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VARIATIONS OF PHYSICO-CHEMICAL PARAMETERS IN SULINA BRANCH AND ADJACENT MEANDERS DURING TWO SEASONS IN 2023

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Abstract

The Sulina Branch, situated in the Delta`s midpoint, features a distinct straight course requiring continuous dredging for maritime navigation. Stretching 71 km, it conveys 18% of the Romanian lower sector of Danube`s water and historically served as a pivotal fluvial transport route, despite navigational challenges posed by sinuosities. It underwent a significant transformation that shortened it by 21.2 km (25.30%), converting it into a nearly straight navigable canal. This led to adverse effects like benthic habitat destruction, increased turbidity, and altered flooding patterns, impacting local ichthyofauna and avifauna. Navigation along the now straight Sulina Branch faced disruptions from sediment shoals at the mouth, due to the synergistic action of fluvial and coastal currents. In spring and autumn 2023, we measured physico-chemical parameters at 30 stations along Sulina Branch and adjacent Meanders, correlating them with bathymetry, water flow, and currents. Clear distinctions were observed, especially between upstream and downstream locations. Oxygen measurements both in spring and autumn, indicated good status water quality. Results demonstrated a good status in water quality at most stations during the study period.

Key words*: meanders, physico-chemical parameters, Sulina branch, water quality.*

INTRODUCTION

The Black Sea is the main recipient of liquid and solid contributions from Central Europe (via the Danube) and Eastern Europe (Ukrainian rivers like the Dniester, Dnieper, Southern Bug, Don, and Kuban). The catchment basin covers approximately 1864000 km², predominantly consisting of river basins from the northwest, notably the Danube (43.8%), Dniester, Bug, Dnieper, and Kuban. These rivers have a total discharge of about 276 km³/year, with the Danube contribution of approximately 70%. Current sedimentary processes on the continental shelf of the northwest Black Sea are significantly influenced by sediment contributions from rivers discharging into this area (Panin and Jipa, 1998), with the Danube playing a predominant role in the sedimentation of the northwest shelf of the Black Sea (Panin, 1999). These rivers transport and deposit around 61 x 10^6 tons of sediment on the continental shelf annually, with the Danube accounting for about 81% of this (Wong et al., 1994). Other tributaries are not as significant in providing water and sediment to the northwest Black Sea, mainly because they deposit their sediment load into lagoon, separated from the sea by coastal barriers (Panin, 1999). In the last century, numerous rivers have been impacted by dam construction, affecting morphology, hydrology, and sediment transfer (Williams and Wolman, 1984; Knox, 2006; Assani and Petit, 2004). Furthermore, anthropogenic interventions on rivers, such as embankments, meander cuts, caused significant changes of their longitudinal profiles (Keller, 1972). On the Danube, flood control, navigation improvement, irrigation systems, and energy production have driven engineering works since the 17th century, involving the construction of dams, reservoirs, dikes, bank protections, canals, dredging, and meander straightening. The Danube's entire course has a hydroelectric potential of 29,000 MW, achieved by constructing numerous dams (850, including 700 on tributaries), such as at Bad Abbach, KM 2041, Regensburg KM 2381, Geisling KM 2354, and Gabcikovo KM 1842. Post-1970, hydroelectric developments in Romania, notably the Iron Gates I and II dams and hydrotechnical arrangements on Romanian tributaries (Jiu, Olt, Vedea, Siret) disrupted the Danube's lower course hydrological and sedimentary functions. The average long-term liquid discharge measured at the delta's entrance (Tulcea hydrometric station) is 6,550 m^3/s, resulting from the catchment's water balance (average precipitation of 816 mm, average evaporation of 547 mm) (Almazov et al., 1963). Anthropogenic alterations in the river's upper and middle basin have reduced the downstream sediment flow. Since 1970, the construction of the Iron Gates I and II dams and hydrotechnical works on Romanian Danube tributaries have affected the regime of liquid and solid discharges downstream. These works have led to a significant reduction in sediment discharge at the Danube's mouths. Over 130 years, Bondar et al. (1991) have estimated the Danube's average sediment discharge at its mouths at 51.7 x 10^6 tons/year, with a progressive decrease over time. Later, Panin and Jipa, 2002; Walling, 2003 have estimated that sediment discharge has decreased from 67.5 x 10^6 tons/year to 25-30 x 10^6 tons/year. The Danube River, besides its natural biodiversity component, holds significant economic and political importance for Europe. The delta formed at its mouth reflects the evolution of climatic and anthropogenic conditions that have intensely transformed the natural state of the watershed over the last centuries. These basin-scale changes (morphological, hydrological, sedimentological, etc.) have been amplified by climate changes within the delta, causing variations in liquid and solid fluxes and local adjustments in channel morphology, significantly affecting local hydro-sedimentary dynamics. At its sea outflow, the Danube has created one of Europe's most significant deltas over an area of 5800 km^2, the Danube Delta, designated a UNESCO World Heritage Site and a biosphere reserve. Its geographical location, acting as a "buffer zone" for the Danube-Delta-Black Sea system, begins at the first bifurcation of the Danube (at Ceatal Izmail) 83.8 kilometres from the mouth (Gâştescu, 2009). Here, the Danube splits into two branches, the northern Chilia and the southern Tulcea, which further divides into the Sulina and Sfantu Gheorghe branches. The Chilia branch forms a secondary delta at its mouth. The Sulina branch, the central and navigable channel thanks to rectification works, is extended into the sea, with shores consolidated against erosion to maintain the maritime navigation. The Sfantu Gheorghe branch, morphodynamically active at its mouth, forms a secondary delta. Among the main distributaries, the Danube has created a network of primary and secondary channels, both natural and artificial, facilitating water and sediment circulation from the main branches to inter-distributary depressions, vital for the existence and evolution of deltaic ecosystems (Panin and Jipa, 2002). Important developments began with the establishment of the European Commission of the Danube at Galați in 1856 (Gâştescu & Ştiucă, 2008). Early in the 20th century, the Romanian Fishing Authority initiated delta channel regularization works to improve internal navigation. These anthropogenic interventions have influenced the Danube's flow regime, the sediment balance in the coastal area between Sulina and Sf. Gheorghe, and the morphology of the northwest Black Sea shelf (Rose, 1992; Rose et al., 1993).

MATERIALS AND METHODS

Study area

The Sulina Branch, the Danube's central distributary within the delta, has garnered special interest due to meander cuts and developments for navigation between 1858 and 1902. Initially sinuous and 83 km long with varying widths and depths, hydraulic works deepened the channel from less than 2.5 m in 1857 to at least 9.5 m by 1959, altering the Danube's flow regime through increased discharge (Bondar & Papadopol, 1972; Bondar & Panin, 2000). Major rectifications, including cutting two meanders known as the "Big M" (Figure 1), shortened the river and facilitated navigation by ensuring a constant width and depth (Bondar & Panin, 2000; David, 2010).

These interventions increased the liquid flow from 7-9% to 16-17% by 1921, and up to 18-20% presently, significantly changing the hydrological and sedimentary conditions, affecting the annual distribution of liquid and solid discharges (Bondar & Papadopol, 1972). This led to adverse effects like benthic habitat destruction, increased turbidity, and altered flooding patterns, impacting local ichthyofauna and avifauna (Gâştescu, 2009).

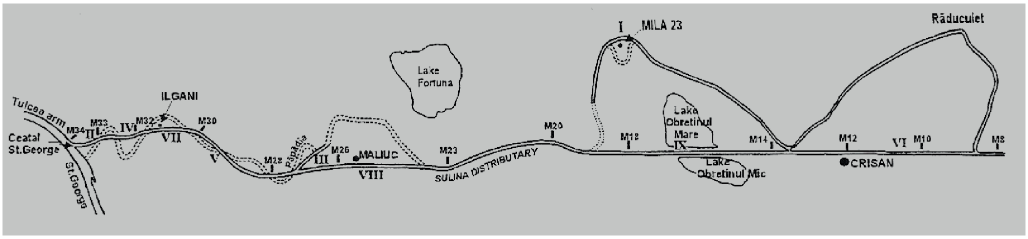

Figure 1. Rectified meanders of the Sulina arm in the period 1968-1902, after Panin, 1999

Navigation along the now straight Sulina Branch faced disruptions from sediment shoals at the mouth, due to the synergistic action of fluvial and coastal currents (Dutu et al., 2023).

In spring and autumn 2023, we measured physico-chemical parameters at 30 stations along Sulina Branch and adjacent Meanders, analysing them in relation with hydrodynamic measurements that were performed with an Acoustic Doppler Current Profiler (ADCP) across 18 profiles (Table 1, Figure 2). Water samples were collected from various locations, including the Sulina Branch, straightened meanders, natural channels, and lakes, as well as areas upstream and downstream of the bifurcation with the main distributary. Measurements were also made on the artificial channel, the cut meanders of Maliuc and the "Big M" (Old Danube), and the connecting channels to the deltaic lakes (Caraorman Channel and Sontea Channel).

Table 1. Sampling stations collected from the studied areas

Station	Location	Depth (m)	Coordinates	
			Lat. (α)	Long. (λ)
SU23-01	Cârjală Channel	2	45^{0}10’31.2"N	29^{0}07’02.6"E
SU23-02	Cârjală Channel	3.5	45^{0}11’18.3 "N	29^{0}05’53.9"E
SU23-03	Sulina Branch Mm 18+300	14	45^{0}10’41.0"N	29^{0}14’15.4"E
SU23-04	Sulina Branch, Upstream Crişan, Mm 14+700	11.4	45^{0}10’34.1"N	29^{0}20’22.3"E
SU23-05	Old Danube, Downstream Lebăda	5.4	45^{0}10’53.9"N	29^{0}20’45.8"E
SU23-06	Old Danube, Downstream Mila 23 (Meander)	8.4	45^{0}13’23.8"N	29^{0}15’47.8"E
SU23-07	Old Danube, Downstream Mila 23 (Meander)	6.4	45^{0}10’49.8"N	29^{0}21’51.6"E
SU23-08	Old Danube, Downstream Mila 23 (Meander)	3.8	45^{0}13’14.9"N	29^{0}14’04.4"E
SU23-09	Şontea Channel	3.5	45^{0}13’06.1"N	29^{0}13’32.9"E
SU23-10	Fortuna Lake	1.9	45^{0}12’42.5"N	29^{0}08’07.7"E
SU23-11	Ledianca Channel (Olguţa)	4	45^{0}14’03.6"N	29^{0}14’03.4"E
SU23-12	Eracle Channel	3	45^{0}14’06.3"N	29^{0}16’07.6"E
SU23-13	Trei Ozere lake	3	45^{0}14’29.3"N	29^{0}19’09.4"E
SU23-14	Bogdaproste lake	1.5	45^{0}13’54.9"N	29^{0}21’32.3"E
SU23-15	Raducu Lake	1.9	45^{0}14’17.5"N	29^{0}27’31.9"E
SU23-16	Bogdaproste Channel	4	45^{0}12’25.9"N	29^{0}22’53.5"E
SU23-17	Old Danube (Meander)	3.5	45^{0}10’41.2 "N	29^{0}21’21.3"E
SU23-18	Magearu Channel	1.9	45^{0}13’10.8 "N	29^{0}29’49.9"E
SU23-19	Old Danube (Meander)	7.4	45^{0}13’22.2"N	29^{0}27’01.7"E
SU23-20	Old Danube (Meander)	5.7	45^{0}11’31.8"N	29^{0}29’03.2"E
SU23-21	Sulina Branch, Mm 8+700	15	45^{0}10’23.0"N	29^{0}28’02.0"E
SU23-22	Sulina Branch, Mm 8+500	14.8	45^{0}10’20.5"N	29^{0}28’54.2"E
SU23-23	Sulina Branch, Downstream Lebăda, Mm 13+000	11.9	45^{0}10’23.7"N	29^{0}28’45.3"E
SU23-24	Canton Dovnica Channel	1.9	45^{0}14’01.7"N	29^{0}24’55.8"E
SU23-25	Sulina Branch, Mm 10+800	14.4	45^{0}10’28.0"N	29^{0}25’52.0"E
SU23-26	Old Danube (Meander)	7.7	45^{0}12’24.8"N	29^{0}18’26.6"E
SU23-27	Sulina Branch Mm 16+000	15.3	45^{0}10’37.2"N	29^{0}17’24.4"E
SU23-28	Caraorman Channel	2	45^{0}10’02.1"N	29^{0}20’55.8"E
SU23-29	Magearu Channel	2.5	45^{0}14’31.8"N	29^{0}30’20.0"E
SU23-30	Eracle Channel	4	45^{0}15’06.3"N	29^{0}18’15.8"E

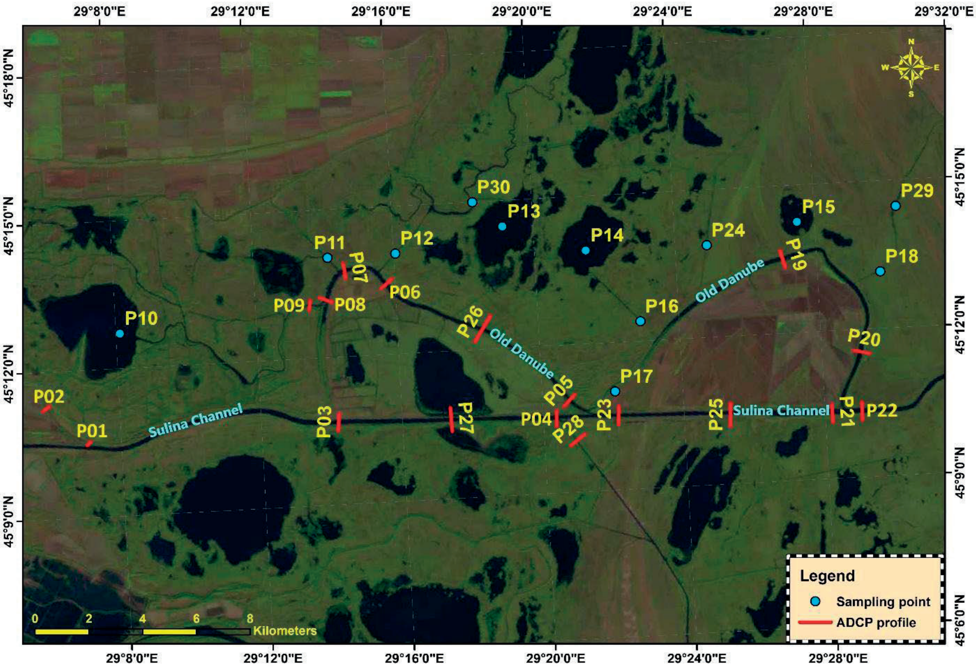

Figure 2. Sampling stations on the Sulina Branch, the straightened meanders of "Maliuc" and "The Big M", the lateral connection channels, and in deltaic lakes

Methodology for analyzing the physico-chemical parameters of water

To evaluate the physico-chemical parameters of aquatic environments within the study area, the following measurements were conducted: Chlorophyll (RFU), Conductivity (µS/cm), Dissolved Oxygen (DO, mg/L), Oxygen saturation (ODO, %), Salinity psu, Total Algal Content (TAL) PC RFU, Total Dissolved Solids (TDS) mg/L, Turbidity (FNU), pH and Temperature (T°C).

For these measurements, the multiparameter instrument model EX02, produced by YSI – USA, was used (Figure 3 left).

Methodology for hydrodynamic measurements (velocities, currents, and water discharges)

The measurements of water flow velocity, discharges, and currents (speeds and directions) were conducted using a high-accuracy ADCP (Acoustic Doppler Current Profiler) system. This system utilizes the Doppler Effect (Acoustic Doppler Current Profiler River Ray 600 kHz produced by Teledyne RD Instruments (Figure 3 right).

Figure 3. Multiparameter instrument model EX02 (left); ADCP River Ray 600 kHz (right)

RESULTS AND DISCUSSIONS

The lotic ecosystem complexes represented by the Danube River and the Danube Delta, according to Annex XI of the WFD, belong to the Pontic Ecoregion (12). Based on the parameters described in the Synthesis of the Project Management Plans at the Basin/Hydrographic Areas level (2022), for the Danube and the Danube Delta, 19 types of natural watercourses have been defined. The areas studied are included in RO15 The Danube River - Isaccea - The Danube Delta.

Hydrological regime during the measurement period

During the measurement period, the water levels of the Danube showed significant fluctuations at both hydrometric stations located near the measurement area, Tulcea and Sulina. In May, a decrease in water level of up to 31 cm in Tulcea and 9 cm in Sulina was recorded. In October, there was a decrease in water level of up to 21 cm at Tulcea, while at Sulina, the level varied, initially increasing by 15 cm followed by a decrease of 10 cm (Table 2, Figure 4).

Table 2. Water levels (cm) of the Danube at the Tulcea and Sulina hydrometric stations during the measurement period

Date	Hydrometric Stations		Date	Hydrometric Stations	
May	**Tulcea**	**Sulina**	**October**	**Tulcea**	**Sulina**
08.05.2023	277	103	**09.10.2023**	56	40
09.05.2023	274	105	**10.10.2023**	54	50
10.05.2023	269	98	**11.10.2023**	52	50
11.05.2023	261	92	**12.10.2023**	49	55
12.05.2023	255	90	**13.10.2023**	41	49
13.05.2023	254	89	**14.10.2023**	37	50
14.05.2023	250	90	**15.10.2023**	38	50
15.05.2023	246	94	**16.10.2023**	35	45

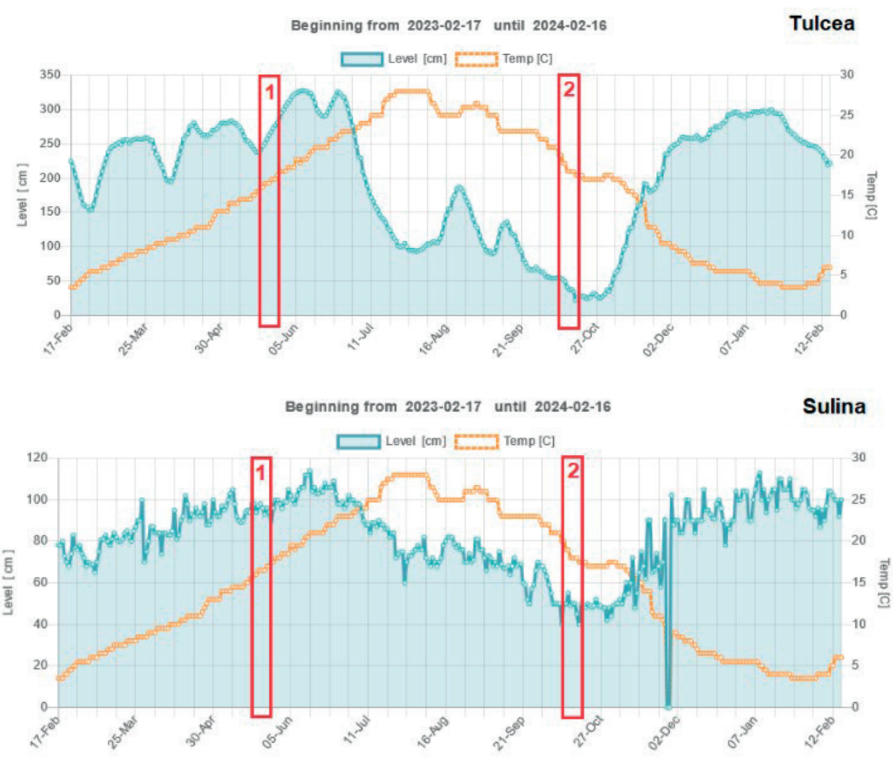

Figure 4. Water Levels of the Danube at the Tulcea and Sulina Hydrometric Stations During the Measurement Periods in May and October
(https://edelta.ro/cote-dunare-365-de-zile)

Hydrodynamic measurements (velocities, currents, and water discharges)

In May, a total of 18 hydrometric profiles were conducted. At the time of measurement, the Sulina Branch was transporting a discharge of approximately 1490 m³/s before entering in the "Big M" meander area (profile SU23-03). Downstream, the discharge increased to 1720 m³/s (profile SU23-22) due to water exchanges within the delta. Water flow in the old Maliuc meander channel proceeds from the Sulina Branch. In the "Big M" meander, the discharge is significantly reduced (between 177 and 269 m³/s). The average water velocities ranged between 0.14 and 1.3 m/s, with maximum velocities reaching their highest at profile SU23-21, at 2.67 m/s. In October, Sulina Branch was transporting a measured discharge of approximately 641 m³/s before entering in the "Big M" meander area (profile SU23-03). Downstream, the discharge decreased to 626 m³/s (profile SU23-22). Water flow in the old Maliuc meander channel, even at low water levels, proceeds from the Sulina Branch with a discharge of 5-6 m³/s. In the "Big M" meander, the discharge is also significantly reduced (between 13.6 and 42.9 m³/s). The average water velocities ranged between 0.01 and 0.54 m/s, with maximum velocities reaching their highest at profile SU23-23, at 2.18 m/s (Figures 5 and 6).

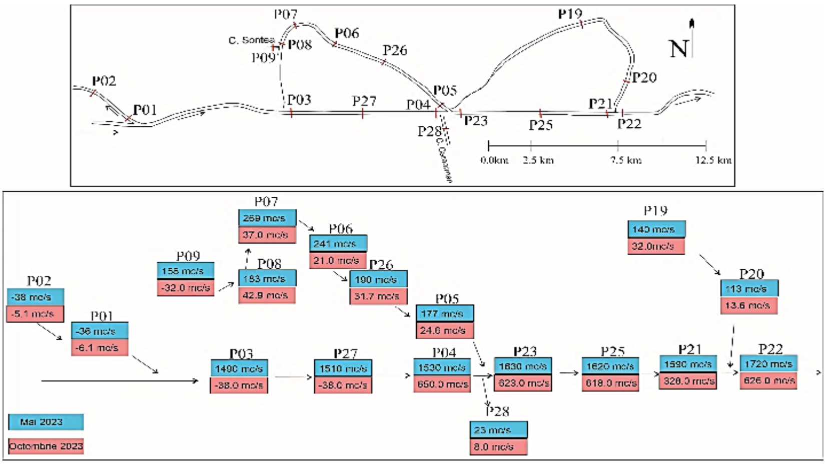

Figure 5. Water Discharge Distribution on the Sulina Branch and the Straightened Meanders During the Two Study Periods

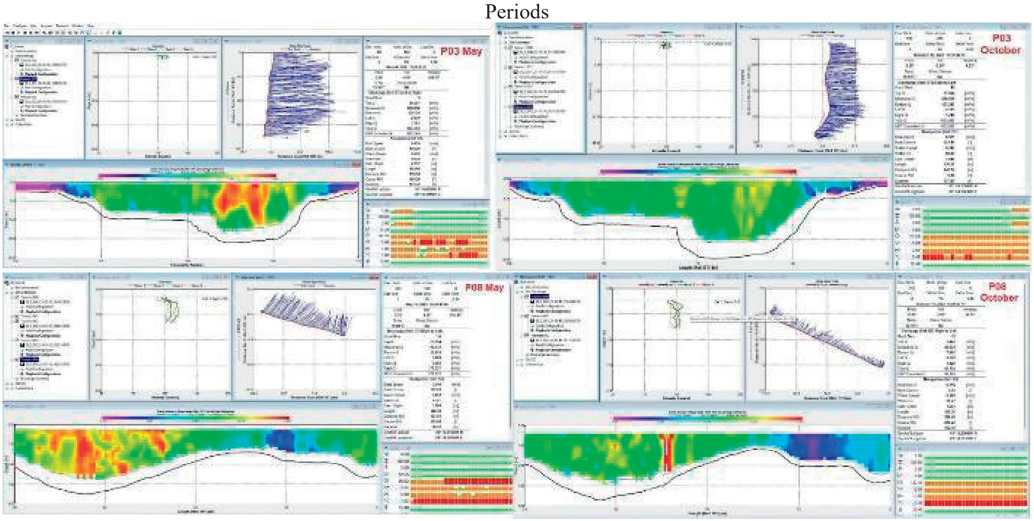

Figure 6. Examples of hydrometric profiles

Analysis of the physico-chemical parameters of water

Water serves as a nexus, integrating diverse environmental concerns and strategies across various human activities, including agriculture, economy, transport, energy, industry, and environmental protection. It is a pivotal factor in development, indispensable for the survival of aquatic life and the well-being of humans, encompassing needs such as sustenance, hygiene, comfort, and health. Water quality is significantly impacted by industrial and agricultural development, energy production, and domestic activities (Vasiliu et al., 2021). The advent of climate change necessitates a resilient and unified approach to water management (Poff et al., 2002; Capon et al., 2013). The EU Water Framework Directive (WFD, 2000/60/EC) mandates both qualitative and quantitative water management to preserve healthy aquatic ecosystems and achieve "good status" for water quality. Conformity with Romanian National Environmental Standards, specifically Normative No. 161/2006 (Approval of the Norm Concerning the Reference Objectives for the Surface Water Quality Classification, Official Journal of Romania, Part 1, No 511 bis), guides the assessment of surface water quality, employing environmental standards to measure indicators like total dissolved solids (https://en.wikipedia.org/wiki/Total_dissolved_solids) and turbidity (STAS 6323 – 88). The evaluation process also aligns with Normative 161/2006, which sets the criteria for classifying surface water quality and assessing ecological status. The aggregated physico-chemical data of sampling sites are shown in Table 3, representing the range (minimal and maximal) and average (±standard deviation) values of each parameter per season.

Table 3. A synopsis of the physico-chemical parameters of water surface samples

The physico-chemical parameters in the studied areas, . May 2023					
	Chlorophyll RFU	**ODO % sat**	**ODO mg/L**	**Sal psu**	**TAL PC RFU**
Min	0.34	42.94	4.28	0.17	0.21
Max	5.16	99.32	9.77	0.24	5.52
Mean±SD	1.14±1.11	85.57±14.55	8.24±1.29	0.19±0.01	0.72±0.95
	TDS mg/L	**Turbidity FNU**		**pH**	**Temp, °C**
Min	230.59	0.30		7.55	15.18
Max	318.69	14.89		8.31	16.12
Mean±SD	260.86±13.07	7.24±4.23		8.04±0.22	15.71±0.26

The physico-chemical parameters in the studied areas, October 2023					
	Chlorophyll RFU	**ODO % sat**	**ODO mg/L**	**Sal psu**	**TAL PC RFU**
Min	0.34	54.80	5.70	0.17	0.08
Max	4.45	106.53	11.16	0.21	2.41
Mean± SD	0.97±0.79	90.05±9.79	8.70±0.93	0.19±0.01	0.55±0.51
	TDS mg/L	**Turbidity FNU**		**pH**	**Temp °C**
Min	228.04	1.02		7.79	12.95
Max	277.53	20.27		8.64	19.66
Mean± SD	257.69±9.29	8.07±4.62		8.21±0.18	17.04±2.25

The physico-chemical parameters values generally varied within the limits set by the environmental standards. The average temperature distribution observed during sampling periods matched anticipated seasonal fluctuations (Radan et al., 2000). Oxygen levels in most sampling locations either exceeded or fell below of the environmental standards' maximum allowable concentrations. Notably, reduced oxygen concentrations were recorded within the stations SU23-24 Canton Dovnica Channel (4.28 mg/l) and the SU23-30 Eracle Channel (5.31 mg/l) and SU23-11 Ledianca Channel (Olguța) (5.41 mg/l) in May, and a concentration of 5.70 mg/l was observed in October only in one station SU23-24 Canton Dovnica Channel. Dissolved Oxygen (DO) levels at these stations categorize them within water quality Classes III and IV, as they exhibit values below 9.00 mg/l threshold requisite for Class I status. Conversely, the rest of the stations are classified within Classes I and II. A high concentration of dissolved oxygen (DO) is critical for the sustenance of aquatic ecosystems. It is recommended that a minimum DO concentration of 5 mg/l be maintained to support aquatic life effectively. Optimal fish health is also associated with this DO threshold. Different species exhibit varying levels of sensitivity to low DO concentrations; however, it is generally observed that fish experience distress when DO levels decline to between 2 and 4 mg/l. Mortality in fish populations is commonly observed when DO concentrations fall below 2 mg/l (https://niwa.co.nz/our-science/freshwater/tools/kaitiaki_tools/impacts/dissolved-oxygen).

Salinity and total dissolved solids measurements fell within the limits set by environmental guidelines. In the water samples evaluated, the Total Dissolved Solids (TDS), encompassing both organic and inorganic matter, ranged within the following values: 230.59 to 318.69 mg/l with a mean value of 260.86 ± 13.07 mg/l in May; and from 228.04 to 277.53 mg/l with a mean value of 257.69 ± 9.29 mg/l in October. pH levels across the study areas varied, indicating a gradual increase towards slightly alkaline water conditions, as depicted in Table 2. The turbidity of water samples yielded a range from 0.30 to 14.89 Formazin Nephelometric Units (FNU), with an average value of 7.24 ± 4.23 FNU in May. In October, the measured turbidity spanned from 1.02 to 20.27 FNU, with an average of 8.07 ± 4.62 FNU. The observed increase in turbidity in some stations, in surface waters may be attributed to factors such as phytoplankton activity, organic detritus, and resuspended bottom sediments. The average values of water quality parameters varied according to local environmental conditions, sampling locations, and seasonal water budget changes. The values recorded for the physical-chemical parameters in the present study are generally comparable with other previous investigations acquired at different water bodies from the DDBR area (Radan et al. 2000, Munteanu et al. 2012). Based on the Euclidian similarity index (Figure 7), it can be observed that the stations were grouped according to the variation in water discharge. Three clusters were formed: one with stations on the Sulina Branch (SU23-21, SU23-22, SU23-23, SU23-25, SU23-03, SU23-04, SU23-27), one with stations on the Old Danube - Meanders (SU23-20, SU23-05, SU23-26, SU23-08, SU23-09, SU23-19, SU23-06, SU23-07), and a third with the channels (SU23-28, SU23-02, SU23-01).

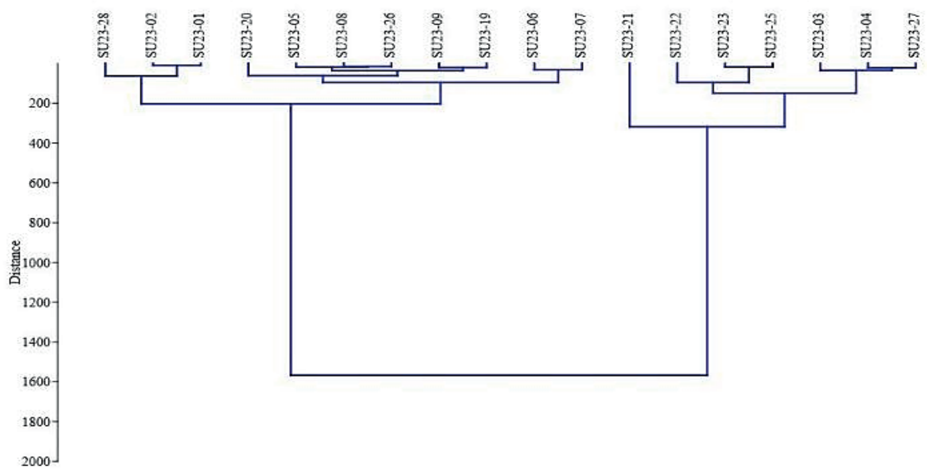

Figure 7. Similarity index based on Euclidian transformed data

The highest discharge in both periods was recorded on the Sulina Branch, followed by the Old Danube-Meanders area, with the lowest discharge on the channels connecting the meander lakes. Water discharge was not measured for the lake stations and several channel stations (SU23-10, SU23-11, SU23-12, SU23-13, SU23-14, SU23-15, SU23-16, SU23-17, SU23-18, SU23-24, SU23-29, SU23-30). High turbidity values were recorded at the Sulina Branch, where high discharge was observed, and also at the Carjala channel in two stations, in both seasons, where a negative discharge was recorded. As expected, high concentrations of dissolved oxygen, pH, and chlorophyll were found in the Caraorman and Carjala channel stations, followed by the meander area, where the water discharge was lower. The lowest dissolved oxygen concentration was recorded on the Sulina Branch in both periods, May and October.

CONCLUSIONS

This investigation aims to address an existing deficiency in the scientific literature by documenting the physicochemical attributes of the surface water within the study area's water-rich ecosystems. The quality of water in the analyzed regions is influenced by a confluence of unique and localized factors, such as variations in the water level of the Danube River, the flood regime, meteorological dynamics, as well as diurnal and seasonal changes. Additionally, anthropogenic activities in the vicinity of the Danube Delta, particularly around the Sulina Branch, meanders, channels, and selected lakes, also play a significant role.

The study's findings indicate that the majority of the evaluated physico-chemical parameters conform to the standards of Classes I and II, which correspond to very good and good ecological statuses, respectively. However, at certain stations, the parameters were consistent with the criteria for Classes III and IV, denoting moderate and poor ecological conditions.

The analysis based on the Euclidian similarity index reveals a clear correlation between water flow and the distribution of physico-chemical parameters across different locations in the studied areas. The formation of three distinct clusters suggests that hydrodynamic conditions significantly influence water quality. The Sulina Branch, with the highest water discharge, exhibited elevated turbidity levels, indicating a strong association between flow dynamics and sediment transport. Conversely, the channels connecting meander lakes, characterized by the lowest discharge rates, showed variations in water quality parameters, including dissolved oxygen, pH, and chlorophyll concentrations. Notably, areas with no water discharge measurements, such as some lake and channel stations, underscore the complexity of hydrodynamic impacts on water quality. High turbidity in the Carjala channel, despite negative discharge rates, further underscores this complexity. The findings suggest that water management strategies in the Danube Delta should consider the intricate relationships between hydrodynamics and water quality to ensure ecological health and sustainability.

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