IDENTIFYING EROSION AREAS ALONG THE DANUBE ON THE BASIS OF GRAIN-SIZE AND HYDROLOGIC PARAMETERS

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Abstract. This paper aims to localize areas along the Danube where erosion is predominant. It starts with an analysis of previous evaluations of riverbed changes in time, suggesting methods of investigation based on interpreting textural and hydrologic parameters. Making use of grain size analysis performed on 140 sediment samples from the Danube riverbed, the skewness/kurtosis diagram is applied identifying the main points in which erosion or deposition are predominant. Given the lack of data, the method of identifying points where erosion is predominant on the basis of the sediment transport capacity/suspension concentration ratio is only applied for demonstration purposes.

Key words: sediment transport capacity, suspension concentration, skewness, kurtosis

1. INTRODUCTION

One of the most serious effects of building transversal barrages on both the Danube and its tributaries is riverbed erosion. The negative effect of sediments trapped behind the barrage is amplified by the excessive exploitation of riverbed sand, used as building material. Although there have been numerous papers on Danube riverbed morphology, few of them have included a sedimentologic approach to erosion. The present paper attempts to identify areas along the Danube where erosion or sedimentation takes place, by interpreting data resulting from grain-size analysis and flow parameters.

2. PREVIOUS EVALUATIONS OF THE RIVERBED CHANGES

Up to the present the identification of points along the Danube where erosion is predominant has been done by comparing bathymetric profiles separated by considerable time intervals. No particularly clear conclusion on riverbed change tendencies can be drawn from the analysis of transversal morphologic profiles that are 10 years apart from one another (Fig. 1, Fig. 2), because the erosion or sedimentation processes coincide with meander evolution, formation and movement of current undulation, or riverbed dredging.

Erosion is more visible in narrow riverbed sectors (Brăila and Vadu Oii). Analysing a riverbed axis comparative longitudinal profile at an interval of 20 years (Fig. 3) reveals that for the largest section of the Danube course downstream of Iron Gates 2, with the exception of the sector upstream and downstream of the confluence with the river Argeş, the riverbed is 1-2 metres deeper. In the case of a large section of the Danube course downstream of Km.170-Brăila, frequent riverbed dredging meant to keep the canal navigable makes it difficult to use comparative morphologic profiles. The reduction of the values of the Danube's sediment discharge following the building of the Iron Gates 1 and Iron Gates 2 barrages, as shown by statistic data analysis (Fig. 4), is another proof of increasing riverbed erosion in the last decades.

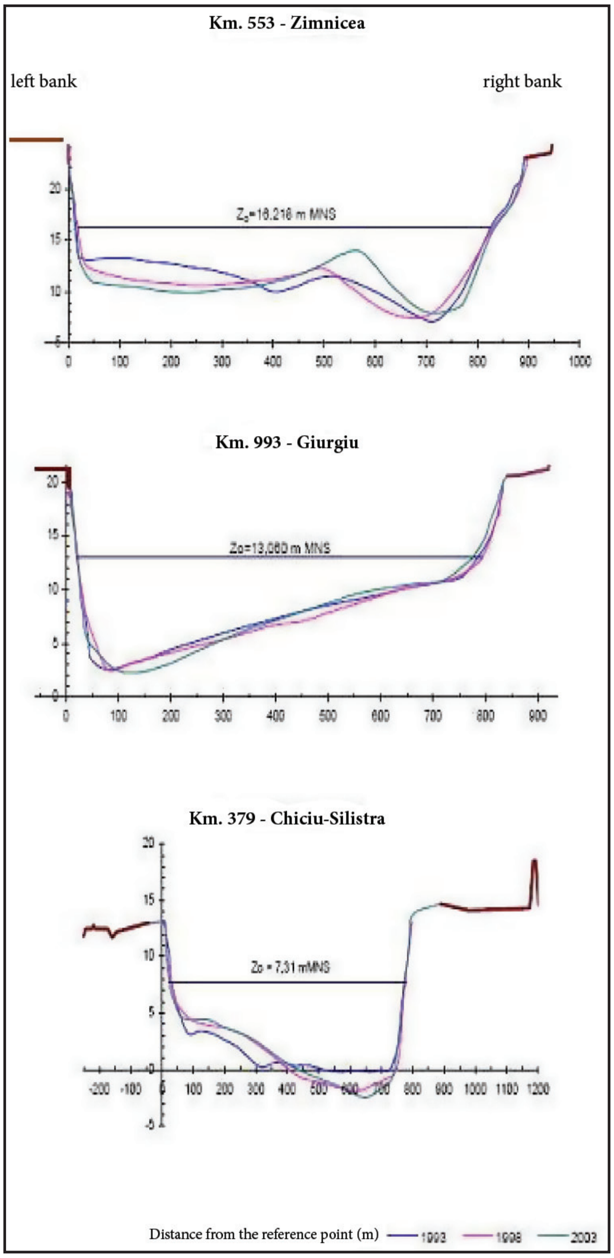

Fig. 1 Comparative morphologic profiles at Zimnicea, Giurgiu and Chiciu-Silistra (measurements made by INHGA)

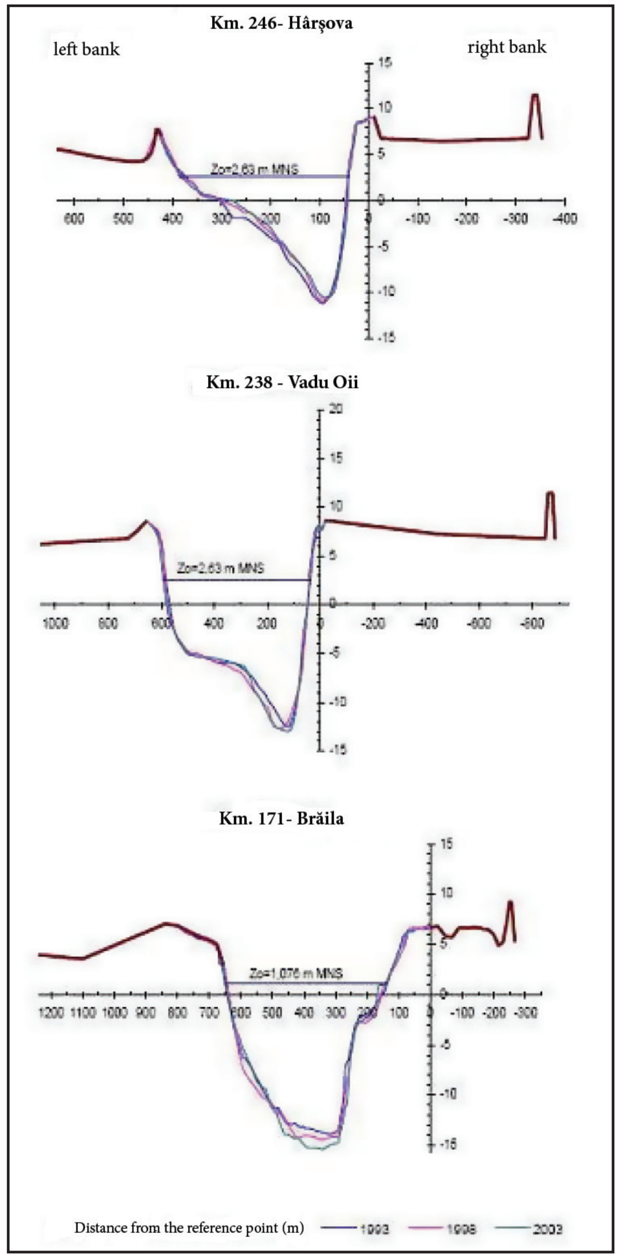

Fig. 2 Comparative morphologic profiles done at Hîrşova Vadu Oii and Brăila (measurements made by INHGA)

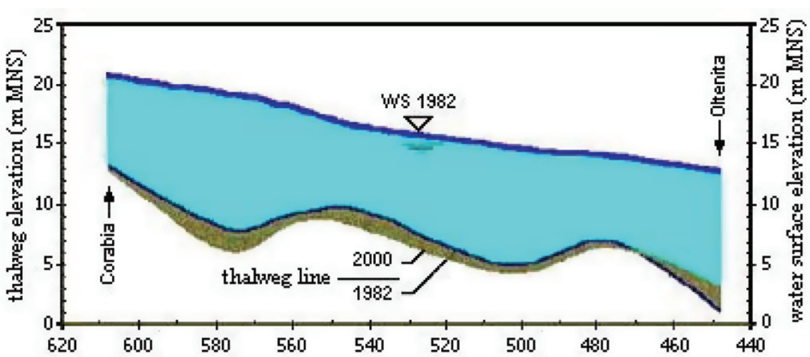

Fig. 3 Morphologic profile on the Danube course between Km. 605 and Km. 450 outlining thalweg features in 2000 compared with 1982 (according to Batuca, 2004)

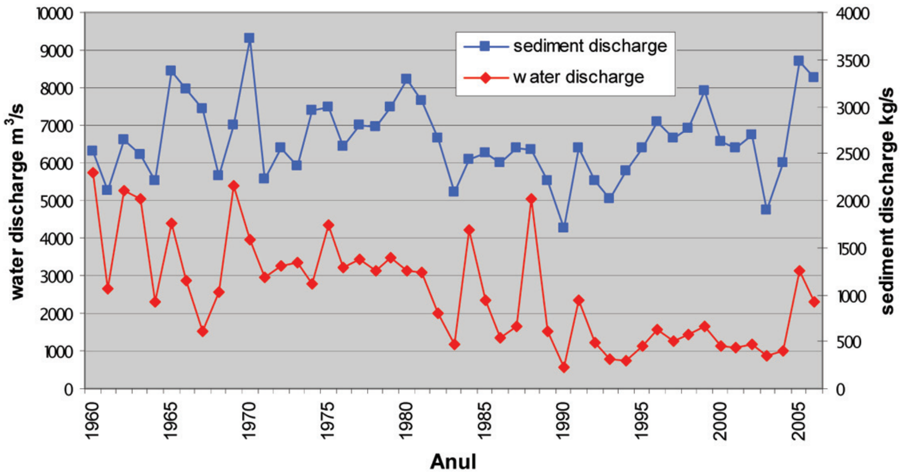

Fig. 4 Variations in the yearly average values of water discharge and sediment discharge between 1960 and 2003, at ML. 44-Ceatal Izmail (statistical data - measurements made by INHGA)

3. MATERIALS AND METHODS

Previous papers focusing on the study of sediments in watercourse beds and their dynamics feature two ways of identifying points of predominant erosion or sedimentation on the basis of interpreting grain-size parameters: applying the skewness/kurtosis diagram and the analysis of the suspension concentration/sediment transport capacity ratio.

The former method was used by Barndorff-Nielsen and Christiansen(1988) who suggested a binary diagram (Fig. 5) to identify areas affected by erosion based on the skewness and kurtosis variation domain, shaped like a triangle. The points projected on the basis of skewness and kurtosis parameters representing sediments from different locations appear in the right half of the triangle in the case of areas affected by erosion, and in the left half in the case of sedimentation. The model was statistically argumented by using sediment grain-size parameters from a large variety of sediment environments ranging from aeolian to alluvial or littoral proven to be characterised by sedimentation or erosion processes. Acknowledging the possible existence of an error, the authors of this model suggest using instead of the bisecting line dividing in two the triangular field of the diagram an empirically drawn curve to separate sediment samples from environments dominated by sedimentation or erosion.

We kept the bisecting line from the original diagram in the case of the diagram applied (Fig. 6). Skewness and kurtosis values are calculated on the basis of grain-size analyses conducted on over 140 sediment samples collected in 2005 from the Danube riverbed starting from Km. 1072-Baziaş to the tributaries' river mouths into the sea. Before projection on the diagram, the samples were separated in several categories according to the area from which they had been collected:

- riverbed axis upstream of the reservoir lake Iron Gates 1 (upper course)
- riverbed axis from Iron Gates 2 to the delta apex (middle course)
- riverbed axis (branches) in the Danube Delta
- points of low water depths in the vicinity of the riverbanks, reservoir lakes excepted
- accumulation lakes (PF1, PF2)

The second method of identifying points dominated by erosion or sedimentation is based on calculating sediment transport capacity. Several studies on sediment river transport (Dou, 1974; Milhous, 2003) showed that erosion occurs when suspension concentration values are lower than suspension transport capacity values. The concept is based on the assumption that if water masses are not alluvia saturated, they can move riverbed particles. According to this concept sedimentation occurs when water speed decreases and suspension transport capacity is lower than suspension concentration.

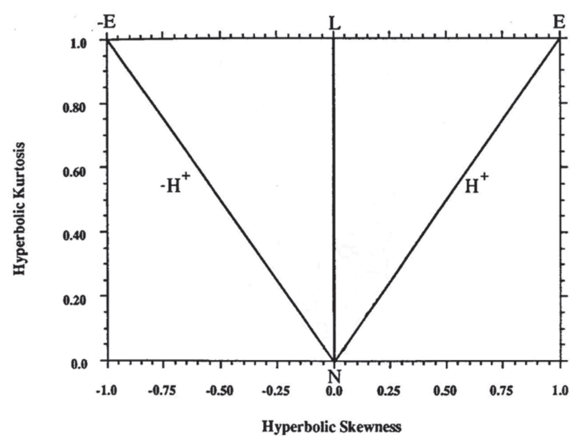

Fig. 5 The original diagram representing the triangular variation domain of skewness and kurtosis values. The N, E, -E points represent the possible limits of distribution according to Barndorff-Nielsen, Christiansen, 1988)

Once suspension concentration values determined on location are available, the only difficulty in the case of the Danube river is raised by calculating sediment transport capacity. In order to estimate transport capacity expressed in the same units of measurement as suspension concentration (g/m^3) we used the formula devised by Dou, G.R., 1974 (original term – STC Sediment Transport Capacity)

$$STC = \frac{f_0 \cdot U^3}{gH\omega}$$

Where U = *average velocity*, H = *flow depth*, ω = *sedimentation velocity*, f_0 = *coefficient* calculated by means of the following formula:

$$f_0 = \frac{K_S}{C_0^2} \cdot \frac{yy_S}{(y_S - y)}$$

where
Ks = *constant* (0.034),
C_0 = *adimensional coefficient*
$C_0 = C/(g)^{0,5}$
C = *Chezy coefficient*,
γ and $γ_s$ = *specific weight of water and solid particles.*

Particle sedimentation velocity was calculated by means of Cheng's formula(1997):

$$\omega = \frac{u\left(\sqrt{\left(25 + 1.2D.^2 - 5\right)^{1.5}}\right)}{D}$$

where D.= *adimensional coefficient* calculated by means of the following formula:

$$D. = \left(\frac{\Delta g}{u^2}\right)^{\frac{1}{3}} D$$

where

$$\Delta g = \frac{(y_S - y)}{y}$$

υ= cinematic viscosity D = average particle diameter

In the STC formula, grain size is an important parameter being expressed in terms of the average diameter of riverbed particles and particle sedimentation velocity. Apart from riverbed sediment particle size, the STC formula also makes use of gradient values (which are taken into account when calculating the Chezy coefficient) and water velocity. Taking into account the fact that some of the parameters in the STC formula (average velocity, median diameter) vary according to depth, very rigorous calculations should be made for several points of the same profile. Another problem that can exist when applying this method consists in the difficulty of comparing STC with suspension concentration, as both of them vary in time. Given the lack of data the calculations were only made for riverbed axis points and are only valid for the period when the samples were collected and the hydrological measurements made (the March-April 2005 campaign).

4. ANALYSIS AND DATA INTERPRETATION

On the skewness/kurtosis diagram, most of the points representing samples collected from the riverbed axis between Iron Gates 2 and the delta apex and uphill of Iron Gates 1 Lake are projected in the right half of the triangle, indicating the predominance of sediment erosion. Several points of the riverbed axis at Km. 247-Hîrşova and Km. 428 downstream of the river Argeş where the analysis of bathymetric profiles reveals a slight decrease in riverbed depth confirm the predominance of sediment deposits. Further samples that are projected in the "deposition" half are those from the riverbed axis at Km. 239-Vadu Oii for which bathymetric profiles show a slight erosion and Mile 78 for which bathymetric profiles cannot be used, the sector also known as the Marine Danube (Brăila-B.Sulina) being frequently dredged. Points representing sediment samples from Iron Gates 1 reservoir lake, where the deposition phenomenon is proved by sedimentation rates (Panin *et al.* 1995), and from the last part of Iron Gates 2 lake are projected in the "deposition" field, (in the vicinity of the erosion-deposition limit NL in the original diagram). There are several points in the Km. 878 profile 14 km upstream of Iron Gates 2 barrage which are projected in the right half of the diagram indicating erosion. Sediment circulation and deposition in Iron Gates 2 lake differ from Iron Gates 1 lake because most of the alluvia are blocked by the Iron Gates 1 barrage (Opreanu *et al.*, 2007). It must be noted that the authors devised the model for the situation in which erosion or sedimentation change the grain-size distribution of existing sediments by introducing or extracting some particles. In the case of reservoir lakes there is an uniform sedimentation at least in the vicinity of the barrages and to a lesser extent a layering of fine particles over coarser sediments. In the Danube Delta the model cannot be applied in the case of locations such as Ceatal Izmail (Mile 44, Mile 42, Km.115-Chilia branch) and Mile 33.5, because fluvial sediments have been frequently removed from the riverbed axis and what can be found is hard clay and very small quantities of sand (Opreanu, 2008). Applying the diagram in these cases erroneously reveals a deposition phenomena because the hard clay in which the riverbed is dug is frequently characterised by positive skeweness. Riverbed axis locations from the profiles before the sea mouths of each branch (Km. 3-Chilia branch, Musura branch, Km.72-Sulina branch and Km.1.3-Sf. Gheorghe branch) are projected in the left half of the diagram indicating sedimentation. In some of these points, deposition phenomena are confirmed by riverbed dredging(at Km. 72-Sulina branch the channel is frequently dredged). In the case of some Danube Delta points: Mile 34-Tulcea branch, Km. 108-Sf. Gheorghe branch, Km. 43 and Km. 20-Chilia branch, skewness values close to zero indicate a constant riverbed depth that cannot be checked by means of other methods. According to the diagram, the samples collected from lateral riverbed sides of the entire course, where depth varies, can be included in either erosion or deposition areas.

According to the STC transport capacity values and suspension concentration values ratio (Fig. 7), the model allows the identification of sectors where erosion or deposit processes are predominant. The graph suggests that for the greatest part of the Danube course current transport capacity is clearly superior to suspension concentration, which demonstrates erosion. The STC and suspension concentration ratio clearly indicates erosion in Danube course areas downstream of Iron Gates 2 barrage for which comparative bathymetric profiles and the previous skewness-kurtosis diagram indicated erosion. STC values thus range from 175 to 350 g/m^3, whereas suspension concentration values fit in the 60-190 g/m^3 interval. The graph was drawn only in the case of Chilia due to the higher number of profiles on this branch. In most riverbed axis points throughout the delta differences between STC and suspension concentration are too small to be taken into consideration.

The reduced number of locations that the model considers to belong to sedimentation areas are characterised by very small differences between the two parameters. For points where erosion is indicated, the relatively high number of locations and the concordance with the other methods can prove the model's validity and applicability. Thorough calculations require data resulting from measurements separated by the shortest time intervals possible.

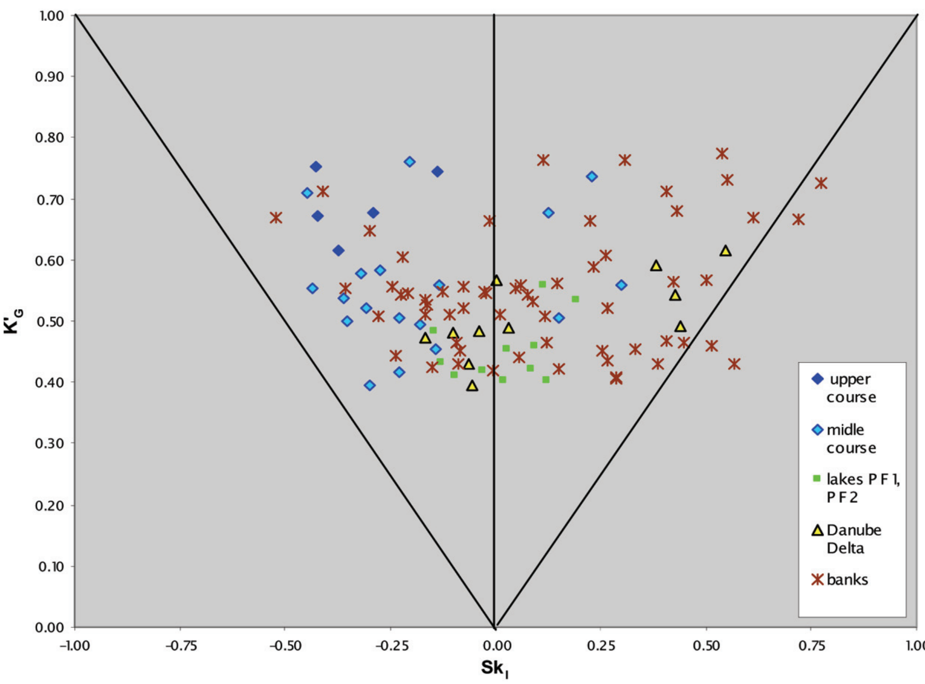

Fig. 6 Kurtosis-Skewness diagram with projection points representing Danube course sediments

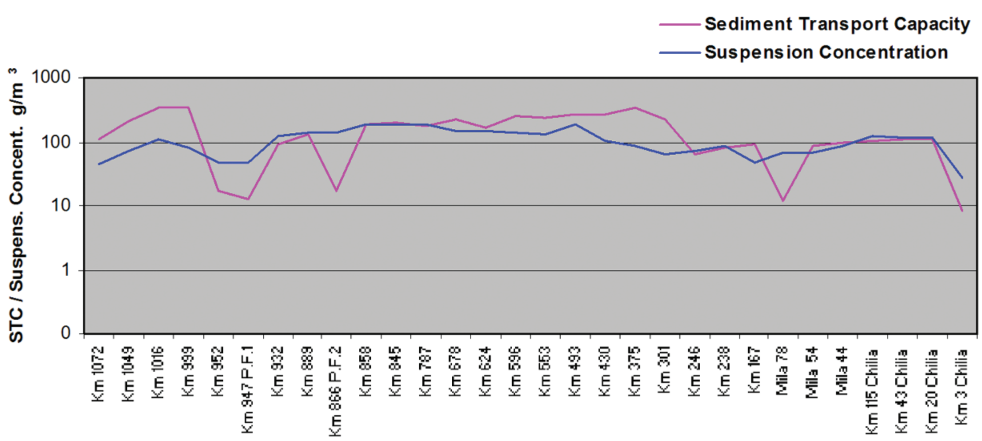

Fig. 7 The distribution of sediment transport capacity values in parallel with suspension concentration calculated in maximum depth points along the Danube course during the 2005 spring campaign.

5. CONCLUSIONS

Although the increase in Danube riverbed erosion has been proved, the complexity of fluvial environment dynamics makes it very difficult to separate areas with predominant erosion from areas with predominant sedimentation. Comparative bathymetric profiles that did not cover the entire course have provided information concerning changes in time at the level of riverbed morphology and have established the predominance of erosion or sedimentation processes for limited areas. The interpretation of grain-size results, which are easier to obtain than bathymetric measurements repeated at large intervals of time confirms the predominance of erosion processes especially in the riverbed axis downstream of Iron Gates 2. The similar results obtained by means of the three methods, the analysis of morphologic profiles, the skewness/kurtosis diagram and the analysis of the STC/suspension concentration ratio, confirm the validity of each of them. The ambiguous results obtained in a high number of locations does not invalidate the three methods but the possibility that erosion or sedimentation can alternate in the same point according to fluctuations in hydrologic parameters. It must be noted that the STC/suspension concentration method which was used for demonstration purposes cannot be regarded as a very solid argument in the absence of detailed measurements but could constitute in the future a stating point for a more complex study.

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