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Sediment Transport and River Channel Dynamics in Romania – Variability and Control Factors

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1. Introduction

Sediment transport and river channel dynamics are the result of the complex interaction between natural and human factors, at both local and regional scale. The study of sediment transport and river channel dynamics may be an important way to better know and understand the mechanisms that rule the functioning of fluvial system, allowing forecasts of its future evolution to be made and appropriate adaptation measures to be taken by society in front of the risks related to the fluvial dynamics and sediment transfer.
The purpose of this chapter is to present specific aspects concerning the sediment transport and river channel dynamics in Romania and to reveal the role of various control factors. Our contribution consists mainly in regional analyses that highlight the following aspects: i) the spatial and temporal variability of suspended sediment transport; ii) the relationships between suspended sediment yield/load and some control variables (precipitation, water discharge, catchment's characteristics, and human activities), and iii) the vertical and lateral dynamics of selected river channels.
The chapter summarizes a part of the significant results of our previous studies and some more recent researches in the field of sediment transport and channel dynamics in Romania. It also includes new issues and approaches, based especially on case studies, which further develop the proposed topic. The analyses focus preeminently on two areas: the Carpathian's Curvature region, and the central part of the Romanian Plain (Fig. 1A). We have chosen the first area because it has the highest sediment yield in Romania: over 20 – 25 t ha^{-1} yr^{-1}, meaning more than 10 times the average sediment yield on a national scale, which is about 2 t ha^{-1} yr^{-1} (Mociorniță & Birtu, 1997). The central part of the Romanian Plain is characterized by an intense lateral dynamics of the river channels, making it vulnerable to the risks induced by fluvial dynamics, because of the economic importance of the area and the significant density of population and settlements. The data used and the methodologies employed are mentioned in the text.
This chapter is structured in four main parts concerning: i) previous researches on sediment transport and fluvial dynamics in Romania; ii) sediment transport and control variables; iii) river channel dynamics and iii) human impact on sediment transfer.

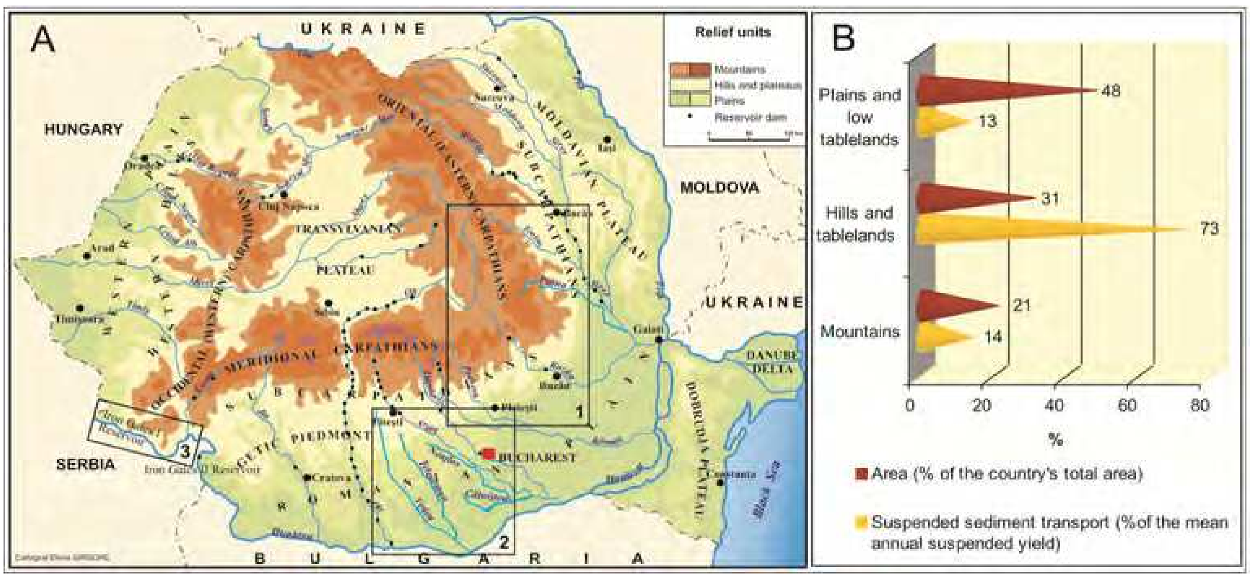


Fig. 1. A The main morphological units in Romania and the location of the study areas: 1: Carpathian's Curvature region; 2: Central part of the Romanian Plain; 3: Iron Gates Region. B. The distribution of suspended sediment yield over the Romanian territory at the scale of the major landform units.

2. Overview on previous researches on sediment transport and river bed dynamics in Romania

In Romania, although researches in the fields of hydrology and fluvial geomorphology date back to the early 20th century, the systematic gauging of sediment load within the national hydrometric network started after 1950. Initially, the recordings were only concerned with suspended sediment concentration (turbidity) and sediment load. In the 1960s, however, the efforts were also aimed at the systematic investigation of sediment granulometry and bed load transport. Yet, over the time, most of the recordings have dealt with suspended sediment load, while the measurements of bed load amounts have been fewer. An important role in the scientific research in this field was played by the specialized national institutes (of hydrology, pedology, geography, etc.), the universities and the "Stejarul" research station in Piatra Neamț.

Significant researches on sediment transport. One of the first significant synthesis studies on suspended sediment load of the Romanian rivers belongs to Diaconu (1964), who highlighted the vertical zonation of suspended sediment yield. Seven years later, in 1971, Diaconu published a more ample study, which became a landmark for all subsequent investigations concerning river sediment transport in the country. In it, he presented the results given by the processing of suspended load data recorded between 1952 and 1967 on 202 catchments. For the first time in Romania, the author included maps showing the spatial variability of suspended sediment yield and suspended sediment concentration (turbidity) on a national scale. In 1972, Ujvári identified the relationships between the rivers turbidity and the suspended sediment load on the one hand, and between the former and the elevation, on the other hand, under different geological and morphological conditions. Another reference work dealing with the investigation of suspended sediment load in Romania was accomplished by Moțoc in 1984. The study emphasized the contribution of erosion processes and land use to suspended load transport along the Romanian streams. In

1987, Mociorniță and Birtu updated the previous information regarding the spatial and temporal variability of suspended load in Romania. The results and discussions relied on the processing of the data recorded between 1950 and 1984 by the national gauging network. These datasets also included information about the exceptional flood events, which occurred in 1970, 1972, 1975 and 1979, and about the alterations of the flow and sediment load regimes induced by the increased number of reservoirs.

A more recent synthesis study that highlighted the relationship between suspended sediment yield and the catchment area for different morpholithological conditions of Romania was the one conducted by Rădoane (2005). Many studies (methodological and at a regional scale) dealing with sediment origin, transport, alluvial budget and granulometry, as well as with the factors controlling the river sediment load have been published in recent decades. The most relevant ones are authored by Dumitriu (2007), Ichim (1992), Ichim & Rădoane (1990), Ichim et al. (1998), Olariu et al. (1999), Rădoane & Rădoane (2001, 2005), Rădoane et al. (1998, 2003a, 2006), Roşca & Teodor (1990), Teodor (1992, 1999), Zaharia (1998), Zaharia & Ioana-Toroimac (2009), Zăvoianu & Mustățea (1992). Important papers on sediments and fluvial processes are included in the four volumes of the Symposium "Proveniența şi efluența aluviunilor" ("Sediments Origin and Outflow") held in Piatra Neamț (1986, 1988, 1990 and 1992).

Researches on river bed dynamics. In Romania, the studies on riverbed dynamics started in the 1960s. Of the first papers, those accomplished by Diaconu et al. (1962) and Urziceanu (1967), clearly stand out from the others. For instance, the study authored by Urziceanu is important, inasmuch as it identifies on a national scale some zonal relations among the channel dynamics, the sediments diameter and the water velocity based on an index expressing the channels mobility. In his turn, Diaconu (1971) tackles the channels variations by analyzing the influence of water flow on the hydraulic elements of the channel's cross section (area, mean and maximum depth). Other important contributions to the study of the channel vertical dynamics and the river long profiles are those of Ichim et al., (1989), Pandi & Sorocovschi (2009), Rădoane et al. (1991, 2003b, 2008a, 2010), Rădoane & Rădoane (2007), etc. Aspects concerning fluvial dynamics are presented in the works authored by Cocoş & Cocoş (2005), Feier & Rădoane (2007), Ioana-Toroimac et al. (2010), Rădoane et al. (2008b), and Grecu et al. (2010 a, b, c).

Given its practical significance in the context of sustainable development, the hydrogeomorphological dynamics has either turned into a major issue or has only been tangentially tackled in many doctoral theses, of which are worth mentioning the papers accomplished by Popa-Burdulea (2007), Ioana-Toroimac (2009), Ghiță (2009), Cârciumaru (2010) and Văcaru (2010).

3. Suspended sediment transport – the role of control variables

The spatial and temporal variability of sediment transport is controlled by a combination of different variables, including the natural features of the catchments and human activities. Because these variables generally act in a synergistic manner, sometimes it may be very difficult to isolate the effect of a particular one (Charlton, 2008).

3.1 Spatial variability of suspended sediment transport in Romania

The Romanian rivers, except for the Danube, carry, on the average, 1550 kg s^{-1} of suspended sediments every year, which means a sediment yield of 48.9 million t yr^{-1} and a specific sediment yield of 2.06 t ha^{-1} yr^{-1} (Mociorniță & Birtu, 1987). These values account for a relative high erosion rate in Romania, which makes it necessary that adequate measures to reduce it should be taken in order to mitigate the negative consequences generated by this phenomenon.

The analysis of the distribution of liquid flow and suspended sediment yield at the scale of the major landform units in Romania shows that 73% of the mean annual suspended sediment yield come from the hilly and piedmontane areas (with elevations of 300 to 800 m), which account for 31% of the Romanian territory and 24% of the mean annual water volume of the rivers (Fig. 1B). These areas are extremly favourable for sediment production. In the mountain realm, as well as in the plains and the low tableland regions the percentage of suspended sediment yield is only 14% and 13% respectively of the mean annual sediment yield, while these areas hold 21% and 48% respectively of the entire Romanian territory. One should also notice that the mountain realm is responsible for two-thirds (66%) of the mean annual water volume of the rivers, while the plain areas contribute by only 10% (Mociorniță & Birtu, 1987; Pişota & Zaharia, 2002).

The largest amounts of suspended load are carried by the rivers draining the Subcarpathian region, where the values of the mean specific suspended sediment yield exceed 10 t ha^{-1} yr^{-1}. As far as the maximum values are concerned, these are found in the Curvature Subcarpathians (more than 20 – 25 t ha^{-1} yr^{-1}) (Fig. 2A). The high erosion rate in this area, which is controlled by natural (geological, morphological, climatic and hydrological) and anthropogenic causes (massive deforestations), is mirrored by the extremely high values of water turbidity, which exceeds 25,000 g m^{-3} (Fig. 2B). In the Carpathian realm and the plain areas, the values of specific suspended sediment yield are less than 0.5 t ha^{-1} yr^{-1}, while water turbidity keeps below 250 g m^{-3}.

The values of specific sediment yield increase with the elevation from the sea level to 200 – 600 m a.s.l., where they reach the maximum. From here upwards, the values generally decrease as the elevation grows. At low altitudes, although the rocks are crumbly, the faint slopes and low water velocities hinder the erosion. At high elevations, even though the steep grades encourage erosion, the protective vegetal cover and especially the hard rocks are responsible for the low suspended load values. The most favorable erosion conditions, which explain the high values of suspended sediment transport, are encountered between 200 and 600 m a.s.l. (Diaconu & Şerban, 1994).

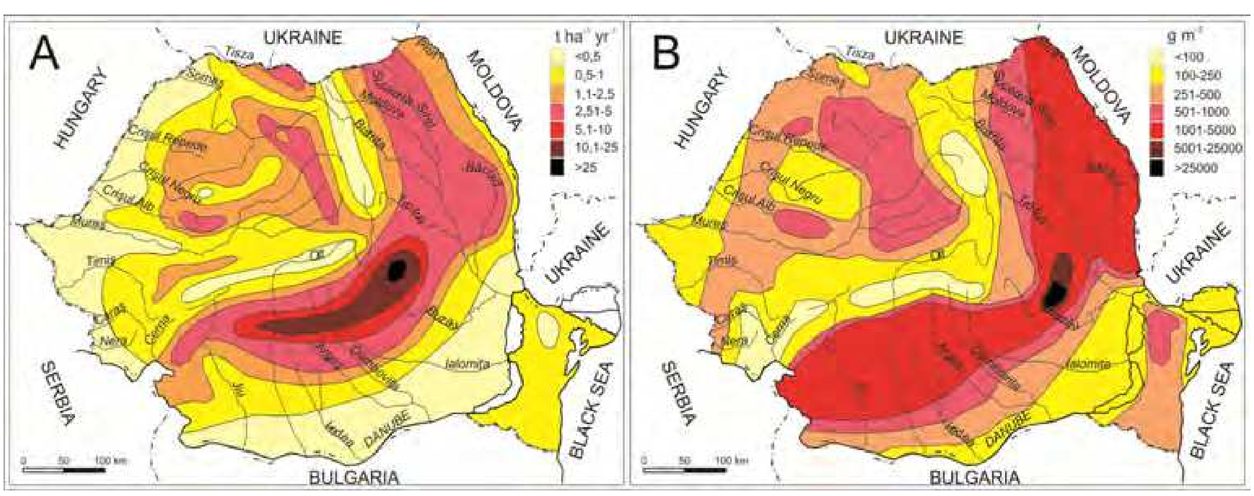


Fig. 2. The map of suspended sediment yield (A) and river turbidity in Romania (B) (according to Mociorniță & Birtu, 1987, for A, and to Diaconu, 1971, for B)

The year-to-year variability of suspended sediment load is more significant than the water discharge. The study accomplished by Mociorniță & Birtu (1987) at the scale of 10 catchments having different geographical conditions (for the period 1950 – 1985) shows variation coefficients for suspended sediment load ranging from 0.5 to 1.12, which is two to three times higher than those of the mean annual water discharge. As far as the yearly variability of the mean sediment transport is concerned, this is mainly determined by the variability of precipitation regime and water flow under the specific geographical conditions of each drainage basin. For Romania, the highest suspended sediment transport occurs during the interval March – July, when the abundant precipitation combined with the spring snow melting, on the one hand, and the summer rain showers, on the other hand, encourage sediment supply. This happens because the erosion processes along the slopes and within the channels intensify when water discharge increases. During this interval, the percentage of the mean monthly suspended sediment load can exceed 20 – 25% of the mean annual volume. The lowest suspended sediment loads (less than 5% of the mean annual volume) occur in autumn, when both precipitation and water discharges are low (Mociorniță & Birtu, 1987).

3.2 The Carpathians' Curvature region – the area with the most important suspended sediment transport in Romania

The analysis takes into account the external part of the Carpathians' Curvature region, which records the highest values of suspended sediment yield in Romania. The study area includes two distinct morphological units: the Carpathians (lying to the north-northeast) and the Subcarpathians (which are found east-southeast from the Carpathian area) (Fig. 3).

One of the main factors that encourage sediment formation and sediment transport is **geology**. In the Subcarpathian region, the crumbly sedimentary rocks belonging to the Miocene and Pliocene molasse prevail, while in the Carpathian area, Cretaceous and Paleogene flysch formations are common. They include a mosaic of rocks, like sandstones, marls, limestones, conglomerates, marly-sandy schists, etc (Mutihac et al., 2007).

The Carpathian realm is affected by uplift movements of 2 – 3 mm per year, whereas the Subcarpathian area rises by 0.5 to 2 mm per year (Cornea et al., 1979). These movements influence the channel dynamics and consequently the sediment transport. Besides, because the area has a high degree of seismic activity it is often rattled by earthquakes, some of them with magnitudes exceeding 6 – 7 degrees on the Richter scale. Of the most powerful events of this kind, which occurred during the last century, one can mention the earthquakes of 10 November 1940 and 4 March 1977, with magnitudes of 7.4 and 7.2 respectively on the Richter scale. The shock waves generated by earthquakes may trigger various relief shaping processes, such as landslides, mudflows, and collapses, which bring sediments into the river channels (Bălteanu, 1983; Zaharia, 1999).

A major control for the erosion processes and sediment transport is represented by **climatic conditions** in general, and by precipitation in particular. The annual amounts of precipitation in the mountain area have values ranging from 70 to 1000 mm in the mountain realm and 600 to 700 mm in the Subcarpathian area (Zaharia, 2005). The high erosion rate, mirrored by the high amounts of suspended sediment load, is explained by the precipitation regime, corroborated with the lithological conditions. In June and July, due to the torrential regime of precipitation the maximum amounts fallen in 24 hours may exceed 100 or even 250 mm (Administrația Națională de Meteorologie, 2008; Bogdan & Mihai, 1981).

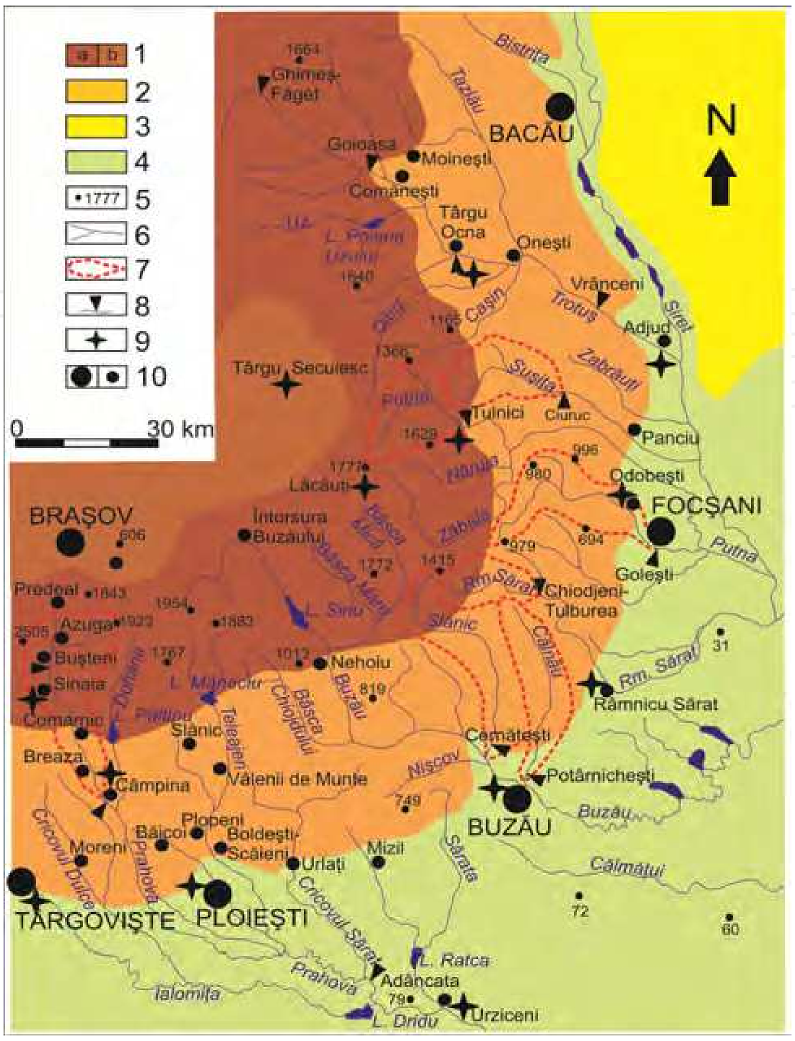


Fig. 3. The Outer Carpathians' Curvature: location of the study catchments, and of hydrometric and meteorological stations. 1: Carpathian area (a: mountainous area; b: depression area), 2: Subcarpathian area; 3: Tableland region; 4: Plain area; 5: Elevation (m a.s.l.); 6: Drainage network; 7: Watershed boundary of the study catchments; 8: Hydrometric station; 9: Weather station; 10: Cities.

Suspended load transport is closely related to **water discharge**. Throughout the outer area of the Carpathians' Curvature, the mean specific discharge varies between 10 and 16 l s^{-1} km^{-2}, in the Carpathian realm and between 3 and 12 l s^{-1} km^{-2}, in the Subcarpathian area. The flow regime is characterized by high discharges in spring (41 – 43 % of the mean annual water volume) and summer (24 – 30%), whilst during the winter and fall the flow is more reduced (less than 15% of the mean annual water volume). The highest sediment amounts are carried during the flood events. These are generated by the abundant rainfalls falling especially in summer and spring (Zaharia, 2005). For instance, during the flood event of July 2005, the Milcov River recorded at Goleşti 94,000 kg s^{-1} of suspended sediments, which is over 5,000 times higher than the mean multiannual sediment load (according to the data provided by the Vrancea Water Management System).

The erosion processes affecting the slopes are controlled to a large extent by **vegetation cover**. In the Carpathian catchments, the degree of afforestation averages 50 – 70%, while in the Subcarpathian area it drops to less than 30 – 40% (according to AQUAPROIECT, 1992).

Massive deforestations took place in the Carpathians' Curvature region in the second half of the 19th century and they continued until the third decade of the 20th century. After 1976, with the implementation of a national program to control soil erosion, significant reforestations associated with anti-erosion measures were accomplished in this area (Zaharia, 1998). After 1989, the restitution of the forest to the former owners was followed by massive and abusive deforestations.

Human activities. The main activities in the area, which control the sediment transport in the study region, are the massive deforestations, pasture expansion, grazing, mining of sand and gravel from river channels, and dam building (in this area there are four important reservoirs and a small impoundment). Because of the specific lithological conditions of the Curvature Subcarpathians, deforestations and overgrazing have induced intense slope erosion processes and landslides, which generated significant amounts of sediments.

The favorable natural features and the human activities have accelerated the erosion processes in the Subcarpathian area and consequently the values of suspended sediment yield are high: over 10 t ha^{-1} yr^{-1} and for some parts even 20 – 25 t ha^{-1} yr^{-1}. In the mountain area, suspended sediment yield is less than 5 t ha^{-1} yr^{-1}. This is explained by the hardness of flysch rocks and the higher degree of aforestation, which mitigate the action of the rather abundant precipitation.

During the year, suspended sediment load varies from month to month as a result of hydrological and meteorological conditions. The rivers carry the largest amounts of suspended sediments in the interval April – July. In the Putna catchment, the percentage of each month within this interval may exceed 20 – 30% of the mean annual suspended sediment yield. The winter months have the lowest share of suspended load (less than 3 – 4% of the total mean annual suspended sediment yield) (according to Zaharia, 1999, for the period 1956 – 1992).

The interannual variability of the mean suspended sediment load is more significant for the river catchments that are mostly developed in the Subcarpathian area, where the values of the variation coefficient (Cv) of the mean annual suspended sediment load are generally higher than 1. As far as the rivers flowing in the Carpathian area are concerned, they have Cv values lower than 1 (Zaharia, 2005).

3.2.1 Relationships between suspended sediment yield and hydrometeorological variables

As mentioned previously, an important part in sediment formation and sediment transport is played by climatic conditions (especially precipitation) and flow discharge features. With this in mind, we will try to reveal the influence of precipitation and runoff on suspended sediment yield.

3.2.1.1 Precipitation role in suspended sediment load

In a previous study (Zaharia & Ioana-Toroimac, 2009) we analyzed the link between the erosion dynamics and precipitation in the Carpathians' Curvature region. Now, we will briefly discuss again the results making at the same time some additional comments. The study was based on the monthly and annual precipitation values recorded at 24 weather stations lying in the Carpathians' Curvature area and in its immediate vicinity during the period 1961 – 2000 (data provided by the National Meteorological Administration – N.M.A.). Likewise, we took into account the water discharge and suspended sediment load (mean monthly and annual values) recorded for seven catchments during the same period (data provided by the National Institute of Hydrology and Water Management – N.I.H.W.M.). Table 1 gives the morphometric and geographical features of the study catchments, whereas Fig. 3 shows their geographical location.

River	Hydrometric station	A (km^2)	H_m (m)	S_m (degree)	FR (%)	CMP (1961 – 2000)*
Şuşiţa	Ciuruc	172	556	2.6	74	634.7
Putna	Tulnici	365	1014	5.6	54	713.5
Milcov	Goleşti	406	422	3.1	55	630
Rm. Sărat	Chiojdeni-Tulburea	177	790	4.5	58	571.3
Câlnău	Potârnicheşti	194	338	2.2	27	544.2
Slănic	Cernăteşti	422	524	3.8	47	569.4
Prahova	Câmpina	484	1124	5.5	58	926.4

* Based on the data provided by the N.M.A.

Table 1. Morphometric and geographical features of the study catchments (according to Zaharia & Ioana-Toroimac, 2009, with additions). A: catchment area; H_m: catchment mean elevation; S_m: catchment mean gradient; FR: forest ratio; CMP: catchment mean precipitation.

By interpolating the mean annual values of precipitation recorded at the 24 weather stations (employing the Natural Neighbor method in Vertical Mapper module from MapInfo soft, version 6.5.) and by overlaying the results on the maps of the study catchments, the mean annual precipitation falling on each of them was estimated. The data regarding the suspended sediment load allowed us to determine the mean specific sediment yield, computed as a ratio of suspended sediment load, expressed in t yr^{-1}, and the catchment area (in hectares). Table 2 shows data on water discharge and suspended sediment load for the study catchments.

River	Hydrometric station	Q_m* (1961-2000)		Qmax*/year (m^3 s^{-1})	R (1961–2000)		CVQ_m	CVR
		(m^3 s^{-1})	(l s^{-1} km^{-2})		(kg s^{-1})*	(t ha^{-1} yr^{-1})		
Şuşiţa	Ciuruc	1.39	8.08	491/1991	3.33	6.1	0.51	1.17
Putna	Tulnici	4.75	13.0	333/1971	3.92	3.38	0.36	0.93
Milcov	Goleşti	1.50	3.69	560/1970	18.4	14.3	0.63	1.01
Rm. Sărat	Chiojdeni-Tulburea	1.51	8.53	335/1991	9.19	16.4	0.47	0.94
Câlnău	Potârnicheşti	0.392	2.02	146/1972	8.27	13.4	0.77	1.19
Slănic	Cernăteşti	1.38	3.27	410/1975	15.4	11.5	0.47	1.23
Prahova	Câmpina	8.27	17.1	369/1988	10.9	7.1	0.25	0.95

* Based on the data provided by the N.I.H.W.M.

Table 2. Data on water discharge and suspended sediment load for the study catchments (according to Zaharia & Ioana-Toroimac, 2009, with additions). Q_m: mean multiannual discharge; R: mean multiannual suspended sediment load; CVQ_m: variation coefficient of the mean annual discharge; CVR: variation coefficient of the mean annual suspended sediment load.

The analysis of the linear correlations between the mean annual precipitation fallen over the catchment and the mean suspended sediment yield highlights significant statistical links (for an error risk α = 0.02, according to the Bravais-Pearson statistical test), despite the fact that correlation coefficients are relatively low (between 0.42 and 0.64) (Table 3). The correlation between the mean multiannual suspended sediment yield and the mean multiannual precipitation fallen over the catchment accomplished for the seven study catchments shows a correlation coefficient of 0.57, which points at a relatively low connection between the two parameters.

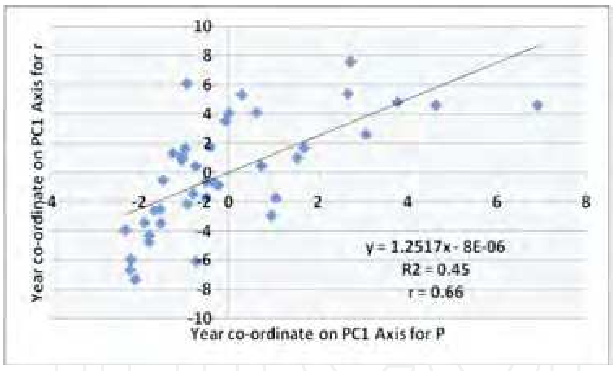
In order to identify the precipitation regional trends and the suspended sediment yield variability (at annual scale) the statistical method of Principal Component Analysis (PCA), applied with turnover, was employed (with XLSTAT 5.1. soft). This method allowed the determination of the regional synthetic indexes for the catchment mean precipitation (PC1P), as well as for the mean specific suspended sediment yield (PC1r). These indexes correspond to the information retained by the first principal component. The Mann-Kendall test was applied to establish the statistical significance of the temporal variability trends of the two regional synthetic indexes (PC1r and PC1P). In order to identify the intensity of the relationship between the mean specific suspended sediment yield and the precipitation variability on regional scale, the linear correlation between the two indexes was accomplished, and correlation and determination coefficients were analyzed. The statistical relevance of the correlations was established by using the Bravais-Pearson test (Chadule, 1997).

River	Hydrometric station	Correlation coefficients between suspended sediment yield and:		
		CMP	Q_{max}	Q_m
Şuşiţa	Ciuruc	0.64	0.78	0.69
Putna	Tulnici	0.62	0.72	0.62
Milcov	Goleşti	0.42	0.81	0.8
Rm. Sărat	Chiojdeni-Tulburea	0.46	0.56	0.78
Câlnău	Potârnicheşti	0.54	0.54	0.83
Slănic	Cernăteşti	0.56	0.54	0.74
Prahova	Câmpina	0.55	0.62	0.64

Table 3. Correlation coefficients of the relationships between suspended sediment yield and the hydrometeorological parameters of the study catchments (1961 – 2000). CMP: catchment mean annual precipitation (mm); Q_{max}: maximum annual discharge ($m^3 s^{-1}$); Q_m: mean annual discharge ($m^3 s^{-1}$). (according toZaharia & Ioana-Toroimac, 2009, with alterations)

On regional scale, the linear correlation between the annual synthetic index of specific suspended sediment yield (PC1r) and the annual synthetic index of precipitation (PC1P) has a correlation coefficient (r) of 0.66 (Fig. 4). According to Bravais-Pearson statistical test, for $\alpha = 0.02$ level of significance, the correlation between the analyzed parameters is statistically significant. However, the value of the determination coefficient ($R^2 = 0.45$) shows a low quality of the correlation, which reveals the importance of other local factors in controlling the sediment transport.

Based on the mean monthly and annual amounts of precipitation recorded at the 24 weather stations taken into account, we computed the climatic erosive index for each of them as the ratio between the squared precipitation of the month with the maximum pluviometric value and the total annual amount of precipitation (Pătroescu, 1996). The values of these indexes range from 25 (at Râmnicu Sărat, 152 m a.s.l.) to 39.2 (at Lăcăuţi, 1776 m a.s.l.) (Fig. 6A). The highest values (over 35) are specific for altitudes between 400 and 1700 m a.s.l. (Fig. 6B). The high values of climatic erosive index, in conjunction with the specific lithological conditions and the low degree of afforestation, reflect a great potential for sediment generation.



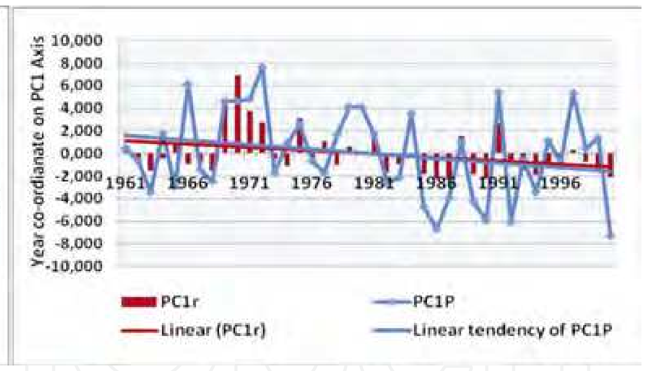


Fig. 4. (left). Linear correlation between the regional index for the annual precipitation (year co-ordinate on PC1 Axis for P) and the regional index for the annual specific suspended sediment yield (year co-ordinate on PC1 Axis for r) in the Carpathians' Curvature region (according to Zaharia & Ioana-Toroimac, 2009, modified)

Fig. 5. (right). Interannual variability of the regional index for the annual precipitation (PC1P) and of the regional index for the annual specific suspended sediment yield (PC1r) in the Carpathians' Curvature region (according to Zaharia & Ioana-Toroimac, 2009, modified)

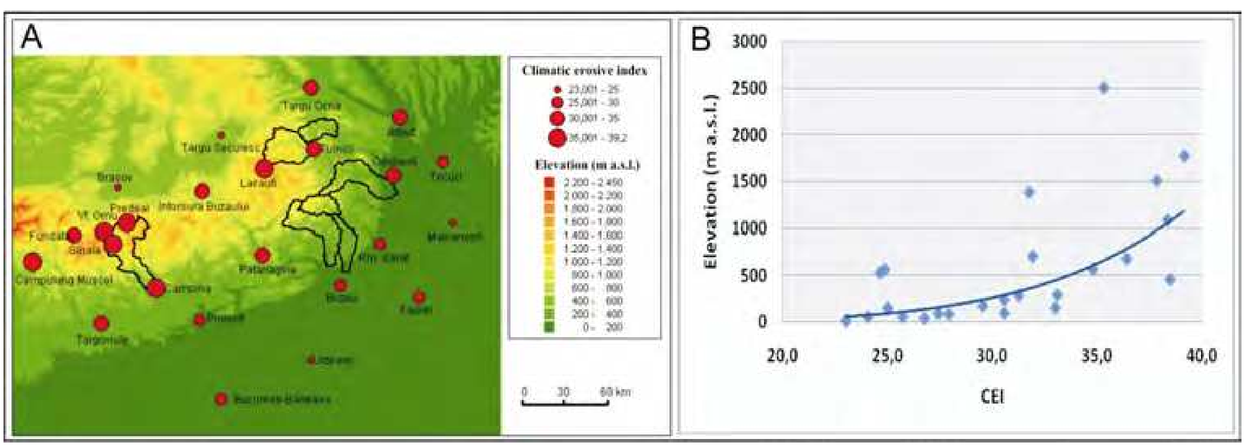


Fig. 6. The variation of climatic erosive indexes in the Carpathians' Curvature region (A) and their correlation with the weather station's elevation (B) (1961 – 2000) (the delimited areas in Fig. A correspond to the studied watershed boundaries).

3.2.1.2 The flow regime and its influence on suspended sediment load

Suspended sediment load is directly influenced by liquid flow. The investigated rivers have mean multiannual water discharges ranging from 0.392 to 8.27 $m^3\ s^{-1}$ (corresponding to specific discharges of 2.02 and 8.27 $l\ s^{-1}\ km^{-2}$ respectively) (Table 2). During the flood events, water discharges may become 300 times higher than the mean multiannual values and consequently the rivers carry huge amounts of sediments. In the study area, the highest floods within the investigated period occurred in 1970, 1971, 1975, 1981, 1988 and 1991. These were also responsible for the maximum annual discharges (Table 2).

The influence of liquid flow on suspended sediment load is emphasized by the relatively high values (0.54 – 0.83) of the linear correlation coefficients between suspended sediment yield and the flow parameters (mean and maximum water discharge) (Table 3). However, the interannual variability of suspended sediment yield (expressed by the variation coefficient - CVR) is two to three times higher than the mean annual water discharge (Table 2), which mirrors a higher irregularity of sediment supply. Generally, the sediment regime is similar to the flow one. Yet, no simple relationship exists between suspended sediment concentration and water discharge for a given cross-section (Charlton, 2008). Figure 7 shows the monthly and seasonal variability of suspended sediment load of the Slănic River.

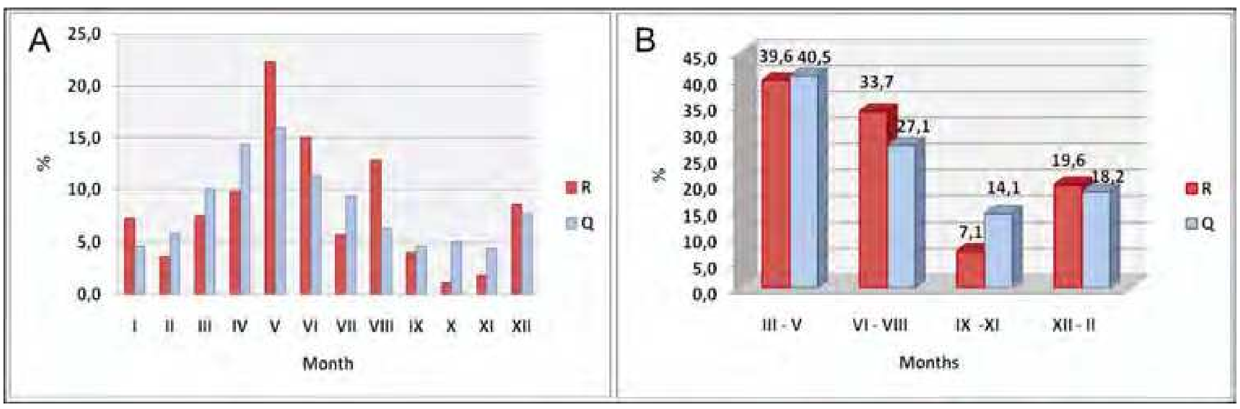


Fig. 7. Monthly (A) and seasonal (B) variations of suspended sediment load (R) and water discharge (Q) for the Slănic River at Cernăteşti gauging station (1971 – 2000) (% from the mean annual total volume)

3.2.2 Relationships between suspended sediment yield and catchment features

In our previous study (Zaharia & Ioana-Toroimac, 2009) we analyzed the outer Carpathian Curvature area from the standpoint of the intensity of the relationships between suspended sediment yield and three features of the catchments: catchment mean elevation, catchment mean gradient and forest ratio. In addition to the present study, we have also taken into account the drainage area.

The accomplished correlations between suspended sediment yield (for the period 1961 – 2000) and the above mentioned characteristics of the catchments, show that the most important role in suspended sediment transport is played by the catchment mean altitude (correlation coefficient = 0.52). Catchment size, catchment mean slope and the degree of afforestation have a lower influence, which is mirrored by the low correlation and determination coefficients (Table 4). The four control variables are inversely related to suspended sediment yield, which is shown by the negative values of the "a" parameter of the regression line equation (Table 4).

Relationship	Correlation coefficient	Coefficient of determination	Regression line equation
r - A	0.25	0.063	y = -6.578x + 386.08
r - H_m	0.52	0.28	y = -31.305x + 1009.2
r - S_m	0.38	0.15	y = -0.1035x + 4.9842
r - Fr	0.37	0.14	y = -0.0106x + 0.6441

Table 4. Correlation and determination coefficients of the relationships between suspended sediment yield and the catchment's characteristics (according to Zaharia & Ioana-Toroimac, 2009, with additions). r: mean multiannual specific suspended sediment yield (t ha^{-1} yr^{-1}; 1961 – 2000); A: catchment area; H_m: catchment mean elevation (m a.s.l.); S_m: catchment mean gradient (degrees); Fr: forest ratio.

Because the number of catchments taken into account in the correlative analysis is relatively low, we consider that the results are only informative. They might be further improved by considering more catchments, but this would require additional information, which for the time being is not available.

4. River channel dynamics

River channel morphology is the result of liquid and solid flow transiting the hydrological system, associated with the catchment features and human influences. These control variables may induce channel adjustments at a certain time scale. For example, lateral and vertical adjustments are noticed at a time scale inferior to 10 years (Knighton, 1984). In this general framework, our analysis focuses on four examples (the Trotuş, Prahova, Câlniştea and Vedea rivers) in order to contribute to a better understanding of the river dynamics and ofthe responsible factors.

4.1 Vertical dynamics of the Trotuş riverbed

The study of the bed processes, conducted by Rădoane et al. (2010), for 60 cross-sections belonging to the gauging stations in the Eastern Carpathians, highlighted the fact that there is no standard model for the river channel evolution. According to this study, there is a large variety of evolutions regarding the vertical change of the bed elevation; incision processes are dominant (in 52% of the cases) in spite of the aggradation processes (29% of the cases). In this context, this section aims to analyze the vertical variations of the riverbed elevation of the Trotuş River (162 km in length, with a 4456 km^2 catchment area, and a 34.6 $m^3 s^{-1}$ annual mean discharge at Vrânceni station), which crosses the Eastern Carpathians and Subcarpathians (Fig. 1A and Fig. 3).
The channel's vertical dynamics is analyzed for a period of 45 – 48 years for four gauging stations (Ghimeş-Făget, in the mountain section; Goioasa, at the border between the mountain and Subcarpathian areas; Târgu Ocna, lying in the Subcarpathian realm, and Vrânceni, placed at the outer extremity of the Subcarpathian section) (Fig. 3). This study extends the analysis period with almost 20 years (unlike the studies of Rădoane & Ichim, 1987, and Rădoane et al., 1991, which analyzed only half of this period), taking into account four gauging stations (unlike the study of Rădoane et al., 2010, which relied on the Goioasa gauging station only). The riverbed dynamics is indicated by the "hp oscillation", which represents the difference between the water stage (measured from the "0" elevation of the gauging station's staff) and the maximum depth, computed for every water discharge measurement (based on the data provided by the N.I.H.W.M.). The values of this parameter allow comparisons to be made between different years, because the "0" elevation of the gauging station's staff does not change (Chirilă, 2010). The evolution of the "hp oscillation" is analyzed through the linear and polynomial trends.
During the entire investigated period, the Trotuş River revealed a general trend to deepen its channel at Ghimeş Făget (Fig. 8A), where a significant incision was noticed after 1973. Downstream, at Goioasa, despite the general trend of aggradation, several intervals of vertical erosion (1971, 1987, 2004-2005) and aggradation (1967-1971, 1975, 1984-1985, 1990-1994, 2007) were noticed (Fig. 8B). Generally, the aggradation intervals are either synchronous or follow important flood events (like those of 1969, 1970, 1975, 1978, 1979, 1983, 1984, 1989, 1991, 2002, 2004, and 2005). This is due to important degradation processes in the river catchment, which are more intense during the floods. The gap between flood

occurrence and aggradation processes depends on other factors belonging to the river catchment, which influence the time of alluvium evacuation into the main river. At Târgu Ocna (Fig. 8C), where the channel has a downcutting tendency, a significant incision was noticed after the construction of a reservoir dam on its tributary, the Uz, between 1967 and 1973. At Vrânceni (Fig. 8D), one can notice a general aggradation trend, which has been more intense after 1972. In 2005, the intense degradation processes can be put to the account of the strong flood waves that occurred along the Trotuş, of which the most powerful was the one in July.

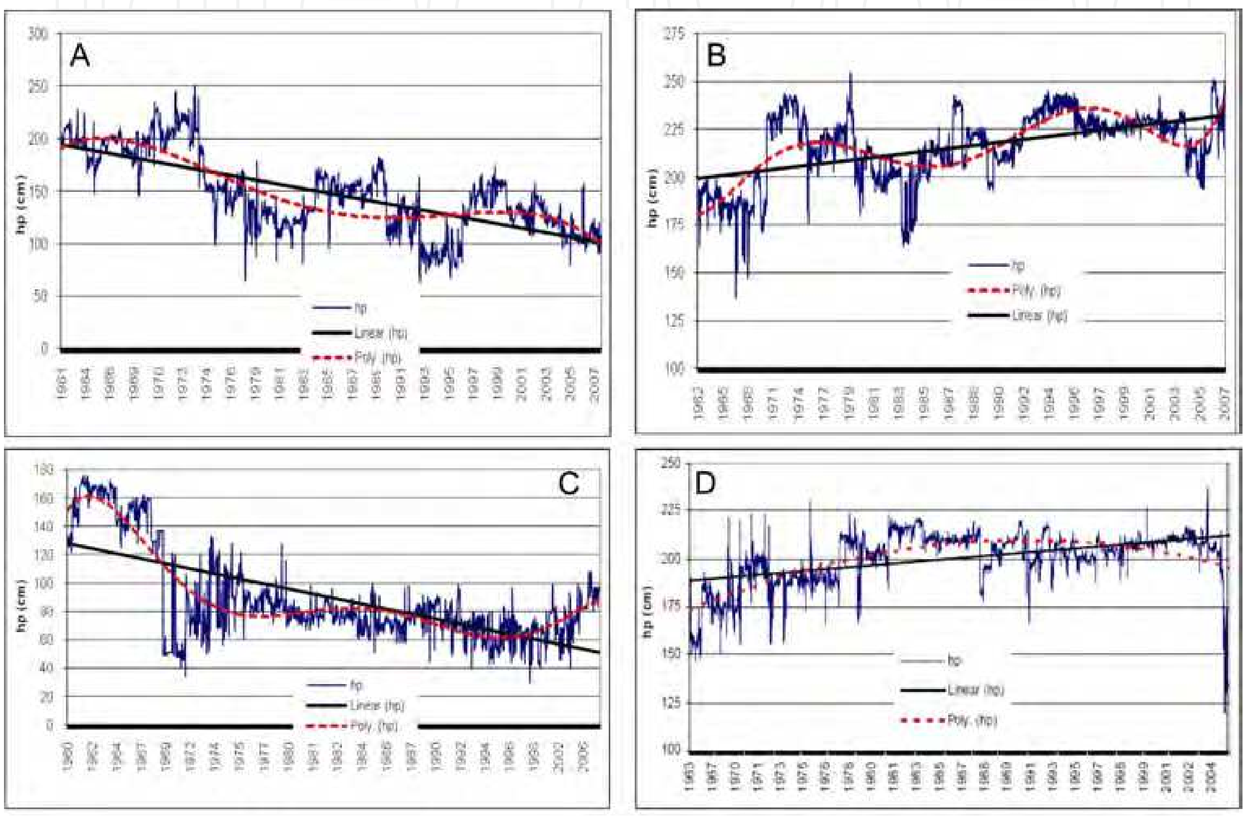


Fig. 8. Temporal variability of the bed elevation (hp) for the Trotuş River and the trends (linear and polynomial) at selected gauging stations: A) Ghimeş-Făget (study period 1961-2007; lying 35 km downstream the river's origin; catchment area, 381 km²; mean elevation of the catchment upstream the gauging station, 1116 m); B) Goioasa (study period 1962-2007; lying 52.4 km downstream the river's origin; catchement, area 765 km²; mean elevation of the catchment upstream the gauging station, 1052 m); C) Târgu Ocna (study period 1960-2007; lying 89 km downstream the river's origin; catchment area, 2091 km²; mean elevation of the catchment upstream the gauging station, 1924 m); D) Vrânceni (study period 1963-2007; lying 126 km downstream the river's origin; catchment area, 407 km²; mean elevation of the catchment upstream the gauging station, 734 m).

4.2 The Prahova's channel lateral adjustments

Several rivers coming down the French and Italian Alps and the Polish Carpathians have recently experienced downward erosion, narrowings and metamorphoses (*sensu* Schumm, 1977) of their braided channels, due to the changes in liquid and solid discharge (Arnaud-Fassetta & Fort, 2004; Bravard et al., 1999; Kondolf at al., 2002; Liébault & Piégay, 2002;

Surian & Rinaldi, 2003; Surian & Cisotto, 2007; Zawiejska & Wyzga, 2009). Within this general framework, this section aims to analyze the lateral dynamics of the braided channels. Because of the lack of information concerning the bedload sediment discharge, a secondary purpose is to provide an overview of the indirect responsible factors that influence this evolution, be they natural or human.

The study watercourse is the Prahova River (193 km long, with a catchment area of 3754 km^2, and a mean annual discharge of 8 $m^3 s^{-1}$ at Câmpina and 27 $m^3 s^{-1}$ at Adâncata), which comes down the Carpathians and crosses the Subcarpathians and the Romanian Plain (respectively the piedmont plain of Ploieşti and the subsidence plain of Gherghiţa-Sărata) (Fig. 9A). This evolution is analyzed starting from a diachronic study, which is based on several documents: Ordnance Survey maps of 1895-1902 (of scale 1:20000), topographic maps of 1953 – 1957 and 1977 – 1980 (of scale 1:25000) and aerial photographs of 2003 – 2005 (of scale 1:5000). These documents are calibrated, georeferenced and corrected in order to have the same geographic reference frame and to eliminate most of the geometric distortions. The analysis focuses on the active braided channels, which represent all the channels filled with water and separated by sandy bars. They indicate an active flooding of this area, which moves the sand grains downstream, and allow us to infer an annual frequency of occurrence (Peiry, 1988). For this discussion, the width of the active braided channel has been measured perpendicularly on its axis, every 250 m along the river.

The reconstruction of channel pattern with this methodological approach indicates that, around the year 1900, the Prahova River formed braided channels both in the Subcarpathians and in the Ploieşti piedmont plain. Between 1900 and 1955, on the first 17 and the last 10 km, the river branches joined into a single channel and the average width was reduced by 33% (Fig. 9B, C). This narrowing is probably the result of a hydrological recovery after the system had suffered the impact of the hydro-climatic hazards that occurred at the end of the 19th century, when several rainy and flood events were recorded in the Prahova's catchment (Mustăţea, 2005). This conclusion is reinforced by the finding that the braided channels of the Doftana River, one of the Prahova's Subcarpathian tributaries, also shrank by 35% (Ioana-Toroimac, 2009). Between 1955 and 1980, the Prahova's active channel narrowed by 15%. Despite the construction of dams, on the Doftana between 1968 and 1971, and on the Prahova in 1968, the relatively small narrowing of the active channel downstream the junction can be explained by the flood of July 1975 (recurrence interval of 20 years at Prahova-Doftana junction according to Ioana-Toroimac, 2009). It probably had a morphogenetic character and neutralized the effects of the human interventions in the hydrological system. Between 1980 and 2005, the last 10 km of the ancient braided stretch turned completely into a single channel, while the average width of the active channel diminished by 48%. This drastic retraction coincides with the creation of some water management engineering works in Romania (Şerban & Gălie, 2006). We can mention here the construction of a small dam on the Carpathian reach of the Prahova River in 1982, the setting up of gravel and sand workings (20 areas in 2005 comparing to 3 in 1980), the reinforcements with gabions and the building of low-head dams. During this period, no significant flood affected the Prahova's catchment. At the same time, a riparian forest covered some sections of the active channel, thus preventing its expansion.

During the entire study period, some shrinkage was noticed upstream, in the Carpathian section, on the Prahova's single channel, but this was less intense (37% between 1900 and 2005 in comparison with 68% for the braided stretch). This difference of intensity is explained by the channel pattern: the braided channels are more sensitive to liquid discharge variations and especially to bedload sediment discharge (Ioana-Toroimac et al., 2010). Nevertheless, it is still difficult to distinguish the role of each factor in the general evolution, because all the factors act simultaneously. At the same time, the feedback loops of the hydrological system are hard to understand and there is a lack of cartographic sources in-between the four analyzed moments.

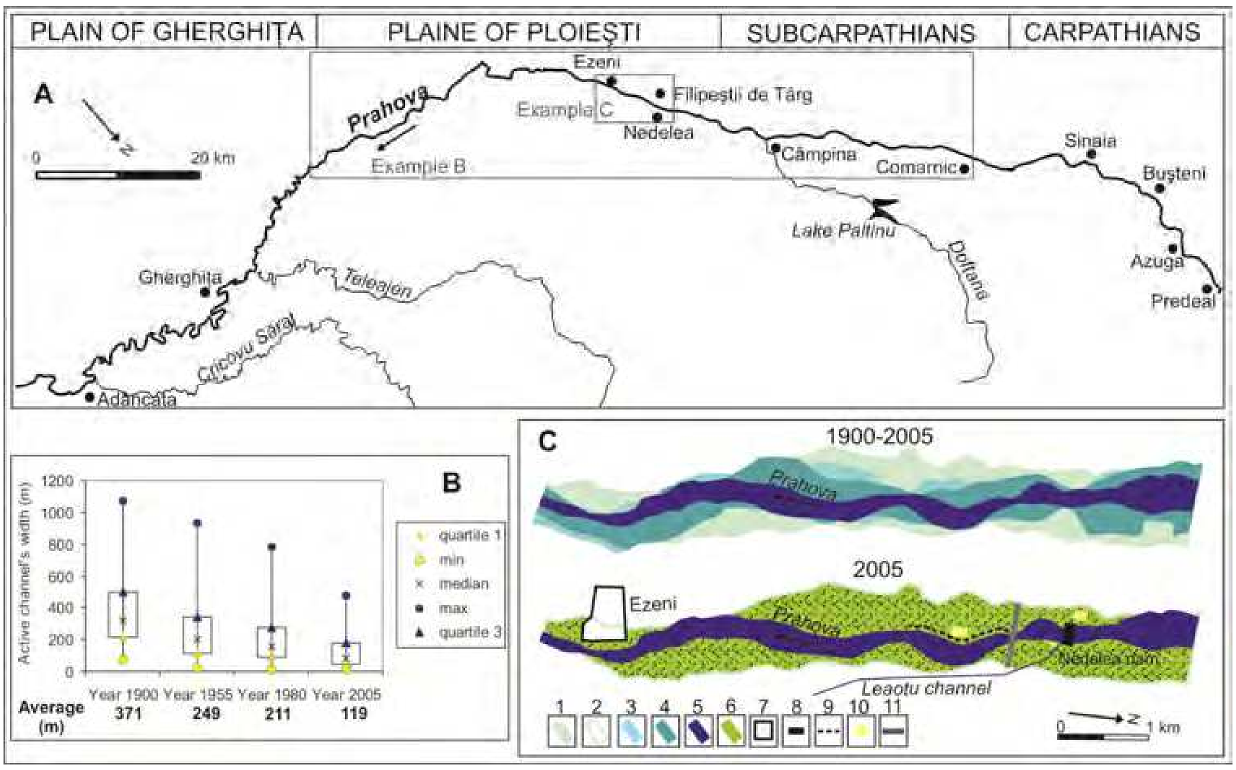


Fig. 9. The Prahova's active channel lateral adjustments. A. The physiographic units crossed by the Prahova River; B) Active channel's width variations; C) Retraction of the active channel between 1900 and 2005; in 2005 the ancient active channel, which was covered by pastures, was locally used for settlement expansion and gravel and sand mining; 1: the active channel in 1900; 2: the limits of the active channel in 1900; 3: the active channel in 1955; 4: the active channel in 1980; 5: the active channel in 2005; 6: pasture; 7: town; 8: dam; 9: gabions; 10: gravel and sand extraction area; 11: road.

4.3 Dynamics of the meandering channels: case studies in the Romanian Plain

This section aims to analyze the dynamics of the sinuous channels. The evolution of the meanders mirrors the horizontal dynamics of the channel through lateral cutting, as well as the rivers tendency to acquire the graded condition (Grecu & Palmentola, 2003). River gradient, liquid and solid flow, tectonics and some local conditions may influence the meanders formation and dynamics. The studies accomplished so far on the meander loops of some rivers belonging to the Romanian Plain show that these factors act in a synergistic way (Grecu et al., 2010c).

Our analysis is based on selected rivers in the Romanian Plain, because the winding process represents a specific feature of the evolution of this area during the Holocene (Grecu et al., 2009; Grecu, 2010). Besides, the significant alterations of the river system that took place over the time suggest an evolution similar to that of the Panonic Basin (Popov et al., 2008;

Timar et al., 2005, as cited in Grecu et al., 2010c). The analyzed rivers are the Vedea and Câlniştea, which cross a region affected by tectonic uplifts, more intense in the neighborhood of the Danube, where they exceed 2 mm yr^{-1} (Badea, 1983, 2009). The relationship between tectonics and meandering processes is tackled in a paper authored by Grecu et al. (2010b). Along these rivers, on the winding stretches, morphometric and diachronic analyses were accomplished in order to highlight the channel dynamics in the long and cross profile.

The Vedea River (251 km long, with a drainage area of 5364 km^2 and a mean annual discharge of 11 $m^3 s^{-1}$ according to Ujváry, 1972) has an allochtonous character: it originates in the Getic Piedmont, but more than 2/3 of its length and drainage basin lies in the Romanian Plain area (Fig. 10A). The river has a mean gradient of 2.1‰, which drops in the lower stretch to 0.5‰. This low inclination is one of the responsible factors for the tortuous aspect of the watercourse. In order to highlight the channel dynamics of the Vedea River, we proceeded to a diachronic analysis of the stream stretch lying near the junction of the Teleorman River (Fig. 10B), which is the Vedea's most important tributary (178 km long, with a drainage area of 1408 km2, a mean annual discharge of 3 $m^3 s^{-1}$ and a mean suspended load of 2 kg s^{-1}, according to Ujvári, 1972). This stretch has a high evolution potential due to the water and sediment contribution of the Teleorman, especially during the flood events. For instance, the balance analysis of suspended sediment load shows that between Alexandria and Cervenia (gauging stations placed upstream and downstream the junction of the Vedea and Teleorman rivers), the sediment accumulation amounts to 31,360 t yr^{-1} (value computed based on the data collected by Ujvári, 1972, for the period 1952 – 1967).

The diachronic analysis of this stretch relied on a series of maps developed in 1970 (scale 1:50000) and on aerial photographs taken in 2006 (scale 1:5000), which had been georeferenced and calibrated beforehand. It was ascertained that between 1970 and 2006 the section of the Vedea channel lying within the investigated area grew shorter by 2.5 km (from 12.7 km to 10.2 km). This shortening was due, on the one hand, to the natural adjustments (through rectifications and meanders migration) and on the other hand, to the engineering works. In its turn, the Teleorman River experienced the same pattern of development, and consequently the channel got shorter by 1.1 km, while the mouth changed its position. The Vedea's meanders lying upstream the junction of the Teleorman grew shorter by 600 m and the joint alluvial fan of the Vedea and Teleorman displaced the junction point by 0.83 km (Cârciumaru, 2010). Beside the meanders evolution, the comparison of the channel cross-sections accomplished for Alexandria station for the period 1979 – 2005 allowed us to understand the gradual aggradation of the riverbed.

Meanders formation largely depends on the interactions between the water flow and the materials eroded from the riverbed and the banks. Within the study period the highest discharges of the Vedea River (recorded at Alexandria station) occurred in October 1972 (949 $m^3 s^{-1}$), July 2005 (834 $m^3 s^{-1}$), July 1975 (544 $m^3 s^{-1}$) and July 1970 (463 $m^3 s^{-1}$) (Grecu et al., 2010c). Likewise, during these floods the solid load grew significantly, as it is proven by the flood of July 2005, when the suspended load recorded at Alexandria station amounted to 5,838 kg s^{-1}. Therefore, we may conclude that the natural evolution of the meanders and riverbed changes are influenced by these extreme hydrological events, with high morphogenetic potential.

The **Câlniştea River** (112 km long, with a catchment area of 1748 km^2 and a mean annual discharge of 3 m3 s^{-1} ; according to Ujvári, 1972), which originates in the Romanian Plain,

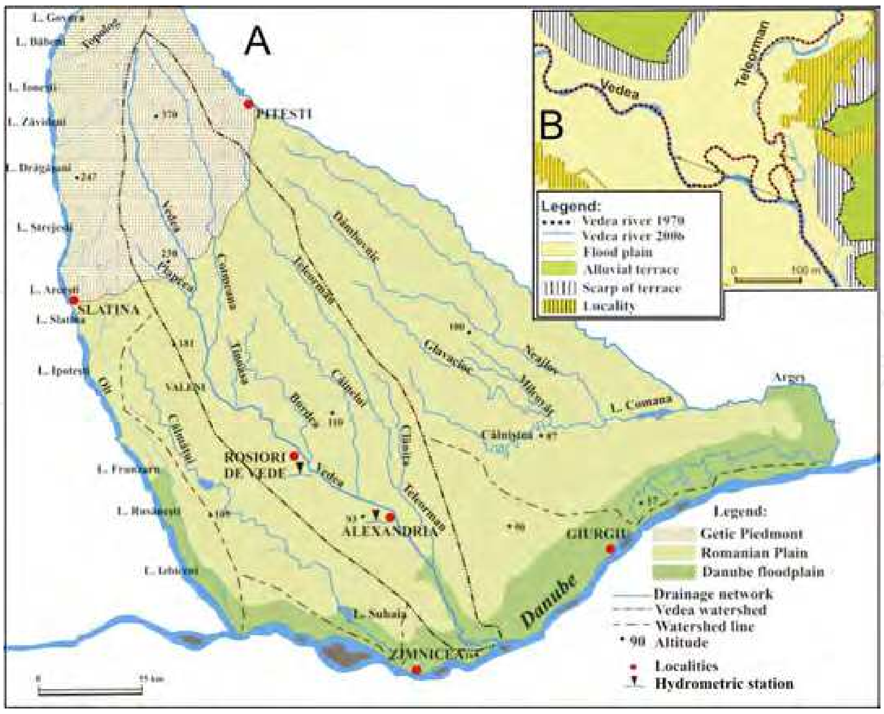
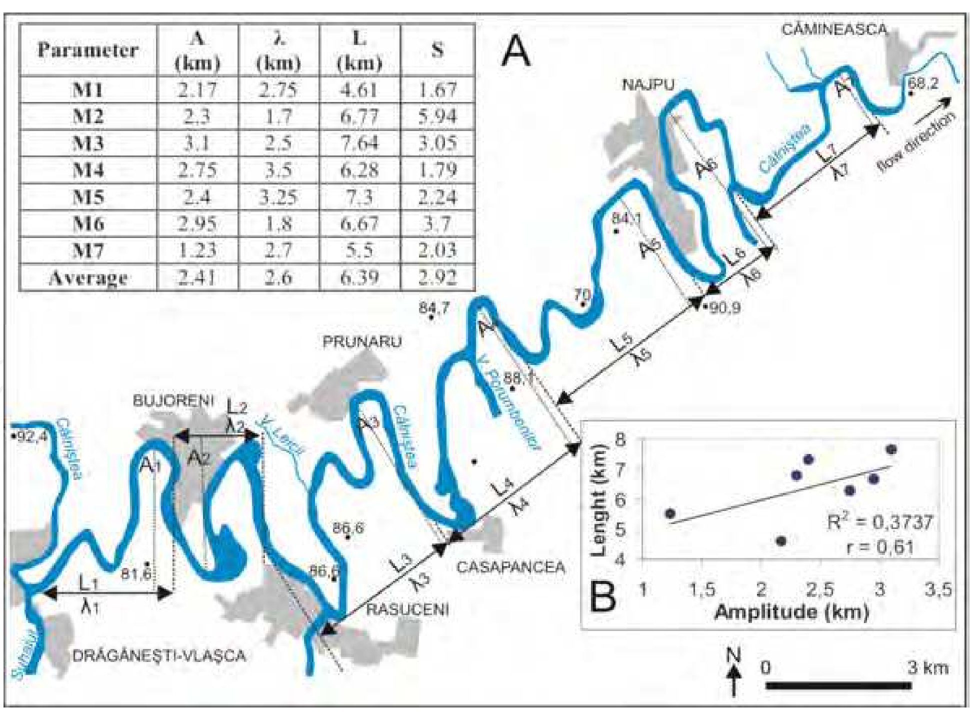


Fig. 10A. The central sector of the Romanian Plain, and the location of the Vedea and Câlniştea rivers. B. The lateral dynamics of the Vedea channel near the junction of the Teleorman between 1970 and 2006 (according to Grecu et al., 2010c, modified). The arrows in B show the most modified sectors.



Parameter	A (km)	λ (km)	L (km)	S
M1	2.17	2.75	4.61	1.67
M2	2.3	1.7	6.77	5.94
M3	3.1	2.5	7.64	3.05
M4	2.75	3.5	6.28	1.79
M5	2.4	3.25	7.3	2.24
M6	2.95	1.8	6.67	3.7
M7	1.23	2.7	5.5	2.03
Average	2.41	2.6	6.39	2.92

Fig. 11A. The meander morphometry of the Câlniştea River (according to Grecu et al., 2010b, modified). B. Corellation between the length and the amplitude of the meanders of the Câlniştea River in the study reach.M1...M7: meander number; A: meander amplitude; λ: meander wavelength; L: channel length; S: sinuosity ratio.

has a general west - east flow direction, which might be explained by the presence of a fault in the bedrock (Coteţ,1976). The accomplished analysis focused on a reach of about 45 km long (between Drăgăneşti - Vlaşca and Căminească settlements), and was based on the topographic maps of scale 1:25000 (edited in 1972). This river reach having a sinuosity coefficient of 2.45 (determined as a ratio between channel and valley lengths), was divided into seven sections, each of them encompassing a well-developed meander loop. These river bends have lengths varying from 4.61 to 7.64 km, amplitudes of 2 to 3 km and wavelengths of 1.7 to 3.5 km (Fig. 11A). We have determined a relatively close relationship between the meanders amplitudes and lengths (correlation coefficient $r = 0.61$) (Fig. 11B).

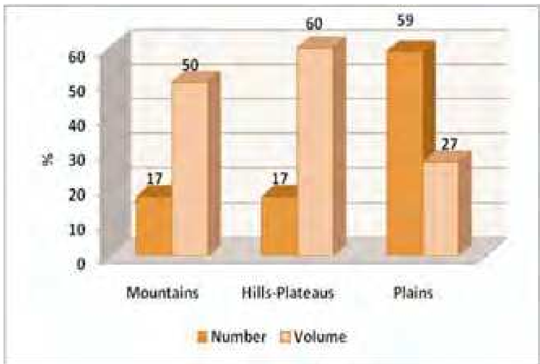
The meander dynamics was analyzed by overlaying the topographic map of 1972 and the Szathmary map of 1856, both georeferenced and calibrated beforehand. For this period, we noticed a shortening of the meander lengths, a reduction of their amplitudes and a diminution of the channel sinuosity (from 2.89 to 2.45), which on the one hand are the result of a natural rectification process, and on the other hand suggest a possible tendency for the river to reach the graded condition.

5. Human activity and the sediments: the role of dam construction in sediment transport

Human activities are an important control factor both for the processes regarding sediment generation, transfer and accumulation and for the channel dynamics. At the same time, these processes are responsible on short and long run for the alteration of the river channels, which entail negative socio-economic and environmental consequences. If in the previous sections we have mentioned some human activities (deforestation, sand and gravel extraction from river channels, dam construction, etc.), which induce alterations of sediment transport and bring about morphological changes of the channels, now we reveal some significant aspects concerning the impact of reservoirs on sediment yield, based on examples from Romania.

On a national scale, there are at present more than 2100 anthropogenic lakes, serving various functions. Of these, 246 lie behind dams higher than 15 m, for which they are considered reservoirs. From this point of view, Romania holds the 19th position among the 80 member states of the World Commission on Dams, and the 9th position in Europe (Rădoane, 2005). Of the total number of reservoirs, 406 exceed a volume of one million cubic meters of water (according to AQUAPROIECT, 1992) and hold together about 85% of the storage capacity of the anthropogenic lakes in Romania (Zaharia & Pătru, 2009). More than half of the reservoirs (59%) lie in the plain area (Fig. 12), but the highest water volumes (60% of the total capacity) are stored by the reservoirs lying in the hilly and tableland areas, where rocks are crumbly and erosion rates high, which largely explains the intense silting processes.

A study accomplished by Rădoane (2005) shows that on the Romanian territory, during a mean interval of 15 years, the amount of sediments deposited on the bottom of the reservoirs was about 200 million m^3 , while the annual deposition rate was 13.4 million m^3, representing more than a quarter (27%) of the mean annual suspended load. Silting processes mostly affect the reservoir chains built on the Olt and Argeş rivers (Fig. 1A), which store nearly half of the total sediment volume deposited in the Romanian reservoirs. Of the 13 impoundments that exist in the upper and middle catchment of the Argeş River, five are more than 70% silted and one is completely filled with sediments (Ogrezeni Reservoir) (Teodor, 1999; Rădoane, 2005).



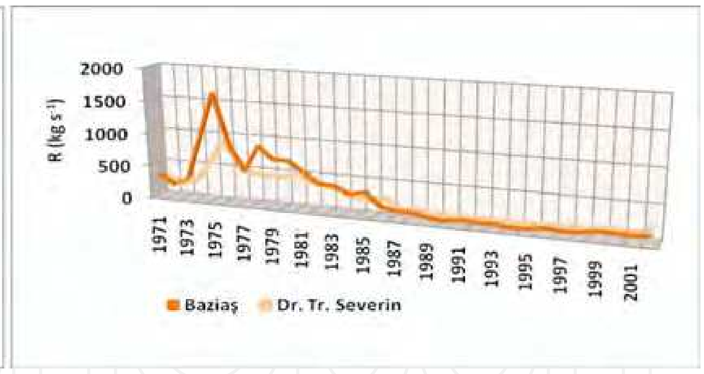


Fig. 12. (left). The percentage of the dam reservoirs of each major relief unit in the total number and in the total volume of the reservoirs exceeding 1 million m^3

Fig. 13. (right). The variability of the Danube mean annual suspended load at Baziaş and Drobeta Tr. Severin (according to the data provided by the "Romanian Waters" National Administration)

The largest reservoir in Romania is the Iron Gates I, placed on the Danube and making up the natural border between Romania and Serbia (Fig. 1A). It came into existence during the period 1964 – 1972, when the Iron Gates I Hydropower and Navigation System (H.N.S) was created, which is one of the most impressive engineering works in Europe and the biggest on the Danube. The reservoir is about 140 km long, covers 100 km^2, and at the maximum retention level (69.5 m a.s.l.) is capable of storing a water volume of 2400 million m^3 (AQUAPROIECT, 1992).

The balance of the sediments deposited in the Iron Gates I reservoir during the period 1971 – 2002, computed based on the cumulated differences between the Baziaş gauging station (lying where the Danube enters the reservoir) and Drobeta Tr. Severin station (lying downstream the dam), shows that the total volume of the deposited sediments amounted to 117.8 million tons (according to the data provided by the "Romanian Waters" National Administration). This volume corresponds to a mean annual rate of 3.7 million tons. The mean multiannual suspended load outflow was 33% lower than the inflow, the values decreasing from 353.2 kg s^{-1} (at Baziaş) to 236.5 kg s^{-1} (at Drobeta Tr. Severin) (data provided by the "Romanian Waters" National Administration). Significant reductions were recorded in the first decade after the reservoir creation and especially in the years with major flood events (1975, 1978). After 1987, however, one can note a relative homogeneousness of the suspended load on the two sections considered, as well as a decrease of sedimentation rate (Fig. 13).

In 1982, the Iron Gates II reservoir (Ostrov) was created 80 km downstream, with an area of 5200 ha and a water volume of 800 million m^3 (AQUAPROIECT, 1992). The creation of the two impoundments along the lower course of the Danube was responsible for the drastic reduction of the sediment load carried downstream. Thus, before entering the Danube Delta (at Ceatal Chilia), the mean annual values of suspended sediment load dropped during the interval 1970 – 2000 by 55% in comparison with the period 1921 – 1960 (from 66 million to 30.4 million t yr^{-1}) .

6. Chapter summary

Sediment transport and river channel dynamics are fluvial processes that may have on short or long run significant societal and environmental consequences. For this reason, they need to be studied thoroughly in order to mitigate their negative effects. These processes are controlled by a combination of variables acting on different spatial and temporal scales. Although it is very difficult to isolate the effect of a particular one, in the present work we have tried to identify the role played by some natural and human control factors on suspended sediment load/yield and on the river channel variability in Romania. In order to do that, we have used several case studies focused on two main physiographic units: the outer Carpathian's Curvature (characterized by the highest erosion rate in Romania) and the central part of the Romanian Plain (which experiences an intense lateral dynamics of the river channels).

The paper is based on three major types of analyses (statistical, correlative, and diachronic), which have helped us emphasize the following aspects: i) the space and time variability of suspended sediment load (at the Romanian scale and in the Carpathian curvature region); ii) the intensity of the relationships between suspended sediment yield and some control variables (precipitation, water discharge, catchment characteristics, and human activities), and iii) the vertical and lateral channel dynamics of some representative rivers in the Carpathian curvature region and the central part of the Romanian Plain.

In the years to come, we intend to improve these results by integrating more control variables (multiple and non-linear correlations), so that to better explain the relationships on regional scale. We wish we could take into account a bigger number of catchments, provided that we get the necessary information. For a more rigorous analysis of the relationship between suspended sediment yield and precipitation, we will take into account not only the amounts of precipitation, but also their intensity and frequency.

7. Acknowledgment

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8. References

Administrația Națională de Meteorologie. (2008). *Clima României*, Editura Academiei Române, ISBN 978-973-27-1674-8, Bucharest, Romania

AQUAPROIECT. (1992*). Atlasul Cadastrului apelor din România*, Ministerul Mediului, Bucharest, Romania

Arnaud-Fassetta, G. & Fort, M. (2004). La part respective des facteurs hydroclimatiques et anthropiques dans l'évolution récente (1956-2000) de la bande active du Haut Guil, Queyras, Alpes françaises du Sud, *Méditerranée*, No. 1-2, pp. 143-156, ISSN 0025-8296

Badea, L. (1983). Mişcările neotectonice, In: *Geografia României. I. Geografie fizică*, Badea L., Gâştescu P., Velcea V. (Ed.), pp. 84-88, Editura Academiei Republicii Socialiste România, Bucharest, Romania

Badea, L. (2009). *Relieful României şi neotectonica*, Editura Universitaria, ISBN 978-606-510-682-6, Craiova, Romania

Bălteanu, D. (1983). *Experimentul de teren în geomorfologie. Aplicații în Subcarpații Buzăului*, Editura Academiei, Bucharest, Romania

Bogdan, O. & Mihai, E. (1981). Intensité des pluies dans la région des Subcarpates de Buzău, *Revue roumaine de Géologie, Géophysique, Géographie – Géographie*, Vol. 25, No. 1, pp. 109-120, ISSN 0556-8099

Bravard, J.P.; Landon, N.; Peiry, J.L. & Piégay, H. (1999). Principles of engeneering geomorphology for managing channel erosion and bedload transport, examples from French rivers, *Geomorphology*, No. 31, pp. 291-311, ISSN 0169-555X

Cârciumaru, E. (2010). *Geneza, evoluția şi dinamica actuală a bazinului morfohidrografic Vedea*, PhD thesis, Bucharest University, Romania

Chadule (group) (1997). *Initiation aux pratiques statistiques en géographie*, Editions Masson, ISBN 2-200-01534-8, Paris, France

Charlton, R. (2008). *Fundamentals of fluvial geomorphology*, Routledge, ISBN 978-0-415-33454-9, New York, USA

Chirilă, G. (2010). *Resursele de apă din bazinul râului Trotuş – studiu de hidrologie şi calitatea apelor*, PhD thesis, Bucharest University, Romania

Cocoş, A. & Cocoş, O. (2005). Particularitățile rețelei de văi din bazinul hidrografic al râului Câlniştea, *Comunicări de geografie*, Vol. IX, pp. 311-316, ISSN 1453-5483

Cornea, I.; Drăgoescu, I.; Popescu, M. & Visarion, M. (1979). Harta mişcărilor crustale verticale recente pe teritoriul R.S. România, *Studii şi cercetări de Geologie, Geofizică, Geografie*, Vol. 17, No. 1, pp. 3-30

Coteț, P. (1976). *Câmpia Română – studiu de geomorfologie integrată*, Editura Ceres, Bucharest, Romania

Diaconu, C. (1964). Rezultate noi în studiul scurgerii de aluviuni în suspensie a râurilor R.P.R., *Studii de hidrologie,* No. XI, pp. 81-223, ISSN 0378-9810

Diaconu, C. (1971). Probleme ale scurgerii de aluviuni a râurilor României, *Studii de hidrologie*, No. XXXI, pp. 5-213, ISSN 0378-9810

Diaconu, C.; Avădanei, A.; Ciobanu, S. & Motea, I. (1962). Despre stabilitatea albiilor râurilor R.P.R. în ultimii 30-40 ani, *Studii de hidrologie*, No. III, pp. 53 – 63, ISSN 0378-9810

Diaconu, C. & Şerban, P. (1994). *Sinteze hidrologice*, Editura Tehnică, ISBN 973-31-0638-0, Bucharest, Romania

Dumitriu, D. (2007). *Sistemul aluviunilor din bazinul râului Trotuş*, Editura Universității, ISBN 978-973-666-237-9, Suceava, Romania

Feier, I. & Rădoane, M. (2007). Dinamica în plan orizontal a albiei minore a râului Someşul Mic înainte de lucrările hidrotehnice majore (1870-1968), *Analele Universității Suceava*, No. XVI, pp. 13-26, ISSN 1583-1469

Ghiță, C. (2009). *Geneza, evoluția si dinamica actuală a bazinelor morfohidrografice autohtone din Campia Romană de est cu aplicații la bazinul Mostiştea*, PhD thesis, Bucharest University, Romania

Grecu, F. (2010). *Geografia câmpiilor României*, Editura Universității, ISBN 978-973-737-859-0, Bucharest, Romania

Grecu, F. & Palmentola, G. (2003). *Geomorfologie dinamică*, Editura Tehnică, ISBN 973-31-2132-0, Bucharest, Romania

Grecu, F.; Săcrieru, R.; Ghiță, C. & Văcaru, L. (2009). Geomorphological landmarks of the Eastern Romania plain Holocene evolution, *Zeitschrift für Geomorphologie*, Vol. 53, No. 1, pp. 99-110, ISSN 0372-8854

Grecu, F.; Zaharia, L.; Ghiță, C.; Ioana-Toroimac, G. & Cârciumaru, E. (2010a). Episodes pluvio-hydrologiques extrêmes et dynamique hydro-géomorphologique dans la Plaine Roumaine: Le cas de la rivière Vedea, *Actes du XXIII-ème Colloque International de Climatologie*, pp. 251-256, ISBN: 978-2-907696-16-6

Grecu, F.; Ghiță, C. & Săcrieru, R. (2010b). Relation beetwen tectonics and meandering of river channels in the Romanian Plain. Preliminary observation, *Revista de Geomorfologie*, No. 12, pp. 97-104, ISSN 1453-5068

Grecu, F.; Zaharia, L.; Ghiță, C. & Văcaru, L. (2010c). The dynamic factors of hydrogeomorphic vulnerability in the central sector of the Romanian plain, *Metalurgia International*, Vol . XV, No . 9, pp. 139-148, ISSN 1582-2214

Ichim, I. (1992). Probleme ale cunoaşterii sistemului aluviunilor din România, *Lucr. celui de al IV-lea Simpozion Provenineța si efluența aluviunilor* , No. 4, pp. 7-15

Ichim, I.; Bătucă, D.; Rădoane, M. & Duma, D. (1989). *Morfologia şi dinamica albiilor de râu,* Editura Tehnică, ISBN 9733100056, Bucharest, Romania

Ichim, I. & Rădoane, M. (1990). Channel sediment variability along a river: a case study of the Siret River (Romania), *Earth Surface Processes and Landforms*, Vol. 15, No. 3, pp. 211-225, ISSN 0197-9337

Ichim, I.; Rădoane, N. & Rădoane, M. (1998). *Dinamica sedimentelor: aplicații la râul Putna-Vrancea*, Editura Tehnică, ISBN 9733111686, Bucharest, Romania

Ioana-Toroimac, G. (2009). *La dynamique hydrogéomorphologique de la rivière Prahova (Roumanie): fonctionnement actuel, évolution récente et consequences géographiques*, PhD thesis, Université Lille 1, France

Ioana-Toroimac, G. ; Dobre, R.; Grecu, F. & Zaharia, L. (2010). Evolution 2D de la bande active de la Haute Prahova (Roumanie) durant les 150 dernières années, *Géomorphologie : relief, processus, environnement*, No. 3, pp. 275-286, ISBN 2-913282-49-0

Knighton, D. (1984). *Fluvial forms and processes,* Arnold, ISBN 0-7131-6405-0, London, UK

Kondolf, G.M.; Piégay, H. & Landon, N. (2002). Channel response to increased and decreased bedload supply from land-use change: contrasts between two catchments, *Geomorphology*, No. 45, pp. 35-51, ISSN 0169-555X

Liébault, F. & Piégay, H. (2002). Causes of the 20th century channel narrowing in mountain and piedmont rivers of Southeastern France, *Earth Surface Processes and Landforms,* No. 27, pp. 425-444, ISSN 0197-9337

Mociorniță, C. & Birtu, E. (1987). Unele aspecte privind scurgerea de aluviuni în suspensie în România, *Hidrotehnica*, Vol. 32, No. 7, pp. 241-245, ISSN 0439-0962

Moțoc, M. (1984). Participarea proceselor de eroziune şi a folosințelor terenului la diferențierea transportului de aluviuni în suspensie pe râurile din România, *Bul. Inf. ASAS*, No. 13, pp. 16-28

Mustățea, A. (2005). *Viituri excepționale pe teritoriul României*, Editura Tipografică S.C. Onesta Com. Prod 94 S.R.L., ISBN 973-0-03611-X, Bucharest, Romania

Mutihac, V.; Stratulat, M.I. & Fechet, R.M. (2007). *Geologia României*, Editura Didactică şi Pedagogică, ISBN 973-30-1858-2, Bucharest, Romania

Pandi, G. & Sorochovschi, V. (2009). Dinamica verticală a albiei râurilor în dealurile Clujului si Dejului, *Riscuri si catastrofe*, Vol. VIII, No. 7, pp. 218-226, ISSN 1584-5273

Pătroescu Nardin, M. (1996). *Subcarpații dintre Râmnicu Sarat şi Buzău, Potențial ecologic şi exploatare biologică*, Editura Carro, ISBN 973-97751-1-X, Bucharest, Romania

Peiry, J.L. (1988). *Approche géographique de la dynamique spatio-temporelle des sédiments d'un cours d'eau intra-montagnard : l'exemple de la plaine alluviale de l'Arve (Haute-Savoie)*, PhD thesis, Université Jean Moulin Lyon 3, France

Pişota, I. & Zaharia, L. (2002). *Hidrologie*, Editura Universităţii din Bucureşti, ISBN 973-575-587-4, Bucharest, Romania

Popa-Burdulea, A. (2007). *Geomorfologia albiei râului Siret,* PhD thesis, „Al.I.Cuza" University Iaşi, Romania

Olariu, P. & Gheroghe, D. (1999). The effects of human activity on land erosion and suspended sediment transport in the Siret hydrographic basin, In: *Vegetation, land use and erosion processes*, Zăvoianu I., Walling D. E., Şerban P. (Ed), pp. 40-50, Institul de Geografie, ISBN 0730009813, Bucharest, Romania

Rădoane, M. (2005). Raport de Cercetare, Grant: A 448, *Revista de Politica Ştiintei şi Scientometrie*, ISSN- 1582-1218

Rădoane, M. & Ichim, I. (1987). Tendinţe în dinamica patului albiilor de râu în timp lung din Carpaţii Orientali, *Lucr. Ses. St. „Curgeri bifazice industriale"*, pp. 2172 – 2173

Rădoane, M.; Ichim, I. & Pandi, G. (1991). Tendinţe actuale în dinamica patului albiilor de râu din Carpaţii Orientali. *St. cerc. geol., geofiz., geogr., ser. geogr.*, Vol. 38, pp. 21 – 31, ISSN 0039-3967

Rădoane, M.; Rădoane, N.; Dumitriu, D. & Miclăuş, C. (1998). Probleme ale transportului de aluviuni în lacuri de interes hidroenergetic din România, *Analele Universităţii Ştefan cel Mare*, Vol. VII, No. 41-57, ISSN 1583-1469

Rădoane, M. & Rădoane, N. (2001). Eroziunea terenurilor şi transportul de aluviuni în sistemele hidrografice Jijia şi Barlad, *Revista de Geomorfologie*, No. 3, pp. 73-86, ISSN 1453-5068

Rădoane, M.; Rădoane, N. & Ichim, I. (2003a). Dinamica sedimentelor în lungul râului Suceava. *Analele Universităţii Ştefan cel Mare*, Vol. X, pp. 37-48, ISSN 1583-1469

Rădoane, M.; Rădoane, N. & Dumitriu, D. (2003b). Geomorphological evolution of river longitudinal profiles, *Geomorphology*, No. 50, pp. 293-306, ISSN 0169-555X

Rădoane, M. & Rădoane, N. (2005). Dams, sediment sources and reservoir silting in Romania, *Geomorphology*, No. 71, pp. 112-125, ISSN 0169-555X

Rădoane, M.; Rădoane, N.; Dumitriu, D. & Miclăuş, C. (2006). Efectele surselor de aluviuni asupra distribuţiei materialului de albie al râurilor est-carpatice, *Studii şi cercetări de Geografie*, No. LI-LIII, pp. 153-168, ISSN 1220-5281

Rădoane, M. & Rădoane, N. (2007). Răspunsul unei albii adâncite în roci coezive la acţiunea factorilor de control naturali şi antropici, *Studii şi cercetări de geografie*, No. LIII-LIV, pp. 117-136, ISSN 1220-5281

Rădoane M., Rădoane N., Cristea I. & Oprea-Gancevici D. (2008a). Evaluarea modificărilor contemporane ale albiei râului Prut pe graniţa românească, *Revista de Geomorfologie*, No. 10, pp. 57-73, ISSN 1453-5068

Rădoane, M.; Rădoane, N.; Cristea, I.; Persoiu, I. & Burdulea, A. (2008b). Quantitative analysis in the fluvial geomorphology, *Geographia technica*, No. 1, pp. 100-111, ISSN 2065-4421

Rădoane, M.; Pandi, G. & Rădoane, N. (2010). Contemporary bed elevation changes from the eastern Carpathians, *Carpathian Journal of Earth and Environnemental Sciences*, Vol. 5, No. 2, pp. 49-60, ISBN 1842-4090

Roşca, D. & Teodor, S. (1990). Influenţa lacurilor de acumulare asupra transportului de aluviuni, *Lucr. celui de al III-lea Simpozion „Provenienţa şi efluenţa aluviunilor"*, pp. 57-65

Schumm, S.A. (1977). *The fluvial system*, Wiley and Sons, ISBN 0-471-01901-1, New York, USA

Surian, N. & Rinaldi, M. (2003). Morphological response to river engineering and management in alluvial channel in Italy, *Geomorphology*, No. 50, pp. 307-326, ISSN 0169-555X

Surian, N. & Cisotto A. (2007). Channel adjustements, bedload transport, and sediment sources in a gravel-bed river, Brenta River, Italy, *Earth Surface Processes and Landforms*, No. 32, pp. 1641-1656, ISSN 0197-9337

Şerban, P. & Gălie, A. (2006). *Managementul apelor. Principii si reglementări europene*, Editura Tipored, ISBN 978-973-86083-8-2, Bucharest, Romania

Teodor, S. (1992). Transportul total de aluviuni (suspensii şi târâte) din bazinul hidrografic Argeş şi unele implicații asupra colmatării lacurilor de acumulare, *Lucr. celui de al IV-lea Simpozion „Proveniența şi efluența aluviunilor"*, pp. 165-169

Teodor, S. (1999). *Lacul de baraj şi noua morfodinamică, Studii de caz pentru râul Argeş*, Editura Vergiliu, ISBN 973-98540-4-4, Bucharest, Romania

Ujváry, I. (1972). *Geografia apelor României*, Editura Ştiințifică, Bucharest, Romania

Urziceanu, D. (1967). Considerații privind caractrerizarea stabilității albiilor râurilor, *Hidrotehnica, gospodărirea apelor, meteorologie*, Vol. 12, No. 1, pp. 27-31, ISSN 0018-134X

Văcaru, L.C. (2010). *Bazinul hidrografic Neajlov – Studiu de geomorfologie dinamică*, PhD thesis, Bucharest University, Romania

Zaharia, L. (1998). Tendances dans l'évolution des transferts de matières en suspension dans les Subcarpates de Courbure, en relation avec les modifications du milieu naturel, *Géomorphologie: relief, processus, environnement*, No. 1, pp. 3-15, ISSN 1266-5304

Zaharia, L. (1999). *Resursele de apă din bazinul râului Putna. Studiu de hidrologie*, Editura Universității din Bucureşti, ISBN 973-575-334-0, Bucharest, Romania

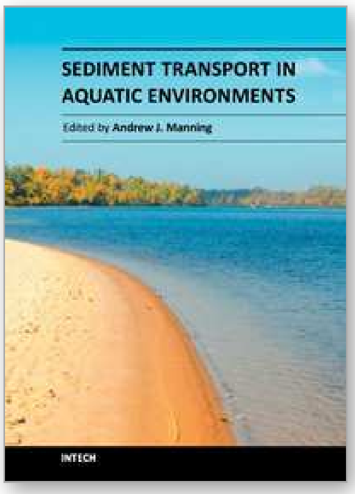
Zaharia, L. (2005). Studiul resurselor de apă din Carpații şi Subcarpații Curburii, *Lucrări şi rapoarte de cercetare*, Vol. 1, pp. 137-171, ISBN 973-737-012-0

Zaharia, L. & Ioana-Toroimac, G. (2009). Erosion dynamics – precipitation relationship in the Carpathians' curvature region (Romania). *Geografia fisica e dinamica quaternaria*, No. 32, 95-102, ISSN 0391-9838

Zaharia, L. & Pătru, I. (2009). Considerations on the Anthropic Romanian Lakes and their Impact on the Environement, Lakes, reservoirs and ponds, *Romanian Journal of Limnology*, No. 1, pp. 128-132, ISSN: 1844-6477

Zawiejska, J. & Wyzga, B. (2010). Twentieth-century channel changes of the Dunajec River, southern Poland: Patterns, causes and controls. *Geomorphology*, No. 117, pp. 234-246, ISSN 0169-555X

Zăvoianu, I. & Mustățea, A. (1992). Legătura dintre debitele de apă şi de aluviuni în suspensie pe râurile din România, *Lucr. celui de al IV-lea Simpozion „Proveniența şi efluența aluviunilor"*, pp. 158-164



Sediment Transport in Aquatic Environments
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Sediment Transport in Aquatic Environments is a book which covers a wide range of topics. The effective management of many aquatic environments, requires a detailed understanding of sediment dynamics. This has both environmental and economic implications, especially where there is any anthropogenic involvement. Numerical models are often the tool used for predicting the transport and fate of sediment movement in these situations, as they can estimate the various spatial and temporal fluxes. However, the physical sedimentary processes can vary quite considerably depending upon whether the local sediments are fully cohesive, non-cohesive, or a mixture of both types. For this reason for more than half a century, scientists, engineers, hydrologists and mathematicians have all been continuing to conduct research into the many aspects which influence sediment transport. These issues range from processes such as erosion and deposition to how sediment process observations can be applied in sediment transport modeling frameworks. This book reports the findings from recent research in applied sediment transport which has been conducted in a wide range of aquatic environments. The research was carried out by researchers who specialize in the transport of sediments and related issues. I highly recommend this textbook to both scientists and engineers who deal with sediment transport issues.