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Environmental impacts of dredging operations on the condition of surface waters of the Danube River

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SUMMARY

The conducted analysis allowed determination of the main factors influencing the quality of surface waters in the estuarine part of the Danube River. The hypothesis regarding the absence of environmental threats from dredging operations conducted by Ukraine in the Bystre estuary of the Kiliya marine delta of the Danube was confirmed. It has been proven that as a consequence of water management measures implemented by Romania, the annual average discharges of the Tulcea branch and Sulina estuary increased, while the water discharge of the Kiliya branch significantly decreased. The consequence was a significant deterioration of ecological conditions in the Ukrainian Danube region, manifested by an increase in the content of biogenic elements and periodic decreases in oxygen content. In contrast, with the start of dredging operations and increased water discharge through the Bystre estuary, the dissolved oxygen content became stable while the BOD5 level decreased (below MPC), indicating improved water quality. Although simultaneously, navigation activity through the estuary increased significantly, and the ammonium ion level significantly increased. The year 2024 became critical for the dissolved oxygen level, when the phosphate ion content significantly increased, despite the fact that the ammonium ion content decreased to the 2019 level. Thus, the analysis results confirm the conclusion that the decisive factor affecting water quality in the Danube River is not navigation. Therefore, there is a need for further research regarding the impact of other pollutants and their sources, beyond those analyzed, on the condition of the Danube River surface waters.

Introduction

River ecosystems play a key role in the natural environment, as they provide fresh water, contribute to biodiversity conservation, and participate in natural self-purification processes. The Danube is one of Europe's largest rivers, flowing through numerous countries, supplying water resources to a large population, and playing a significant role in supporting many economic and ecological processes. Therefore, the estuarine areas of the Danube River deserve special attention in the context of finding opportunities to reduce anthropogenic pressure on them.

Method and Theory

In the analysis, general-scientific methods (analysis and synthesis, induction and deduction) and special methods of phenomena and processes analysis (abstraction, econometric and econometric-mathematical modelling) have been used.

Results

To assess the impact of anthropogenic pressure, including intensified navigation and war on the condition of surface waters in the Danube River, an analysis of water quality indicators was conducted for the monitoring station: Danube River, 163 km, Reni city, border with Romania (45°46′72″ N, 28°22′95″ E). This analysis was based on data from the Water Monitoring Laboratory of the Basin Management of Rivers of the Black Sea Region and Lower Danube. The study examined the following indicators: biochemical oxygen demand over 5 days (BOD5), dissolved oxygen, phosphate ions, and ammonium ions. They were compared with the MPC (Order, 2022).

The BOD5 indicator, as is known, indicates the presence of organic pollution in the water body. Microorganisms in the water utilize organic substances while consuming oxygen. Thus, during the oxidation and decomposition of these substances, the BOD5 value should decrease. It is well established that biological processes intensify during the summer period, thus increasing oxygen demand, which causes the dissolved oxygen indicator to decrease and BOD5 to increase. As we can see, during 2004-2019, periodic exceedances of the BOD5 indicator beyond the standard, which is 3.0 mg/dm³, were observed. This was not limited to the summer period (Fig.1). For example, during the winters of 2008-2009 and 2009-2010, the BOD5 indicator increased, including above the normative value. However, the overall situation somewhat improved from 2013. This indicates that the quantity of organic pollutants in the Danube water decreased. Further improvement occurred from 2020: exceedances of the BOD5 indicator above the standard became practically nonexistent, coinciding with a rather high and stable level of dissolved oxygen.Incidentally, regarding the dissolved oxygen content indicator, throughout the entire study period, no maximum permissible concentration (MPC) violations were observed: the level remained above 4.0 mg/dm³ in any season. This indicates that a sufficient amount of oxygen entered the Danube River surface waters from the atmosphere, saturating the water with dissolved oxygen to compensate for oxygen losses during the decomposition of organic substances in the water.

As we can see, throughout the study period, MPC exceedances for phosphate ions were observed only on February 12, 2024, but the general content level also increased significantly to 3.0 and overall became higher in 2024 (Fig. 2). There is a need to identify the causes of such an increase. The main sources of phosphate ions in surface waters, as is known, are anthropogenic pressures: untreated or insufficiently treated wastewater from municipal, industrial, and agricultural enterprises, the use of detergents, surface runoff from agricultural lands, and others. For these, the MPC is 3.5 mg/dm³. Ammonium ions can enter surface waters through surface runoff from agricultural lands (residues of applied fertilizers), as part of industrial wastewater, and as a result of pollution from livestock farms. The MPC for ammonium ions in surface waters is 0.5-1.0 mg/dm³.

As we can observe, regarding the ammonium ion level during 2004-2013, its level was close to the MPC, with periodic exceedances. The situation changed during 2013-2019, when the content in the

Danube River surface waters significantly decreased. Substantial deterioration began at the end of 2019, when MPC exceedances were recorded almost constantly. The ammonium ion content in the Danube River water significantly decreased in 2024.

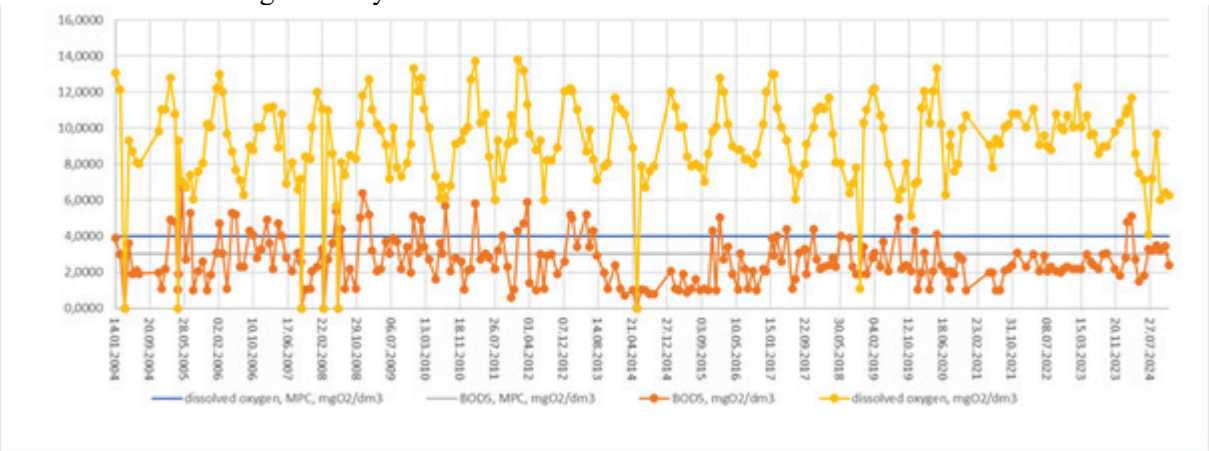

Figure 1 *Dynamics of biochemical oxygen demand over 5 days (BOD5) and dissolved oxygen from 2004 to 2024.*

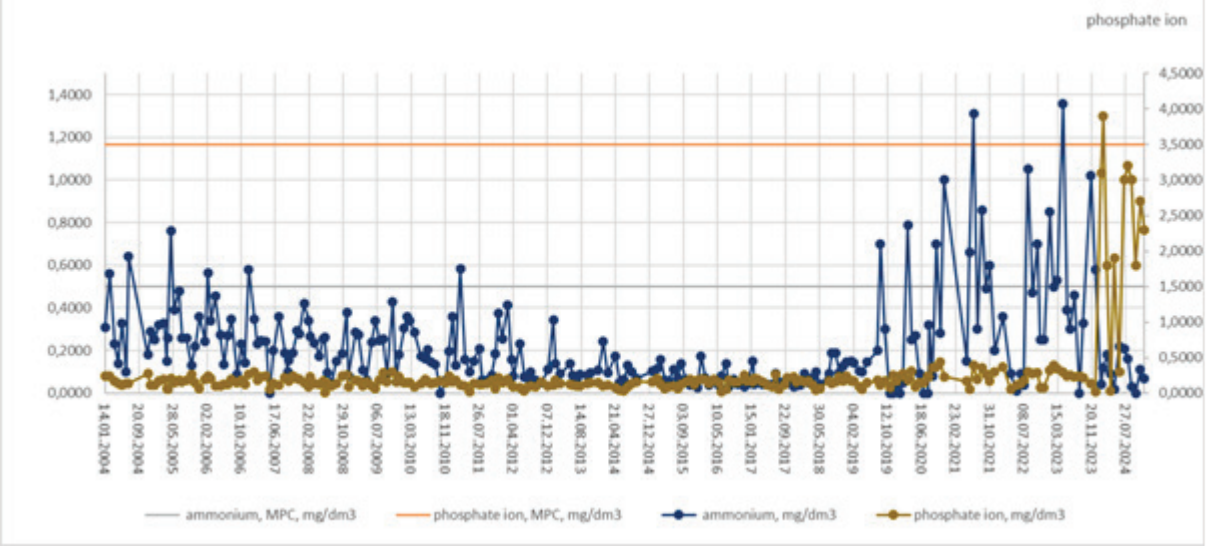

Figure 2 *Dynamics of phosphate and ammonium ion concentrations from 2004 to 2024.*

Increased phosphate and ammonium ion content in the Danube River surface waters can lead to increased algal biomass, which in turn can stimulate two processes. On one hand, this increases oxygen production. On the other hand, due to their biochemical decomposition in water (especially during the summer period), surface water eutrophication can be observed.

The cardinal changes and differences in trends regarding phosphate and ammonium ion content since 2020 can be explained by a decrease in ammonia supply and, consequently, its application as fertilizer. The significant change in ammonium ion content in 2024 may indicate the further substitution of ammonium fertilizers with phosphate-based (non-ammonium type) fertilizers, particularly superphosphates, specifically due to military actions, including intensified shelling of the port of Reni in 2024. Extraordinary situations caused by superphosphate emissions are also not excluded. However, this assumption requires additional research.

In our opinion, one of the reasons for changes in phosphate and ammonium ion content in the Danube River surface waters is navigation. Therefore, we analyzed the dynamics of cargo turnover in countries that use the Danube River for navigation during 2014-2024. During 2014-2019, this volume remained at a practically unchanged level. Romania was always the leader, increasing transportation

volumes from 2020. Serbia and Bulgaria also significantly increased their transportation volumes on the Danube. Ukraine, during 2014-2019, had a cargo turnover level that remained practically unchanged, which began to decrease in 2020-2021. The reason for this, as is known, was a significant decrease in depths at the Bystre estuary, which made its use impossible. Instead, transportation volumes through the Romanian Sulina Canal increased. With the beginning of the war and the blockade of the Greater Odesa ports, the importance of the Danube ports of Reni, Izmail, and Ust-Dunaisk increased for Ukraine. Comparing the trends in cargo turnover changes at Danube ports with the content of phosphate and ammonium ions in the Danube River surface waters gives grounds to conclude that it was due to the increased volume of transportation on the Danube that their content in surface waters increased. And the main polluter, as the analysis showed, was not Ukraine, but countries with ports upstream of the Danube River.

Certain changes in the situation regarding water quality in the Danube River occurred in 2024. On one hand, the phosphate ion content in surface waters increased; on the other hand, the ammonium ion content significantly decreased. At the same time, in 2024, the dissolved oxygen content somewhat decreased (compared to 2023) not only in summer but also in winter. Simultaneously, BOD5 indicators increased to the MPC level. Until 2020, BOD5 almost constantly exceeded the MPC, with an improvement in the situation observed during 2020-2023. Thus, in 2024, a return to negative trends was observed. As we can see, the increase in ammonium ions in the Danube River surface waters had a lesser negative impact on the quality of the Danube River surface waters than the increase in phosphate ion content (which occurred in 2024). These phenomena indicate that in the Danube River (port of Reni), self-purification processes were ensured to a certain extent during 2021-2023, despite the increase in ammonium ion content. At the same time, the increased level of phosphate ion pollution negatively affected water quality, deteriorating self-purification mechanisms.

Figure 3 presents the results of modeling the impact of navigation on the Danube River on the levels of phosphate and ammonium ions in surface waters. To forecast expected trends, the average annual concentrations of phosphate and ammonium ions in the water (arithmetic mean) were determined. Naturally, this approach smooths out seasonal variations in concentration levels; however, the corresponding cargo turnover values were also taken as annual averages. These values also exhibit seasonal fluctuations, which were similarly not considered. Therefore, the obtained values are comparable. As we can see, these dependencies can be described using a linear trend line for ammonium ions and a second-degree polynomial for phosphate ions. Forecast estimates, made based on data from 2014-2023, indicate that there are all grounds to expect a decrease in ammonium ion content. Regarding phosphate ions, the negative quadratic dependence allows us to expect a slowdown in the increase of phosphate ion content.

The obtained results indicate that navigation is not the only important factor affecting the pollution level of the Danube's surface waters, since, for example, in 2022-2023, when navigation significantly increased, the phosphate ion content remained at the 2020 level, and ammonium ions actually decreased. Furthermore, it cannot be considered that the intensification of navigation in Ukraine significantly affected the pollution level, since the maximum pollution by phosphate ions was present precisely in 2020, when cargo transportation through the Ukrainian ports of Reni, Izmail, and Ust-Dunaisk had not yet been restored. As mentioned above, this only occurred in 2022-2024 thanks to dredging operations in the Bystre estuary. Thus, as we can see, besides navigation, there are other anthropogenic pressures, discussed above, that cause pollution of the Danube's surface waters. Additionally, it should be considered that pollutants are located not only on Ukrainian territory, and the impact is more noticeable due to pollutants moving downstream, with the greatest impact being felt precisely in the Ukrainian waters of the Danube.

Figure 4 presents the results of modeling the impact of navigation on the Danube River on the levels of dissolved oxygen and BOD5 in the surface waters of the Danube (Reni city). As in the previous

case, to forecast expected trends, the average annual values of dissolved oxygen and BOD5 were determined for the period from 2014 to 2023. As we can see, these dependencies can be described using a linear trend line for dissolved oxygen and a second-degree polynomial for BOD5. Forecast estimates, made based on data from 2014-2023, indicate that there are all grounds to expect an increase in dissolved oxygen in the Danube River surface waters. Regarding BOD5, the quadratic dependence allows us to expect fluctuations in the BOD5 level. Regarding forecasts of dissolved oxygen levels, they are quite positive unlike the BOD5 level, as fluctuations are expected around the MPC value with possible exceedance.

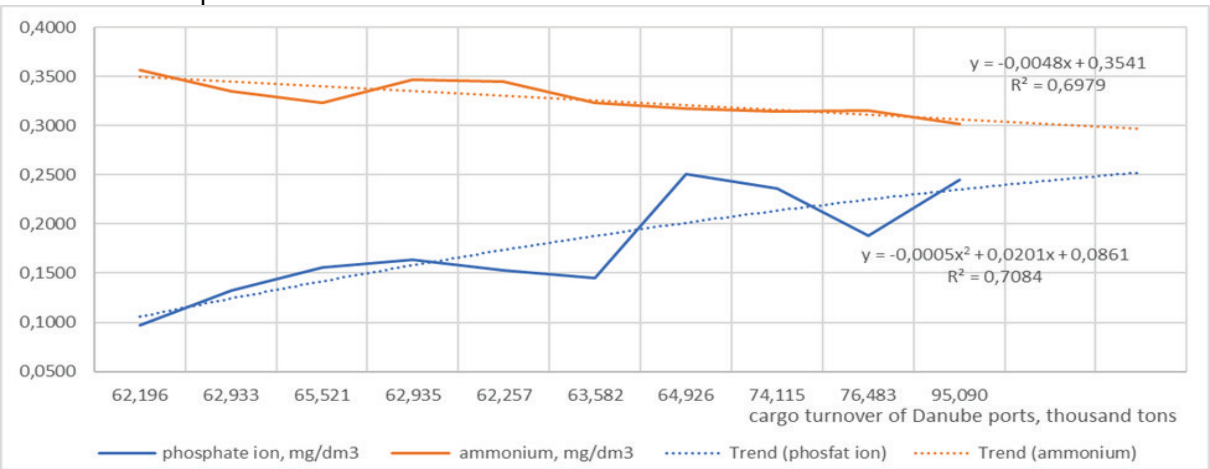

Figure 3 *Interdependence between phosphate and ammonium ion content in the Danube River (Reni) and cargo turnover of Danube ports from 2014 to 2023.*

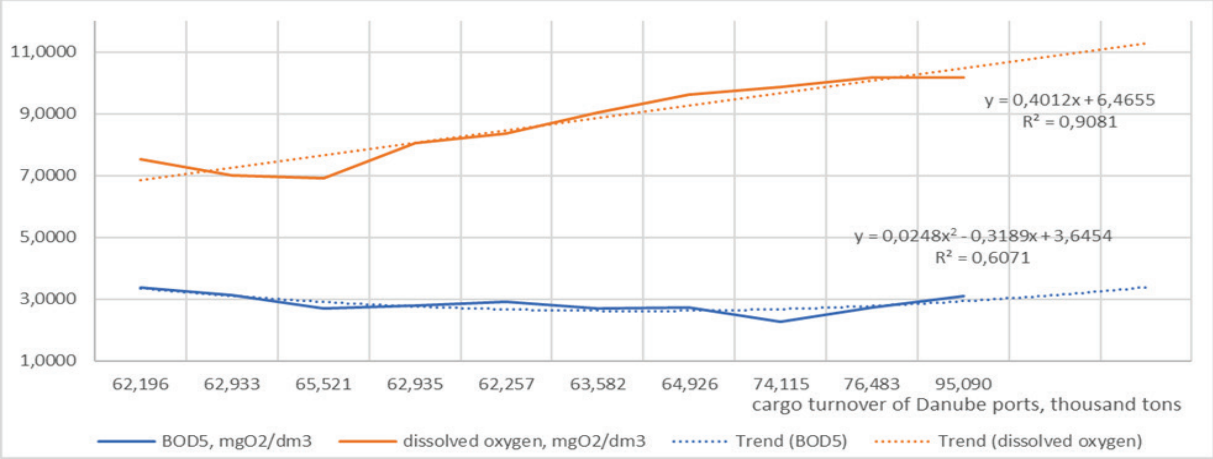

Figure 4 *Interdependence between dissolved oxygen content and BOD5 in the Danube River (Reni) and cargo turnover of Danube ports from 2014 to 2023.*

Conclusions

Thus, the analysis results confirm the conclusion that the decisive factor affecting water quality in the Danube River is not navigation. Therefore, there is a need for further research regarding the impact of other pollutants and their sources, beyond those analyzed, on the condition of the Danube River surface waters.

References

On approval of Hygienic Standards for Water Quality of Water Bodies to Meet Drinking, Household and Other Needs of the Population: Order of the Ministry of Health of Ukraine dated 02.05.2022 No. 721. https://zakon.rada.gov.ua/laws/show/z0524-22#Text