person to another depending on person's perception (Dash S. and Kalamdhad A. S., 2021). To minimize the effect of subjective judgements, mathematical tools, also known as environmetrics or chemometrics tools, have been used in recent years. The development of a WQI involves the following four steps (Abbasi T. and Abbasi S. A., 2012):

1) selection of priority hydrochemical quality parameters;
2) calculating subindex values by converting parameters into a standard scaling factor;
3) weight assessment according to all parameters;
4) aggregating subindex values to obtain the final WQI.

A very large body of literature regards water quality indices. Horton (Horton R.K., 1965) and Brown (Brown R.M. et al., 1970) pioneered developing indices for assessing pollution in aquatic ecosystems. Since then, many different methods for calculating the WQI have emerged (Smith D.G., 1989; Romanenko V.D. et al., 1998; Khan F. et al., 2003; Sarkar C. and Abbasi S.A., 2006).

All indices use many of the same variables (e.g. dissolved oxygen, temperature, ammonium), but they differ in the way they integrate and interpret parameter values. The use of the WQI in pollution studies is a very valuable tool because it summarizes on a simple numerical scale the level of pollution for a given water resource. This enables comparing surface water quality within catchments over space and time, which helps, for instance, to assess the progress of monitoring programs and simplifies the communication of results (González P.S. et al., 2024).

It should be noted that many studies use biological indicators to assess water quality, since biological communities reflect a combination of current and past conditions in a catchment area that shape surface water quality (Klymenko M. et al., 2024; Barroso G.R. et al., 2024). Use of biomonitoring methods surface water has a long tradition, and there are numerous examples of including bioindication factors in the calculations of water quality indices (Tulp T. et al., 2024; Ciecierska H., Dynowska M. 2013; Grzybowski M. et al., 2023; Myroslav S. Malovanyy, et al., 2022.).

Overall, the review of the available scientific literature provides a fairly comprehensive understanding of the existing methodologies in the issue under study. On one hand, it provides a deeper understanding of the limitations of existing approaches, and on the other hand, a development of the direction towards systematic innovations (Malovanyy A., et al., 2014 ; Malovanyy M., et al., 2021; Malovanyy M., et al., 2020).

A clear position in all the analytical works cited is the perception of the WQI as a valuable research tool, since it summarizes the level of pollution for a particular water body in a simple numerical scale. At the same time, there are also other objective views on the WQI which see the classification of water quality by the degree of pollution or purity as insufficient (Gupta S. and Gupta S.K., 2021). This is because most WQIs target reusable functions (Fortes A.C.C. et al., 2023), i.e. they claim their universality for various kinds of water use. Such unified approaches are considered debatable, because many scientists adhere to still quite strong beliefs about the need for certain indices for each kind of water use. This reflects the idea that water quality depends on its planned use (fitness for purpose) (Gupta S. and Gupta S.K., 2021). Some available WQIs do define water quality for one specific use function, such as drinking water (Li J. et al, 2025) or recreational water (Isaac R. et al., 2024). However, this approach is also not perceived as objective, since WQIs for recreation take into account only traditional water quality parameters, neglecting physical safety indicators (Van der Meulen E.S. et al., 2022).

Thus, the literature review suggests that water quality indices (WQIs) are an important tool for assessing the state of surface waters, providing a quick and accessible interpretation of monitoring data. At the same time, the use of WQIs has limitations, which are associated with their universality and the attempt to cover different kinds of water use with a single indicator. This highlights the need for further research and improvement of methodologies that would take into account the specifics of various kinds of water use and respond to modern environmental and social challenges.

The objective of this study was to analyze the quality of surface water bodies of the upper Pripyat River basin by the hydrochemical indicators and to determine the ecological quality index (I_E) of the state of surface waters, using integral methods of assessment and analysis of the relationship between the results obtained.

Materials and methods

According to the hydrographic zoning of the territory of Ukraine, the Pripyat River is marked out as a separate sub-basin in the Dnieper basin (Khilchevskyi et al., 2019). The total length of the river is 775 km, of which 254 km is in Ukraine. Part of the Pripyat riverbed within the Volyn region, 72 km long, has been converted into the main channel of Upper Pripyat drainage system, one of the largest in Europe (Characteristics of the Pripyat River Basin, 2021). The upper reaches of the Pripyat River include the sub-basins of its tributaries, the Tsyr River, the Vyzhivka, the Turia, the Stokhid, the Styr, as well as the course of the Pripyat River itself (Fig. 1).

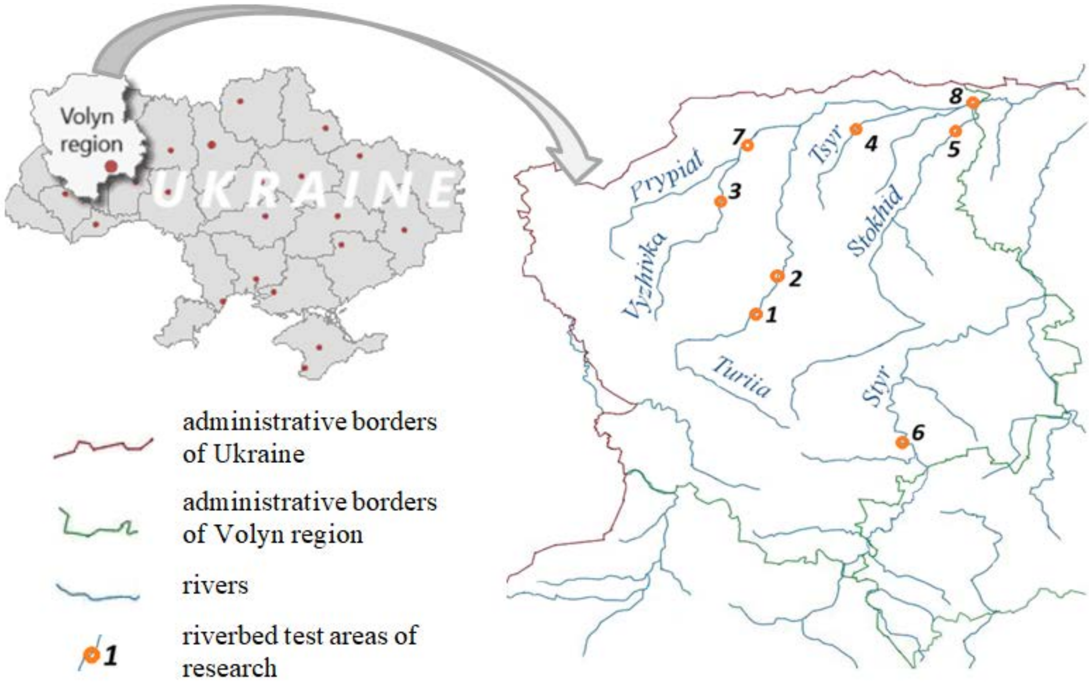

Fig. 1. Territorial location and hydrographic network of the Upper Pripyat River

The quality of the surface water of rivers was analyzed according to statistical reporting data of the Department of Ecology and Natural Resources and the Department of Agro-Industrial Development of the Volyn Regional State Administration, which were formed within the framework of the implementation of the “National Target Program for the Development of Water Management and Ecological Improvement of the Dnipro River Basin for the Period Until 2021” and the Regional Environmental Program “Ecology 2016–2023”.

Eight sampling sites were selected along the channel as representative observation sites and for ecological assessment of the quality of river surface water (Table 1).

Table 1. General characteristics of the representativeness of the sampling sites

No.	Administrative location	Distance from the mouth, km	Justification, territorial community (TG)
the Turia River			
1	City of Kovel, 500 m above the Kovelvodokanal sewage treatment plant	79.29	Control site, impact of agricultural development, middle part of the river course, Kovel TG
2	Village of Bakhiv, 500 m below the outlet of the Kovelvodokanal sewage treatment plant	78.29	Control site, impact of wastewater discharge from the Kovelvodokanal wastewater treatment plant, middle part of the river course. Kovel TG
the Vyzhivka river			
3	Town of Stara Vyzhivka, 500 m above the outlet of the Stara Vyzhivka sewage treatment plant	34.58	Control site, impact of agricultural development, middle part of the river course. Stara Vyzhivka TG
the Tsyr River			
4	Town of Kamin-Kashirskyi	41.33	Background site, before the recreation area.

			Kamin-Kashirskyi TG
the Stokhid River			
5	Town of Lyubeshiv	20.26	Control site, near the mouth of the river. Lyubeshiv TG
the Styr River			
6	City of Lutsk	338.3	Control site, impact of wastewater discharge from the Lutskvodokanal sewage treatment plant, middle part of the river course. Lutsk TG
The Pripyat River			
7	Village of Richytsia	751.4	Background site, river outlet. Shatsk TG
8	Town of Lyubeshiv	623.9	Control site, middle part of the river course. Lyubeshiv TG

The research used statistical methods to calculate the average values of the multi-year average hydrochemical indicators. Graphical visualization of the results utilized the standard Microsoft Office Word tools.

The chemical composition of water and the hydrochemical regime of the Pripyat River basin assessed the following groups of indicators: main ions and water mineralization; physico-chemical indicators; biogenic substances; trace elements; specific pollutants.

The hydrochemical regime was studied using the minimum, maximum and average annual values of the observation period. The quality of river waters was assessed using the "Hygienic standards for the quality of water bodies for meeting drinking, household and other needs of the population" (2022).

The current ecological state of surface water bodies of the Pripyat River basin was assessed according to the data of systematic observations of the State Agency for Water Resources and the Central Water Management Center in the Volyn region. The integral ecological index I_E was determined by the "Methodology of ecological assessment of surface water quality by relevant categories" (Romanenko V.D. et al., 1998) from the values of component indices, i.e. salt composition of water (I_1), tropho-saprobiological bloc (I_2), and specific toxic substances (I_3). Based on unified ecological criteria, the method allows to compare water quality in separate areas of water bodies and consists in calculating the integral index of water quality I_E by the formula:

$$Ie = (I_1 + I_2 + I_3)/3 \quad (1)$$

Obtained values of component and integral ecological indices were assigned, according to the ecological classification, to following water quality status: excellent condition 1.0–1.4 (standard of comparisons); excellent to good 1.5–1.6; good 1.7–3.4; good to satisfactory 3.5–3.6; satisfactory 3.7–5.4; satisfactory to poor 5.5–5.6; poor 5.7–6.4; poor to very poor 6.5–6.6; very poor 6.7–7.0.

Results and discussion

The mineralization of surface water bodies of the Pripyat basin within the Volyn region depends on natural factors, namely, moderate moisture, alluvial clayey sands, loams, limestones, the development of karst, and the presence of iron of swamp origin in the territory of the Polissia lowland. The hydrochemical regime of the rivers is closely related to the hydrological regime. The waters are mainly of the calcium bicarbonate type with a mineralization of 0.2–0.5 mg/l (Fig. 2).

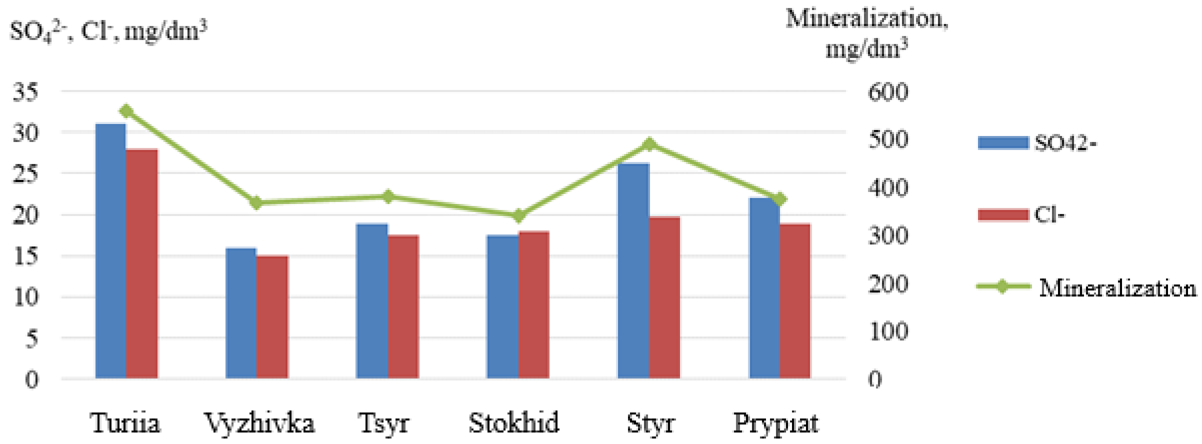

Fig. 2. Mean annual concentrations of major ions and water mineralization (mg/dm^3) of the right-bank tributaries of the Pripyat River (2019–2023)

Obtained results show that the mean annual concentration of major ions and mineralization of water of the right-bank tributaries of the Pripyat River in Volyn is 376–560 mg/dm^3. It decreases during the summer-autumn low water period, and increases in the winter low water, which is explained by the hydrological regime with spring and summer floods typical of the Volyn rivers.

Among the most important physico-chemical indicators are pH and dissolved oxygen O_2 (Biedunkova et al., 2023). pH values of the right-bank tributaries of the river Pripyat in Volyn vary in the range from 7.5 in the Pripyat itself to 8.64 in the Vyzhivka. According to the classification of natural waters by pH (Khilchevskyi et al., 2021) they belong to slightly alkaline ones. Mean annual values of O_2 vary from 9.14 mg/dm^3 in the Turia to 5.20 mg/dm^3 in the Tsyr (Fig. 3). This factor is important, as it is oxygen that creates the conditions for the existence of hydrobionts. The maximum dissolved oxygen values in the studied rivers are observed during the periods of spring and summer floods. During the summer low water period oxygen content decreases, which is especially dangerous due to the presence of industrial and municipal wastewaters that can cause the death of hydrobionts and the development of flowering in reservoirs in the warm season.

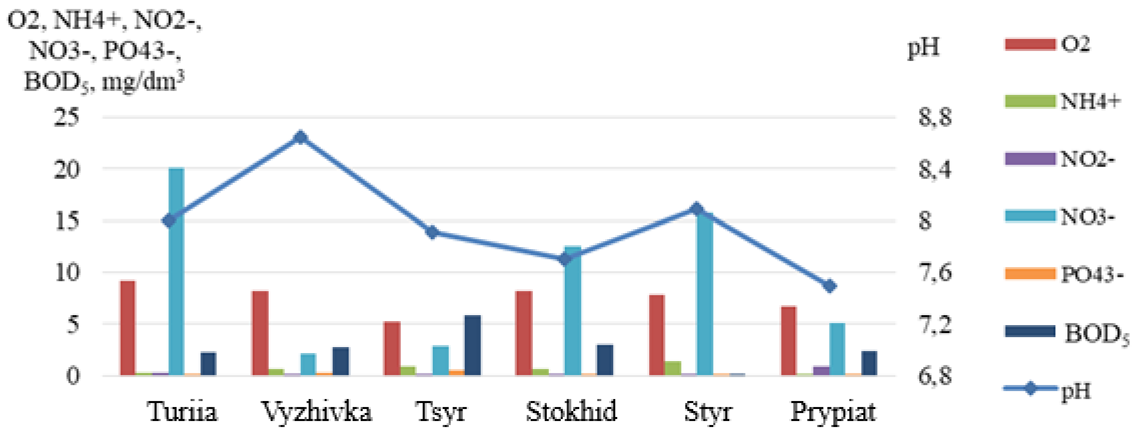

Fig. 3. Mean annual values of pH, oxygen content, nitrogen and phosphorus compounds (mg/dm^3) of the right-bank tributaries of the Pripyat River (2019–2023)

Biogenic substances, namely nitrogen and phosphorus compounds are no less important for the existence of aquatic organisms and the suitability of water for domestic needs. Increased biogenic content may also indicate the supply of nutrients into the water body with surface runoff from agricultural lands and domestic wastewater (Malovanyy et al., 2014). The concentration of ammonium NH_4^+ in surface waters varies little over the year and ranges from 1.35 mg/dm^3 in the Styr River to 0.02 mg/dm^3 in the Pripyat River. It should also be noted that the highest values of the indicator are observed during the spring and summer floods, and the lowest during the winter low water period, but in any case did not exceed the existing MPC, which is 2.0 mg/dm^3 (Khilchevskyi et al., 2021).

The content of nitrites (NO_2^-) in river waters is insignificant and ranges from 0.08 mg/dm^3 in the Vyzhivka River to 0.86 mg/dm^3 in the Pripyat River. This did not exceed the MPC for the entire observation period, regardless of the hydrological regime of the rivers.

The content of nitrates (NO_3^-) in the surface waters of the right-bank tributaries of the Pripyat River also did not exceed the MPC for the entire observation period, regardless of the hydrological regime of the rivers, and was in the range of 2.16 mg/dm^3 in the Turiya River to 20.11 mg/dm^3 in the Vyzhivka River. A decrease in the nitrate concentration during the summer low water period due to the active growth of aquatic vegetation and an increase in the NO_3^- concentration during the winter low water were also observed.

The concentration of phosphates (PO_4^{3-}) in the surface waters ranged from 0.02 mg/dm^3 in the Turia River to 0.48 mg/dm^3 in the Tsyr River, which does not exceed the MPC and is an active source of phosphorus nutrition for aquatic organisms; therefore, the phosphate content decreases during the summer low water period.

Microelements in the surface waters of the right-bank tributaries of the Pripyat River are contained in small concentrations (Fig. 4), usually not exceeding hundredths or thousandths of a part.

This applies to all microelements, except for iron (Fe) due to its weak mobility and naturally increased content in the surface waters of Volyn.

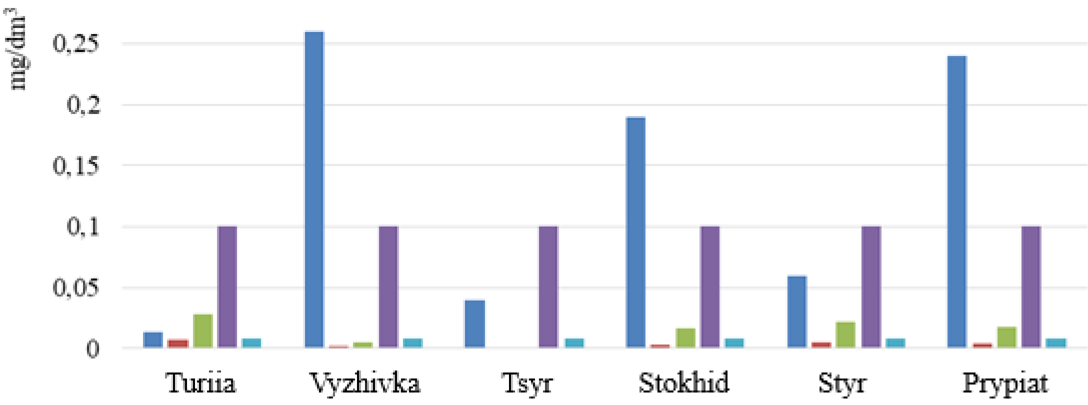

Fig. 4. Mean annual concentrations of trace elements (mg/dm^3) of the right-bank tributaries of the Pripyat River (2019–2023)

The available database of hydrochemical parameters of the studied rivers enabled an ecological assessment of the quality of surface waters using component and integral indices. Thus, mean values of the salt composition index I_1 on the tributaries of the rivers of the Pripyat basin for the 2019–2023 period varied from 1.0 to 1.5 and characterized the river waters as category 1 ("excellent" condition, "very clean" in degree of pollution) (Fig. 5a). The highest values of I_1 (1.5 and 1.7) were recorded on both sampling sites of the Turia River during 2019–2023 and on the Stokhid River site in 2021. The worst values of the salt composition index ranged from 1 to 1.8, which corresponds to categories 1 and 2. The maximum value I_1 =2 was recorded on the site of the Turia River (9 km below the city of Kovel) in 2022 and on the site of this river within Kovel in 2021.

Mean values of the tropho-saprobiological index I_2 at all sampling sites varied from 3.1 (the Stokhid, 2022) to 3.8 (the Tsyr, 2021) which classified the water quality as category 3 ("good" condition, "fairly clean" in degree of pollution) and category 4 ("satisfactory" condition, "slightly polluted" in degree of pollution). The worst value of the index I_2=5.0 was observed at the site of the Turia River 9 km below the city of Kovel making it category 5 of the III class of water quality ("average" condition, "moderately polluted") in 2021 (Fig. 5b).

Mean values of the index of specific toxic substances I_3 ranged from 3.4 (the Prypiat), i.e. "good" condition, "fairly clean" degree of pollution, to 3.7 (the Turia), i.e. "satisfactory" condition, "slightly polluted" (Fig. 5c) .

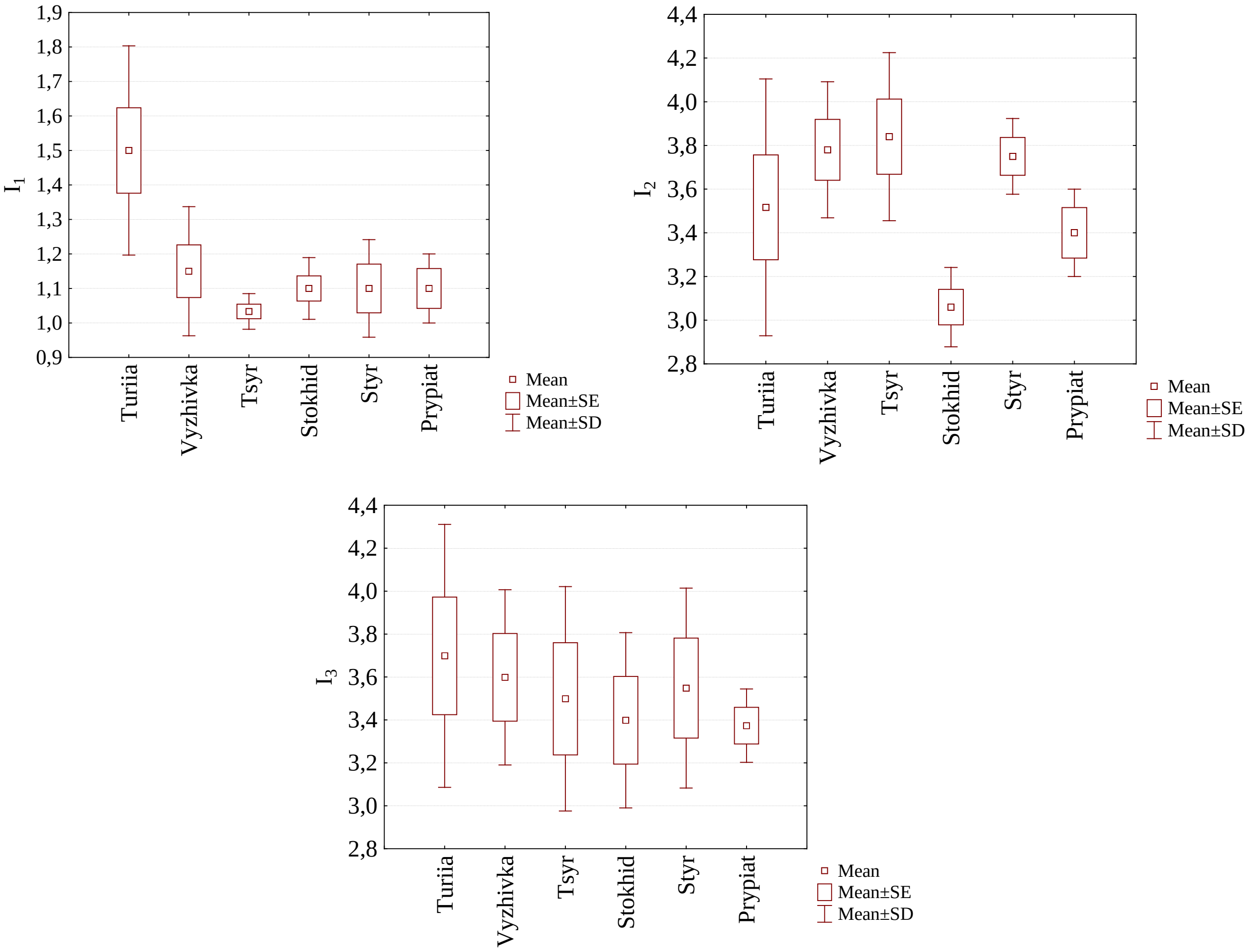

Fig. 5. Statistically refined values of component indices of surface water quality of right-bank tributaries of the Pripyat River: a) salt composition index I_1; b) tropho-saprobiological composition index I_2; c) index of specific toxic substances I_3.

The calculated values of the integral ecological index of water quality I_E for 2019–2023 for all sampling sites in the Upper Pripyat basin were within class II, both in terms of mean values and of the worst values. This characterized the surface waters as "good" condition and "clean" in terms of the degree of pollution (Fig. 6).

The highest mean values of the integral ecological index I_E on the tributaries of the Pripyat River (3.2) were recorded on the Turia River site, 9 km downstream of the city of Kovel in 2021. The lowest mean I_E values (2.2) were recorded on the Turia River site in Kovel in 2022.

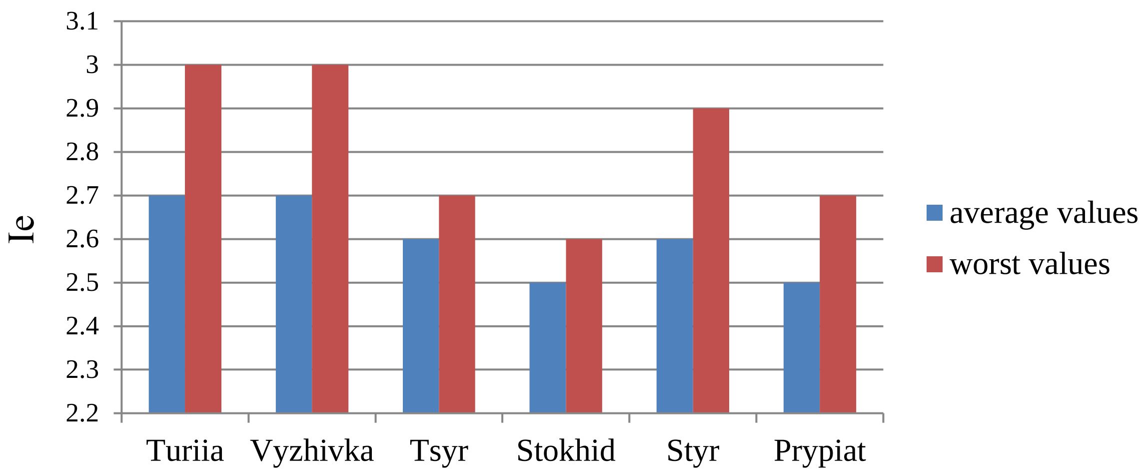

Fig. 6. Integral ecological index of surface water quality of the right-bank tributaries of the Pripyat River

Therefore, the water quality of the Upper Pripyat basin at all sampling sites was characterized by stability during 2019–2023, i.e. it corresponded to categories 2 and 3 ("very good" or "good" condition; "clean", "fairly clean" in degree of pollution). It is also worth noting that from 2021 to 2023 there was a trend towards improving water quality with a transition from category 3 to 2 of the II class of water quality.

Absent large industrial and municipal enterprises, the major factors affecting the water quality of the Upper Pripyat River basin are:

– discharge from Ratne municipal wastewater treatment facilities (MWTF) that are classified as "discharged without treatment or poorly treated". The average yearly volume of wastewater discharge from Ratne MWTF is 80,000 m^3. (Gulay et al., 2022). This volume of wastewater also discharges approximately 111 tonnes of pollutants into the river, the majority of which consist of solids, chlorides and sulphates. As a result, BOD_5 and COD levels exceed the maximum permissible limits (Gulay et al., 2022).

– discharge into the river from Stara Vyzhivka MWTF that are classified as "discharged without treatment or poorly treated". The average yearly discharge by the Stara Vyzhivka MWTF is 50,300 m^3, carrying about 37 tons of pollutants, most of which are dry residue, chlorides, sulfates, BOD_5 and CSD (Hopchak, 2007);

– wastewater discharge from Kovel MWTF. The average yearly discharge by the Kovel MWTF is 3,500,000 m^3, with a tendency to decrease. Carrying about 1800 tons of pollutants, the amount of discharge of these is increasing yearly (Gulay et al., 2022);

– wastewater discharge from Kamin-Kashirskyi MWTF, with the average yearly volume of 118,000 m^3. Carrying about 121 tons of pollutants, the amount of discharge of these is increasing yearly (Fesiuk, 2016);

– the location of fairly large villages on the riverbank, a significant part of which lack centralized wastewater drainage. Sewage is discharged either directly into water bodies or filtered through groundwater from cesspools in conditions of high groundwater levels;

– development of farms in conditions of unsatisfactory state of the amelioration network. Recent years oversaw, with the increase in average annual temperatures, a transformation in the structure of crop production, in particular, the cultivation of heat-loving rapeseed, corn, and sunflower. These crops, in addition to heat, require a large amount of nutrients that sod-podzolic soils cannot provide. Due to the lack of such substances, as well as organic fertilizers, farmers apply large amounts of mineral fertilizers, pesticides, fungicides, etc. In addition to changing the thermal regime, the distribution of precipitation changed, which has become less frequent, but at the same time has become more voluminous. Land reclamation systems, which have overgrown channels dammed by beavers and lack locks, are unable to timely remove excess water beyond the boundaries of agricultural lands. As a result, the groundwater level rises, which washes away chemical elements from arable land, carries them into the main canals, and then into the Pripyat and the lakes of the valley (Yatsyk et al., 2019);

– increased anthropogenic load due to development and plowing of the river floodplain.

Thus, the transformation of agriculture, including the expansion of certain nutrient-intensive crops, has increased the use of fertilizers and pesticides. It is clear that these facts contribute to the increase in nutrient loads on surface waters within the basin, which explains the relatively poor values of the ecological indices for the tropho-saprobiological component and emphasizes the need for continuous monitoring of surface water quality to maintain ecological stability and optimize water use.

Conclusions

The study results indicate that the water quality of the upper reaches of the Pripyat River at all sampling sites was characterized by stability during 2019–2023, i.e. it corresponded to categories 2 and 3 (“very good”, “good” condition, “clean”, “fairly clean” in degree of pollution), with a trend from 2021 to 2023 towards improving water quality from category 3 to category 2 of the II class of water quality. Among the analyzed substances, the components of tropho-saprobiological indicators had relatively worse values of environmental indices, which is a consequence of the ingress of agricultural runoff into the rivers, insufficiently treated wastewater, and the impact of unregulated discharges from local wastewater treatment facilities.

Obtained results can facilitate the development of strategies to increase the ecological sustainability of the Upper Pripyat River to maintain and further improve the quality of water resources of the entire basin, and the findings can also be used to develop strategies for improving the environmental sustainability of other rivers.

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