RECENT DYNAMICS (1975 - 2012) OF COŞUŞTEA RIVER'S SUSPENDED SEDIMENT LOAD AT CORCOVA HYDROMETRIC STATION

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ABSTRACT. – Recent evolution of solid discharge (1975 – 2012) at Corcova Hydrometric Station, Coșuștea River. This paper aims to assess, from a statistical standpoint, the solid discharge at Corcova hydrometric station for the recent period between 1975 and 2012. The Corcova hydrometric station is located in the lowermost sector of the Coşuştea River Basin, at a distance of 2 km north-west from its confluence with Motru River. The usefulness of this study results from the endeavor to determine the years and months when the river presents an accumulation potential due to a higher transmission rate of the suspended sediment load. The statistical techniques applied in this study made use of the monthly, as well as the annual averages, minimum and maximum values of suspended sediment loads, in order to obtain the multiannual trends, seasonal and monthly differences. Thus, by using the Mann-Kendall test, the statistical distributions and frequency analysis, we could notice that the average solid discharge decreased in the last decades during the winter period, while between April and November, average solid discharge rose slightly, with a greater significance in May. Conversely, minimum solid discharge values were likely to indicate the years and months when the river's solid intake was low, with the potential for bank erosion. The minimum values of suspended sediment loads showed little variation from year to year in all months, except for May and June, based on the influence of the peak liquid discharge on the potential erosion and sediment transport of Cosustea river. As a general conclusion, the most important aspects turned out to be the variations in April - June period, an interval well known for flash floods and high waters records, as well as for rapid changes in average, minimum and maximum solid flows.

Keywords: suspended sediments yield, frequency analysis, trends, Coșuștea River, Corcova hydrometric station.

1.INTRODUCTION

Assessing suspended sediment loads (*SSL*) is important in order to establish a river's contribution to the general fluvial morphological dynamics (Chow et al., 1981). At the same time, sediment transport in the riverbed can affect water quality and may cause sediment-induced problems or impact upon the hydraulic design of the river (Tramblay et al., 2010; Nejc et al., 2015).

As solid discharge is one of the driving factors of fluvial morphological changes, monitoring and understanding the temporal and spatial dynamics of the suspended sediment loads becomes a growing necessity in the field of integrated river management (Nejc et al., 2015). Relevant examples of the practical value of

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SSL analysis have been acknowledged by a significant number of authors (Réméniéras, 1960; Savin, 2003; Tramblay et al., 2010; Bîrsan et al., 2012; Nejc et al., 2015), who have succeeded in establishing a direct connection between the volumes, frequency and source areas of suspended sediment loads on the one hand and land use, ecological conditions of the catchments and streams (including, of course, soil erosion and other fluvial geomorphological disruptions) on the other.

Around the world, it is nowdayas possible to find a vast body of hydrological studies in which suspended sediment loads are investigated from multiple perspectives, such as trends and frequency analysis (Drobot and Carbonnel, 1996; Musy, 1996; Tramblay, 2010), the relationship between sediment yield and liquid discharge, or the modeling of SSL, according to the rating curves or directly from the climatic data (Nejc et al., 2015). In some cases, very accurate correlations were obtained, when the influence of moderate and high magnitude of SSL and their frequency were accounted for, while in other cases, moderate magnitude and high frequency flows may exert a greater influence on suspended sediment loads (Tramblay et al., 2010). Furthermore, SSL seasonality and lag between peak discharges and corresponding peak sediment concentrations are another subject of concern found in international scientific literature (Nejc et al., 2015). This type of research is seldom performed, but it is suitable when investigating SSL behavior in time, in order to better estimate future trends.

In Romania, and particularly in the Jiu River hydrological area, suspended sediment loads data series have been part of some regional studies, in which the Coşuştea river was treated either as a stand-alone entity or as part of a regional synthesis (Savin, 2003). However, most of these studies ended years or even decades ago and, over the last years, no update has taken place in of SSL analysis.

As we shall see in the following chapters, this paper aims to find possible trends in the SSL series from the Corcova hydrometric station, in order to determine the most appropriate distribution function for analysing SSL frequency. In the end, the research examines the scatter and seasonality of SSL and Q peaks and the lag between the maximum SSL and corresponding peak *Q*.

2. STUDY AREA

The Corcova hydrometric station is located in the lower sector of Coșuștea river (with a total length of 77 km), a first order tributary of the Motru River and a third order tributary of the Danube.

Since more than 50% of the Cosustea basin belongs to a hilly area, with altitudes between 300-400 m, this characteristic will impose a specific land use regime, a certain density of the vegetation, which both lead to a more contoured sediment transport along the riverbed. Geologically, it is also important to note the difference between the upper basin (karst and crystalline geology in the fundament and fine unconsolidated sediments in the riverbed) and lower basin (coarse sand and gravel and a smaller percentage of silt). As a result, these specific two types of lithology (harder and weakly erodible rocks toward the upper basin, whilst loose gravel and clay type in the lower sector) are decisive modeling factors of the different sediment transport dynamics (*Fig. 1*).

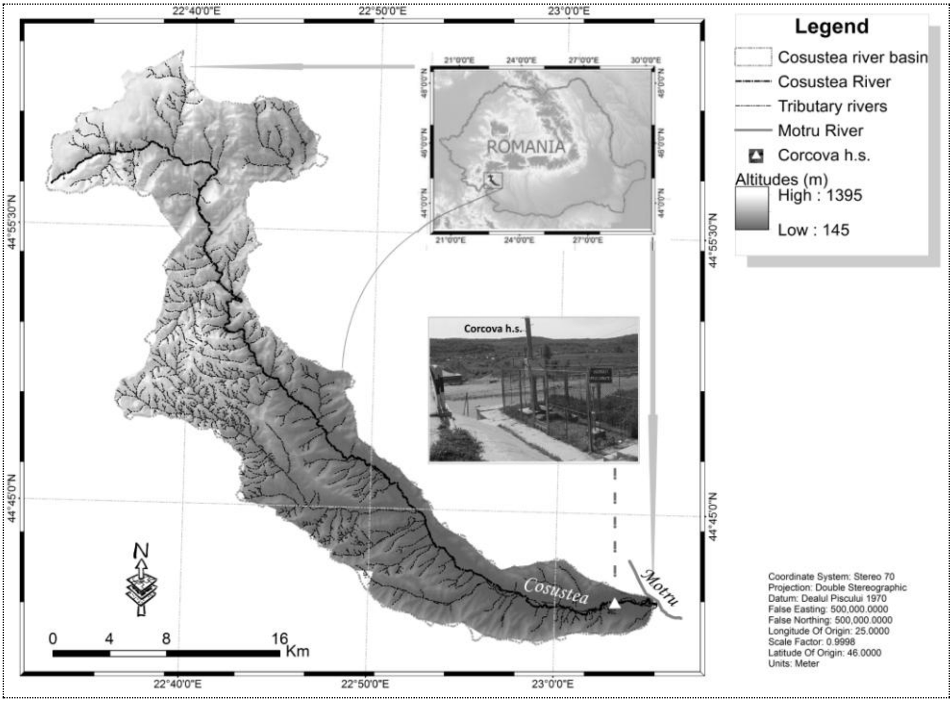

Fig. 1. ***Location of the study area***

In terms of hydrological regime, for the analyzed hydrometric station, Corcova, the river has an average liquid flow (*Q*) of 2.62 m^3/s and an average suspended sediment load (*SSL*) of 1.7 kg/s. Not least, with regards to the climatic aspect, under the general climate spectre exhibitingMediterranean influences, we can emphasize an interesting seasonal distribution, which manifests through notable differences between the cold season (with less precipitations ~ 249 mm) and the warm season (when pluviometric highs are recorded, with a total annual average of 355 mm). However, in the context of specific geological and topographical features of the Coşuştea river basin, also confirmed by the statistical analysis, the discharges are much more strongly influenced by the physical-geographical charactersitics.

3.DATA AND METHODS

In this paper, most of the work was performed on daily, monthly and annual averages and minimum and maximum values of suspended sediment loads from the Corcova hydrometric station, located in the lower sector of the Coşuştea basin, close to its confluence with Motru River. Additionally, for a small part of the statistical analysis employed in the current study, we also used the monthly and annual data of the liquid discharge (1975 – 2012).

In order to illustrate the regime, the frequency and trends laws of the SSL data series, as well as their correlations with the liquid peak flow, we turned to the methodological fundaments used in hydrological statistics (Réméniéras, 1960; Chow et al., 1981; Drobot & Carbonnel, 1996; Musy, 1998; Pişota et al., 2005).

First of all, we began by observing the seasonal and monthly behavior of the suspended sediment loads, but not before calculating the minimum, maximum and average values. After finding the best function describing the frequency of SSL, we moved to the Mann-Kandall method, in order to examine the monthly and seasonal trends of SSL. Lastly, we determined the maximum event (SSL and Q) of each year, by selecting the highest (maximum) 3^{rd} quartile value, so as to calculate the lag between the highest *SSC* values and corresponding peak *Q*.

The abovementioned suspended sediment loads data at the Corcova station (1975 – 2012) with the following software programs: CumFreq and Makesens, applied in Microsoft Excel.

4. RESULTS AND DISCUSSIONS

This section is divided into three parts. The first part shows the best frequency laws for our SSL data, the second section involved to the seasonality and extreme trends analysis, while the third part was devoted to the lag analysis between the peak *Q* and the corresponding *SSC*, together with the corresponding Pearson correlation coefficients.

4.1. Trends and frequencies

The first step of our statistical analysis was to find the most suitable laws to characterize the temporal variation of the SSL values.

With regards to the *average suspended sediment loads*, the most appropriate law for our data series was the Frechet type (Van Hauwermeiren and Vose, 2008). This law, used for the cumulated frequency function (*Fig. 2*), highlighted an average SSL with a return period of 100 years, $R_{avg1\%}$ = 13.85 kg/s, and an average SSL with a return period of 10 years, $R_{avg0.1\%}$ = 4.14 kg/s.

Correspondingly, for an average solid discharge of 1 kg/s, the exceedence period is 1.77 years.

We should note that, according to ISI Glossary of Statistical Terms, the Frechet distribution is usually applied to the maximum values (as we would have expected for the maximum SSL). The best correspondence depends nevertheless on the lower threshold of the values, which adopts, as we shall see in our case, for the maximum flows, another type of distribution, in order to avoid a situation where the minimum values are not plotted (the risk of the Frechet distribution).

The analysis of *maximum suspended sediment load*s proved to be useful for determining the years or months when the river exhibits a potential for accumulation because of its high or low rate of sediment transport and deposit.

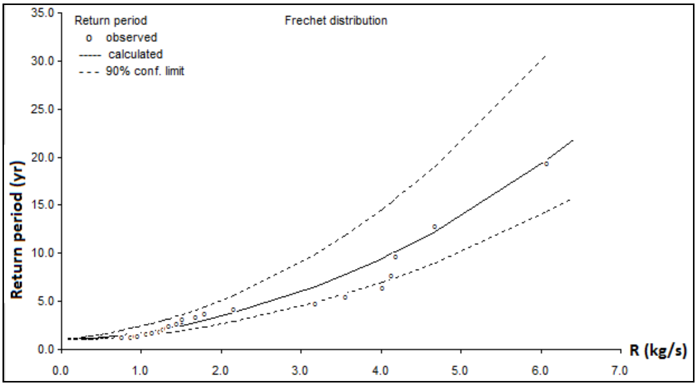

Fig. 2. ***Chart of ranked average suspended sediment load (R) and its return period***

Through the statistical operations on the maximum SSL, we established that the most adequate function for our data series is the general logistic cumulative frequency function (*Fig. 3*), applied when the distribution of values tends towards symmetry (Van Hauwermeiren and Vos, 2009).

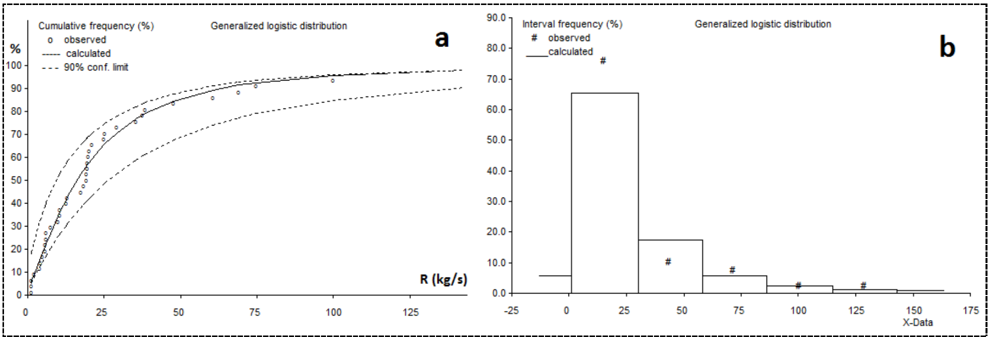

Fig. 3. ***Chart of yearly maximum SSL and its cumulative frequency (a) and Histogram of monthly SSL (b)***

We can see that nearly 75% of elements have values between 0 and 250 kg/s, according to the histogram (*Fig. 3.b.*). In this case, the variation of discharges is also interesting because the measured values are close to the upper limit of the confidence interval for estimated discharges, in accordance with the frequency function that was used.

Thus, from a frequency point of view, it is possible to notice the solid discharge of 1692.7 kg/s with a 1% frequency, whereas the 0,1% discharge is only four times smaller (464.9 kg/s).

The minimum suspended sediment loads examination shows us the years or months when the sediment intake of the river is low, which brings the potential of bank erosion (Helsel & Hirsch, 2002). By using the Fisher-Tippet 2 type cumulative frequency function, we could calculate an average of the values amounting to 0,141 kg/s and a standard deviation of 0.131. The chart illustrating the distribution of cumulative frequency (*Fig. 4*) has a parabolic shape and a confidence limit situated symmetrically with regards to the measured values of discharges exhibiting frequencies of up to 80% and with an upper limit closer to values of minimum suspended sediment loads with a frequency greater than 80%.

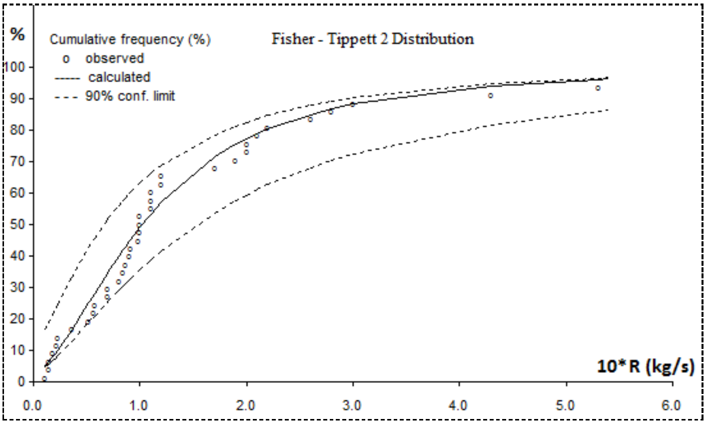

Fig. 4. ***Chart of minimum suspended sediment load (R) and of its cumulative frequency***

Correlated and complemented by the maximum SSL, the minimum values exhibit a weak variation from one year to another, except for the months of May and June, when the minimum values decrease substantially in the context of a slight increase of maximum SSL and of a massive increase of peak Q.

4.2. Monthly and seasonal analysis

As far as the seasonal and monthly statistics are concerned, the Mann-Kendall test and Sen's slope estimates (Esterby, 1998, Salmi et al., 2002) were used for determining the trends and significance, where appropriate (*Table 1*).

Table 1. ***Results of the Mann-Kendall test on average maximum monthly solid discharges at Corcova station (period of analysis: 1975 – 2012)***

Month	Average SSL			Maximum SSL		
	Sen's slope	**Significance**	**Trend type**	Sen's slope	Significance	Trend type
I	1.11	+	up	1.13	+	up
II	0.38		up	-0.48		down
III	0.74		up	0.52		up
IV	0.47		up	0.40		up
V	-1.78	*	down	-2.20	*	down
VI	-1.47	+	down	-1.58	+	down
VII	-0.94		down	-0.58		down
VIII	-0.21		down	-0.19		up
IX	-0.18		down	-0.25		up
X	-0.38		down	-0.64		down
XI	-0.69		down	-0.62		down
XII	0.44		up	0.33		up

To note that "+" and "*" mark a significance level of 0.1 and 0.05, respectively. On the contrary, the "-'' sign indicates there is no statistical significance (Salmi et al., 2002; Bîrsan et al., 2012).

Concerning the average SSL, the test brought to light that in the cold season (December through March), the average solid discharge decreased in the period between 1975 and 2012, whereas between April and November during the same interval, the average solid discharge experienced a slight increase, the highest degree of significance being in May.

For the maximum SSL, May was once again the most significant month, due to a 0,3 kg/s decrease in discharge, while in the summer and autumn months (August and September), the difference was close to zero. From a hydro-morphological standpoint, this decrease of the maximum solid discharge during spring months, when maximum liquid discharge increases, is responsible for the increased intensity of fluvial erosion. Hence, the Mann-Kendall test for the maximum SSL indicates the time of the year between April and June when sediment transport reaches its greatest levels during the year, because the liquid discharge is also increasing, leading to more intense bank erosion in the upper sector of the Coșuștea River Basin and to an enhanced sediment accumulation in the lower sector.

Both for the average and maximum SSL, we could highlight the late spring – early summer period, marked by a downward trend in solid transport, with the highest significance during the year.

Regarding the minimum SSL, no significance was detected and a generally downward trend was identified for the period between 1975 and 2012.

4.3. Lag analysis

The last part of our study concerned the correlation between maximum SSL and peak Q. Thus, we selected for each of the 38 years (1975-2012) the statistical peaks, our interest focusing on the period when they occurred. According to Nejc et al., 2015, we considered that a close relationship and mutual influence between maximum SSL and peak Q would be emphasized if the maximum values were recorded with a lag of +/-5 days.

By using the Pearson III method (Réméniéras, 1960; Helsel & Hirsch, 2002), we could determine that there is a moderately positive correlation between maximum SSL and peak Q (the value of R^2, the coefficient of determination, being 0.4261). In the end, the Pearson III correlation method was applied separately for the two periods with very good, respectively low correlation coefficient, $r= \sum[(X - My)(Y - Mx))/ \sqrt{((SSx)(SSy)}]$, too. The results showed that for the 1994 – 2012 period, the time when the maximum SSL is recorded almost always coincides with the peak Q (r = 0.98). However, between 1975 and 1993 (r=0.22), only five years feature such a coincidence between peak Q and maximum SSL, and in other cases (3 years), between the maximum SSL and the peak Q there was a lag of five days to one month, while in other cases, there is no correlation between these two aspects. One possible explanation for the low levels of correlation coefficient between 1975 and 1993 should be further investigated and, if possible, attributed to the former hydrological regime of Coșuștea River, more natural and less influenced by recent hydraulic designs for the banks's stabilization.

5. CONCLUSION

Suspended sediment loads in the period 1975-2012 at the Corcova h.s. generally exhibit a downward trend, more significantly in the cold season. At a monthly scale, the most important trends and significances are the discharge variations occurring in April and June, a period also characterized by peak discharge and flash flood which may be at a leading factor of the SSL.

Annually, there is an exceptional correlation in the lag time of maximum SSL and peak Q over the last 20 years, perhaps because of the dam recently built and due to the river-morphological alteration relationships, anthropogenically induced, between the minor bed and the slopes. On the contrary, before 1994, SSL did not seem to have been very strongly influenced by Q during the high waters period.

REFERENCES

1. Bîrsan M.V., Zaharia L., Chendeș V., Brănescu E. (2012), *Recent trends in streamflow in Romania (1976-2005)*, Romanian Reports in Physics, *64(1)*, 275-280.
2. Chow, V.T., Maidment, D.R. Mays, L.W. (1981), *Applied Hydrology*, McGraw Hill Book Company, New York, USA.
3. Drobot R. & Carbonnel, J.P. (1996), *Bazele statistice ale hidrologiei*, Editure Didactică şi Pedagogică, Bucureşti.
4. Esterby, S.R. (1998), *Review of methods for the detection and estimation of trends with emphasis on water quality applications*, Hydrological Processes, *10*, 127-149.
5. Helsel, D.R., Hirsch, R.M. (2002), *Statistical Methods in Water Resources*, U.S. Geological Survey, USA.
6. Musy, A. (1998), *Hydrologie appliquée*, Editure H.G.A., București.
7. Nejc, B., Mojca, Š., Matjaž M. (2015), *Analyses of suspended sediment loads in Slovenian Rivers*, Hydrological Sciences Journal, 1-30.
8. Réméniéras, G. (1960), *Eléments d'hydrologie appliquée*, Editure Eyrolles, Paris.
9. Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., Amnell, T. (2002), *Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates - The excel template application Makesens*, Finnish Meteorological Institute, Helsinki.
10. Savin, C. (2003), *Râurile din Oltenia, Fenomene hidrologice de risc excepțional*, Editure Universitaria, Craiova.
11. Tramblay, Y., Ouarda, T., Saint-Hilaire, A., Poulin, J. (2010), *Regional estimation of extreme suspended sediment concentrations using watershed characteristics*, Journal of Hydrology, *380(3-4)*, 305-317.
12. Van Hauwermeiren, M., & Vos, D. (2009). *A Compendium of Distributions* [ebook]. Vose Software, Ghent, Belgium. Available at www.vosesoftware.com.
13. http://isi.cbs.nl/glossary/ accessed on January, 12, 2016