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ASSESSMENT OF SURFACE WATER QUALITY IN THE SFÂNTU GHEORGHE BRANCH OF THE DANUBE DELTA

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Abstract

The aquatic ecosystems of the Danube Delta are highly vulnerable to ecological pressures caused by natural and anthropogenic factors. This study investigates the surface water quality along the Sfântu Gheorghe Branch, (km 85-km 15), including control sections such as Mahmudia Meander, Uzlina Lake, Isac Lake, Dunavăț Meander, Dranov Meander, and Ivancea Meander. Surface water samples were collected from 58 locations during spring and autumn (May and September 2024). Physico-chemical parameters were measured in situ using the multiparameter EXO2 probe. Key indicators assessed included water temperature, pH, dissolved oxygen, chlorophyll "a", conductivity, total dissolved solids, salinity, turbidity, and redox potential (ORP). The results revealed generally stable seasonal and spatial trends, with most parameters falling within Class I and II water quality categories, as defined by Romanian Order 161/2006. Noteworthy findings include well-oxygenated waters (>5 mg/L DO), low chlorophyll "a", concentrations (<25 µg/L), and stable pH values, all indicative of good to very good ecological status. Variations in turbidity and ORP were primarily localized and attributed to sediment resuspension or flow dynamics. Overall, the findings suggest that the monitored sections of the Sfântu Gheorghe Branch maintain resilient freshwater conditions, with limited signs of ecological degradation.

***Key words**: chlorophyll a, Danube Delta, ecological status, nutrient input, physico-chemical indicators, seasonal variation, Sfântu Gheorghe Branch, surface water quality.*

INTRODUCTION

Aquatic ecosystems are characterized by remarkable diversity, shaped by both the concentration of dissolved salts (freshwater vs. brackish water) and the dynamic movement of water masses (Chapman, 1996). In the predeltaic region of the Black Sea, brackish waters cover approximately 100,000 hectares, supplemented by the expansive Razelm-Sinoe lagoon complex, which spans 1,015 km². This system falls into the oligo-mixohaline category, with salinity levels ranging between 0.50 and 6.00 g/L (Coteț, 1960; Almazov et al., 1963; Bondar & Panin, 2000; Cazacu & Adamescu, 2017). Despite this, freshwater ecosystems are predominant within the Danube Delta's aquatic environment (Chiriac & Udrescu, 1965; Kirschner et al., 2009).

The rheophilic ecosystems of the Danube Delta encompass the river's main branches and a secondary network of channels. These watercourses vary in flow permanence and intensity - from channels with a continuous, column-wide current to shallow gullies where flow is weak and generally restricted to near-bottom layers, becoming more pronounced during floods (Driga, 2004; Gâştescu & Ştiucă, 2008). Compared to the main river channel, the Danube branches exhibit distinct ecological characteristics due to biotopic variations such as reduced depth and current velocity, greater isolation from adjacent land, consolidated alluvial banks, and differences in nutrient concentrations and turbidity levels (Gâştescu, 2009).

At the apex of the deltaic triangle, the Danube splits into two main branches: the Chilia to the north and the Tulcea to the east. Seventeen kilometers downstream from Izmail Ceatal, the Tulcea Branch divides again at Sfântu Gheorghe Ceatal into the Sulina Branch (continuing eastward) and the Sfântu Gheorghe Branch (turning southward) (Panin & Jipa, 2002; Romanescu, 2013). Each branch has unique morphological and hydrological features. Water discharge is unevenly distributed: 58% flows through the Chilia

Branch, 22% through the Sulina, and 20% through the Sf. Gheorghe (Panin, 2003; Driga, 2004; Sommerwerk et al., 2022). Sediment transport also varies significantly, with the Chilia Arm carrying about 66% of the annual alluvium load (80,000-300,000 tons), followed by the Sulina (14%) and Sfântu Gheorghe (20%) Arms, with considerable interannual variability (Tiron Duţu, 2014; Syeed et al., 2023).

The Sfântu Gheorghe Arm, due to its substantial solid discharge, experiences significant sediment accumulation, resulting in higher banks compared to the other branches. Unlike the Chilia Arm, neither the Sulina nor the Sf. Gheorghe Arms form internal deltas, though they feature sinuous courses with multiple meanders. This is particularly true for the Sf. Gheorghe Arm, which originally extended 109 km with a high meandering coefficient (2.35). Before discharging into the Black Sea, it forms a secondary delta (Sfântu Gheorghe Secondary Delta II). Rectification efforts carried out between 1985 and 1990 eliminated six meanders, reducing the arm's length to approximately 70 km. While these modifications improved navigability, they significantly impacted flow distribution among the Danube's branches (Habersack, 2016; Oaie, 2015; Madhav et al., 2020; Duțu, 2023).

This study aims to evaluate the overall surface water quality along the Sf. Gheorghe Arm by analysing the spatial distribution and variability of key environmental indicators across several control sections. Specifically, the research investigates water quality along a longitudinal gradient from upstream (km 85) to downstream (km 15) on the Sf. Gheorghe Arm.

Relevance and impact of the study

This research provides a comprehensive assessment of water quality using advanced analytical techniques, enabling immediate and accurate measurement of multiple physicochemical parameters. Such an approach offers valuable insights into the spatial variability of essential water quality indicators.

The findings significantly enhance our understanding of both anthropogenic influences and natural dynamics affecting aquatic ecosystems within the Danube Delta. The study holds substantial environmental relevance by supplying critical data for ecosystem monitoring, resource management, and policy decision-making. Ultimately, it not only advances scientific knowledge but also supports practical, sustainable strategies for the conservation and management of one of Europe's most important wetland ecosystems.

MATERIALS AND METHODS

Study area

The study was conducted in the Danube Delta, a vast wetland system covering approximately 5,600 km², which serves as the primary source of freshwater and sediment input to the Black Sea via its three main distributary branches: Chilia, Sulina, and Sfântu Gheorghe (Botnariuc, 1985). The Sfântu Gheorghe Branch, the southernmost of these, originates at the Ceatal Sfântu Gheorghe bifurcation and flows approximately 108 km before discharging into the Black Sea. This branch conveys about 23-24% of the Danube's total water discharge and approximately 21% of the suspended sediment load (Bondar & Panin, 2000; 2001). It is characterized by a pronounced morphological dynamic, having a sinuous course with active, migratory meanders (Popa, 1997; Jugaru et al., 2006; Tiron, 2010; Tiron Duțu et al., 2014), as well as a rapid evolution of the mouth, manifested by the progradation of the deltaic lobe and significant displacements of the Sakhalin barrier island throughout the 20th century (Panin, 2003). The width of the Sf. Gheorghe arm varies between 150 and 550 m, and the water depth is between 3 and 27 m compared to the local low water level (Bondar & Panin, 2000). The banks of this arm are covered by dense and continuous vegetation, consisting of poplars, trees and reed communities. During the period 1984-1988, significant anthropogenic interventions were carried out to facilitate navigation. Six natural meanders were artificially cut, reducing the total length of the arm from 108 km to approximately 70 km. The newly created navigable channels were initially 7-8 m deep and 75-100 m wide (Popa, 1997). These hydrotechnical works caused substantial changes in the local dynamics of water and sediments, increasing water flows and sediment flux through the Sf. Gheorghe arm and influencing sedimentary processes at the level of the entire deltaic system (Ichim & Rădoane, 1986; Popa, 1997; Panin & Jipa, 2002; Panin, 2003; Tiron, 2010). During the same period, earthen dams, with heights of approximately 2-3 m, were built along the banks.

Methodology

To evaluate the overall condition of surface water quality, the study investigated the longitudinal distribution of key environmental indicators along a gradient from upstream to downstream. Sampling was conducted at multiple control points located across the Sfântu Gheorghe Branch, including rectified meanders, natural channels, and adjacent lakes, covering the river stretch between kilometer 85 and kilometer 15.

Notable locations included Mahmudia Meander, Uzlina Lake, Isacova Lake, Dunavăț Meander, Dranov Meander, and Ivancea Meander. Surface water samples were collected at 58 sites during two separate field campaigns in May and September 2024, as shown in Figure 1, which maps the spatial distribution of sampling points. Several sampling points were strategically positioned in zones where water and sediment are redistributed from the main branch to the secondary network of channels, smaller distributaries, and adjacent floodplain depressions (such as lakes and temporary shallow ponds).

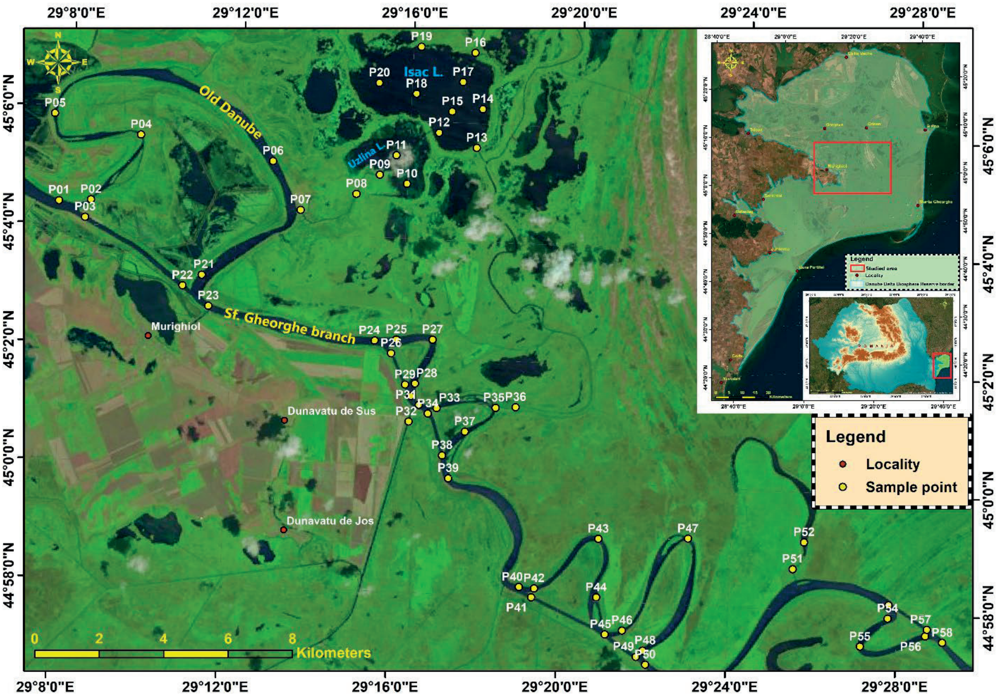

Figure 1. Sampling stations from the Sf. Gheorghe Arm

The general characterization of surface water quality was conducted through *in situ* measurements of various physico-chemical parameters using the EXO2 multiparameter probe (YSI, USA) (Figure 2).

This device is equipped with advanced sensors that utilize physical, optical, and electrochemical detection methods to measure a wide range of water quality indicators (Lipps et al., 2023).

Figure 2. Multiparameter probe, model EX02

The recorded parameters include: temperature (°C), pH (pH units), turbidity (FNU), total dissolved solids (TDS, mg/L), conductivity (µS/cm), dissolved oxygen (ODO, mg/L), oxygen saturation (ODO, %), oxidation-reduction potential (ORP, mV), salinity (PSU), nitrate (NitraLED, mg/L), chlorophyll-a (RFU), and total algal content (TAL–PC, RFU).

Water quality classification was primarily based on the criteria set out in Order No. 161/2006, which defines five quality classes: Class I (very good), Class II (good), Class III (moderate), Class IV (poor), and Class V (bad). For a more comprehensive evaluation, both national standards (Order No. 161/2006 regarding reference objectives for surface water quality classification) and international standards, particularly the European Water Framework Directive (WFD 2000/60/EC), were applied. The WFD provides a unified framework for the qualitative and quantitative management of water resources and the preservation of aquatic ecosystem health across member states.

All physicochemical analyses followed internationally recognized methodologies and standard procedures. These included: SR EN ISO 5667-1:2023 for water sampling; SR EN ISO 10523:2012 for pH determination; and SR EN ISO 5814:2013 for measuring dissolved oxygen concentrations.

Statistical analysis

Statistical analyses were conducted using xlSTAT version 7.5.2 software (Addinsoft, 2020) and PAST version 4 (https://past.en.lo4d.com/download). To examine the relationships between physicochemical parameters, Pearson correlation analysis was applied. This method was chosen to identify the strength and direction of linear associations among the measured variables.

All analyses were performed on data sets obtained from the two sampling campaigns (May and September 2024), with significance levels set at $p < 0.05$ unless otherwise specified.

RESULTS AND DISCUSSIONS

The lotic ecosystems formed by the Danube and its deltaic network fall within the Pontic Ecoregion (Ecoregion 12), as defined in Annex XI of the European Union Water Framework Directive (EU-WFD, 2000).

According to the Synthesis of the Draft Management Plans for River Basin Districts (2022), a total of 19 natural watercourse types has been identified within the Danube and Danube Delta regions. The areas investigated in this study fall within the classification RO15 – Danube River (Isaccea) to Danube Delta.

The results presented in this study provide valuable input for enhancing current water quality databases and contribute to fulfilling the data requirements outlined in the EU-WFD. By integrating multiple data sources and conducting high-resolution, in situ analyses, this study enables a more detailed and spatially explicit assessment of water quality conditions across the Sfântu Gheorghe Branch. In line with the objectives of the EU-WFD, which mandates all member states to ensure that rivers, lakes, groundwater, estuaries, and coastal waters reach at least "good" ecological status by 2027, this research offers insight into the current state of surface water in a critical section of the Danube Delta.

Physico-chemical parameters of surface water

Table 1 summarizes the physicochemical properties of surface water - minimum, maximum, and mean values (± standard deviation) - recorded at control points during the May and September 2024 campaigns. Measurements along the Sfântu Gheorghe Branch (km 85 to km 15) showed typical seasonal and spatial variations, with no major anomalies, though some local deviations were noted.

Water temperature (°C). Water temperature followed seasonal trends and was strongly influenced by air temperature fluctuations typical of the spring and early autumn periods (AccuWeather, 2024). In May, values ranged from 16.31 to 20.30°C with a mean of 18.50 ± 0.70°C, remaining within the expected seasonal variation for the region. The lowest temperature was recorded at station P36 (Gârla Perivolovca), while the highest occurred at station P19 (Isacova Lake). In September, temperatures increased notably, ranging from 23.82 to 29.98°C with an average of 25.90 ± 0.98°C. The coolest site was station P20, while the warmest was station P27 (Figure 3).

Table 1. A synopsis of the physico-chemical parameters of water surface samples from Sf. Gheorghe Arm in May and September 2024

May			
Parameter	**Min.**	**Max.**	**Mean ± SD**
Temperature (°C)	16.31	20.30	18.50±0.70
pH	8.06	9.42	8.58±0.21
Turbidity (FNU)	0.18	57.55	10.91±10.27
Total Dissolved Solids (TDS mg/L)	182.36	290.38	246.02±17.49
Conductivity (µS/cm)	254.11	382.14	331.19±19.75
Dissolved Oxygen (ODO mg/L)	6.82	14.81	10.67±1.20
Oxygen Saturation (ODO % sat)	69.66	163.92	114.09±14.29
Oxidation-Reduction Potential (ORP mV)	1.74	100.96	41.04±20.79
Salinity (PSU)	0.13	0.22	0.18±0.01
Nitrate (NitraLED mg/L)	0.01	16.28	1.49±2.24
Chlorophyll (RFU)	0.26	8.57	3.93±2.06
Total Algal Content (TAL - PC RFU)	0.05	1.83	0.70±0.41

September			
Parameter	**Min.**	**Max.**	**Mean ± SD**
Temperature (°C)	23.82	29.98	25.90±0.98
pH	7.88	8.83	8.19±0.24
Turbidity (FNU)	2.58	53.86	10.17±9.34
Total Dissolved Solids (TDS mg/L)	228.91	277.73	242.13±6.54
Conductivity (µS/cm)	354.47	419.31	378.83±11.97
Dissolved Oxygen (ODO mg/L)	3.44	14.57	7.84±2.05
Oxygen Saturation (ODO % sat)	40.97	178.84	96.55±25.15
Oxidation-Reduction Potential (ORP mV)	14.60	66.09	48.70±12.18
Salinity (PSU)	0.17	0.21	0.18±0.01
Nitrate (NitraLED mg/L)	0.04	9.34	1.70±1.87
Chlorophyll (RFU)	0.27	12.65	2.55±3.78
Total Algal Content (TAL - PC RFU)	0.01	14.62	2.13±3.85

Water pH (pH units). pH levels across the study area generally conformed to acceptable limits for freshwater ecosystems (6.5-8.5 pH units, Order 161/2006), although slight alkalinity was observed at several stations. In May, pH ranged between 8.06 and 9.42 (mean 8.58 ± 0.21), with values exceeding the upper guideline limit at station P16 (Isacova Lake). The lowest value was recorded at P36 (Gârla Perivolovca). In September, pH ranged from 7.88 to 8.83 (mean 8.19 ± 0.24), remaining mostly within the regulatory threshold. Elevated values were observed at P12, while P35 showed the lowest pH (Figure 4).

Turbidity (NTU). The turbidity values measured in the water samples from the control sections showed variations within the normal limits for surface waters (1-1000 NTU) (Chapman, 1996). In May, turbidity values varied widely between 0.18 and 61.61 NTU, with an average of 11.42 NTU. In September, turbidity varied between 2.58 and 53.86 NTU, with an average of 10.17 NTU. The lowest turbidity in May was recorded at station P20 (Isacova Lake), while in September, the lowest was at station P22. The highest turbidity in May occurred at station P42 (M. Dranov – bifurcation – rectified mead), while in September, the highest was measured at station P24. Remarkably, some samples showed higher turbidity levels compared to the values provided by SR ISO 5667-5:2017 (5 NTU – permitted, 10 NTU – exceptionally permitted), indicating a localized deterioration of water quality. In general, increased turbidity is due to Danube River inflows, which carry dissolved and suspended organic and inorganic materials through secondary necks and internal channels (Figure 5).

Total dissolved solids (TDS, mg/L). TDS concentrations, representing the sum of dissolved organic and inorganic substances, were well within freshwater standards (<1000 mg/L) (Lehr, 1980; De Zuane, 1997). In May, values ranged from 182.36 to 290.38 mg/L (mean: 246.02 ± 17.49 mg/L), and in

September from 228.91 to 277.73 mg/L (mean: 242.13 ± 6.54 mg/L). The lowest concentrations were recorded at P16 (May) and P14 (September), while the highest occurred at P52 (Erenciuc Lake) in May and P36 in September (Figure 6).

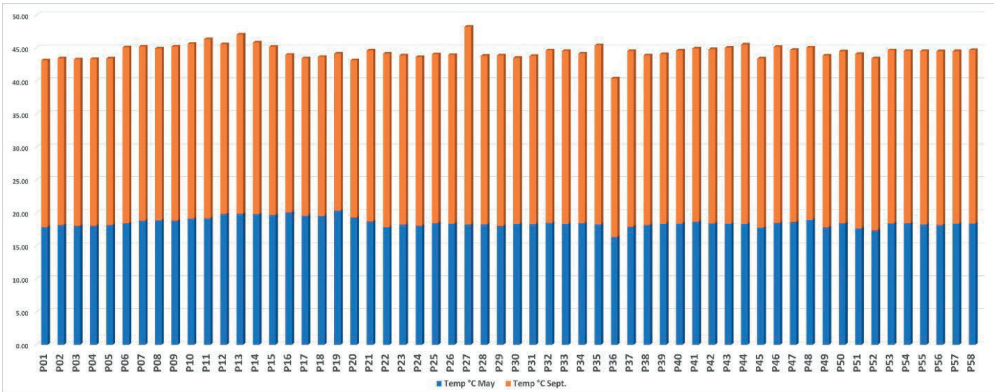

Figure 3. Evolution of the Temperature indicator in the investigated surface water samples

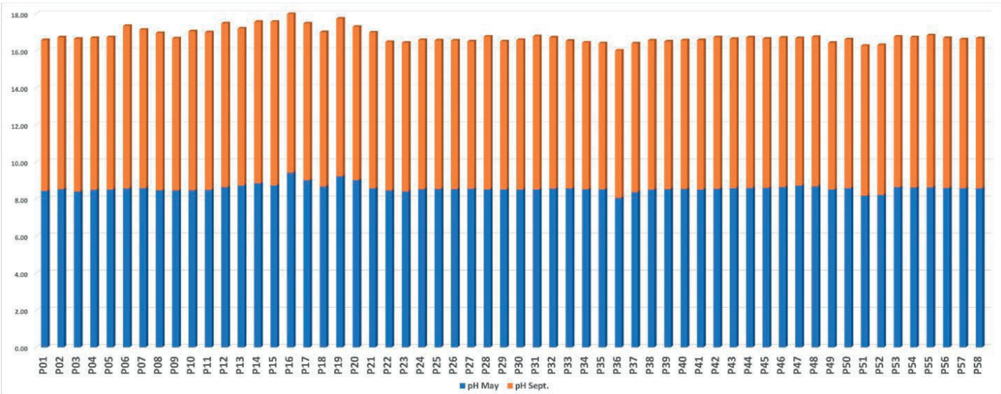

Figure 4. Evolution of the pH indicator in the investigated surface water samples

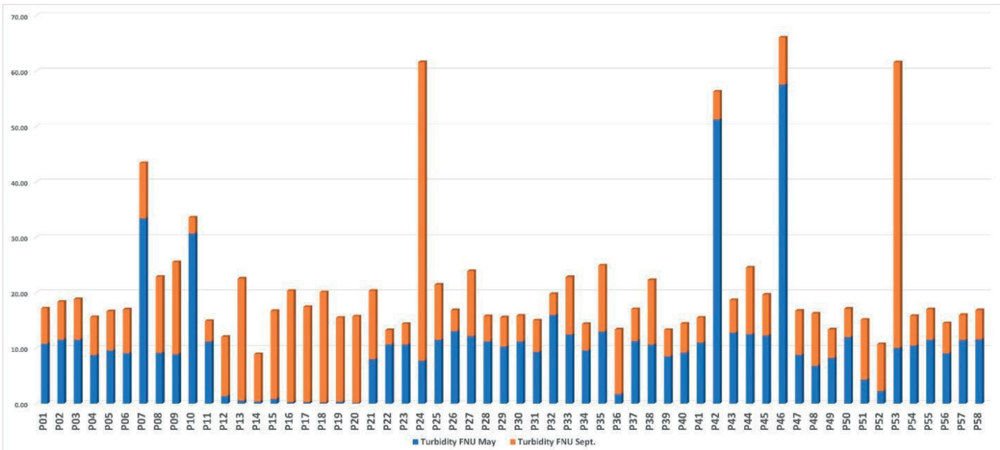

Figure 5. Evolution of the Turbidity FNU indicator in the investigated surface water

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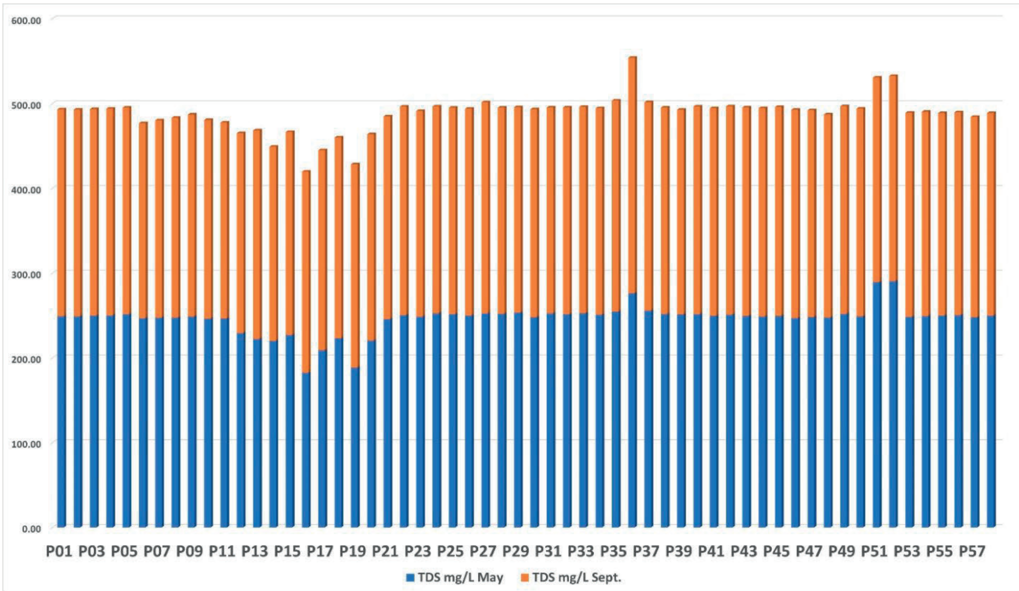

Figure 6. Evolution of the TDS mg/L indicator in the investigated surface water samples

Electrical conductivity (µS/cm). All measured conductivity values classified the water samples in quality class I (≤500 µS/cm, Order 161/2006). In May, conductivity values ranged from 254.11 to 382.14 µS/cm (mean: 331.19 ± 19.75 µS/cm), increasing slightly in September, with values between 354.47 and 419.30 µS/cm (mean: 378.83 ± 11.97 µS/cm). The highest readings were recorded at P51 (May) and P36 (September) (Figure 7).

Dissolved Oxygen (mg/L). Dissolved oxygen concentrations indicate that all water samples tested fall into the well-oxygenated surface water category (quality class I, ≥9 mg/L, Order 161/2006), with all values exceeding the recommended minimum level of 5 mg/L required to support aquatic life (www.niwa.co.nz). Dissolved oxygen varied significantly in May, from 6.82 to 14.81 mg/L, with an average of 10.67 mg/L. In September, values ranged from 3.44 to 14.57 mg/L, with an average of 7.84 mg/L. The lowest values in both May and September were recorded at station P36 (Gârla Perivolovca), while the highest concentrations were observed at station P19 (Isacova Lake) in May and at station P12 in September (Figure 8).

Oxidation-Reduction Potential (ORP, mV). ORP values serve as an indicator of the oxidation state of the water body and its potential to support aerobic processes. In both sampling periods, values fell within the typical range for natural waters (–500 to +700 mV) (Chapman, 1996; Sigg, 2000), suggesting stable redox conditions. In May, ORP values ranged from 1.74 to 100.96 mV (mean: 41.04 ± 20.79 mV), while in September, values ranged from 14.60 to 66.09 mV (mean: 48.70 ± 12.18 mV). The lowest ORP was observed at P19 (Isacova Lake) in May and at P55 in September. The highest values were recorded at P58 (Ivancea Meander – confluence) in May and P35 in September (Figure 9).

Salinity (‰). Salinity levels remained low and consistent throughout the monitoring period, reflecting the freshwater character of the Danube Delta system. All values were well below the 0.5 PSU threshold commonly used to define freshwater ecosystems (Montagna et al., 2013). In May, salinity ranged from 0.13 to 0.22 PSU (mean: 0.18 ± 0.01 PSU), and in September, from 0.17 to 0.21 PSU (mean: 0.18 ± 0.01 PSU), confirming minimal marine influence and dominance of fluvial inputs.

Distribution of nitrate concentrations. Nitrate concentrations (NitraLED, mg/L) showed significant spatial variability between measurement stations. In May, values ranged from 0.01 to 16.28 mg/L (mean: 1.49 ± 2.24 mg/L), with the highest value at P42

(Dranov – bifurcation) and the lowest at P54. In September, concentrations ranged from 0.04 to 9.34 mg/L (mean: 1.70 ± 1.87 mg/L), peaking at P24 and reaching a minimum at P12 (Figure 10). While most values remained within acceptable ecological thresholds, elevated readings at isolated sites may indicate localized nutrient enrichment.

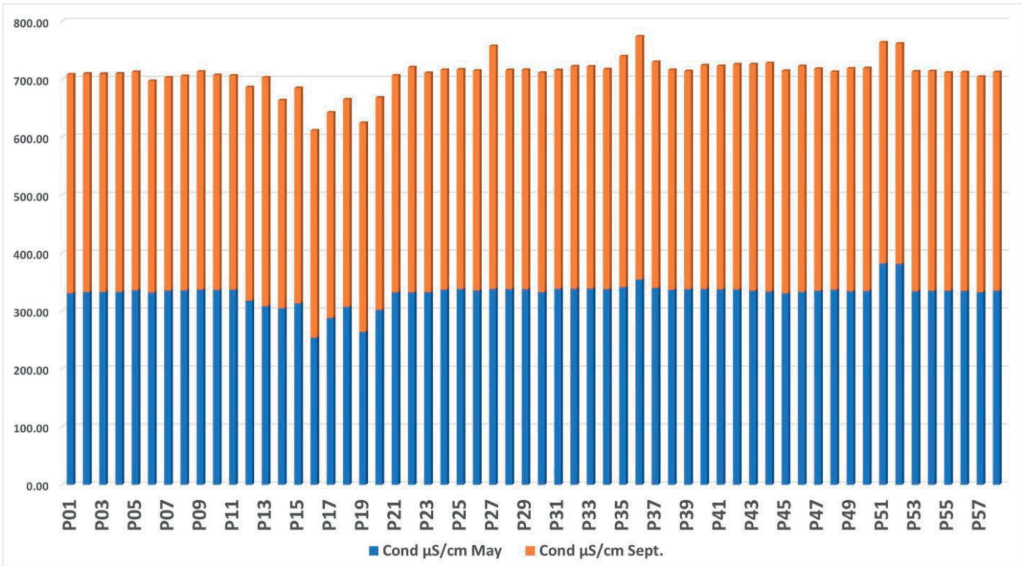

Figure 7. Evolution of the Cond µS/cm indicator in the investigated surface water samples

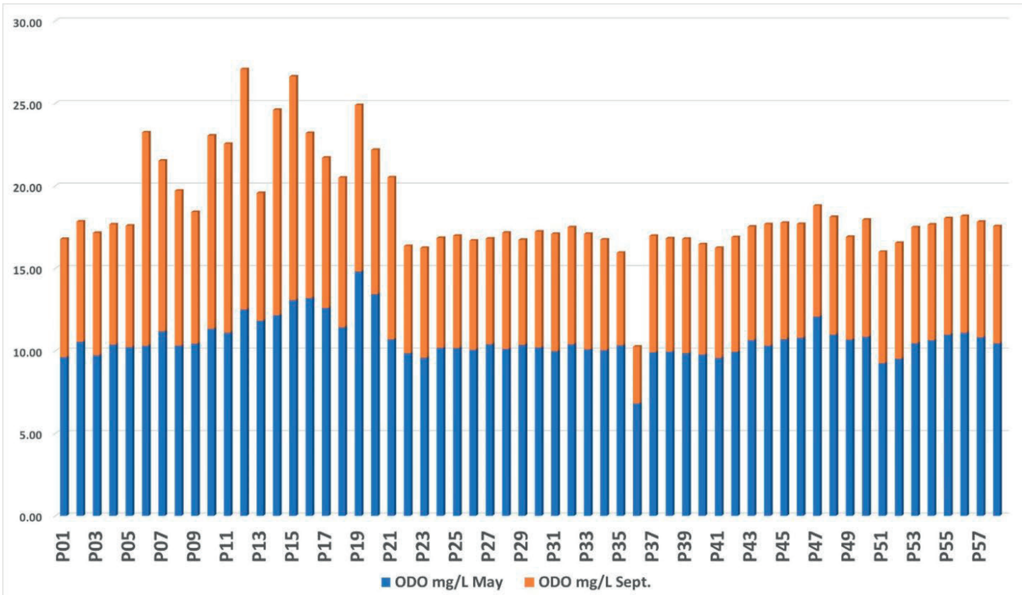

Figure 8. Evolution of the ODO mg/L indicator in the investigated surface water samples

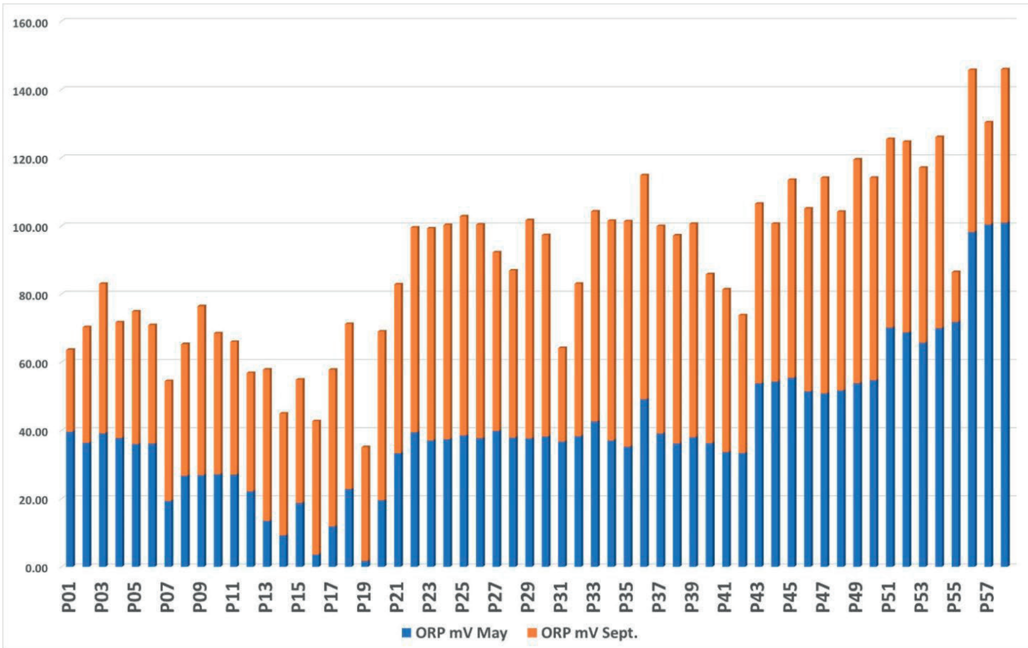

Figure 9. Evolution of the ORP mV indicator in the investigated surface water samples

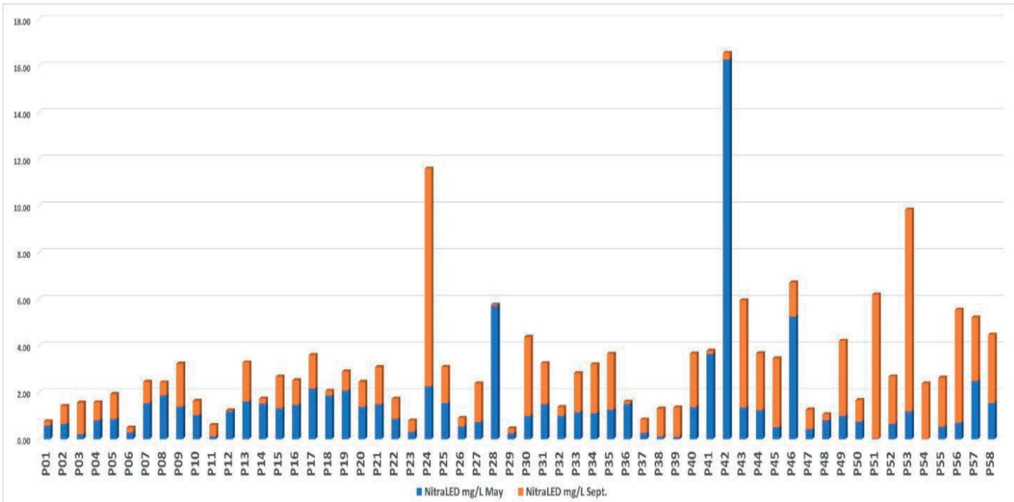

Figure 10. Evolution of the NitraLED mg/L indicator in the investigated surface water samples

Chlorophyll a (µg/L). The concentrations of chlorophyll *a* in the water samples from the investigated sections showed considerable variability. In May, values ranged from 0.26 to 8.57 µg/L (mean: 3.93 ± 2.06 µg/L), while in September, they varied more widely—from 0.27 to 12.65 µg/L (mean: 2.55 ± 3.78 µg/L). Lowest concentrations were found at P20 (May) and P22 (September), while the highest were measured at P46 (May) and P19 (September). All recorded values remained below the class I threshold of 25 µg/L (Order 161/2006), indicating low-to-moderate algal productivity and absence of eutrophic conditions (Figure 11).

Total Algae Content (TAL - PC RFU). TAL values, indicative of overall algal abundance (including cyanobacteria), showed greater variability in September compared to May. In May, TAL ranged from 0.05 to 1.83 RFU (mean: 0.70 ± 0.41 RFU), while in September, values spanned from 0.01 to 14.62 RFU (mean: 2.13 ± 3.85 RFU). Minimal algal content was recorded at P20 (May) and P27 (September), while peak values were observed at P30 (May) and P17 (September) (Figure 12). The overall range suggests a localized increase in algal activity toward the end of the warm season, potentially linked to temperature and nutrient availability

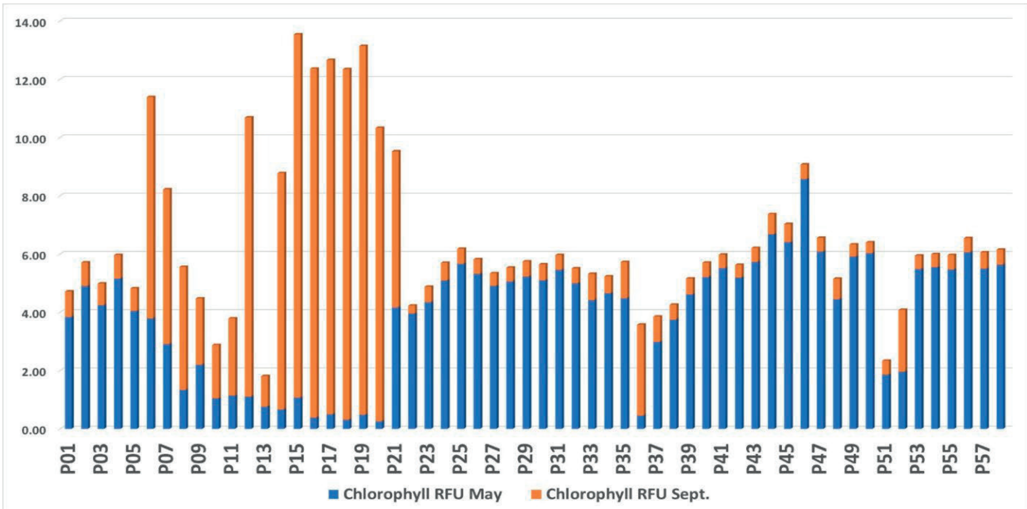

Figure 11. Evolution of the chlorophyll *a* RFU indicator in the investigated surface water samples

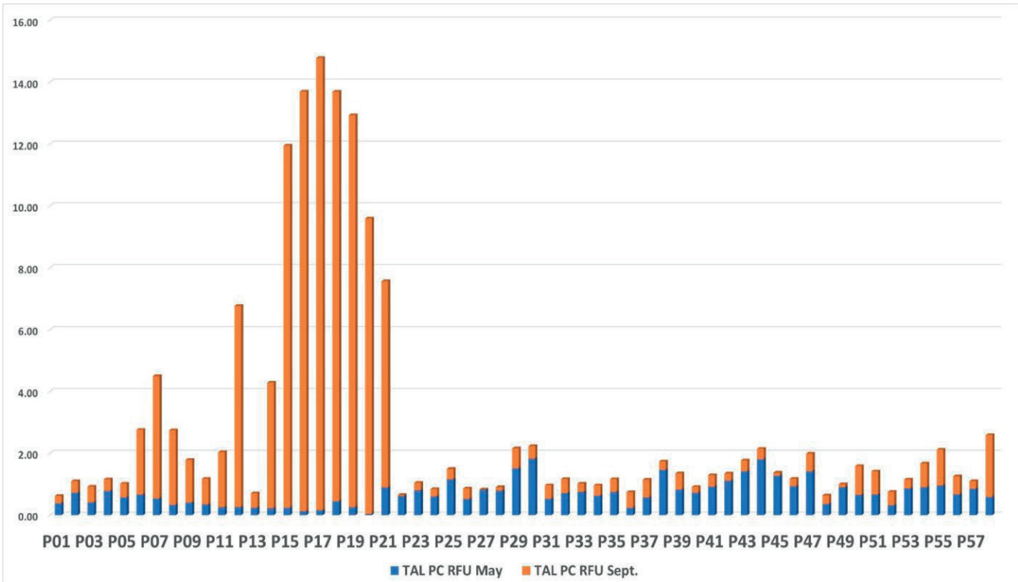

Figure 12. Evolution of the Total Algal Content (TAL - PC RFU) indicator in the investigated surface water samples

Interpretation of seasonal and spatial variability

The seasonal increase in Temperature in September is expected due to higher solar radiation and air temperatures in late summer. Water temperature plays a crucial role in biochemical reactions, dissolved oxygen levels, and biological activity. Higher temperatures generally correlate with lower dissolved oxygen concentrations, as observed in September. Localized differences in temperature values may indicate areas of variable flow dynamics, depth variations, or thermal influences from adjacent land areas. The relatively stable range suggests that there have been no extreme temperature fluctuations that would otherwise indicate thermal pollution or abrupt environmental changes.

Slightly *alkaline conditions*, particularly in stations such as Isacova Lake, indicate biological influences, notably the photosynthetic activity of aquatic plants and phytoplankton. In May, elevated pH levels may result from increased photosynthesis, which reduces CO_2 concentrations and shifts water chemistry toward alkalinity. In contrast, the slight decline in *pH* observed in September could be linked to enhanced respiration and decomposition of organic matter, which releases CO_2 into the water. Nonetheless, all values remained within the acceptable range for freshwater ecosystems, suggesting no immediate risk of acidification or excessive alkalinity.

Turbidity is influenced by sediment transport, organic matter and the presence of phytoplankton. Recent studies, such as Sandu et al. (2023), have reinforced this perspective by demonstrating how elevated turbidity levels in freshwater systems can be linked to nutrient input, sediment resuspension, and decreased water transparency, particularly in areas affected by anthropogenic influence. Higher values at certain stations suggest localized resuspension of sediments or particle growth due to water flow dynamics, bank erosion or anthropogenic influences. The slight decrease in mean turbidity from May to September suggests potential settling of suspended particles as the water flow stabilizes. The high turbidity values at P42 (May) and P24 (September) could be related to increased sediment input from channels or main arm, algal blooms or stormwater runoff. Excessively high values could have a negative impact on submerged vegetation and aquatic organisms by reducing photosynthetic efficiency. Comparisons with standard limits (SR ISO 5667-5:2017: 5 NTU permitted, 10 NTU exceptionally permitted) indicate that some samples exceed these thresholds, indicating localized deterioration of water quality.

Total Dissolved Solids (TDS) values remained within the normal range for freshwater systems (0-1000 mg/L, Lehr, 1980; De Zuane, 1997), indicating good water quality. Seasonal variations were minimal, suggesting that the system maintains stable ion concentrations, without significant dilution or concentration effects. The higher TDS values at P52 (May) and P36 (September) could be due to localized groundwater influence, mineral dissolution, or reduced flushing rates.

Electrical conductivity, closely linked to TDS, increased slightly from May to September, likely due to ion accumulation driven by reduced flow rates and evaporation during late summer. Spatial variation suggests that areas such as the Erenciuc Canal may experience greater mineralization, potentially due to limited water exchange or specific geochemical conditions.

Dissolved oxygen levels were sufficient to support aquatic life during both campaigns, although a noticeable decline from May to September points to temperature-driven oxygen depletion and increased organic matter decomposition. The lowest DO values at P36 may reflect slow circulation, organic accumulation, or microbial respiration. Despite this, most values exceeded the 5 mg/L threshold required for aquatic fauna (NIWA, 2024), indicating overall good oxygenation.

Oxidation-Reduction Potential (ORP) values suggest that the water body remains well oxygenated and capable of supporting aerobic biochemical processes. The slight variations in ORP values between May and September could be attributed to fluctuations in microbial activity, decomposition of organic matter and seasonal variations in dissolved oxygen levels. The highest ORP values at the confluence points probably indicate higher oxygenation due to increased water mixing.

Salinity remained low across all stations, reinforcing the freshwater character of the Sfântu Gheorghe Branch. Minor variations between May and September can be attributed to precipitation, evaporation, and localized mineral input. The consistently low salinity values indicate hydrological stability with minimal marine influence.

Nitrate levels in freshwater systems are influenced by agricultural runoff, wastewater discharge and natural biological processes. The increase in the average nitrate concentration from May to September suggests a seasonal accumulation of nutrients, potentially due to lower dilution rates, organic matter decomposition or anthropogenic inputs. The high values at P42 and P24 warrant closer monitoring as they could indicate localized pollution sources or increased nitrogen inputs from surrounding land use activities.

Chlorophyll a serves as an indicator of phytoplankton biomass and primary productivity. The results suggest a moderate algal growth, with some seasonal and spatial variation. The decrease in mean values from May to September could reflect nutritional limitations or grazing pressures from zooplankton. However, localized peaks (e.g. at P46 and P19) may indicate areas of higher nutrient availability or reduced water flow, favouring phytoplankton accumulation.

The increase in *Total Algal Content (TAL)* values from May to September suggests that phytoplankton biomass was higher in late summer, possibly due to increased water residence time, higher temperatures, and nutrient availability. The peaks observed at P30 and P17 may indicate localized eutrophic conditions where algal growth is enhanced. Further investigation is needed to determine whether these fluctuations are natural seasonal trends or signs of nutrient enrichment from external sources.

Correlation analysis and interpretation - Pearson Correlation – May 2024

Based on the Pearson correlation matrix for May (Table 2, Figure 13), several strong and statistically significant relationships were identified ($\alpha = 0.05$)

1. *Strong positive correlations (directly proportional)*

- ODO % sat and ODO mg/L (r = 0.998): a near-perfect correlation, indicating the expected interdependence between oxygen concentration and its saturation in water.
- Conductivity, TDS, and Salinity: very strong positive correlations were found among Conductivity (μS/cm) and TDS (mg/L) (r = 0.990), Conductivity and Salinity (r = 0.960), and Salinity and TDS (r = 0.978), confirming their shared dependence on dissolved ion concentrations.
- pH and DO (r ≈ 0.881-0.877): higher pH is positively associated with higher dissolved oxygen and percent saturation.
- Temperature and DO (r ≈ 0.895-0.869): increasing temperature is strongly positively associated with higher dissolved oxygen levels.
- Chlorophyll and TAL (r = 0.713): increased chlorophyll concentration (an indicator of primary productivity) is positively correlated with TAL PC RFU, suggesting a link between chlorophyll and other fluorescent particles or phytoplankton.
- Turbidity and Nitrate (r = 0.589): suggests that higher nitrate concentrations are associated with increased turbidity, potentially due to suspended organic material or nutrient-rich runoff.

2. *Strong negative correlations (inversely proportional)*

- pH vs Conductivity, Salinity, TDS (r ≈ -0.914 to -0.923): lower pH is associated with increased values of conductivity, salinity and total dissolved substances, which indicates acidification in more mineralized waters.
- Temperature vs Conductivity, Salinity, TDS (r ≈ -0.783 to -0.870): higher temperatures are associated with lower conductivity and lower salinity, suggesting dilution or the influence of other processes that reduce ion concentration with warming.
- Conductivity vs DO (r ≈ -0.809 to -0.794): higher conductivity correlates negatively with dissolved oxygen, suggesting that waters with more dissolved substances have lower dissolved oxygen levels.
- Chlorophyll (May) vs Chlorophyll (September): a previously observed strong negative correlation (r = -0.732) highlights significant seasonal variability in primary productivity.

Table 2. Correlation matrix (Pearson), in May 2024

Variables	Chla RFU May	Cond µS/cm May	ODO % sat May	ODO mg/L May	ORP mV May	Sal psu May	TAL PC RFU May	TDS mg/L May	Turbidity FNU May	pH May	Temp °C May	NitraLED mg/L May
Chla RFU May	**1**	**0.404**	**-0.417**	**-0.384**	**0.588**	**0.402**	**0.713**	**0.426**	**0.470**	-0.254	**-0.496**	0.112
Cond µS/cm May	**0.404**	**1**	**-0.809**	**-0.794**	**0.567**	**0.960**	**0.319**	**0.990**	0.248	**-0.914**	**-0.783**	-0.059
ODO% sat May	**-0.417**	**-0.809**	**1**	**0.998**	**-0.442**	**-0.858**	**-0.323**	**-0.858**	-0.213	**0.881**	**0.895**	-0.009
ODO mg/L May	**-0.384**	**-0.794**	**0.998**	**1**	**-0.409**	**-0.840**	**-0.298**	**-0.840**	-0.204	**0.877**	**0.869**	-0.017
ORP mV May	**0.588**	**0.567**	**-0.442**	**-0.409**	**1**	**0.523**	**0.359**	**0.591**	0.124	**-0.419**	**-0.586**	-0.097
Sal psu May	**0.402**	**0.960**	**-0.858**	**-0.840**	**0.523**	**1**	**0.332**	**0.978**	0.209	**-0.902**	**-0.870**	-0.032
TAL PC RFU May	**0.713**	**0.319**	**-0.323**	**-0.298**	**0.359**	**0.332**	**1**	**0.336**	**0.309**	-0.215	**-0.383**	0.084
TDS mg/L May	**0.426**	**0.990**	**-0.858**	**-0.840**	**0.591**	**0.978**	**0.336**	**1**	0.232	**-0.923**	**-0.861**	-0.066
Turbidity FNU May	**0.470**	0.248	-0.213	-0.204	0.124	0.209	**0.309**	0.232	**1**	-0.181	-0.171	**0.589**
pH May	-0.254	**-0.914**	**0.881**	**0.877**	**-0.419**	**-0.902**	-0.215	**-0.923**	-0.181	**1**	**0.798**	0.078
Temp°C May	**-0.496**	**-0.783**	**0.895**	**0.869**	**-0.586**	**-0.870**	**-0.383**	**-0.861**	-0.171	**0.798**	**1**	0.076
NitraLED mg/L May	0.112	-0.059	-0.009	-0.017	-0.097	-0.032	0.084	-0.066	**0.589**	0.078	0.076	**1**

Values in bold are different from 0 with a significance level alpha=0.05

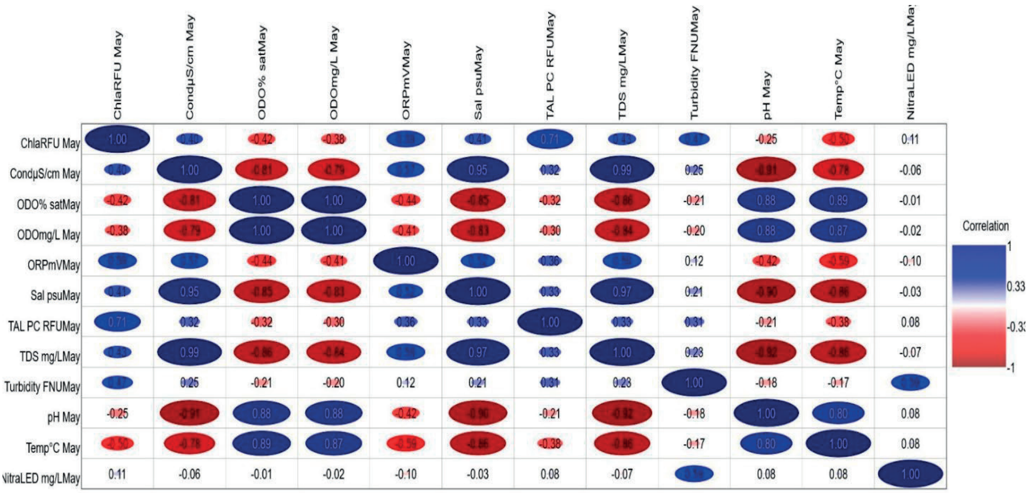

Figure 13. Correlation matrix (Pearson), in May 2024

Pearson Correlation – September 2024

In September (Table 3, Figure 14), the correlation matrix also revealed several statistically significant relationships

1. *Significant positive correlations (directly proportional):*

- ODO % sat and ODO mg/L (r = 0.998). Strongly positive and almost perfect relationship, demonstrating that oxygen saturation and its concentration are directly related and interdependent.
- Chlorophyll and TAL (r = 0.950): An extremely strong correlation indicating that the presence of chlorophyll (an indicator of algal activity) is directly related to the fluorescence of other organic or biological substances.
- Salinity and TDS (r = 0.928): Reflects the direct relationship between salinity and total dissolved solids, being indicators that vary simultaneously.
- pH and ODO mg/L (r = 0.932), ODO % sat (r = 0.923), Chlorophyll (r = 0.739). High pH is associated with increased dissolved oxygen levels and increased chlorophyll concentrations, suggesting high photosynthetic activity, which generates oxygen and raises the pH of the water.
- Turbidity and NitraLED (r = 0.633): Indicates that higher nitrates are related to

increased turbidity, possibly due to organic loading or nutrient input.

- TDS and Conductivity (r = 0.807): Increased conductivity indicates increased ions and dissolved substances, explaining the positive relationship with TDS.

2. *Significant negative correlations (inversely proportional):*

- Conductivity and Chlorophyll (r = -0.612): Suggests that high conductivity is associated with lower chlorophyll values, possibly indicating the negative influence of high salinity on algae growth.
- DO vs TDS (r = -0.711) and Conductivity (r = -0.653): High dissolved solids and high conductivity are negatively associated with dissolved oxygen, indicating that waters with high salt and other substances are poorer in dissolved oxygen.
- pH vs ORP (r = -0.639) and Conductivity (r = -0.618): Higher pH (basic) is associated with lower ORP and conductivity values, suggesting that alkaline water has a lower redox potential and lower mineralization.
- Temperature vs Chlorophyll (r = -0.517) and TAL (r = -0.568): Higher temperatures are associated with decreases in chlorophyll concentration and fluorescence of other organic substances, possibly due to thermal stress on photosynthetic organisms.

General observations on specific parameters

Chlorophyll (May) have moderate positive relationships with Turbidity, ORP, and TAL, suggesting the influence of biological activity (algae and phytoplankton) on physicochemical parameters.

Nitrates (NitraLED) did not show strong correlations with most variables, except Turbidity, possibly indicating its association with suspended particles or runoff rather than in situ biological processes.

Table 3. Correlation matrix (Pearson) in September 2024

Variables	Chla RFU Sept.	Cond µS/cm Sept.	ODO % sat Sept.	ODO mg/L Sept.	ORP mV Sept.	Sal psu Sept.	TAL PC RFU Sept.	TDS mg/L Sept.	Turbidity FNU Sept.	pH Sept.	Temp °C Sept.	NitraLED mg/L Sept.
Chla RFU Sept.	**1**	**-0.612**	**0.675**	**0.712**	**-0.334**	**-0.370**	**0.950**	**-0.363**	0.239	**0.739**	**-0.517**	-0.255
Cond µS/cm Sept.	**-0.612**	**1**	**-0.616**	**-0.653**	**0.438**	**0.721**	**-0.615**	**0.807**	-0.086	**-0.618**	**0.539**	0.117
ODO % sat Sept.	**0.675**	**-0.616**	**1**	**0.998**	**-0.513**	**-0.667**	**0.531**	**-0.714**	0.049	**0.923**	-0.014	-0.247
ODO mg/L Sept.	**0.712**	**-0.653**	**0.998**	**1**	**-0.518**	**-0.662**	**0.575**	**-0.711**	0.060	**0.932**	-0.082	-0.254
ORP mV Sept.	**-0.334**	**0.438**	**-0.513**	**-0.518**	**1**	**0.497**	**-0.283**	**0.464**	0.068	**-0.639**	0.077	0.211
Sal psu Sept.	**-0.370**	**0.721**	**-0.667**	**-0.662**	**0.497**	**1**	**-0.368**	**0.928**	0.003	**-0.568**	-0.102	0.066
TAL PC RFU Sept.	**0.950**	**-0.615**	**0.531**	**0.575**	**-0.283**	**-0.368**	**1**	**-0.335**	0.252	**0.610**	**-0.568**	-0.186
TDS mg/L Sept.	**-0.363**	**0.807**	**-0.714**	**-0.711**	**0.464**	**0.928**	**-0.335**	**1**	-0.015	**-0.596**	-0.062	0.034
Turbidity FNU Sept.	0.239	-0.086	0.049	0.060	0.068	0.003	0.252	-0.015	**1**	0.127	-0.126	**0.633**
pH Sept.	**0.739**	**-0.618**	**0.923**	**0.932**	**-0.639**	**-0.568**	**0.610**	**-0.596**	0.127	**1**	-0.188	**-0.275**
Temp°C Sept.	**-0.517**	**0.539**	-0.014	-0.082	0.077	-0.102	**-0.568**	-0.062	-0.126	-0.188	**1**	0.148
NitraLED mg/L Sept.	-0.255	0.117	-0.247	-0.254	0.211	0.066	-0.186	0.034	**0.633**	**-0.275**	0.148	**1**

Values in bold are different from 0 with a significance level alpha=0.05

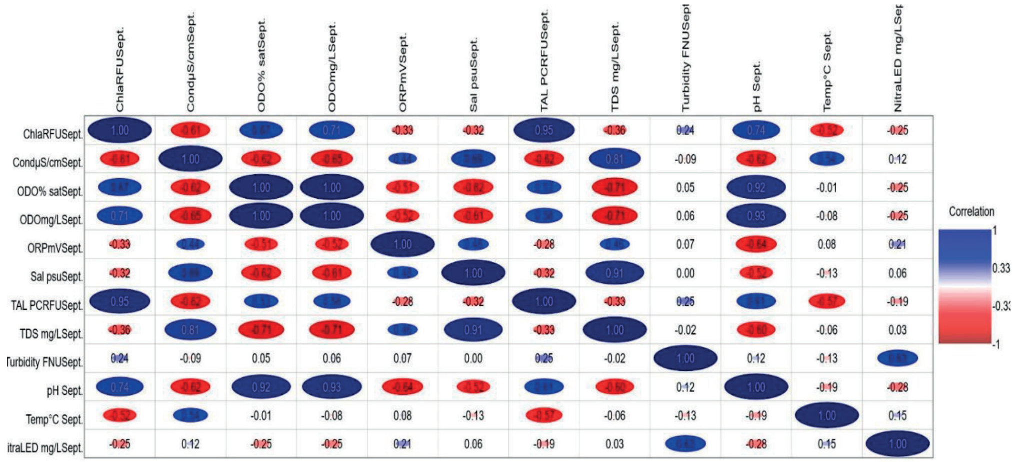

Figure 14. Correlation matrix (Pearson), in September 2024

Practical significance of the results

Conductivity and salinity are inversely related to oxygen availability and pH, emphasizing the impact of mineralization on water quality.

Temperature plays a pivotal role in modulating *DO, pH,* and *ion concentration*, reinforcing its importance in ecosystem metabolism and management.

Chlorophyll correlates with biological productivity and responds to both physicochemical conditions and seasonal shifts.

The *strong link between nitrates and turbidity* suggests external nutrient inputs that may degrade water transparency and stimulate eutrophication.

Comparison with previous studies

The results of this study are consistent with previous findings reported for the Danube Delta and lower Danube River, including those by Calmuc et al. (2021), Catianis et al. (2024), Isvoranu (1979), Iticescu et al. (2014), Najamuddin et al. (2016), Bashir et al. 2020, Teodorof et al. (2021), Ene et al. (2024), and Podlasek et al. 2024.

These studies also highlighted the influence of seasonal dynamics, hydrological variation, and anthropogenic factors such as sediment input and nutrient loading.

The current findings support these trends and contribute additional spatial and seasonal resolution to the understanding of ecological variability in the Danube Delta.

CONCLUSIONS

This study highlights the influence of *seasonal dynamics* - particularly temperature, hydrological conditions, and biological activity - on the water quality of the Sfântu Gheorghe Arm. Observed variations in *temperature, dissolved oxygen,* and *oxidation-reduction potential (ORP)* are consistent with expected physicochemical responses to seasonal change, especially the inverse relationship between temperature and dissolved oxygen driven by thermal stratification and increased biological oxygen demand in late summer.

Turbidity and *nitrate* concentrations exhibited localized fluctuations, likely influenced by sediment resuspension, surface runoff, and biological productivity. Although certain stations (e.g., P42, P24, and P53) recorded nitrate peaks exceeding recommended thresholds, the overall water quality remained within acceptable ranges for freshwater ecosystems. These sites may be subject to nutrient enrichment, warranting further investigation into potential agricultural or wastewater inputs.

The stability of *pH, salinity,* and *TDS* across the sampling campaigns indicates a well-buffered system with consistent hydrological conditions and no significant signs of acidification or salinity stress.

Meanwhile, moderate values of *Chlorophyll a* and *total algal content (TAL-PC)* suggest ongoing primary production, with spatial variation likely influenced by nutrient levels and local hydrodynamic conditions.

RECOMMENDATIONS

Regular Monitoring
Continuous assessment of turbidity, nitrate concentrations and dissolved oxygen levels is essential to detect potential changes in water quality.
Nutrient Management
High nitrate concentrations at P42, P24 and P53 may indicate agricultural runoff or wastewater inputs; further analysis is needed to identify sources and mitigate impacts.
Erosion and Sediment Control
Elevated turbidity values suggest possible sediment transport issues; implementing land use management and erosion control measures could reduce sediment input.
Ecological Risk Assessment
The decrease in dissolved oxygen in September indicates a risk of hypoxic conditions, which should be further examined to assess potential effects on aquatic life.
Hydrodynamic Investigation
Investigation of flow dynamics and mixing processes could provide insights into localized variations in water quality and help optimize water management strategies.
By integrating these findings with long-term monitoring and cross-seasonal studies, a more comprehensive understanding of the ecological functioning of the Sfântu Gheorghe Arm can be achieved. This knowledge is crucial for the development of effective conservation, restoration, and sustainable water resource management practices in the Danube Delta.

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