TRENDS IN LIQUID FLOW AND SEDIMENT DISCHARGE ON SF. GHEORGHE BRANCH – DANUBE RIVER

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ABSTRACT: Trends in liquid flow and sediment discharge on Sf. Gheorghe Branch. The purpose of this article is to identify some trends in the temporal variability of liquid medium flow and solid flow on Sf. Gheorghe branch.

The paper is based on exploiting the liquid medium flow series and the flow of suspended sedimentary discharges (monthly and annual) from three hydrometric stations located on the Sf. Gheorghe Branch. These stations operating periods are: 46 years (Ceatal Sf. Gheorghe station), 42 years (Murighiol station), 47 years (Sf. Gheorghe Port station), but, in order to obtain reliable and conclusive results, it was chosen as the common period of analysis 1971-2012.

In the analysis of temporal variability are used, especially statistical methods, among which the Mann – Kendall test is required for identifying linear trends and its statistical meaning. The methods we have used point towards an increase tendency regarding the liquid discharges (both monthly and annually) and a decrease tendency of the solid discharges.

Keywords: liquid and solid flow, trend analysis, Mann - Kendall test.

1. INTRODUCTION

Sf. Gheorghe branch represents the southern branch of the Danube on its way to reaching the Black Sea. It presents a sinuous course, full of meanders, especially in the part from downstream Mahmudia (km 85) and Small Ivancea (km 18) (Fig. 1).

Five km before the river mouth, Sf. Gheorghe branch has a secondary southern branching, Gura Câinelui, which in turn spreads both north and south.

All sea mouths of these branches are being clogged. Sf. Gheorghe's river mouth varies in depth from 1.50 m to 4.0 m depending on how the wind blows, from sea or land.

The bottom part of the riverbed is composed of fine silt, except the sectors in front of Nufăru and Bălteni villages where the right bank is rocky.

The main morphometric characteristics of the Sf. Gheorghe branch are as follows: catchment area - 975 km2, the total natural length starting from Ceatal until reaching the Black Sea - 109 Km, the length in a straight line across the branch - 68 Km, the length in a straight line from Km 85 (Mahmudia h.s.) until the river mouth - 45 km, the meandering coefficient throughout the branch - 1.6,

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meandering coefficient downstream Km 85 (Mahmudia h.s.) - 1.9; minimum thalweg depth - 3.5 m; average depth throughout the branch - 6.5 m, average width - 280 m, width - 200-500 m.

At its mouth, the branch presents a Vistula type delta with a cone shaped unplaitig of secondary branches. With the help of 3 channels (Lipoveni, Dunavăţ and Dranov) the branch connects to the Razelm - Sinoe lake system (Borcia, 2007).

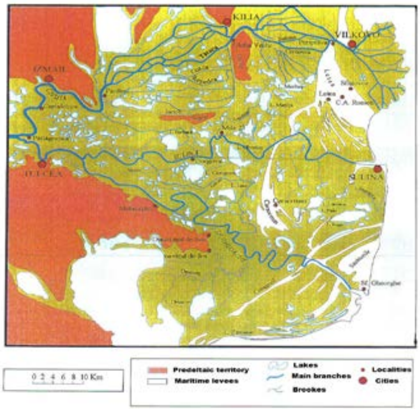


Fig. 1. Sf. Gheorghe branch and Danube Delta

2. DATA AND METHODS

Given the scientific (methodological) and practical (economic) stakes, the objective of this article is focused on identifying trends in temporal and spatial variability of medium liquid flow and of suspended sediments on Sf. Gheorghe branch. The hydrological regime of Sf. Gheorghe branch is controlled by a number of 8 gauging stations (Fig. 2). Mean values of liquid and silt in suspension flow recorded at these stations and times of measurements are shown in Table 1.

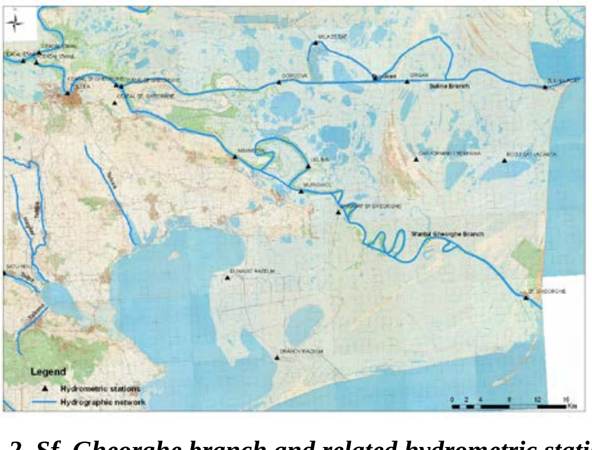


Fig. 2. Sf. Gheorghe branch and related hydrometric stations

To analyze the variability of liquid flow (Q med - cm/s) and of suspended sediments (R - kg/s), from the stations listed in Table 1, only the stations sited on the main course, with a long operating period, were selected. Thus, the analysis was made for the common period, 1971-2012, at 3 hydrometric stations, namely Ceatal Sf. Gheorghe, Murighiol and Sf. Gheorghe Port.

In order to achieve the cartographic material a series of topographic maps, the 1982 edition at a scale of 1: 25 000, were edited. Also used in the analysis were the ArcMap 9.2 extensions and tools used for graphic representations.

The main method used to detect trends in medium liquid flow and suspended sediments (monthly and annual scale) and to establish statistical significance was based on the non-parametric statistical test Mann - Kendall (MK) using the program Makensis 1.0 (Salmi et al. 2002). Mann - Kendall represents an approach that is embraced in climate (Busuioc et al., 2009) and water studies (Burn and Hag Elnur, 2002; Yue et al., 2002, Zaharia and Ioana Toroimac, 2009, Borcan, 2010 Retegan and Borcan, 2011).

Table 1. Morphometric and hydrological characteristics of the network of hydrometric stations associated Sf. Gheorghe branch

River/ Channel	Hydrometric station	Q med (m^3/s)		R (kg/s)	
		Measurement period	Value	Measurement period	Value
Sf. Gheorghe	Ceatal Sf Gheorghe	1967-2012	1590	1967-2012	196
	Mahmudia	1956,1957, 1987,2001-2012	1850	2001-2012	105
	Murighiol	1971-2012	1561	1971-2012	96,1
	Sf. Gheorghe Port	1956, 1957, 1968-2012	1405	1969-2012	148
Dunavăţ	Razelm	1966-1992; 2002, 2004-2012	20,5	1967-1992, 1999-2012	1,06
	Sf. Gheorghe	1957, 1965-2012	83,5	1965-2012	5,11
Dranov	Razelm	1966-1992,2002, 2004-2012	13,3	1967-1992, 1999-2012	0,592
	Sf Gheorghe	1965-2012	20,6	1997-2012	1,26

Source: INHGA, Bucharest

3. RESULTS

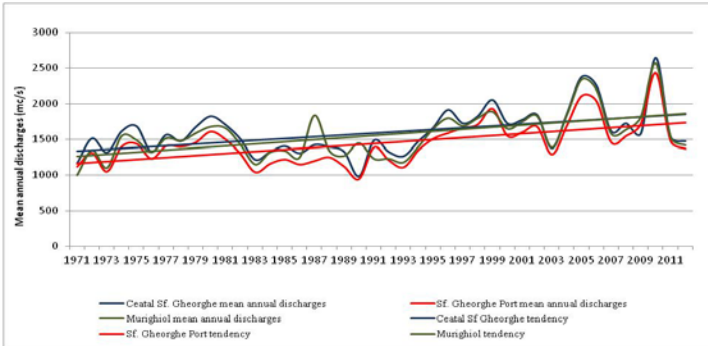
3.1. Liquid flow

Between 1984 - 1988 the main bends on the main course of Sf. Gheorghe branch were cut (Mahmudia - Uzlina – Murighiol loop, between km 84-64 and the loops between km 58.5 - 54.5 and 54 - 49.5). Other dredging works on the channels that cut the remaining bends are: the loop at Ivancea between km 20-16 and the loops from km 44-38 and km 37-29. The effects of these works were felt in the increasing capacity of water transport of Sfântu Gheorghe branch.

With the help of Dunavăţ, Dranov, Palade and Buhaz channels, the Danube Delta area situated south of the Sf. Gheorghe branch receives annual water flow of about 80 m^3/s, of which 78 m^3/s throught Dranov and Dunavăţ channels. Some of the water flows into the Razelm-Sinoe lake system (about 60 m^3/s) and other part into the Black Sea through Ciotic channel and Zătoane mouth.

The loss of water over the banks through the side channels were in average of about 124 m^3/s in the years 1921-1959, 135 m^3/s between 1951-1960 and 183 m^3/s between 1981-1989 (Borcia, 2007). For a summary of the variability of water flow some of its features are shown in figure 3.

Fig. 3. Variability of annual average water flow between 1971-2012 at Ceatal Sf. Gheorghe h.s., Sf. Gheorghe Port h.s. and Murighiol h.s.



By analyzing the figure above, we can observe an increasing trend in annual average flows at the 3 gauging stations studied.

Following the application of the non-parametric MK statistical test, the values of monthly and annual average liquid flows from the mentioned gauging stations (Table 2) at a multi-annual (a) and annual scale (b), the following features have been established:

Table 2. Annual trends in the evolution of the annual liquid flow and the flow of silt in suspension

River	Hydrometric station	Trend (a)
Mean annual liquid flow		
Sf. Gheorghe	Ceatal – Sf. Gheorghe	Increasing (**)
	Sf. Gheorghe Port	Increasing(***)
	Murighiol	Increasing(***)
Mean annual flow of silt in suspension		
Sf. Gheorghe	Ceatal – Sf. Gheorghe	Decreasing (**)
	Sf. Gheorghe Port	Decreasing (**)
	Murighiol	Decreasing

*a - level of significance: ***: a = 0.001, **: a = 0.01, *: a = 0.05; +: a = 0.1. No symbols indicates that the level of significante is greater than 0.1.*

a. *Annual scale*:

- In the region, the trends for the annual liquid flow at the 3 gauging stations analyzed are growing, with different levels of significance (Table 2),
- The highest levels of significance (α = 0,001) are indicated at Sf Gheorghe Port and Murighiol hydrometric stations.

b. *Monthly scale*:

- After applying the Mann – Kendall non-parametric test we can observe an increasing in trends at all the analyzed gauging stations (Table 3),
- Thus, the highest level of significance (α = 0.001) is recorded in March (all three stations) and in April (Sf. Gheorghe Port h.s.),
- The analisys of the largest flows recorded at these stations (first 5 values in the statistic data string for the 1971-2012 period) shows that they have been achieved during the months of April, May and July (Table 4).

Table 3. Average monthly trend in liquid and silt in suspension flow

River	Hydrometric station	T	Months											
		α	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average monthly flow of liquid														
Sf. Gheorghe	Ceatal – Sf. Gheorghe	T	↑	↑	↑	↑					↑	↑	↑	↑
		α	**	*	***	*					+	+	*	+
	Sf Gheorghe Port	T	↑	↑	↑	↑	↑	↑			↑	↑	↑	↑
		α	**	**	***	***	**	+			+	*	*	*
	Murighiol	T	↑	↑	↑	↑	↑			↑	↑	↑	↑	↑
		α	**	**	***	**	*			+	+	*	*	*
Average monthly flow of silt in suspension														
Sf. Gheorghe	Ceatal – Sf. Gheorghe	T		↓		↓	↓	↓						
		α		+		+	*	**						
	Sf Gheorghe Port	T					↓	↓						
		α					**	**						
	Murighiol	T					↓							↓
		α					**							*

Table 4. Maximum liquid flow recorded at Ceatal Sf. Gheorghe, Murighiol and Sf. Gheorghe Port hydrometric stations

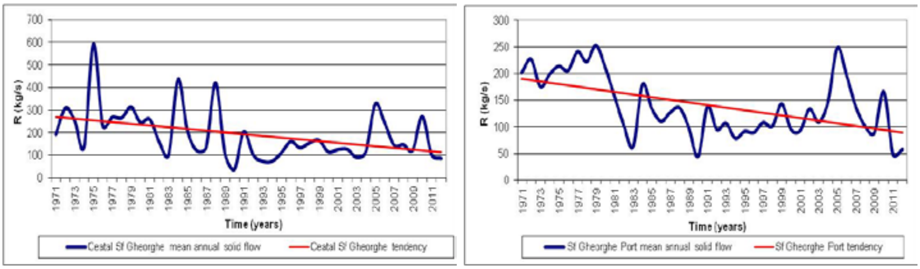
Ceatal Sf. Gheorghe		**Murighiol**		**Sf. Gheorghe Port**	
Q max (m^3/s)	Date	Q max (m^3/s)	Date	Q max (m^3/s)	Date
4440	6.07.2010	4070	12.07.2010	3700	12.07.2010
4040	25, 26.04.2006	3820	25-27.04.2006	3740	25, 27.04.2006
3800	2.05.2005	3730	2.05.2005	2790	21.05.2005
3200	08.05.1999	3020	8.05.1999	2790	08.05.1999
3180	2.04.2000	2920	30.04.2000	2600	30.05.2000
3100	29.04.2004	2980	30.04.2004	2630	6.05.2004

3.2. Solid flow

Sf. Gheorghe branch, on the route between Ceatal Sf. Gheorghe (km 108.9) and Sf. Gheorghe Port (km 8), loses silt through the side channels (Uzlina, Perivolovca, Dunavăţ, Dranov, Ivancea Palade, Buhaz) and through spills over the banks. The annual loss of sediments, for example, have averaged in about 21 kg/s during 1951-1950, approximately 28 kg/s in 1951-1960 and 95 kg/s during 1981-1989.

To illustrate, Figure 4 (*a* and *b*) shows the variability of silt in suspension flow at Sf. Gheorghe Port (km 8) and Ceatal Sf. Gheorghe (km 108) hydrometric stations, for the period under review (1971-2012).

Fig. 4. Variation and trend of silt in suspension flows at Ceatal Sf. Gheorghe (a) and Sf. Gheorghe Port (b hydrometric stations)



The analysis of figure 3 shows that the values of suspended silt flows during the period from 1971 to 2012 have a general downward trend. Since 1992 their values have been under the multi-annual average value of the analyzed period (196,12 kg/s) at Ceatal Sf. Gheorghe hydrometric station. The situation is slightly different at Sf. Gheorghe Port. At this station the suspended silt flows have values falling below the multi-annual average value of the analyzed period (139,74 kg/s), since 1981. In the 2004 - 2006 and 2010 period there is a positive leap recorded in the range of average flow of silt in suspension.

These downward trends have been verified by applying the Mann - Kendall non-parametric test on strings of monthly and yearly suspended silt flows.

After applying this test the following are found in the silt in suspension flows:

a. *Annual scale*:
- Declining trends are recorded at all the analyzed stations (Table 2),
- At Murighiol hydrometric station the downward trend is not statistically significant,
- At Ceatal Sf. Gheorghe and Sf. Gheorghe Port these downward trends have a level of significance of $\alpha = 0.01$.

b. *Monthly scale*:
- As in the annual flow of silt in suspension case, the monthly level values recorded declining trends also (Table 3),

- The most pronounced trends are recorded in February and April (Ceatal Sf. Gheorghe station - $\alpha = 0.1$), May ($\alpha = 0.05$ at Ceatal Sf. Gheorghe station and $\alpha = 0.01$ at Murighiol and Sf . Gheorghe Port stations), June ($\alpha = 0.01$ at Ceatal Sf. Gheorghe and Sf. Gheorghe Port stations) and December ($\alpha = 0.05$ at Murighiol station).

4. CONCLUSIONS

There is a certain tendency of liquid medium flows to increase in time (at a monthly and annually level) at the 3 analyzed gauging stations (Ceatal Sf. Gheorghe, Murighiol and Sf. Gheorghe Port), especially in March.

These increasing trends of liquid flow is mainly due to increasing of the slope by shortening the branch's route due to rectification of meanders, with consequences on the stability of the riverbed, banks and hydraulic works (dams, piers).

Regularization of Sf. Gheorghe branch, made between 1986 - 1992 consisted primarily in gradual correction of the natural riverbed trail by making cuts through six riverbends which reduced its length by 31 km (29%).

Following the execution of regularization works in the riverbed, a downward trend is noticed in the percentage of silt carried by the Sf. Gheorghe branch, pronounced after 1991.

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