INTRA-ANNUAL DYNAMICS DISSOLVED SOLIDS AND SUSPENDED SEDIMENT IN THE EXTREME HIDROLOGICAL EVENTS – CASE STUDY NIŠAVA RIVER

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ABSTRACT

Dynamics of totall dissolved solids (TDS) and suspended sediment concentrations (SSC) were monitored on the river Nišava at the hydrological station Dimitrovgrad. Water samples were collected each day in the period from 01.01.2010–31.12.2010. TDS concentration followed a seasonal pattern imposed by the availability of water, with higher concentrations recorded in low-flow periods and lower concentration in the high-flow period. SSC was extremely variable and dominate mainly with specific high-flow events. Mean annual discharge (Q=6.68 m3/s, q=13.9 l/s/km2) over the year was 3.3 times higher than the average for the period of 50 years. In the study period, the annual transport dissolved load (Qd) was 36962.8 t (specific load Qds=76.7 t/km2/yr) and suspended sediment load (Qs) was 98861.9 t (specific load Qss=205.1 t/km2/yr). The transport of dissolved load and suspended sediment load shows temporal variations in different seasons. The analysis revealed that the maximum loads was transferred during the winter (Qd=43.3% and Qs=56.8% of the annual transport) and spring season (Qd=37.9% and Qs=38.9% of the annual transport). A comparative analysis of Q, Qd, and Qs show that the suspended sediment shows greater variability and exponential pattern of transport. For instance, 90% of the time was required to export 65% of the total water and transported 77% of the total dissolved load and only 22% total suspended sediment load. The most extreme precipitation episodes and extreme temperatures events was recorded in February 2010. The floods in February contributed by 44.8% of the total Qs transport over the study period. These findings have important implications for water resource management in the context of sediments mobilization, erosion, channel management, water quality and ecological functions.

Keywords: dissolved load, sediment load, extreme precipitation, floods, Nišava river

INTRODUCTION

Suspended and dissolved matters in rivers are considered relevant ecological problems. They are related to a wide range of on-site and off-site impacts, such as soil erosion or salinisation [1]. Suspended sediment has several impacts in water courses, such as siltation of reservoirs, desorption of nutrients, various biological impacts. Dissolved solids is being recognized as a major source of surface water quality deterioration. The estimation of the dissolved and sediment load and the transport rate governs the geomorphological, hydrological, sedimentological and ecological processes of river basins. Understanding the relationship between dissolved load and sediment load, i.e. chemical weathering and physical erosion rates is an important issue for environmental science; both processes affect studies of soil and landscape evolution, water quality, or the Earth's climatic evolution [2]. Therefore, research interests pertaining to fluvial transport loads in the river systems have attracted much attention in recent times worldwide [3,4,5,6,7]. In general, comparative studies of the dynamics and transport of both dissolved and sediment loads in Serbia are represented in several papers [8,9,10,11]. In the last few decades, the extremes of meteorological-hydrological events in Europe have been particularly important for the occurrence of natural hazards [12]. Tošić and Unikašević (2014) showed that wet and dry periods become more frequent at the territory of Serbia after 1970 [13], pointing also to more frequent rainfall extremes and consequently torrential flood events [14,15]. Particularly during 2010 Central and Eastern Europe were affected by extreme climate events which had strong consequences on the environment and impact on human society [16]. Several episodes of extreme precipitation leading to dramatic and high-impact floods occurred in Serbia [17,18,19]. In this study, dissolved and sediment loads on the Nišava River (Eastern Serbia) in the period 01.01.2010–01.12.2010. The main objectives were to analyse the dynamics and transport of dissolved load and suspended sediment load at annual and seasonal scales, and to analyse during extreme daily climatic-hydrological condition. This research can serve as a basis for integrated basin management [20]. In the initial phase of implementation of this concept, it is necessary to identify and quantify specific problems in the basin and to enable reliable and timely action of the population.

METHODS AND DATA

Monitoring dissolved solids and suspended sediment concentration on the river Nišava at the hydrological station Dimitrovgrad (φ=43o 01'; λ=22o 45'; A=482 km2) was in the period 01.01.2010–31.12.2010. Analyses of the water samples were performed in the Laboratory for Physical Geography of the Faculty of Geography, University of Belgrade. Here we report the results of the research with the frequency of daily samples. Physic-chemical analyses (titration method, potentiometric method and spectrophotometric method) determined the concentration of dissolved solids (TDS=Ca2++Mg2++Na++K++HCO3-+Cl-+SO42-+SiO2). The hydrotehnical method was used to obtain the suspended sediment concentration (SSC) [21]. The data for water discharge (Q), precipitation (T) and temperature (T) are provided by the Hydrometeorological Office of the Republic of Serbia [22]

Dissolved load (Q_d) and Sediment load (Q_s) was determined by the following equations:

$$Q_d \text{ (t/day)} = Q \text{ (m}^3\text{/s)} \times \text{TDS (mg/l)} \times 0{,}0864 \quad (1)$$

$$Q_s \text{ (t/day)} = Q \text{ (m}^3\text{/s)} \times \text{SSC (mg/l)} \times 0{,}0864 \quad (2)$$

where: Qd – dissolved load, Q – water discharge, TDS – total dissolved solids; Qs – sediment load, Q – water discharge, SSC – suspended sediment concentration. Annual and monthly loads transport was obtained by summing daily values.

Load is then normalized by dividing through the drainage area (A) for interbasin comparison, resulting in the specific dissolved yield (Qds) specific specific sediment yield (Qss) as well as runoff (q) following equations:

$$Q_{ds}\ (t/km^2/yr) = Q_h\ (t/yr) / A\ (km^2) \quad (3)$$

$$Q_{ss}\ (t/km^2/yr) = Q_s\ (t/yr) / A\ (km^2) \quad (4)$$

$$q\ (l/s/km^2/yr) = Q\ (m^3/s) \cdot 1000 / A\ (km^2) \quad (5)$$

Specific dissolved and sediment loads can be converted into denudation rates (DR). For this study, chemical (DRch), mechanical (DRme) and total denudation rates (DRt) were calculated. The denudation rates were estimated by using the equation given by [23,7]:

$$DR_{ch}\ (mm/yr) = Q_{ds}\ (t/km^2/yr) / \rho\ (t/m^3) / 10^3 \quad (6)$$

$$DR_{me}\ (mm/yr) = Q_{ss}\ (t/km^2/yr) / \rho\ (t/m^3) / 10^3 \quad (7)$$

$$DR_t\ (mm/yr) = Q_{ds}\ (t/km^2/yr) + Q_{ss}\ (t/km^2/yr) \quad (8)$$

Rock densities (ρr) vary slightly depending on the mineral composition of source rocks. We used a mean density of 2650 kg/m3 following Hay (1998) and Singh et al (2008) [24,5].

For calculating thresholds of extreme precipitation and water discharge events, the method of peaks was used [25,26]. In this study statistical method were used for calculating the thresholds of extreme precipitation following equation:

$$\phi_P = \frac{1}{n}\sum_{i=1}^{n}\phi_{P_{MD}} \quad (9)$$

$$\phi_Q = \frac{1}{n}\sum_{i=1}^{n}\phi_{Q_{MD}} \quad (10)$$

Here, the value of the threshold was defined as the average value (arithmetic mean) of maximum daily precipitation (PMD, mm) or maximum daily water discharge (QMD, m3/s) for each year (i) during n years (50 in this case) of the analysed period 1961–2010.

RESULTS AND DISCUSION

Climatic and hydrological conditions

The average annual precipitation for the period 1961–2010 is P=642.9 mm. In general, the analysis of the annual precipitation shows an insignificant incease trend of 0.413 mm/year. At the seasonal scale, insignificant trends of decreasing precipitation during the summer, as well as increasing during the autumn, were observed. The positive trend in the autumn season is attributed to short-term atmospheric instabilities that can cause heavy rain [27]. The results show that after 1980, a trend of increasing monthly precipitation in the period from December to May was detected, and a significant increase at the level of significance of 5% was detected in February [28]. According to the climate classification [29], 2010 belongs to the category of wet years [30]. The total annual amount of precipitation in 2010 was P=787.6 mm, which is 18% higher than the multi-year average. In the intra-annual distribution (Table 1), the highest amount of precipitation is in June (P=81.7 mm) and May (P=72.6 mm), and the lowest in January (P=40.8 mm) and February (P=40.5 mm).

The average annual water discharge of the Nišava river at the hydrological station Dimitrovgrad is Q=2.1 m3/s (q=4.26 l/s/km2). According hydrological classification, using the Log-Pearson III distribution, 2010 was classified as an extremely wet [30]. Namely, in the period 1961–2010, the highest average annual flow of Q=6.68 m3/s (q=13.87 l/s/km2) was recorded in 2010. The maximum average monthly water discharge occurs in March and April and has approximately the same values, Q=3.87 m3/s (q=8.02 l/s/km2) and Q=3.84 m3/s (q=7.96 l/s/km2) respectively. The minumum average monthly water discharge is in August (Q=0.98 m3/s, q=1.81 l/s/km2) and September (Q=0.87 m3/s, q=1.54 l/s/km2) (Table 1).

Table 1. Precipitation and water discharge and thresholds for extreme events on a monthly time scale (Q – monthly water discharge in 2010, Pav – average monthly water discharge (1961–2010); PMD – maximum daily water discharge in 2010; PMDav – average maximum daily water discharge 1961–2010; P – monthly precipitation in 2010, Pav – average monthly precipitation 1961–2010; PMD – maximum daily precipitation in 2010; PMDav – average maximum daily precipitation 1961–2010)

Precipitation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P 2010	43.2	64.2	77.3	64.7	117.3	81.3	40.7	25.0	18.7	93.1	71.9	90.2
P_{av} (1961–2010)	40.8	40.5	44.1	52.3	72.6	81.7	61.2	49.6	47.8	47.2	56.5	48.7
P_{MD} 2010	8.9	9.5	22.7	20.4	35.7	21.6	12.6	12.9	6.6	18.1	29.9	29.7
P_{MD} (1961–2010)	12.5	13.2	14.7	14.8	21.0	25.5	25.3	20.0	18.4	17.3	17.7	13.8
Water discharge												
Q_{av} 2010	7.63	20.25	13.75	14.44	11.36	2.71	1.78	0.98	0.87	1.06	1.37	4.01
Q_{av} (1961–2010)	1.85	3.41	3.87	3.84	2.94	2.04	1.31	0.87	0.74	1.02	1.14	1.61
Q_{MD} 2010	17.30	77.00	20.90	32.20	39.80	5.60	4.10	1.20	0.96	1.58	4.10	35.40
Q_{MD} (1961–2010)	6.45	12.93	10.53	10.24	8.30	6.69	5.44	2.88	2.38	3.13	3.91	6.93

DYNAMICS IN TOTALL DISSOLVED SOLIDS AND SUSPENDED SEDIMENT CONCENTRATION

Selected statistics for water discharge, dissolved and suspended sediment concentration and loads are presented in Table 2. The observed dynamics in the behaviour of total dissolved solids (TDS) and suspended sediment concentration (SSC) were significantly different. The degree of variation in TDS concentration was relatively low. In the case of TDS concentration, average and median values were relatively similar (TDSav=251.8 mg/l, TDSme=255.0 mg/l), as well as values of minimum and maximum (TDSmin=78.8 mg/l, TDSmax=375.0 mg/l). In contrast, SSC concentration was extremely variable. Average and median of SSC concentrations were significantly different from TDC concentrations. The average concentration 4.6 times higher than median values (SSCav=141.5 mg/l, SSCme=30.8 mg/l). Also, the range between the minimum and maximum values is much larger (SSCmin=1.7 mg/l, SSCmax=2660.0 mg/l). Regarding the specific values, the obtained SSC concentrations have a highest inter-quartile range than the TDS concentrations (IQR from 22.1 mg/l to 170.0 mg/l and IQR from 195.4 mg/l to 313.0 mg/l respectively). In fact, SSC concentrations have a 6.8 times higher coefficient of variability compared to TDS concentrations.

Table 2. Selected statistics of daily variables in the Nišava river on hydrological station Dimitrovgrad 2010 (Q, m3/s – water discharge, TDS, mg/l – total dissolved solids, SSC, g/l – suspended sediment concentration, Qd, t/day – dissolved laod, Qs, t/day – sediment load; av – average, min – minimum, max – maximum, Quar.– quartile, me – median, IQR – Inter-Quartile Range, Perc.– percentile, Conf.SD – Confidence SD, δ – Standard deviation, CV – coefficient of variation).

Variable	Q (m^3/s)	TDS (mg/l)	SSC (mg/l)	Q_d (t/day)	Q_s (t/day)
av	6.6	251.8	141.5	101.3	270.9
min	0.8	78.8	1.7	24.3	0.7
max	77.0	375.0	2660.0	528.9	17696.4
Quar. 1	1.1	195.4	22.2	29.3	2.0
me	2.4	255.0	30.8	52.3	6.1
Quar. 3	10.2	313.0	170.0	183.1	163.9
IQR	9.1	117.6	147.8	153.8	161.9
Perc. 5	0.9	138.9	20.0	26.3	1.7
Perc. 95	20.9	362.4	560.0	244.4	858.8
Conf.SD–95%	8.3	67.5	259.6	83.7	1278.2
Conf.SD +95%	9.6	78.1	300.3	96.8	1478.4
Δ	8.9	72.4	278.5	89.7	1371.0
CV	136	29	197	89	506

TDS and SSC concentrations represent a different and characteristic seasonal pattern in relation to the same water discharge value. Monthly water discharge along with TDS and SSC concentrations are show in Figure 1. The highest TDS concentrations were observed at the end of the summer to mid-autumn, in the period August–October. In contrast, the lowest recorded TDS concentrations tend to occur in winter months, although in some occasions this period is slightly delayed, with lower concentrations in spring months. Mostly, dissolved matters depend mainly on the lithology and the duration of water circulation, surface runoff, interflow, and groundwater flow [31,32]. The seasonal pattern in TDS concentration is clearly related to the available water discharge. The relationship between monthly Q and monthly TDS is represented by a logarithmic function, with a high coefficient of determination R2=0.91 (Figure 1A). Namely, the highest TDS values were recorded during the lowest flows.

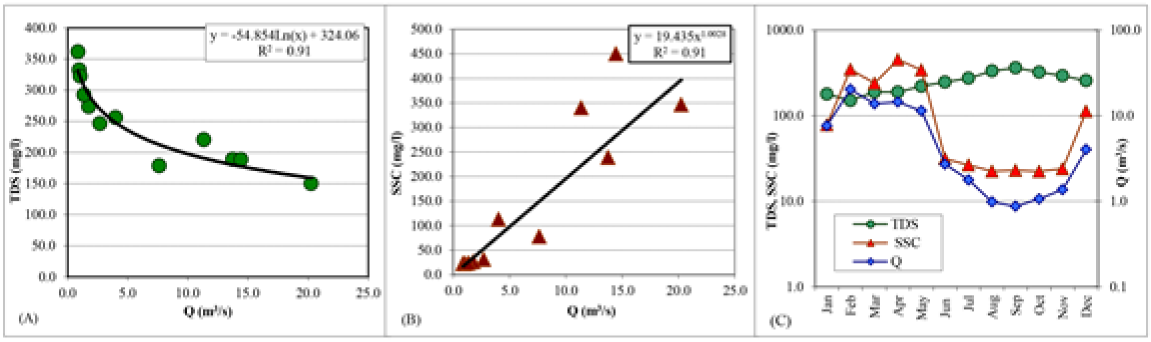

Figure 1. Logarithmic function (TDS=aLn(Q)+b) of the relationship between Q and TDS (A), power function (SSC=aQb) of the relationship between Q and SSC (B) and variability of Q, TDS and SSC (C) on a monthly time scale

In contrast, a different seasonal pattern was observed for SSC concentrations. As shown in Figure 1B, the relationship between monthly Q and monthly SSC is represented by the power function, with a coefficient of determination of R2=0.91. Visual interpretation indicates that, in general, samples with high concentration of SSC collected in months with a significant increase in water discharge. In this case, the highest monthly values of SSC are in the period February–May, when water discharge were recorded (Figure 1C).

DYNAMICS OF DISSOLVED LOAD AND SEDIMENT LOAD AT DIFFERENT TIME SCALE

During the period January–December 2010, the dissolved load and sediment load at the measuring station Dimitrovgrad amounted to Qd=36962.8 t and Qs=135824.9 t, respecively. Monthly transport of dissolved load and sediment load for 2010 are given in Table 3. The minimum transport Qd=818.0 t/month and Qs=51.9 t/month was during September. The maximum values of loads occurred in different months. So the highest monthly transport of dissolved loads was in March Qd=6822.1 t/month, which represents 18.5% of the total annual transport. On the other hand, the highest monthly transport of sediment load was in February Qs=44267.7 t/month, which represents 44.8% of the total annual sediment transport. Daily values of Qs show a much larger range compared to daily transport of Qd (Table 2). The ratio between the maximum and minimum daily transport of Qs is 1:26422, and Qd is only 1:22. The results show a very high daily coefficient of variation Qss of CV=506, as opposed to the coefficient of variation Qd which is CV=89.

Transport of dissolved and sediment loads shows a temporal variation at different seasons. The values of specific dissolved load (Qds) and specific suspended sediment load (Qss) during winter, spring, summer and autumn for the research period are given in Figure 2. Generally, characteristic of loads in the river Nišava on the hydrological profile Dimitrovgrad is the existence of two seasons in the transport of dissolved and sediment loads. The seasons are polarized into wet season (winter–spring) and dry seasons (summer–autumn), which by their characteristics represent extreme values in river loads transport. The presented seasonal distribution of sediment and dissolved transport is determined by the seasonal distribution of runoff (q). Average monthly runoff of approximately q=10 l/s/km2 can be defined as the limit value between wet and dry period. For specific runoff q<10 l/s/km2, 23.3% of annual Qd load and only 4.6% of annual Qs load were transported during the dry season. Both types of loads during the dry season have a small range of monthly values. In the period Jun–December (dry season) dissolved load was in the range of Qd=818.0–2140.5 t/month (Qds=1.7–4.4 t/km2/month) and transport sediment load in the range of Qs=51.9–254.4 t/month (Qss=0.1–0.5 t/km2/month). In contrast, during the wet season (q>10 l/s/km2), 76.7% of Qd and 95.4% of Qs of the annual load were transported. During the period January–May (wet season) sediment load has a larger range in transport compared to dissolved load, Qs=2276.9–44267.7 t/month (Qss=4.7–91.8 t/km2/month) and Qd=3465.9–6822.1 t/month (Qds=7.2–14.2 t/km2/month), respectively.

Table 3. Monthly distribution of water discharge, dissolved load and sediment load and percentage share in annual transport (Q, m3/s – water discharge, q, l/s/km2– runoff, Qd, t/month – dissolved load, Qds, t/km2/month – specific dissolved load, Qs, t/month – sediment load, Qds, t/km2/month – specific sediment load).

Paramet	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Q	7.6	20.2	13.8	14.4	11.4	2.7	1.8	1.0	0.9	1.1	1.4	4.0
q	15.8	42.0	28.5	30.0	23.6	5.6	3.7	2.0	1.8	2.2	2.8	8.3
Q_d	3465.	5719.7	6822.	6553.7	5803.3	1653.	1227.	871.	818.	912.	975.	2140.
Q_{ds}	7.19	11.87	14.15	13.60	12.04	3.43	2.55	1.81	1.70	1.89	2.02	4.44
Q_d %	9.38	15.47	18.46	17.73	15.70	4.47	3.32	2.36	2.21	2.47	2.64	5.79
Q_s	2276.	44267.	9587.	21423.	16733.	254.4	137.0	58.8	51.9	64.0	100.	3906.
Q_{ss}	4.72	91.84	19.89	44.45	34.72	0.53	0.28	0.12	0.11	0.13	0.21	8.11
Q_s %	2.30	44.78	9.70	21.67	16.93	0.26	0.14	0.06	0.05	0.06	0.10	3.95

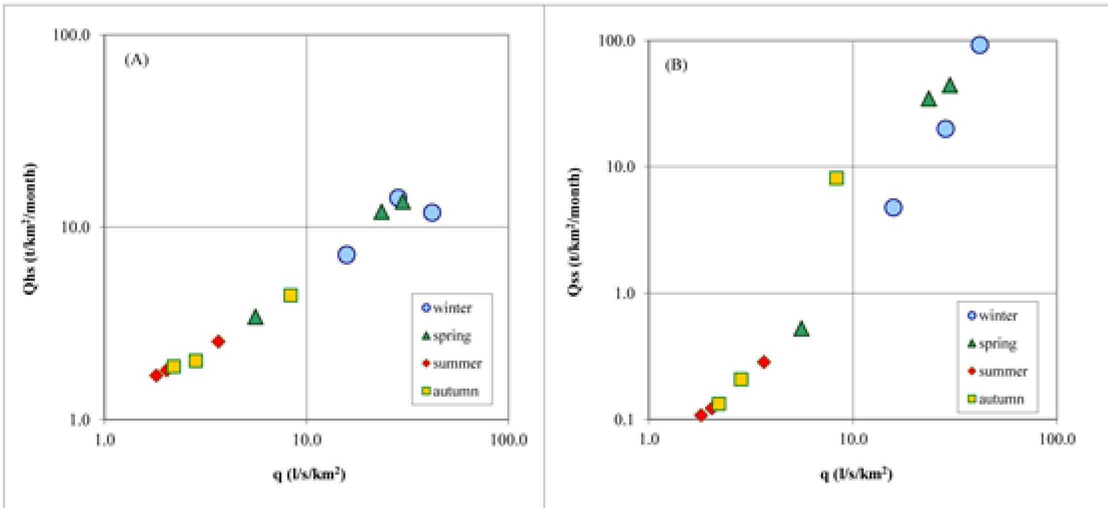

Figure 2. Relationship between average runoff (q) and specific dissolved load (Qds) and specific sediment load (Qss) at a seasonal scale (winter – January, February; March; spring – April, May, June; summer – July, August, September; autumn – October, November, December)

High values of sediment transport during the wet season are a consequence of extreme hydrological conditions during that period. As shown in Table 1, the average monthly water discharge in 2010 were higher than the monthly average water discharge for the period 1961–2010 from 60% in December to a record 83% in February. High water discharge were caused by a large amount of precipitation. Namely, monthly precipitation was higher than the average monthly precipitation for a period of 50 years from 19% to 46%. For a particular understanding of the dynamics and conditions of suspended sediment transport, sediment rating curve (SRC) will be used. The method is based on the relationship between the sediment load and water discharge and can be expressed as a power function Qs=aQb [33,34,35]. The analysis considered temporal changes in the sediment regime differentiated into monthly time scale. Sediment rating curves for each month during 2010 are shown in Figure 3, and the values of the parameters a and b are given in Table 4. Namely, the sediment rating parameters represent the soil erodibility and erosivity of the river [36]. The rating coefficient a represents availability of sediment in the basin and whether the sediment is easily eroded and transported by stream flow. Therefore, the value of the coefficient a at the station is closely related to sediment sources upstream. This coefficient, therefore, is influenced by the soil erodibility and suspended sediment input in the basin upstream of the gauging site. The rating exponent b indicates the changing rate of the suspended sediment load per change of unit water discharge [37].

Table 4. Sediment rating parameters for power function Qs = aQb for monthly time scale.

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
a	0.0163	0.1958	0.0613	0.3481	0.3829	0.9119	1.7732	1.9227	2.0102	1.8992	1.7618	2.7534
b	3.7655	2.5363	3.1987	2.7260	2.7123	2.0805	1.4570	0.7021	1.1030	1.2267	1.5998	1.8923
R^2	0.80	0.94	0.95	0.93	0.96	0.96	0.94	0.81	0.52	0.86	0.99	0.94

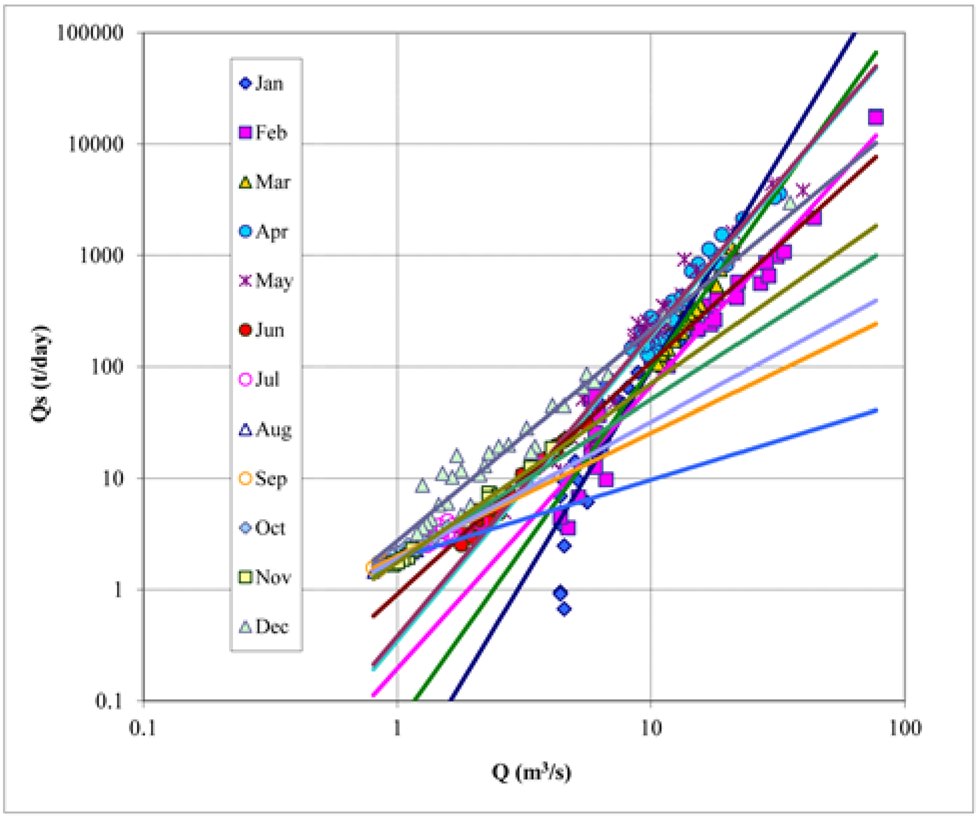

Figure 3. Sediment rating curves (SRC) for decline of sediment load (b) for monthly time scale based on daily data

The ranges of the monthly rating coefficient a are from 0.0163 to 2.7534. Results show that the coefficient a was significantly larger (for 95%) in summer and early autumn than in winter and in early spring. This is explained by the wide availability of sediments in the area of the entire basin upstream of the measuring station during the summer months due to the intensive agricultural activity in that part of the year. Values of monthly exponent b fluctuate between 0.7021 and 3.7655. Since the exponent b>1 in all months except August, the dominant shape of SRC is convex at monthly levels of analysis. The high value exponent b indicating strong increase in erosive power of the river [36,38], that suggests a substantially increasing rate of suspended load with an increase of discharge [39]. Changing the shape and slope of the rating curve means changing the sediment transport regime. In this case, the exponent b for the monthly curve in August is b < 1, which indicates a concave shape. This means that the suspended load increases in a diminishing rate with the increase in discharge. Rivers with this type of SRC are supply-limited, which means that the amount of sediment transported is constrained by the amount of sediment available [40,41]. On the other hand, during the wet season (January–May period) the exponent b has extremely high values, so that the curve has a more pronounced convex shape. Generally, previous studies have shown that the exponent b is significantly higher in spring than in winter [42,43,44]. The spring is the time when the annual peak of the flow occurs. This coincides with the annual snowmelt period. In that conditions, the erosive potential of the stream is higher, which affects the strong increase in the transport of suspended sediment in the river flow. However, in this study the values of exponent b are also high during the winter seasons, which is not typical. This means that some other conditions affected the high transport of Qs in this period, which will be considered on the several events.

TRANSPORT OF DISSOLVED LOAD AND SEDIMENT LOAD DURING SOME EXSTREME DAILY EPISODES

Extreme values of sediment transport in rivers occur most often in response to sudden changes in climatic conditions. Research has shown that the first, the biggest impact is the change in the amount and intensity of precipitation, while the second dominant impact is the change in temperature [45]. In fact, sediment transport is strongly focused on precipitation events and relatively few events are the key to explain the sediment export [46]. The combined impact of extreme precipitation and temperature conditions is a key factor in the occurrence of high water discharge and floods. Generally, the critical periods for floods in Serbia are the end of spring, from May to the first half of June, and the end of winter from February to the first half of March [47,48].

Previous research in Serbia [18,30] suggest that maximum daily precipitation (PMD) was considered as the key factor in excessive erosion. The impact of extreme precipitation on sediment transport will be considered on the example of the flood events in May (Figure 4A). The highest monthly precipitation during 2010 was recorded in May (P=117.3 mm) and is higher than the threshold for precipitation by 68% (Table 5). Specifically, in this case, in May, the maximum daily precipitation (PMD=35.7 mm) was 38% higher than the value of the PMD threshold was determined. Extreme precipitation events caused the occurrence of high flows and SSC concentrations. The average monthly water discharge is Q=11.4 m3/s and is higher than the average long-term by 74%. Maximum daily water discharge (QMD) was observed after the onset of maximum daily precipitation (PMD). Particular in this case, on May 15 the highest daily precipitation was registered, and five days later (May 19), the highest daily QMD = 39.8 m3/s was registered. Sediment transport in these conditions was extremely high. In fact, on May 19, when the largest daily Q was registered this month, were transported Qs=4380.5 t/day (26% total sediment load in May). The next day when the highest SSC values were registered, the daily sediment transport was Qs=4380.5 t/day. It can be concluded that 50% of the monthly sediment load was transported in only two days. On the other hand, on May 19, the highest daily dissolved transport Qd=364.8 t/day was recorded, which represents only 6% of the total monthly dissolved load.

Table 5. Extreme daily values of dissolved load (Qd) and sediment load (Qs) and percentage share in monthly transport.

Parameters	7. Januuary	18. February	7. March	22. April	19. May
Q (m^3/s)	17.3	77.0	20.9	32.2	39.8
Q_d (t/day)	190.5	528.9	257.5	315.3	364.8
%	5.5	9.2	3.8	4.8	6.3
Q_s (t/day)	538.1	17696.4	1175.5	3561.1	4380.5
%	23.6	40.0	12.3	16.6	26.2
Q_s/Q_d ratio	2.8	33.5	4.6	11.3	12.0

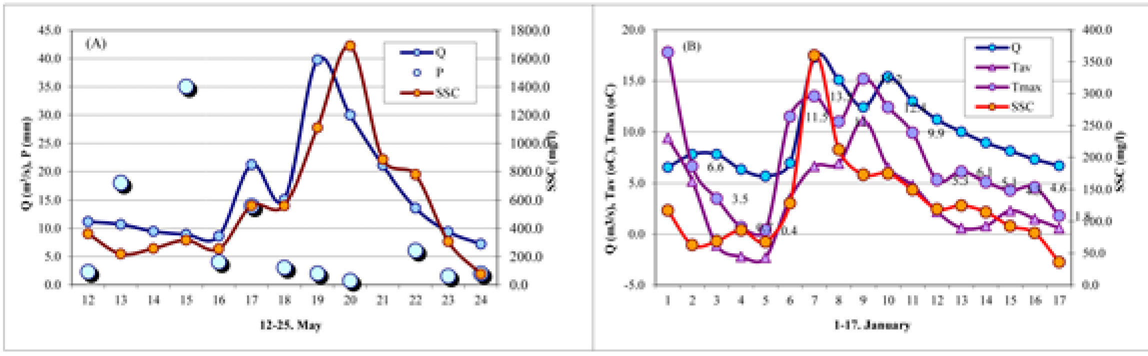

Figure 4. Daily values of water discharge (Q), precipitation (P) and suspended sediment concentration (SSC) for period 12–25. May 2010 (a) and daily values of water discharge (Q), average daily temperature (Tav), maximum daily temperature (Tmax) and suspended sediment concentration (SSC) for period 1–17. January 2010 (b).

Table 6. Correlation matrix between selected variable for January at significant level p=0.001 (Q, m3/s – water discharge; SSC, mg/l – suspended sediment concentration; TDS, mg/l – total dissolved solids; Qs, t – sediment load; Qd, t – dissolved load; Tav oC – average daily temperature; Tmax, oC – maximum daily temperature).

Parameters	Q	SSC	TDS	Q_s	Q_d	T_{av}	T_{max}
Q	1.00						
SSC	0.92	1.00					
TDS	–0.91	–0.84	1.00				
Q_s	0.92	0.96	–0.80	1.00			
Q_d	0.99	0.90	–0.87	0.87	1.00		
T_{av}	0.73	0.73	–0.72	0.62	0.74	1.00	
T_{max}	0.72	0.78	–0.70	0.68	0.72	0.93	1.00

However, precipitation is not the only factor in the excessive erosive process. As mentioned above, the major water discharge and transport of sediment load was in February 2010. In fact, the amount of precipitation in February (P=64.2 mm) was higher than the multi-year average (P=40.5 mm), but PMD was as much as 28 % lower than the threshold for precipitation (Table 1). Actually, the determining factor in the high transport of sediment load, in this case, is a combination of precipitation and temperature events of the current and previous month. The average monthly temperature in January and February was extremely high. Ten days in January and only four days in February with a Tmax>0oC were recorded. As shown in Figure 4B, in the first half of January Tmax ranged from 0.4 oC to 17.8 oC. High daily temperatures were also in February. In the last decade of February, maximum daily values of temperature higher than Tmax>6 oC, and during five days the average air temperature was higher than T>12 oC. High values of temperatures caused the snowmelt and high water discharge, which increased the erosive potential of the river flow. The correlation matrix (Table 6) between climatic parameters, sediment parameters and dissolved parameters show higs significant level (p=0.001). These climatic conditions resulted in extreme transport of sediment load in study period. On February 17, the maximum daily transport sediment load of Qs=1175.5 t/day was recorded, which is 33.5% of the total monthly sediment load. Also on this day, the maximum daily dissolved load was recorded (Qd=528.9 t/day). As presented in Table 5, it can be concluded that in extreme climatic and hydrological conditions, the suspended sediment is dominant. The Qs/Qd ratio ranges from 2.8 in January to 33.5 in February.

COMPARISON OF QD/QS LOADS AND HEMICAL/PHYSICAL EROSION

The pattern of cumulated water discharge (Q), suspended sediment load (Qs) and dissolved load (Qd) in relation with the cumulated time is represented in Figure 5. In general, the accumulated dissolved load presented a pattern similar to that of the water discharge, supporting the conservative behaviour of dissolved solids in water, which is in agreement with other research [1]. For instance, 90% of the time was required to export 65 % of the total water and transported 77% of the total dissolved load. The transport of sediment load shows greater variability and exponential pattern at the measuring station. For the same period, it was required to export 22% of the total sediment load. Regarding sediment load, its episodic character was clearly detectable in following example. More than 70% of the Qs load was discharged during the flood events, i.e. in only 5% of the time period. During the same period, only 16% of Qd load was transported.

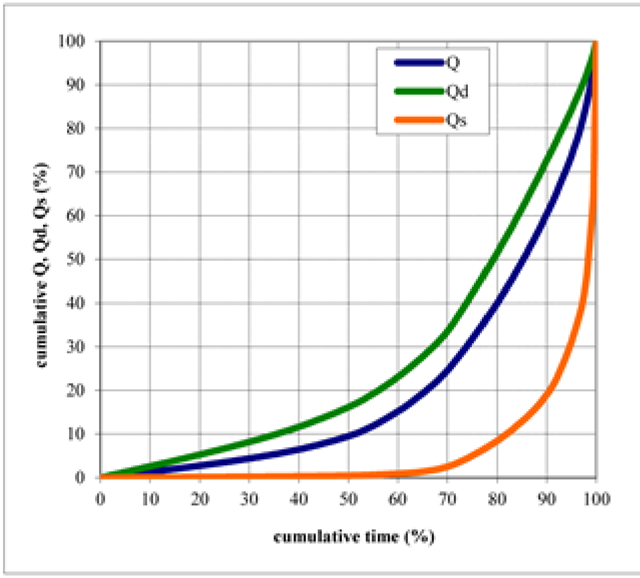

Figure 5. Cumulative water discharge (Q), dissolved loads (Qd), suspended sediment loads (Qs) versus cumulative time in Nišava river, hydrological station Dimitrovgrad

Comparative of chemical erosion and mechanical erosion are given in Table 7. The results show that the mechanical erosion (sediment load)/chemical erosion (dissolved load) ratio at the Dimitrovgrad hydrological stations on the Nišava River is higher than one, indicating overall dominance of mechanical erosion over the chemical erosion. The chemical and mechanical erosion rates during 2010 sampling period were calculated to 76.7 t/km2/yr and 205.1 t/km2/yr, respectively. In particular, during 2010 the mechanical erosion contributed by 73% in total erosion. The lowering rates based on the observations were estimated to be 0.75 mm/yr (0.20 mm/yr due to chemical erosion and 0.54 mm/yr due to mechanical erosion).

Table 7. Comparative chemical denudation rate (DRch) and mechanical denudation rate (DRmc)

Hydrological station	A (km^2)	Q_{ds}	Q_{ss} ($t/km^2/yr$)	Total erosion	P/C ratio	DR_{ch}	DR_{mc} (mm/yr)	DR_t
Dimitrovgrad	482	76.7	205.1	281.8	2.67	0.20	0.54	0.75

CONCLUSIONS

The comparison of dissolved load and sediment load provides important conclusions on the transport processes of river load and erosion rate that occur at the different time scale in the upstream of the Nišava river basin. Over the period under consideration, we observed a larger variation in the suspended sediment concentration and sediment load than in total dissolved concentration and dissolved load. For the Nišava river in hydrological station Dimitrovgrad, the data show that the water discharge (runoff) is the main factor controlling the transport of river loads intra-annual variations. Generally, the main characteristic of loads is the existence of two seasons in the transport of dissolved and sediment loads: dry season – in which 23.3% of annual Qd load and only 4.6% of annual Qs load were transported (2) wet season – in which 76.7% of Qd and 95.4% of Qs of the annual load were transported. We have obtained a more precise estimate value Qd and Qs load over period of study characterized by massive floods. The floods in February contributed by 44.8 % of the total Qs transport over the study period. The relationship between cumulative time and cumulative load suggests that more than 70% of the Qs load and 16% of the Qd load was discharged during the extreme events, i.e. in only 5% of the time period. Comparative of chemical erosion and mechanical erosion during 2010 show that the mechanical erosion contributed by 73% in total erosion. This research would help in understanding the hydrologic responses of river fluvial systems for taking up appropriate soil and water conservation measures leading to integrated river basin management.

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