Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

ASSESSMENT OF THE SEDIMENT (DIS)CONNECTIVITY IN A DELTAIC SYSTEM, DANUBE DELTA, ROMANIA

Florin DUŢU, Bogdan-Adrian ISPAS, Irina CATIANIS, Ana-Bianca PAVEL, Laura DUŢU

National Institute for Research and Development for Marine Geology and GeoEcology (GeoEcoMar), 23-25 Dimitrie Onciul Street, Bucharest, Romania

Corresponding author email: florin.dutu@geoecomar.ro

Abstract

Delta systems, as final receptors of the fluvial systems are under considerable and increasing influence of multiple anthropogenic stresses, such as hydropower plant developments in the basins, extraction of groundwater in delta plains, embankment of banks, dredging of the navigation channel, the land use change, channel engineering, that affect the sediment connectivity. Along the Sulina Canal, the cut-off program and construction of the groins and dikes had important responses in grain size distribution between the main channel, the rectified meanders, and the lakes of the Danube Delta. Two field campaigns (at high and low waters) were made in May and October 2023, focusing on the bed sediment composition and lithological constituents. Sediment samples were acquired throughout several cross-sections, to investigate the bed sediment characteristics. Grain size parameters (such as Median, Standard deviation, and Skewness) show the predominance of fine fraction (medium and fine sand, and silt), moderately and poorly sorted. The data were compared and larger modifications were found between the two analysed periods in the distribution of sediments.

Key words*: connectivity, Danube Delta, grain size, lithology, riverbed sediment.*

INTRODUCTION

Recently, a special consideration has been devoted to the relationship between the concept of connectivity and the sediment transport and delivery to the coastal areas (Crema & Cavalli, 2018; Mishra et al., 2019). The sediment connectivity is assessed as the degree of linkage between the sediment source to downstream area, representing one of the most important factors controlling the landscape evolution (Mishra et al., 2019). The loss of the lateral and longitudinal sediment connectivity affects river systems generally, and mainly the functionality of the deltaic systems (Bunn & Arthington, 2022; Baldan et al., 2023). Sediment (dis)connectivity is governed by the spatial distribution of the sediment sources and the geomorphic conditions of the transfer pathways, as showed by many authors as Poepll et al., 2017; 2020.

In the deltaic systems, the meander cutoffs play an important role in river morphodynamics by increasing local channel slope, decreasing river sinuosity, and reducing floodplain access (Schwenk & Foufoula-Georgiou, 2016).

The reduction of the sediment load has been recorded in the majority of the deltaic systems around the world (Walling & Fang, 2003; Syvitski, 2011) and is generally due to the human activities, such as landscape engineering, construction of reservoirs, hydrotechnical works, dredging (Zaharia et al., 2011; Habersack et al., 2016; Nistor et al., 2021; Duţu et al., 2022; 2023; Constantinescu et al., 2023).

In the Danube Delta, the period of major anthropic interventions began after the establishment of the Danube Commission in 1856 with the meander belt cut-off programme of the Sulina branch (between 1858-1902) shortening this arm by about 25% (of the initial 83 km length). Besides other important transformations affecting the delta, such as cutting and dredging of shallow canals, construction of jetties and new channels, many sinuosities have been corrected. Along the Sulina distributary, a number of 27 belts and sinuosities were cut-off. Only a few meander belts of the former Sulina Canal remained connected to the main channel (such as Maliuc meander (connected to the main channel at Mile 23.7), and the "Big M" meander belt, connected at Mile 13.5 and Mile 8.4). The regulation of the Sulina Canal consisted in the construction of 167 submerged groins and the protection of the banks with rock blocks (along 91.8 km) (Panin, 1999; Panin et al., 2016; Duţu et al., 2022).

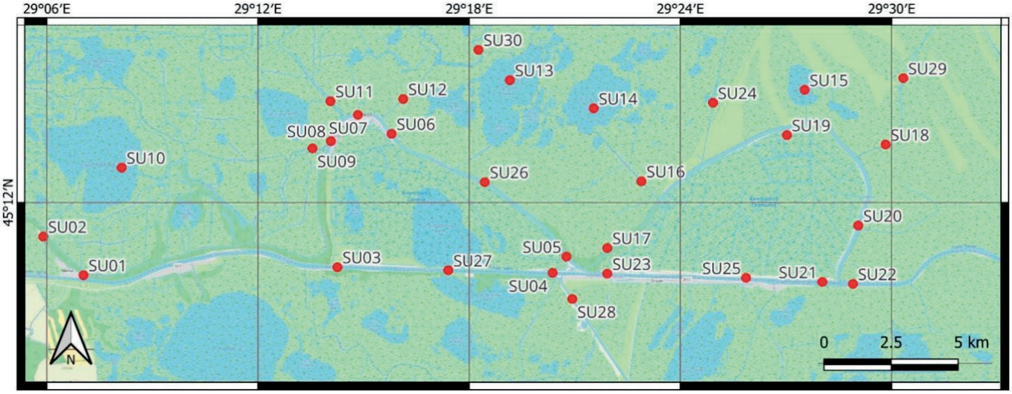

Figure 1. The Sulina Canal with the rectified meander "Big M" and the position of the investigated locations (Global Mapper v17)

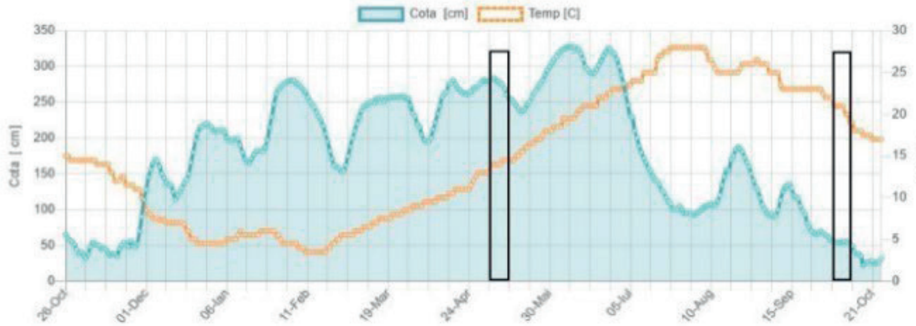

Figure 2. The water level (in blue) and the water temperature (in yellow) at the hydrometrical station Tulcea with the position of the two field campaigns in May and October 2023 (https://edelta.ro/cote-dunare-365-de-zile)

The results are consisting in changes of the river bed morphology, water and sediment fluxes and thus, a perturbation of the sediment transit from the main distributary to the delta depressions through the former meanders and canals, affecting the hydrological connectivity (Pacioglu et al., 2022; Duţu et al., 2023).

The objective of this paper was to investigate the distribution of the bed sediments in the former meanders during two different hydrological conditions (high and low waters, in May and October 2023), and to assess the sediment (dis)connectivity between the main distributary, the former meanders and the interdistributary depressions connected by lateral (natural or man-made) canals.

MATERIALS AND METHODS

The sedimentological data were acquired in May and October 2023, at high and low waters (the water discharge on Profile P03 was 1490 $m^3.s^{-1}$ in May and 641 $m^3.s^{-1}$ in October) (Figure 1 and Figure 2). During the measurements, the water level stage had large variations (at the hydrometrical station Tulcea) with a total of 31 cm in May and 21 cm in October. Reported water depths are expressed in local values.

Bottom samples were collected with a grab sediment sampler, on 30 sediment sampling stations distributed along the main Sulina channel, the former meanders "Big M" and Maliuc) on the lateral canals and connected lakes (Crânjală, Gârla lui Eracle, Dovnica, Şontea, Gârla Ledianca, Magearu, Bogdaproste, Eracle, Caraorman Canals and Fortuna, Răducu, Bogdaproste, Trei Iezere Lakes) (Figure 1).

Grain size was done for all of the sediment samples by diffractometry. The texture categories (sand, silt, and clay) were separated using the Udden-Wenthworth logarithmic scale while the classification of sediments was done according to the Shepard diagram (Udden, 1914, Wenthworth, 1922, Shepard, 1954). Based on the primary data the following granulometric parameters were extracted from the distribution curve (expressed in Φ units): *the median* (Md), *the standard deviation* (σ) and *the asymmetry coefficient* Sk_I (Folk & Ward, 1957; Visher, 1969). Technical approaches regarding the grain size analyses were developed by Duţu et al., (2018).

The lithological content of the sediments was determined using the Loss On Ignition (LOI) method. Primarily, the sediment sub-samples were oven-dried at 105ºC (Memmert Etuve) to determine the moisture content (%) by Loss On Drying (LOD) method (Smith & Mullins, 2000). After oven drying, the samples were weighed and exposed to sequential heating (Snol 8.2/1100 Calcination Furnace) and measuring weight loss between heating stages (%) by Loss On Ignition (LOI) method. The loss in mass by combustion at 550ºC (Dean, 1974), confers an assessment of the total organic matter (TOM%). The loss in mass by calcination at 950ºC (Digerfeldt et al., 2000; www.geog.cam.ac.uk), imparts an estimation associated with the total carbonate content (CAR%). The residual material is ascribed to the siliciclastic fraction (SIL%). The results are expressed as percentages of the total sample mass.

RESULTS AND DISCUSSIONS

Granulometric analyses of the sediments. In May 2023, during high waters, two types of sediments were found: sandy sediments, dominated by the fine subfraction, and silty-clay sediments, consisting of silt and clay, with the clayey fraction subordinate to the silty one. Along with the inorganic material, in most cases, there is also a content of biogenic origin, composed of shells and fragments and/or debris. Some samples had soft pebbles and blackish, unctuous clay with decomposed organic matter.

Along the Sulina Canal the sediments are composed of sands (with more than 90%), with subordinated fractions of clay and shelly material. Among the subfractions of sand, fine and medium sand is dominant (Photo 1, Figure 3). The mean and median values are positive (maximum 2.48Φ). The standard deviation, which has values between 0.56 and 0.63, indicates a relatively good sorting of the particles. The asymmetry has predominantly negative values, covering the range between -0.25 – +0.20 and Kurtosis is in the platykurtic – very leptokurtic range.

Photo 1. Bottom sediments sampled from the Sulina Canal in May 2023 (sample SU-23-03) and the former meander "Big M" (sample SU-23-20)

The sediments of the former meanders are generally composed of sandy silts, with the clayey fraction subordinate to the silty one. Samples SU-23-05 and SU-23-17 are the only ones with a sand content above 50% due to their position near the main stream where the sediments can be mixed by the strong water currents. The most common textural categories are silt and sandy silt. Among the silt subfractions, medium and coarse silt is the most representative, and in the case of sands, the fine subfraction. The mean and median values are positive (with a maximum of 6.57Φ). The standard deviation, which has values between 1.26 and 2.29, indicates weak to very weak particle sorting. The asymmetry has predominantly positive values, covering the range between -0.26 and +0.52, and Kurtosis is platykurtic – mesokurtic.

The sediment samples taken from lakes are composed of sandy mud, in which the silty fraction is predominant. For the silts, medium and coarse silt subfractions are more frequent. Among the silt subfractions, coarse and medium silt is the most representative. The mean and median values are positive (maximum 5.81Φ). The standard deviation, which has values between 1.59 and 1.88, indicates poor particle sorting. Asymmetry has positive values, covering the range between +0.01 and +0.12, and Kurtosis is leptokurtic.

Along the lateral natural or man-made canals, the sediments are sandy silts, with the clayey fraction subordinate to the silty one. Sample SU-23-28, situated on the Caraorman Canal, is the only sample with a sand content of more than 50% (Figure 3). The most common textural category is sandy silt. Among the silt subfractions, coarse and medium silt is the most representative, and in the case of sands, the fine subfraction. The mean and median values are positive (maximum 6.80Φ). The standard deviation, which has values between 1.68 and 2.32, indicates from weak to very weak particle sorting. The asymmetry has positive values, covering the range between +0.05 and +0.52; Kurtosis is platykurtic – leptokurtic.

In October 2023, during the low water levels, two types of sediments were found: medium sand (with plant fibers), and sandy clay-silty sediments (sandy muds), consisting of mud and sand, with the clayey fraction subordinate to the silty one, present in areas where the water velocity is low. Along with the inorganic material, in most cases, there is also a content of biogenic origin, generally made up of shells, fragments, and/or plant remains. Also, some sediments have soft pebbles (sample SU-23-18) and blackish, unctuous mud with decomposed organic matter.

The sediments of the Sulina Canal are composed of sands, with subordinate fractions of mud and shelly material. Sand percentages exceed 70% in most cases (Figure 4, Photo 2). Among the subfractions of sand, fine and medium sand predominate. The mean and median values are positive (maximum 6.20Φ). The standard deviation, which has values between 0.64 and 2.43, indicates relatively good sorting to very poor particle sorting. The asymmetry has predominantly positive values, covering the range between -0.10 and +0.36, and the Kurtosis is in the platykurtic-extremely leptokurtic range. Considering that some samples are composed of high clay percentage (SU-23-04 and SU-23-05), formed by compact material, it is very likely that the samples were collected from the bed substrate.

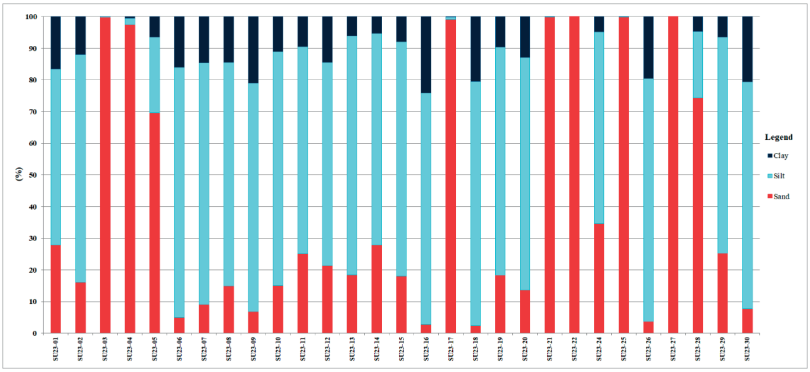

Figure 3. The texture diagram of the sediments in May 2023

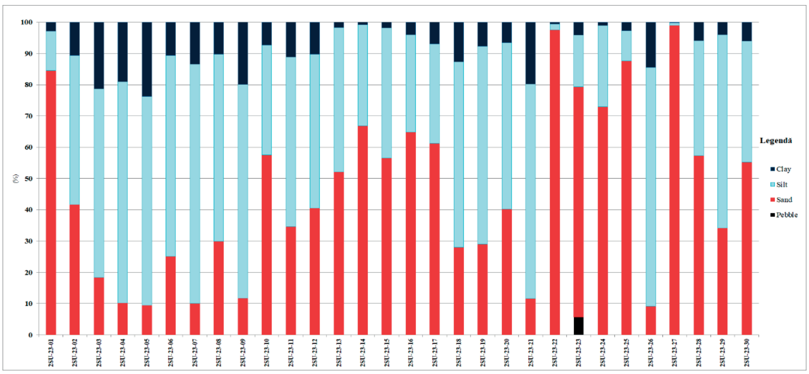

Figure 4. The texture diagram of the sediments in October 2023

Along the former meanders the sediments are composed of sandy silts, with the clayey fraction subordinate to the silty one. Sample SU-23-17 is the only one with a sand content above 50%. The most common textural category is sandy silt. Among the silt subfractions, medium silt is the most representative, and in the case of sands, the medium sand subfraction. The mean and median values are positive (maximum of 6.45Φ). The standard deviation, which has values between 1.74 and 2.51, indicates weak to very weak particle sorting. The asymmetry has predominantly positive values, covering the range between -0.02 and +0.47, and the Kurtosis is platykurtic – mesokurtic.

In the lakes, the sediments are composed of sands, with subordinate fractions of mud and shelly material. The sand percentages are mostly due to existing plant fibres. Among the sand subfractions, very fine sand predominates. The mean and median values are positive (maximum of 4.16Φ). The standard deviation, which has values between 1.67 and 2.15, indicates relatively good sorting to poor particle sorting. The asymmetry has predominantly positive values, covering the range between -0.03 and +0.31 and the Kurtosis is in the platykurtic – leptokurtic interval.

Photo 2. Bottom sediments sampled in October 2023 from the Bogdaproste canal (sample SU-23-14) and the from the Sulina Canal (sample SU-23-27)

Along the canals, sandy silts have been identified, with the clayey fraction subordinate to the silty one, but also from silty sands, in fewer cases. The most common textural categories are sandy silt and silty sand. Among the silt subfractions, in general, medium silt is the most common, and in the case of sands, the very fine and coarse subfractions are the most representative, in most cases. The mean and median values are positive (maximum 6.22Φ). The standard deviation, which has values between 1.47 and 2.65, indicates weak to very weak particle sorting. The asymmetry has predominantly positive values, covering the range between -0.05 and +0.38. The Kurtosis is platykurtic to extremely leptokurtic.

The lithological content of the bottom sediments. The overall composition of sediments includes several primary constituents such as water (moisture) content, organic matter, carbonates, and inorganic (minerogenic) content.

Lithological identification of the main sediment components (total organic matter, carbonate content, and siliciclastic fraction) is essential for studying aquatic sediments, providing relevant complementary information on a variety of factors related to environmental changes (hydrology, watershed weathering, water level, pollution, human activities), including evidence about the formation, deposition, and evolution of the sedimentary environment (sedimentation dynamics).

In May 2023, the sediment samples taken from the Sulina Canal (SU-23-03, SU-23-04, SU-23-21, SU-23-22, SU-23-25, and SU-23-27), from the former meanders (SU-23-05, SU-23-08, and SU-23-17) and lateral channels (SU-23-01, SU-23-09, SU-23-16, SU-23-18, SU-23-28, and SU-23-30) are characterized by a relatively higher level of siliciclastic content (SIL%), with values more than 30% of the total dry sediment weight (Table 1, Figure 5). The siliciclastic component (SIL%) has values included in a wide range, respectively 6.05-90.35%, and the average value is 51.43%. The highest value (90.35% SIL) was recorded in station SU-23-25 (Sulina Canal at Mm 10 + 800), and the lowest value (6.05% SIL) was observed in station SU-23-15 (Răducu Lake).

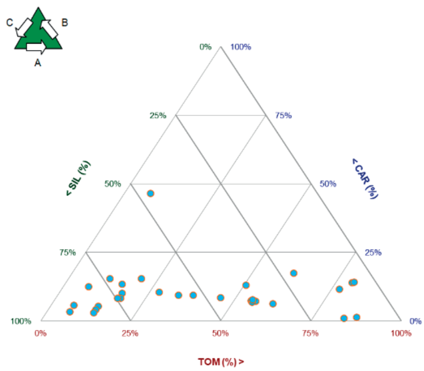

Figure 5. The lithological constituents (%) of the sampled sediments in May 2023 (siliciclastic fraction - SIL, total carbonates - CAR and total matter - TOM)

Instead, the sediment samples taken from various locations along the former meanders (SU-23-06, SU-23-07, SU-23-08, SU-23-19, SU-23-20, and SU-23-26), canals as Gârla lui Eracle, Magearu Canal (SU-23-11, SU- 23-12, SU-23-29), and lakes (SU-23-10, SU-23-13, SU-23-14, and SU-23-15), are characterized by a very high contribution of organic matter, with values over 30% of the total weight of the dry sediment (Table 1, Figure 5).

Table 1. The results of the lithological analyses, May 2023

Sample	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
SU-23-01	18.77	81.23	17.54	10.03	72.43
SU-23-02	14.56	85.44	33.49	9.43	57.08
SU-23-03	10.16	89.84	13.21	5.37	81.41
SU-23-04	12.82	87.18	11.42	15.44	73.14
SU-23-05	29.25	70.75	7.10	12.40	80.50
SU-23-06	16.23	83.77	54.64	7.28	38.08
SU-23-07	24.25	75.75	45.64	8.53	45.83
SU-23-08	26.42	73.58	37.64	9.32	53.04
SU-23-09	28.30	71.70	15.87	13.43	70.70
SU-23-10	23.51	76.49	61.51	17.41	21.08
SU-23-11	20.69	79.31	61.21	6.30	32.49
SU-23-12	23.93	76.07	50.35	13.08	36.57
SU-23-13	26.07	73.93	79.43	13.89	6.68
SU-23-14	28.02	71.98	77.08	11.49	11.42
SU-23-15	23.10	76.90	79.83	14.12	6.05
SU-23-16	18.48	81.52	27.52	10.53	61.94
SU-23-17	17.67	82.33	7.19	46.58	46.23
SU-23-18	25.04	74.96	20.25	15.42	64.34
SU-23-19	25.73	74.27	56.09	7.10	36.80
SU-23-20	22.44	77.56	55.21	6.84	37.95
SU-23-21	11.28	88.72	13.16	4.12	82.73
SU-23-22	12.78	87.22	*6.35*	5.68	87.97
SU-23-24	18.18	81.82	*83.67*	0.90	15.43
SU-23-25	16.31	83.69	*6.36*	3.29	90.35
SU-23-26	18.79	81.21	*54.90*	7.77	37.33
SU-23-27	9.34	90.66	*13.22*	2.88	83.90
SU-23-28	12.98	87.02	*18.05*	8.19	73.76
SU-23-29	24.89	75.11	*86.97*	1.40	11.63
SU-23-30	19.45	80.55	*17.10*	8.21	74.70
Minimum value					
Maximum value					

The distribution of organic matter in the investigated samples has values within a wide range of variation, namely 6.35-86.97% TOM and an average value of 38.35% TOM. The highest value (86.97% TOM) was measured in station SU-23-25 (Magearu Canal), and the lowest value (6.35% TOM) was observed in station SU-23-25 (Sulina Canal Mm 8 +500).

The variation range of carbonates is wide, presenting different values ($CaCO_3 \leq 10\%$; $10\% < CaCO_3 \leq 30\%$) of the total dry sediment weight, respectively, values in the range 0.90-46.58% CAR, with an average value of 10.22% CAR.

The highest value (46.58% CAR) was recorded in station SU-23-25 (meander "Big M"), and the lowest value (0.90%CAR) was observed in station SU-23-25 (Dovnica Canal). Based on the results obtained, the analyzed sediments evidenced mixed sediments ranging from mineral-rich sediments (>15-30% SIL), subsequently followed by organic-rich sediments and a variable carbonate content, as non-carbonated sediments ($CaCO_3 \leq 10\%$) or low calcareous sediments ($10\% < CaCO_3 \leq 30\%$). The high carbonate content found in a single sample in the station SU-23-25 is attributed to the abundant biogenic material (shells, shell fragments and shelly detritus).

In October 2023, it was observed that the sediment samples from the locations located on the bed of the Sulina Canal (SU-23-03, SU- 23-04, SU-23-21, SU-23-22, SU-23-23, SU-23-25, and SU-23-27), channels as Crânjală (SU-23-01, SU-23-02), Șontea (SU-23-09), Dovnica (SU-23-24), and Caraorman (SU-23-28), "the Big M" meanders (SU-23-05, SU-23-08, and SU-23-17) and Fortuna Lake (SU-23-10), are characterized by a relatively higher level of siliciclastic content (SIL%), with values more than 30% of the total dry sediment weight (Table 2, Figure 6). The siliciclastic component (SIL%) has values in a wide range, respectively 4.57-90.96%, and the average value is 51.30%. The highest value (90.96 %SIL) was measured on the Sulina Canal at Mm 16+000 (SU-23-27), and the lowest value (4.57 %SIL) was identified on the Răducu Lake (SU-23-25).

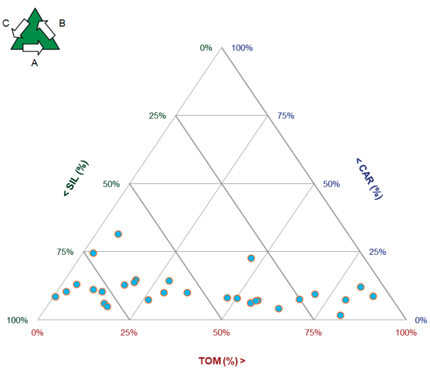

Figure 6. The lithological constituents (%) of the sampled sediments in October 2023 (siliciclastic fraction - SIL, total carbonates - CAR and total matter - TOM)

Carbonates have a wide range of variation, presenting different values (CaCO3≤10%; 10%<CaCO3≤30%) of the total dry sediment weight, respectively, values in the range of 1.72-31.52% CAR, and an average value of 10.73 %CAR. The highest value (31.52% CAR) was recorded in station SU-23-25 (on the Sulina Canal), and the lowest value (1.72% CAR) was found in station SU-23- 29 (Magearu Canal).

Table 2. The results of the lithological analyses in October 2023

Sample	WC (%)	DM (%)	TOM (%)	CAR (%)	SIL (%)
SU-23-01	20.45	79.55	2.53	10.40	87.08
SU-23-02	16.47	83.53	17.03	12.89	70.07
SU-23-03	16.88	83.12	15.00	6.03	78.97
SU-23-04	15.79	84.21	2.79	24.68	72.53
SU-23-05	24.98	75.02	26.30	7.33	66.38
SU-23-06	19.03	80.97	47.25	8.22	44.53
SU-23-07	25.08	74.92	50.14	8.07	41.79
SU-23-08	23.36	76.64	35.57	10.15	54.28
SU-23-09	24.33	75.67	19.29	14.79	65.92
SU-23-10	21.68	78.32	9.43	11.28	79.29
SU-23-11	15.73	84.27	54.57	6.32	39.11
SU-23-12	14.73	85.27	46.53	22.63	30.84
SU-23-13	18.89	81.11	81.58	12.15	6.27
SU-23-14	14.25	85.75	70.46	9.44	20.09
SU-23-15	14.86	85.14	86.68	8.75	4.57
SU-23-16	16.99	83.01	67.19	7.65	25.16
SU-23-17	16.62	83.38	29.23	10.09	60.68
SU-23-18	14.78	85.22	79.84	7.34	12.82
SU-23-19	14.54	85.46	54.67	6.24	39.09
SU-23-20	14.12	85.88	56.09	7.24	36.67
SU-23-21	21.14	78.86	19.25	13.85	66.90
SU-23-22	9.52	90.48	16.46	4.92	78.62
SU-23-23	19.73	80.27	6.01	31.52	62.47
SU-23-24	29.11	70.89	28.42	14.48	57.10
SU-23-25	19.60	80.40	4.04	13.16	82.80
SU-23-26	20.93	79.07	55.60	7.13	37.27
SU-23-27	22.87	77.13	0.44	8.60	90.96
SU-23-28	16.84	83.16	12.23	10.40	77.36
SU-23-29	21.64	78.36	81.32	1.72	16.96
SU-23-30	27.12	72.88	63.29	4.29	32.43
Minimum value					
Maximum value					

The content of total organic matter (TOM%) suggests a spatial variability correlated with the location of the sampling stations and the specific local conditions of the transition area between the fluvial and lacustrine environment. For example, the sediment samples situated along the former meanders (SU-23-06, SU-23-07, SU-23-08, SU-23-19, SU-23-20, and SU-23-26), canals (SU-23-11, SU- 23-12, SU-23-16, SU-23-18, SU-23-29, and SU-23-30), and lakes (SU-23-13, SU-23-14, and SU-23-15), are characterized by a very high amount of organic matter, with values over 30% of the total weight of dry sediment (Table 2, Figure 6).

The distribution of organic matter in the investigated samples has values within a wide range of variation, respectively 0.44-86.68% and an average value of 37.97% TOM. The highest value (86.68% TOM) was recorded in station SU-23-15 (Răducu Lake), and the lowest value (0.44% TOM) was observed in station SU-23-25 (Sulina Canal, at Mm 16 +000).

Based on the results obtained (Figure 6), it can be appreciated that the superficial sediments (sediment-water interface) can be included in the domain of mineral-rich sediments (>15-30% SIL), subsequently followed by organic rich-sediments and a variable carbonate content, as non-carbonated sediments (CaCO3≤10%) or low calcareous sediments (10%<CaCO3≤30%). The results of these investigations allowed the recognition of some types of mixed sediments: mineral-rich sediments (>15-30% SIL) and organic-rich sediments (>15-30% TOM), resulting from the local sedimentation conditions, specific to the transition from fluvial to lacustrine environment (sediments with a high content of lithoclastic material – sand, silt, clay and with a subordinate content of organic material). Along with the organic and inorganic content, a bioclastic content is also present, consisting of shells, shell fragments and shelly detritus.

The higher siliciclastic contribution (>15-30%) can be attributed to the allochthonous source (high input of fluvial sedimentary material). Instead, the lower organic matter input (<15-30%) can be attributed to the fluvial, dynamic, active, energetic, dominant natural conditions of the Danube water, which characterize these areas, and do not facilitate a significant accumulation of organic material. In addition, well-aerated/oxygenated waters (high levels of dissolved oxygen content) influence the rate of decomposition of organic matter. Organic matter decomposes much faster when the waters are well aerated, and much more slowly in stagnant waters. On the other hand, it can be appreciated that the superficial sediments taken from certain locations located on tributaries, side channels, and lakes, can be included in the field of organic-rich sediments (>15-30% TOM), subsequently followed by mineral-rich sediments and a variable carbonate content, as non-carbonated sediments (CaCO3≤10%) or low calcareous sediments (10%<CaCO3≤30%).

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

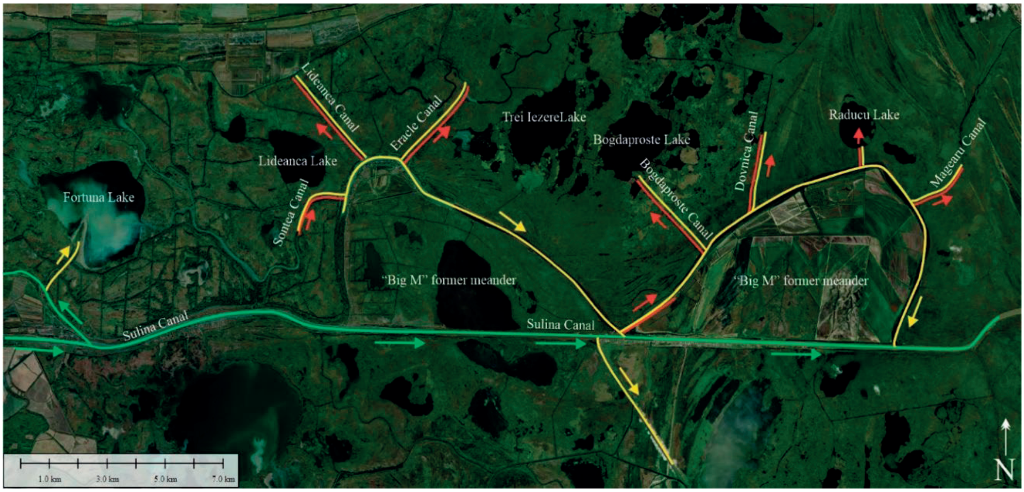

Figure 7. The assessment of the sediment (dis)connectivity in the study area (the main stream in green, in yellow the former meanders and the lateral canals, occasionally disconnected for the main steam at very low discharge and, in red the areas disconnected when the lateral connectivity is lost)

At the Sulina Canal, hydrotechnical works to improve navigation led to disruptions in the exchange of fresh water and sediments between the river arm and the entire delta. The effects were widespread erosion of the main channel and aggradation of the former meanders and side channels. Now, a large number of natural and man-made channels are currently heavily clogged and the sediments accumulated in the bed create sediment blockages and disruptions in the sedimentary transit, especially with the closest lakes as Fortuna, Bogdaproste, Lideanca, Trei Iezere, Răducu Lakes) (Figure 7). Those effects are observed and amplified by climate changes and the anthropic works located upstream, in the basin area.

The lateral connectivity exhibits significant variations both spatially and temporally, in relationship mainly with the water level. Therefore, at low water levels, many areas are isolated from the main distributary producing interruptions of the sedimentary fluxes transfer. Over time, this process tends to separate the former meander channel from the main branch and isolate the interdistributary areas, as is the case of the middle part of the "Big M" meander (Figure 7) where at low waters the connectivity can be completely interrupted. As in a chain process/effect, the partial or complete disconnection of the lateral natural channels from the former meander (red line in Figure 7) can lead to the physical separation of the interdistributary depressions (deltaic lakes).

CONCLUSIONS

The results show the complex distribution of the bottom sediments in the study area. The superficial sediments (sediment-water interface) can be included in the category of mineral-rich sediments (>15-30% SIL), subsequently followed by organic rich-sediments and variable carbonate content, as non-carbonated sediments ($CaCO_3 \leq 10\%$) or low calcareous sediments ($10\% < CaCO_3 \leq 30\%$). That might be the result of the complexity of the deltaic environment characterized by the transition from fluvial to the lacustrine environment (sediments with a high content of lithoclastic material – sand, silt, clay, and with a subordinate content of organic material). An important factor must be related to past human intervention, especially the shortening of the natural course of the river, which led to an increase in the angle of inclination of the anhydrous surface and thus the inability of the mainstream to distribute the water and sediment flows to the delta area. To understand the sedimentological (dis)connectivity in this complex environment, complementary analyses during different hydrological regimes are required.

ACKNOWLEDGEMENTS

This research was financially supported by the Romanian Ministry of Research, Innovation, and Digitization in the framework of the National CORE Programme projects: PN23300304 and PN23300302 (Contract no. 4N/30.12.2022).
The authors thank Stănescu Ion from GeoEcoMar for collecting the sediment samples.

REFERENCES

Baldan, D., Cunillera-Montcusi, D., Funk, A., & Hein, T. (2022). Introducing 'riverconn': an R package to assess river connectivity indices. *Environmental Modelling and Software, 156,* 105470.

Bunn, S.E. & Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management 30*, 492–507.

Constantinescu, A.M., Tyler, A.N., Stanică, A., Spyrakos, E., Hunter, PD., Catianis, I., Panin, N. (2023). A century of human interventions on sediment flux variations in the Danube-Black Sea transition zone. *Front. Mar. Sci.* 10:1068065. doi: 10.3389/fmars.2023.1068065

Crema, S., & Cavalli, M. (2018). SedInConnect: a stand-alone, free and open source tool for the assesment of sediment connectivity. *Computers & geosciences 111*, 39-45.

Dean, W.E. Jr. (1974). Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. *J. Sediment. Petrol., 44(1),* 242-248.

Digerfeldt, G., Olsson, S., Sandgren, P. (2000). Reconstruction of lake-level changes in lake Xinias, central Greece, during the last 40000 years. *Palaeogeography, Palaeoclimatology Palaeoecology*, *158(1-2)*, 65-82.

Duţu, F., Panin, N., Ion, G & Tiron Duţu, L. (2018). Multibeam bathymetric investigations of the morphology and associated bedforms, Sulina channel, Danube Delta. *Geosciences, 8*(7) 8010007.

Duţu, F., Duţu, L., Catianis, I., & Ispas, B-A. (2022). Sediment dynamics and hydrodynamical processes in the Danube Delta (Romania): A response to hydrotechnical works. *Zeitschrift fur Geomorphologie, 64*(4), 365-378.

Duţu, F., Tiron Duţu, L., Catianis, I. (2023). Dramatic reduction of the water and sediment fluxes in a human modified meandering ecosystem from the Danube Delta, Romania. *Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XII*, 267-274.

Folk, R.L. & Ward, W.C. (1957). Brazos River bar, a study in the significance of grain-size parameters. *Journal of Sedimentary Petrology, 27*, 3-26.

Habersack, H., Hein, T., Stanică, A., Liska, I., Mair, R., Jager, E., Hauer, C., & Bradley, C. (2016). Challenges of river basin management: Current status of, and prospects for, the River Danube from a river engineering perspective. *Science of the Total Environment, 543*, 828-845.

Mishra, K., Sinha, R., Jain, V., Nepal, S., & Uddin, K. (2019). Towards the assessment of sediment connectivity in a large Himalayan river basin. *Science of the Total Environment, 661*, 251-265.

Nistor, C., Savulescu, I., Mihai, B-A., Zaharia., L., Virghileanu, M., & Cacablaisa, S. (2021). The impact of the large dams on fluvial sedimentation; the Iron gates reservoir on the Danube River. *Acta geographica Slovenia, 61*(1), 41–55.

Pacioglu, O., Duţu, L., Duţu, F., & Pavel, A.B. (2022). Habitat preferences and trophic interactions of the benthic invertebrate communities inhabiting depositional and erosional banks of a meander from Danube Delta (Romania). *Global Ecology and Conservation, 38*, e02213.

Panin, N. (1999). Global changes, sea level rising and the Danube Delta. *GeoEcoMarina, 4*, 19-29.

Panin, N., Tiron Duţu, L. & Duţu, F. (2016). The Danube delta an overview of its Holocene evolution. *Mediterranée, 126,* 37-54.

Poeppl, R.E., Keesstra, S.D., & Maroulis, J. (2017). A conceptual connectivity framework for understanding geomorphic change in human-impacted fluvial systems. *Geomorphology, 277*, 237–250.

Poeppl, R.E., Fryirs, K.A., Tunnicliffe, J., & Brierley, G.J. (2020). Managing sediment (dis)connectivity in fluvial systems. *Science of the Total Environment, 736*, 139627.

Shepard, F.P. (1954). Nomenclature based on sand-silt-clay ratios. *J. Sediment. Petrol., 24*, 151–158.

Schwenk, J., & Foufoula-Georgiou, E. (2016). Meander cutoffs nonlocally accelerate upstream and downstream migration and channel widening. *Geophys. Res. Lett., 43*, doi:10.1002/2016GL071670.

Smith K.A. & Mullins C.E. (2000). Soil and Environmental Analysis: Physical Methods. Revised and Expanded. New York, NY, USA: Marcel Dekker, Inc. Soil Survey Division Staff (1993). Soil Survey Manual. Washington, DC, USA: United States Department of Agriculture, pp. 651.

Syvitski, J.P.M. (2011). Global sediment fluxes to the earth's coastal ocean. Appl. *Geochemistry, 26*, S373–S374.

Udden, J.A. (1914). Mechanical composition of clastic sediments. *Geol. Soc. Am. Bull. 25*(1), 655–744

Visher, G.S. (1969). Grain-Size Distribution and Depositional Processes. *Journal of Sedimentary Petrology, 39,* 1074-1106.

Walling, D.E., & Fang, D. (2003). The changing sediment loads of the world's rivers. *Global Planetary Change 39*, 111–126.

Wentworth, C.K. (1922). A scale of grade and class terms for clastic sediments, *J. Geol. 30*(5), 377–392.

Zaharia, L., Grecu, F., Toroimac, I.G., & Neculau, G., (2011). Sediment Transport and River Channel Dynamics in Romania – Variability and Control Factors. In: Manning, A. J., editor. *Sediment Transport in Aquatic Environments*. London: IntechOpen. doi: 10.5772/2141.

https://edelta.ro/cote-dunare-365-de-zile)