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ECOLOGICAL STATUS OF SURFACE WATER IN TERMS OF ENVIRONMENTAL PROTECTION INDICATORS

Abstract: *Current issues related to pollution of aquatic ecosystems necessitate an assessment of the water quality of the Danube River based on environmental protection parameters. This paper analyzes the concentrations of orthophosphate (PO_4–P) and nitrate (NO_3–N) in water, in accordance with the Rulebook on the National List of Environmental Protection Indicators (Official Gazette of RS, No. 37/2011), at the Radujevac monitoring station, which represents the river's exit point from Serbia. The calculated mean annual concentrations of the observed parameters (PO_4–P = 0.129 mg/L and NO_3–N = 0.96 mg/L) correspond to water quality class III and class II, respectively. The ecological status of the Danube River at the Radujevac station is classified as moderate (class III), due to the orthophosphate concentration exceeding the reference value. These results highlight the need for measures aimed at preventing pollution and improving the water quality of the Danube River in the context of environmental protection.*

Keywords: pollution of the Danube, nutrients, ecological status

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INTRODUCTION

Ecological status is an expression of the quality of the structure and functioning of aquatic systems belonging to surface waters, providing an essential basis for evaluating the overall state of the environment. It is a multidimensional concept that encompasses various biological, chemical, and physical parameters that collectively define the health of water ecosystems. This status reflects not only the condition of aquatic ecosystems but also the extent to which they have been affected by anthropogenic activities and natural processes. The Water Framework Directive (WFD, 2000), a cornerstone of EU water management policy, sets specific goals for surface waters, emphasizing the achievement of a high ecological status as a priority. Specifically, the main goal of the WFD is to ensure that water bodies attain class II of ecological status or better, where class II is defined as a state of water quality exhibiting low levels of natural changes, confirming that the environment remains largely intact and in a near-natural state. The Directive emphasizes the prevention of deterioration and enhancement of aquatic ecosystems, aiming to restore and protect the quality of water resources across the European Union (WFD, 2000).

The classification and monitoring of the ecological status of water bodies, in line with the WFD, are based on a range of environmental protection indicators. These indicators serve as a critical tool for assessing the health of aquatic ecosystems, identifying potential environmental stressors, and determining the effectiveness of management measures. The Rulebook (2011), which governs water quality management in Serbia, provides comprehensive guidelines for the classification of environmental protection indicators according to specific thematic units and areas. This document defines the relevant parameters that must be monitored to accurately evaluate the state of the environment, including key indicators for nutrient concentration in surface and groundwater.

In Serbia, the classification and monitoring process for surface waters involves key parameters such as orthophosphate (PO_4–P) and nitrate (NO_3–N) concentrations in rivers, as well as total phosphorus (P) and nitrate (NO_3–N) in lakes and reservoirs. These indicators are essential for understanding the spatial distribution of nutrients and their long-term trends. The concentration of orthophosphate and nitrates is particularly important because excessive nutrient loading, often a result of agricultural runoff, untreated wastewater, and industrial discharge, can lead to eutrophication. This process depletes oxygen levels in water, disrupts aquatic life, and fosters the growth of harmful algal blooms. As a result, these nutrient indicators serve as primary signals of water quality

degradation and are critical in identifying areas at risk of ecological damage. Furthermore, monitoring concentrations of NO_3–N in groundwater is essential to assess the broader implications of nutrient pollution on terrestrial ecosystems and drinking water quality.

The study and monitoring of these indicators provide valuable insights into the spatial variation of nutrient concentrations across Serbia's rivers and lakes, offering data on their temporal fluctuations and long-term trends. Such data are invaluable for detecting potential environmental risks and identifying regions requiring targeted interventions to prevent or mitigate further ecological degradation. Numerous studies have demonstrated that nitrogen and phosphorus are the principal contributors to the pollution of the Danube River and its tributaries. These studies underscore the critical importance of effectively managing nutrient inputs to protect aquatic biodiversity and preserve the ecological integrity of the river system (Mladenović-Ranisavljević et al., 2022; Savic et al., 2022).

In this context, phosphorus is often considered a limiting factor in freshwater ecosystems, as excessive concentrations can significantly alter the composition of aquatic flora and fauna, leading to imbalance and loss of biodiversity. Similarly, nitrogen compounds, particularly nitrates, pose a significant risk to water quality, contributing to both eutrophication and the contamination of water supplies, which has serious public health implications.

Given the importance of these nutrients, their monitoring is integral to sustainable water management, enabling the early detection of pollution trends and providing a scientific basis for policy-making aimed at improving water quality. Furthermore, the data generated from such monitoring efforts are critical in assessing the effectiveness of environmental regulations and identifying regions where additional mitigation measures are necessary.

In this work, the state of the water quality of the Danube River is assessed as a function of nutrients (orthophosphates and nitrates) at the exit point of the river flow from Serbia, monitoring station Radujevac. The selected measuring point, Radujevac, represents a key location at the exit of the Danube River from Serbia, making it highly significant for assessing water quality at the boundary between different ecological regions and geographical influences on the aquatic ecosystem. At this point, the Danube River marks a transition zone between the effects of inland activities and those of cross-border river flows. Therefore, the measurement of nutrient concentrations at this site is crucial. The Danube flows through several countries, exposing it to combined anthropogenic pressures, including industrial pollution, agriculture and urban waste.

At the Radujevac monitoring station, concentrations of nutrients such as nitrates and orthophosphates reflect the cumulative effect of all these activities, which manifests as changes in water quality and potentially threatens aquatic ecosystems.

Monitoring the levels of these nutrients at the exit point from Serbia enables the detection of the spatial distribution of pollution and provides a better understanding of the natural and anthropogenic factors influencing the river.

This is particularly relevant because the Danube, as one of the largest European waterways, connects many ecological regions and acts as a bridge between various aquatic systems and ecosystems. Precise measurement and analysis of nutrient concentrations at Radujevac allow for the detection of changes caused by human activities in real-time and offer insights into the long-term effects of eutrophication, often driven by excessive nitrogen and phosphorus inputs into the water.

Thus, this monitoring station is a critical point in defining the boundaries of ecological regions in the Danube River, as it helps determine whether water exiting Serbia has high or low levels of pollution, providing data that can serve as the basis for further research frameworks in the area of integrated water resource management and the formulation of protection strategies. The monitoring process at Radujevac not only contributes to the qualitative assessment of water quality, but also helps identify key intervention points for improving water quality management across the entire watershed.

METHODOLOGY

For precise classification of the ecological status of water, a classification system was used based on the following categories: very good, good, moderate, poor, and very poor. This classification system is used for an objective assessment of water quality based on physicochemical, biological, and hydromorphological parameters, as well as their interrelations. Each of the mentioned categories corresponds to specific standards, which are aligned with EU directives and regulations, such as the Water Framework Directive (WFD), which sets the basic guidelines for assessing and protecting aquatic ecosystems.

The classification was carried out by comparing the obtained data with the reference values prescribed for each of these categories. These values encompass specific limits for parameters such as nutrient concentrations, temperature changes, biodiversity, oxygen levels, pH, and the presence of pollutants. By considering all analyzed parameters and their interactions, the classification enables a precise determination of the current ecological balance in a given water body, providing insight into its functionality and resilience to various ecological and anthropogenic stressors.

For each category, specific boundary conditions are defined to encompass both chemical and biological aspects of water quality. For example, a very good ecological status is characterized by high biodiversity and minimal deviation from the natural state, while a very poor ecological status indicates serious degradation of the ecosystem, with high pollutant

concentrations, reduced biodiversity, and disrupted ecological balance. These classifications provide essential guidelines for water resource management and help in determining the necessary steps for water protection and restoration.

The classification of the ecological status of water is not based on a single parameter but results from a comprehensive analysis of all significant factors influencing water quality. For instance, high levels of nitrates may indicate eutrophication and a loss of biodiversity, while changes in water temperature can signal the negative effects of global warming. This holistic approach to classification allows for accurate and relevant decisions to be made regarding water protection strategies, and helps identify priority areas for the implementation of ecosystem restoration measures and pollution reduction.

For the purposes of the research, publicly available data from the annual surface and groundwater monitoring report published by the Environmental Protection Agency, Ministry of Agriculture and Environmental Protection of the Republic of Serbia (SEPA, 2024) were used. Based on the monthly measured values of the defined nutrient parameters, the average annual nutrient values were calculated, which, by comparative analysis with the current Regulation on emission limit values of polluting substances in surface and groundwaters and deadlines for their achievement (Regulation, 2012), ecologically classifies the state of the water quality of the Danube.

RESULTS AND DISCUSSION

Based on the monthly measurements conducted and published by the Serbian Environmental Protection Agency (SEPA, 2024), the average annual values of the parameters at the observed measuring station Radujevac in Serbia were calculated. The calculated values of the nutrient indicators were compared with the limit values of the quality classes defined by the Regulation, thus, the corresponding water quality class of the Danube River was determined. This enabled the assessment of the actual water quality at the observed measuring station. The calculated values, together with the prescribed limit values, are presented in Table 1.

Table 1. *Calculated and limit values of the observed parameters*

Parameter		**NO_3–N**	**PO_4–P**
Unit		mg/L	mg/L
Average annual values		0.96	0.129
The prescribed limit values and classification			
Class	I	1	0.02
	II	1	0.02
	III	6	0.2
	IV	15	0.5
	V	>15	>0.5

The average annual value of NO_3–N classifies water quality into class II, while the value of PO_4–P belongs to class III of the ecological status of water quality. Therefore, the overall water quality of the Danube River in terms of environmental protection indicators - nutrients corresponds to class III of the ecological status of water quality at the observed location of Radujevac.

The reasons for the elevated concentrations of NO_3–N and PO_4–P at the Radujevac measuring station, exceeding the prescribed limit values, are primarily linked to the increased nutrient input into the Danube River. A major contributor to this nutrient load is agricultural runoff, which plays a significant role in nutrient pollution of surface waters. The extensive use of chemical fertilizers containing nitrates and phosphorus in agriculture leads to an excess of nutrients that are carried off the land during rainfall events or irrigation. These nutrients, being in soluble forms like NO_3–N and PO_4–P, easily dissolve in water and are transported into nearby rivers. This issue is exacerbated in regions with soil erosion, as it increases the amount of nutrients being washed into water systems. This problem is particularly prominent in intensive agricultural areas, where the continuous application of fertilizers increases nutrient levels in local water systems, contributing to pollution.

In addition to agricultural runoff, municipal wastewater discharge and industrial effluents are significant factors in the pollution of the Danube. In regions with insufficient wastewater treatment capacity, municipal sewage treatment plants may fail to adequately remove nutrients before they are released into the river. With the growth of urbanization, there is an increase in the volume of wastewater, much of which contains nitrates and phosphates from household waste, detergents, and other domestic activities. This problem is especially notable in areas where wastewater treatment infrastructure is outdated or not functioning optimally. Similarly, industrial discharges, particularly from food processing, textile, and chemical manufacturing industries, can contribute to nutrient pollution when wastewater containing phosphorus and nitrogen compounds is released into the water.

The combination of these sources-agricultural runoff, municipal wastewater, and industrial discharges-significantly increases the concentration of nitrates and orthophosphates in the Danube, particularly at the exit point from Serbia. This nutrient pollution, if not addressed, can lead to serious environmental consequences, such as eutrophication, which promotes harmful algal blooms, depletes oxygen levels in water, and disrupts the balance of aquatic ecosystems. It also poses risks to human health, as increased nutrient levels in the water can affect the quality of drinking water and ecosystem services that the river provides to local communities.

Addressing these challenges requires integrated management approaches, such as improving agricultural practices, upgrading wastewater treatment

facilities, and strict regulation of industrial discharges. By reducing nutrient inputs from these key sources, it is possible to mitigate the impact of pollution and improve the ecological status of the Danube River.

CONCLUSION

The ecological status of the Danube River at the Radujevac measuring station was classified as moderate (class III), primarily due to the observed concentration of PO_4–P exceeding the reference values for this category. This classification signals a significant environmental issue, as elevated levels of orthophosphate are a clear indicator of nutrient pollution, which is largely a result of human activities such as agricultural runoff and insufficiently treated wastewater. The presence of excess nutrients, especially phosphates, leads to eutrophication, a process that disrupts the natural balance of aquatic ecosystems, impairs water quality, and may severely affect biodiversity.

The results from this study underline the urgent need for stronger protective measures to prevent further degradation of the water quality in the Danube River. These measures should be implemented not only at the exit point of the river in Serbia but also along its entire stretch through the country. The findings emphasize that the current state of water quality reflects broader issues that must be addressed on a national and regional scale to mitigate the ongoing impact of pollution.

A key recommendation from the research is the alignment of Serbian water management practices with European directives, particularly the Urban Wastewater Treatment Directive (91/271/EEC) and the Nitrates Directive (91/676/EEC). These directives provide guidelines for effectively managing wastewater and controlling nitrate pollution originating from agricultural sources. By ensuring the proper implementation of these directives, Serbia could significantly reduce the entry of harmful nutrients into the river, thereby alleviating the eutrophication problem and improving the overall health of the aquatic environment.

The study further emphasizes the necessity of adopting sustainable water management practices, which encompass both preventive and corrective actions. These include better management of agricultural fertilizers, enhancing the capacity of wastewater treatment plants, and improving monitoring and enforcement of environmental regulations. Adopting principles of Integrated Water Resources Management (IWRM, 2000) would help ensure a holistic approach, addressing all factors affecting the water quality, and promoting long-term sustainable solutions.

The adoption of these measures would not only contribute to improving the ecological status of the Danube River, but also ensure its continued ability to deliver essential ecosystem services. These services include providing a habitat for diverse species, serving as a source of freshwater for human consumption, supporting agriculture, and maintaining recreational areas. In doing so, it would help maintain the ecological integrity of the river, which is critical for the well-being of both local populations and the broader environment.

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