https://doi.org/10.1051/e3sconf/20184004023

Questions in the quantitative analysis of sediment load - example of three major rivers in Hungary

Enikő Anna Tamás[1,*], and *Johanna* Ficsor[2]

[1]National University of Public Service, Faculty of Water Sciences (NUPS FWS) Institute for Hydraulic engineering and Water management, H-6500 Baja, Hungary

[2] National University of Public Service, Faculty of Water Sciences (NUPS FWS) Institute for Hydraulic engineering and Water management, H-6500 Baja, Hungary

Abstract. The importance of the monitoring of sediment processes is unquestionable: sediment balance of regulated rivers suffered substantial alterations in the past century, affecting navigation, energy production, fish habitats and ecosystems alike. The changes in flood characteristics and rating curves of our rivers are being researched and described, involving state-of-the-art measurement methods, modeling tools and traditional statistics. Sediment processes however, are much less known. Sediment-related research is scarce, which is partly due to the outdated methodology and poor database background in the specific field. Regular sediment sampling was developed in the first half of the 20th century, with different station density and monitoring frequencies in different countries. Sampling frequency of suspended load is 3 to 7 per year in Hungary, and even lower for the bed-load, not only on the Danube river but also on large tributaries like the Drava and the Tisza rivers. Data related to sediment quantity are unreliable and often contradictory. It is difficult to produce high quality long-term databases that could enable the calibration of sediment transport models. It is a challenge to compare measurements on international rivers. The authors give an overview of sediment sampling methods, an inventory of the available datasets and data management in Hungary on the rivers Danube, Drava and Tisza, based on field data.

1. Introduction

The most important parameters describing fluvial sediment transport are sediment load, Q_s, meaning the amount of sediment (volume or mass) passing through a given cross-section during a specified time; sediment yield, G_s, which is the mass of sediment passing by during a specified period of time; and, for suspended sediments, sediment concentration, c_s, which is the ratio of the mass of sediment and the volume of the water in which it is contained.

Precise information on suspended sediment loads is required for many purposes. Usually, the sediment loads of rivers and streams are evaluated by a sediment sampling programme

* Corresponding author: tamas.eniko.anna@gmail.com

to describe the variation of sediment concentration with time [1], as a result of which, based on protocols, sediment load and concentration can be calculated. It is essential to estimate the correlations between flow characteristics and sediment parameters, for different water regime conditions. A generally and widely used way to achieve this has been to draw up sediment rating curves [2], i.e. to derive a relationship between sediment concentration or load and stream discharge, and this is applied to the streamflow record to estimate sediment transport. The sediment rating curve technique has the advantage that once a transport relationship has been developed, it can be applied to past streamflow data to reconstruct long-term sediment records, although the necessary assumptions of stationarity may sometimes need to be questioned. Critical evaluation of the data and appreciation of the limitations of the sediment rating curve method are required. A suspended sediment rating curve is usually presented either as a suspended sediment concentration/streamflow or a suspended sediment discharge/streamflow relationship [1].

1.1. Introduction to the case studies

Sediment monitoring in Hungary started as early as the end of the 19th century, with scattered measurements carried out. Regular sediment sampling was developed until the end of the 1950's. After the first few decades of regular sampling, the concept of (mainly industrial) development and data needs changed as well, and the complicated and inexact methods of sampling bed load were not developed further.

Nowadays – due to the increased interest in waterway development – some detailed but occasional surveys were carried out. The analysis of these data was executed in frame of projects, but as these sampling campaigns are rare and contrained to short river reaches, in our study we only used the data collected at regular monitoring sections [3].

1.1.1. Danube river, Dunaújváros station

The Danube is the second largest river of Europe and the largest in Hungary. Dunaújváros is located at the 1580,6 rkm of the river Danube, near the upstream end of the originally meandering alluvial reach of the river. Measurements have taken place at this station since the 1950's. There is usually a parallel discharge measurement associated with sediment sampling. Bed-load and bed material samples were collected between 1950 and 1958 [3].

1.1.2. Tisza river, Szolnok station

The Tisza is a major left-bank tributary of the Danube, one of the main rivers of Central Europe. It joins the Danube in Serbia. The Szolnok gauge is at the 334,60 flow km of the river. Apart from a few sampling campaigns in 1891 and 1901, regular sampling and the development of the sediment monitoring activities was started in 1942 with the lead of J. Bogárdi. Regular monitoring started in 1978, and there is only suspended load sampling [4].

1.1.3. Drava river, Barcs station

The Drava river is an important right-bank tributary of the middle section of the Danube. It joins the Danube in Croatia. Barcs is situated at river km 154,1. Sediment transport data collection started in 1961 at Barcs station [5]. Sediment investigation of the Drava River in recent times included different sampling campaigns as well as regular monitoring activities of both Hungarian and Croatian water management bodies. Regular monitoring only includes suspended load sampling. Bed-load and bed material samples are occasionally collected.

1.2. Sediment sampling methods used

In the following, the method of suspended sediment sampling in Hungary is described.

The most effective way of sampling suspended load is with a pump. An advantage is that it is not needed to regain the sampler onboard between the points. Thus, this method is the fastest, which is an issue, particularly at high velocities and when sampling is done in the navigation route. During sampling it is very important to ensure that the sampling nozzle faces the flow, the pipe is not bent and to let enough time before taking samples to flush the pipe. Sampling needs to be carried out with care to adjust the revolutions per minute value (RPM) or the discharge of the pump for the velocity through the nozzle V_{in} should not differ much from the velocity of the flow v at the given point:

$$0{,}8\mathrm{v} \leq V_{in} \leq 1{,}5\mathrm{v}$$

In case the velocities are outside this range, the RPM of the pump should be accordingly adjusted, or a tap should be installed at the end of the pipe to ensure that intake velocities match. In order to determine intake velocity, the discharge of the pump (qp) has to be divided by the cross-section area of the nozzle (fn):

$$v_{in} = q_p / f_n$$

In practice, we perform sampling with a constant pumping discharge, assigning a fixed intake velocity to different velocity ranges of the flow, keeping the hydraulic coefficient between the values 0.8 and 2.0. This ensures a maximum 20 % difference in concentrations, which is acceptable.

The samples are then analysed for concentration and grain size distribution in a laboratory.

2. Data and data quality

Sampling is carried out in frame of a regular monitoring programme by the Water Directorates, and the data used in the present article were provided by them. On the Drava river there is a parallel monitoring activity in Croatia as well, but we didn't use Croatian datasets, because of possible inhomogeneity issues. In Croatian methodology, for example, it is a common practice to determine suspended load concentrations from a single, near-surface sample [6].

In 2015, we surveyed the different sampling methodologies of Hungarian Water Directorates in a diploma thesis [4] in a questionnaire. Out of 12 Water Directorates in Hungary only 8 perform regular sediment sampling, and bed-load is only sampled at 2 Water Directorates (both on Danube river).

Suspended load sampling is regular but rare in the country (5 to 12 samples a year), and it is not harmonized in time and to flood events. The number of sampling verticals and points differ at the different stations and on the different rivers. Water Directorates only investigate grain size distribution averaged per vertical.

It is not common to survey the cross-section and measure the discharge when sampling sediment. Sampling is done with different pump samplers. Laboratory analysis is subcontracted to different firms, and analysis and use of the data collected is rather occasional.

The above facts describe well that sediment datasets in Hungary are of rather questionable quality.

3. Analyses

Using the data series provided by the Water Directorates, we performed basic quantitative analyses and have set up the rating curves of suspended sediment, furthermore aimed at the estimation of yearly sediment yields and their changes over time.

First we give the basic statistical characteristics of the data series used in the present study, summarized in Table 1.

Table 1. Characteristic values of suspended sediment load (Qss; g/s) and concentration (css; g/m^3) data series on the three major Hungarian rivers

Station name	rkm	Data series beginning	Data series end	N	type	min	max	avg	std dev
Dunaújváros Danube	1580,6	1950	2017	302	Q_{ss}	8320	1908549	124667	210493
					c_{ss}	7	422	41	42
Szolnok Tisza	334,6	1987	2016	550	Q_{ss}	532	3929877	79282	228991
					c_{ss}	6	1196	84	124
Barcs Dráva	151,4	1991	2016	164	Q_{ss}	697	198158	22161	27617
					c_{ss}	3	182	33	31

It can be seen from the table (Table 1) that the differences in the minimum and maximum values are very big, and the standard deviations are as great as, or even greater than the average. This suggests that the data series is still too short, it does not cover the extremities well. It doesn't represent well the examined phenomenon. However, a correlation between the discharge (Q, m^3/s) and the suspended sediment load (Qss, g/s) was sought for and is given in Fig. 1 to 3.

It can be seen from the figures (Fig. 1-3.) that the number of sediment samplings over the investigated period is relatively low and does not cover the high waterlevel range sufficiently to establish a reliable correlation between sediment concentration and discharge. Sediment sampling during high dicharges can be difficult. As floodwaves are usually short, the time interval between flood forecast and the occurence of the peak waterlevels is sometimes too short to organize measurements. It is also to be noted that navigating and anchoring a measurement boat on the river, and particularly in the floodplain during high waterlevel can also be dangerous or even impossible because of the high velocities [7], and because the floodplains are usually much overgrown. For the Tisza river, floodplain measurements were only seldom carried out with appropriate sediment sampling in the floodplain. For the above reasons, we re-plotted the correlation for the Szolnok station using the data which represent the samplings carried out when no overbank flow occurs (Fig. 4) and the correlation is much better.

For all the stations examined, a power function ($c_k = a\ Q^b$) was found to fit best.

Another consideration to improve correlations is to distinguish between steady and non-steady flow in order to take the hysteresis effect into account. This, however, is not possible in the case of the Drava river, where changes in waterlevels during sediment sampling were not recorded. For the Danube and Tisza rivers, the plots are visualized in Fig. 5 and 6.

It can be seen in the graphs that separation based on flow conditions does not help improve the correlations, and there is no significant difference between the concentration corrrelations calculated for different stages. This again proves the previous supposition that the number of samplings is insufficient to describe the phenomena of sediment transport.

 https://doi.org/10.1051/e3sconf/20184004023

This leads to the consequence that it is currently not possible to determine changes in sediment yields over time.

We also intended to investigate sediment transport capacities, which can be calculated as function of discharge and slope but, as slope was not measured and recorded, this is not possible either [8].

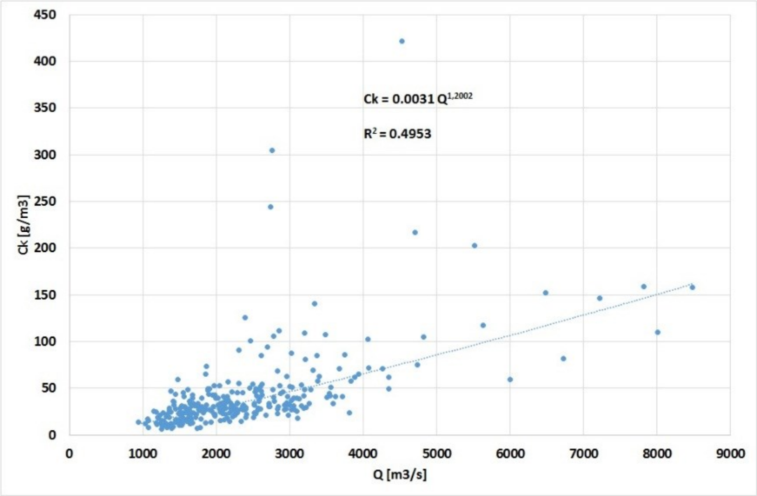

Fig. 1. Suspended load concentration plotted against discharge at Danube rkm 1580,6 (Dunaújváros) 1950–2017 (n=302), all data in one plot.

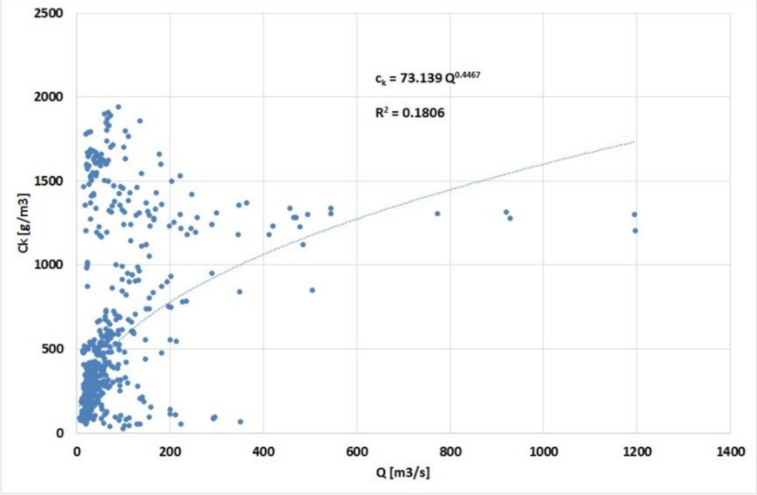

Fig. 2. Suspended load concentration plotted against discharge at Tisza 334,6 rkm (Szolnok) 1987–2016 (n=550) , all data in one plot.

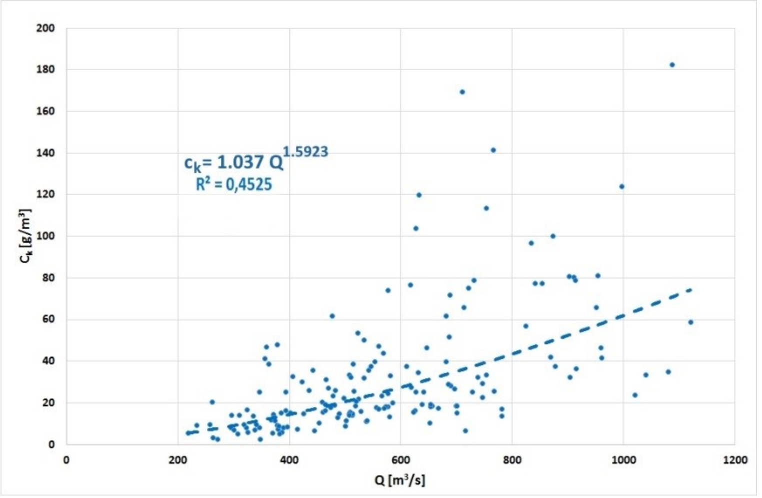

Fig. 3. Suspended load concentration plotted against discharge at Dráva 154,1 rkm (Barcs) 1991–2016 (n=164), all data in one plot.

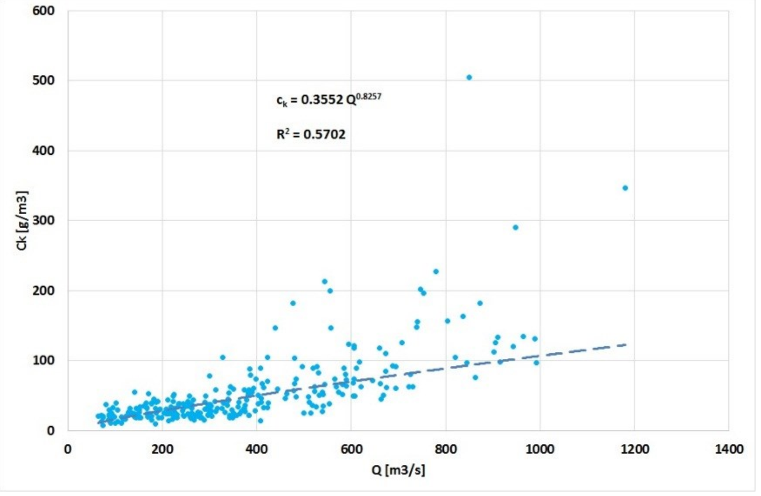

Fig. 4. Suspended load concentration plotted against discharge at Tisza 334,6 rkm (Szolnok) 1987–2016 (n=331) , overbank flow measurements excluded.

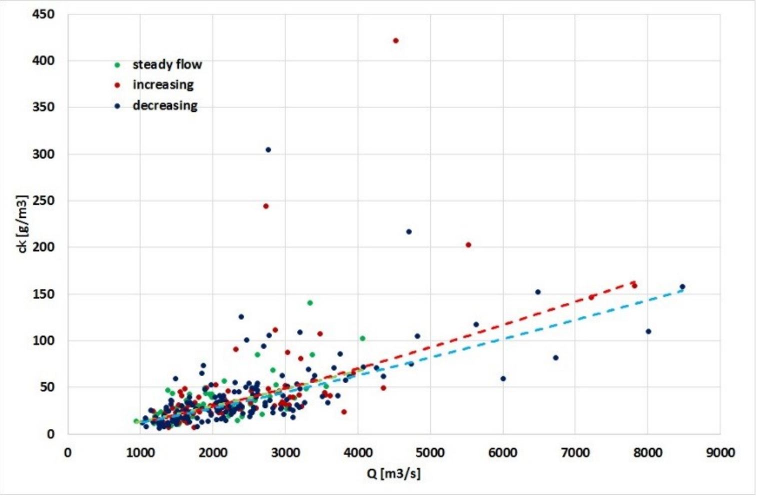

Fig. 5. Suspended load concentration plotted against discharge at Danube rkm 1580,6 (Dunaújváros) 1950–2017 (n=302), with separation of the measurements done during increasing, decreasing and steady stages.

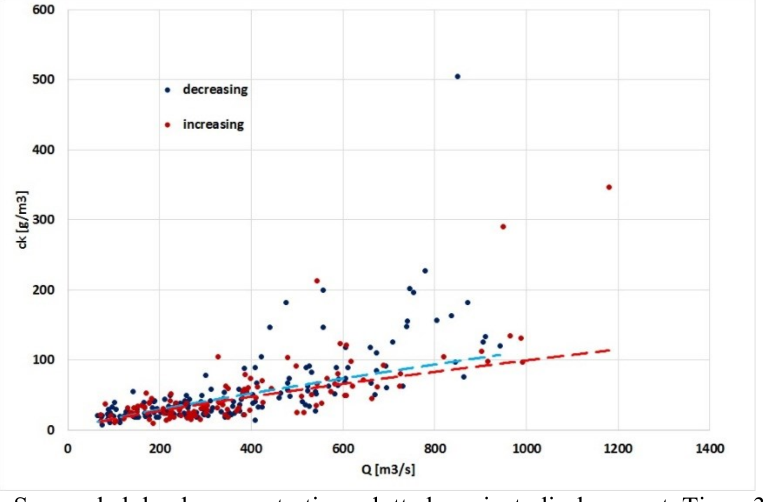

Fig. 6. Suspended load concentration plotted against discharge at Tisza 334,6 rkm (Szolnok) 1987–2016 (n=331) , with separation of the measurements done during increasing and decreasing stages (no steady flow measurements available).

4. Conclusions

Investigating all available suspended sediment measurement data for three major rives in Hungary we came to the conclusion that there are no harmonized methodologies and procedures applied in the country. Data related to sediment quantity are unreliable and often contradictory and we cannot expect that there will be enough detailed datasets to support sediment transport models.

Time-consuming and resource-demanding sampling campaigns have to be executed in order to get reliable data. Sediment sampling should be more regular and more frequent, harmonized in time to get data on flood events. There is a strong need to reintroduce bed-load and bed material sampling, to harmonize and standardize methodologies of sampling and processing alike. In connection to this, there's an urgent need to improve sediment awareness and improve education, and further development of field equipment and lab technologies is needed in order to improve efficiency and reduce costs.

Today the goal of the sediment sampling is not only to describe sediment transport in the flow, but further to provide calibration and validation data for numeric modeling. Sediment measurements are different in the different countries in Europe [9]. Even in Hungary, sampling and laboratory techniques have been modified several times in the past.

Sampling has to be carried out as to be able to obtain a true picture about the changes of sediment transport across the flow, along the flow and with respect to variability with depth. The sampling points have to be determined based on morphological and flow conditions. Discharge measurement and slope determination has to be executed in parallel to sediment sampling. For a few years, water autorities in both Hungary have been using Acoustic Doppler Current Profilers (ADCP) for the measurement of the discharge. This opens up new possibilities for future analyses. Despite this fact, we still have to emphasize that the availability of hydromorphological data is extremely important for assessments under the Water Framework Directive, also to support ecological status evaluation. However, the lack of information on some large rivers is evident. The changes in the hydrological and sediment regime of river systems induced by hydromorphological alterations are not well understood, so in the near future there is an urgent need for a harmonised database, and in order to achieve this, the intensification and reorganization of hydro-morphological monitoring is needed.

The authors wish to thank for the provision of data for the Lower-Danube, the Middle-Tisza District and the Southern Transdanubian Water Directorates.

References

1. D.E : Walling *Limitations of the rating curve technique for estimating suspended sediment loads, with particular reference to British rivers*, IAHS (1977)
2. W.H. Graf *Hydraulics of sediment transport*. McGraw-Hill, New York (1984)
3. E.A. Tamás, S. Baranya *Sediment Balance for the Danube River Interim Report – Hungary*, UNESCO IHP, manuscript (2008)
4. A.M. Süveggyártó *Hordalékmérési módszerek és eljárások Magyarországon (Sediment sampling methodologies and procedures in Hungary)* [Diploma thesis, Eötvös József College, Baja, Hungary] (in Hungarian) 2015
5. VITUKI *A Dráva hordalékjárásának vizsgálata a legfrissebb adatok figyelembevételével (Investigation of the sediment regime of the Drava based on the newest data).* [Research report 714/1/6128-01], (in Hungarian) (2003)
6. G. Gilja, D. Bekić, D. Oskoruš *Processing of Suspended Sediment Concentration Measurements on Drava River*, International Symposium on Water Management and Hydraulic Engineering, Ohrid/Macedonia, Paper: A672009 (2009)
7. L. Rákóczi, L. Szlávik, J. Sziebert, E.A. Tamás, A.M. Süveggyártó, G. Koch *Sediment analysis study under the project of "Dráva morphological monitoring" HUHR/1001/1.1.2/0009*., Research report (in Hungarian with English summary) (2012)
8. S.C. Finkner, M.A. Nearing, G.R. Foster, J.E . Giller A simplified equation for modeling sediment transport capacity Transactions of the ASAE Vol 32(5) September-October 1989 p 1545-1550 (1989)
9. U. Schwarz, M. Babić-Mladenović, C. Bondar, G. Gergov, K. Holubova, S. Modev, L. Rákóczi, G. Rast, J. Steindl, T. Sorin, E.A. Tamás *Assessment of the balance and management of sediments of the Danube waterway: Current status, problems and recommendations for action.* Working paper for the Danube River Basin. 1–60 (2008)