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ORIGINAL PAPER

Impact of precipitation and human activities on suspended sediment transport load in the Velika Morava River Basin (Serbia)

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Abstract

Sediment transport time series have shown a severe change in the suspended sediment load transported by the Velika Morava River (Republic of Serbia) during the last few decades. The research objectives of this study were to determine the suspended sediment trends, and to assess the impact of variations in precipitation and human activities on the suspended sediment load. The causes and timing of this severe decrease were analyzed, and the results show that there has been a significant sudden shift downwards for the suspended sediment load ($p < 0.0001$) during the research period. The change points for sediment load were very similar and the transition years all ranged between 1982 and 1984. The combined effects of precipitation and human activities are responsible for the decrease in the suspended sediment load, with human activity being the most active factor in the sediment regime changes. The contribution rate for human activities amounts to 87.7–91.9%, while precipitation explains 8.1–12.3% of the reduction in the suspended sediment load. The processes of deagrarization and depopulation had an influence on the sediment load decrease in the study area. The results of the spatial autocorrelation analysis of rural settlements showed that the reduction in sediment was due to the process of depopulation and the large reduction in the amount of arable land in rural areas and settlements. The changes in sediment regimes were also influenced by soil and water conservation programmes.

Keywords Suspended sediment · Precipitation · Trends and change-point analysis · Human impacts · Deagrarization process · Spatial autocorrelation

Introduction

Suspended sediment loads and their variability over time have received much attention over the past decades. With more focus on contemporary climate changes and the influence of different human activities, research into the dynamics and transport of suspended sediment in river basins is gaining importance all over the world (Walling 2006). Walling and Fang (2003) point out that sediment load is more affected by human activity than by climate change. The human activities

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that have an impact on sediment transport can take various forms. Some past studies indicate that the construction of dams has one of the greatest impacts on the reduction of suspended sediment (Panda et al. 2011; Peng et al. 2010; Vericat and Batalla 2006; Wang et al. 2007). Damming, water extraction, and urbanization stand out as the most important direct anthropogenic impacts in the Mediterranean region of Europe (Liquete et al. 2009). Human activities that have brought changes in the transport of the suspended sediment load include mining (Bobrovitskaya et al. 2003), soil and water conservation, and sediment control programs (Walling and Fang 2003), and integrated soil conservation projects in the context of ecological restoration (Zhang et al. 2017). The results of some studies have shown that different socioeconomic measures and agricultural policies (Boardman et al. 2003; Zhong et al. 2020), as well as land composition and land use patterns are the dominant factors determining sediment yields and soil loss rates (Erskine et al. 2002; Shi et al. 2014).

A quantification of the impact of climate and human activities on water and sediment load has become a central theme of many studies in different regions around the world (Gao et al. 2011; Wang et al. 2007). Previous research has only partially studied trends in water discharge and suspended sediment load in Serbia (Manojlović et al. 2021). This paper presents a comprehensive study, focusing on suspended sediment load (Qs) trends and quantifying the impact of variations in precipitation and human activity on the sediment regime in Serbian rivers. The human activities considered in this study are the depopulation process, deagrarization process, and soil and water conservation measures. The main objectives of this study are (1) to determine trends in suspended sediment load, (2) to quantify the impact of variations in precipitation and human activities on the suspended sediment load in rivers, and (3) to analyze the impact of the demographic processes and changes in arable land on suspended sediment transport.

Data set and methods

Study area

The study area is located in the Velika Morava River basin (Fig. 1). The Velika Morava River is formed from the confluence of the Južna Morava and the Zapadna Morava, near the town of Stalać, and it is the largest national river system in Serbia. The Velika Morava River catchment covers an area of 37,561 km^2, accounting for 42.5% of the territory of the Republic of Serbia. The catchment area covers 6.7% of the Danube River basin and can be divided into three hydrographic units: the direct basin of the Velika Morava River (6242 km^2), the Južna Morava River basin (15,469 km^2), and the Zapadna Morava River basin (15,850 km^2). The relief of the Velika Morava catchment area is represented by the mountains of the Serbian-Macedonian mass and parts of the Carpathian-Balkan Mountains in the east and southeast, and the Dinarides in the west and southwest. The central part is the wide valley of the Velika Morava River. The lowest point is 67 m above sea level, at the confluence of the Velika Morava River and the Danube, and the highest point is on Hajla Mountain, at 2500 m above sea level.

A high degree of spatial variation in the amount of precipitation is expected in the basin. The mean annual precipitation ranges from 600 mm in the Velika Morava and Južna Morava valleys to 1200 mm in the westernmost and south westernmost mountainous areas of the Zapadna Morava River basin and the mountains in the eastern part of the Južna Morava River basin (Milovanović et al. 2017). The average annual air temperature ranges from 10 to 12 °C in terrains up to 250 m above sea level, while the highest mountainous parts have average temperatures below 3 °C (Bajat et al. 2015). An integral vulnerability map of the natural hazards in the territory of Serbia shows that the valley of the Velika Morava River, as well as the valleys of its constituents, the Južna Morava River and the Zapadna Morava River, represent potential flood zones (Dragicević et al. 2011; Ristić et al. 2012).

Data set

Data on water discharges (Q), suspended sediment concentration (SSC) and suspended sediment load (Qs) were obtained from 16 hydrological stations located along the main streams of the Velika Morava, Južna Morava and Zapadna Morava, and their main tributaries. The location and general information regarding the hydrological stations is shown in Fig. 1 and Table 1. For this study, 21 precipitation (P) stations were analyzed for the period 1961–2007. Data sets were obtained from the Republic Hydrometeorological Service of Serbia (www.hidmet.gov.rs).

The monitoring of suspended sediment in Serbian rivers was established in the 1960s. Table 1 and Fig. 2 present a database of suspended sediment load, based on suspended sediment concentration and water discharge data over 20–47 years of measurements at gauging stations. The longest observation period of 47 years for suspended sediment was in the JM/M and N/N stations, and then in the N/D at 43 years, and the VM/B and VN/LJM at 41 years. In three rivers (J/TO, V/B, J/P), suspended sediment measurements were stopped in the middle of the 1980s and for one river at the end of the 1980s (V/L). For the Zapadna Morava and its largest tributary, the Ibar River, suspended sediment monitoring was established in early and late 1980 respectively. The systematic measurement of suspended sediment in all Serbian rivers by the Republic Hydrometeorological Service stopped in 2007. The data were collected and analyzed on

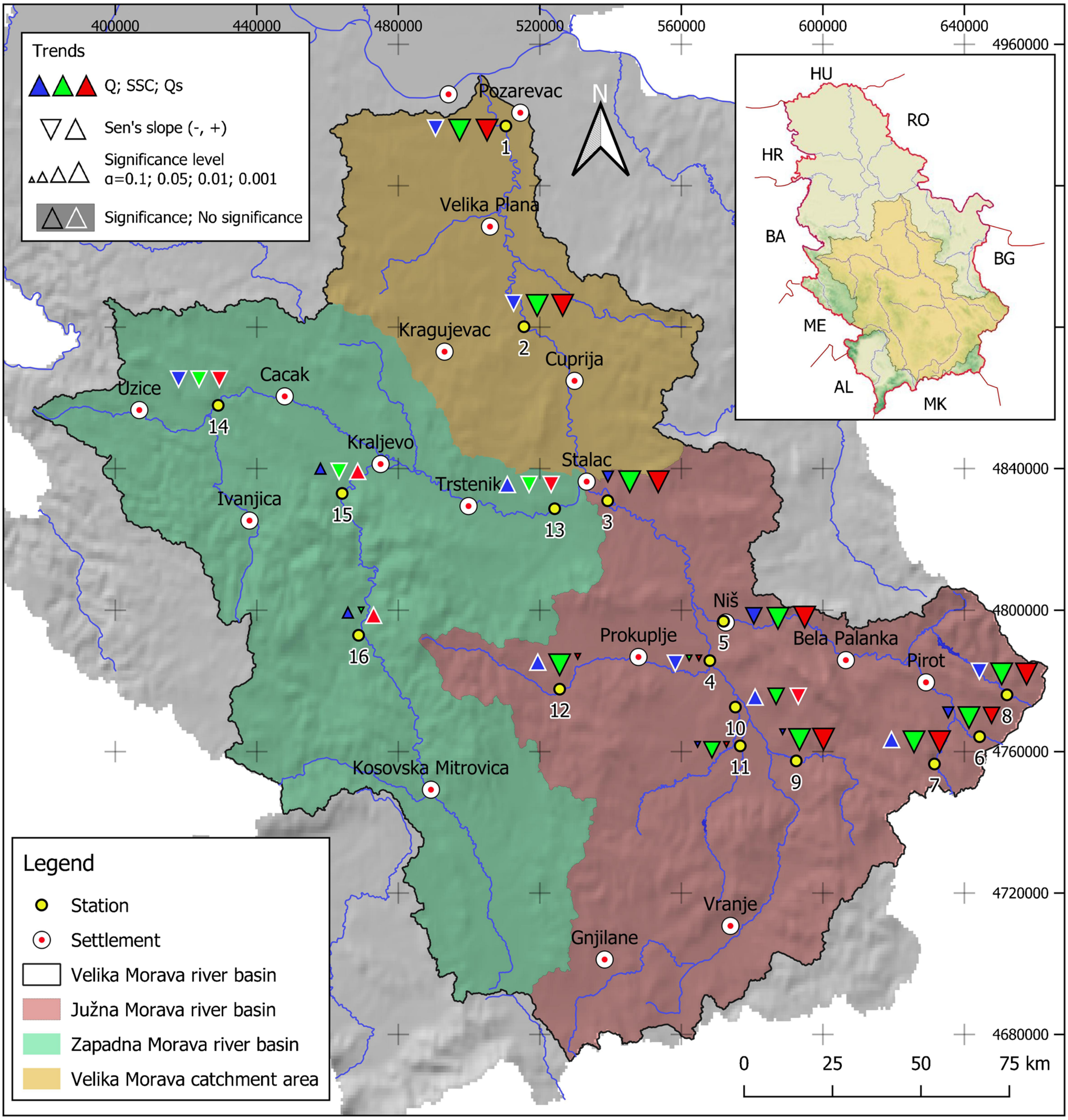

Fig. 1 The locations of hydrological stations in the Velika Morava catchment area. The numbers of hydrological stations are given in accordance with their numeration in Table 1. The spatial distribution of trends of decrease or increase of water discharge (*Q*), suspended sediment concentration (SSC) and suspended sediment load (Qs) are represented by the sign Δ, based on the data in Table 2. The size of the mark indicates the significance level

an annual basis (calendar years). For some river basins (V/V and T/P), the complete suspended sediment load time-series data are not available, and for this reason the years with missing data were not considered in this analysis.

For the purposes of this research, agricultural and population data sets from 2737 rural settlements and 72 urban and municipal centers in the central part of Serbia were processed. Settlements in the territory of Kosovo and Metohija were not analyzed, due to a lack of data and the unsolved status issue of the territory. The spatial distribution of the population and arable land was analyzed for the period 1961–2011. Data on the population in rural and urban

Table 1 General information of hydrological stations and period observation of suspended sediment load (Qs) (V/V*–no observation 1980–1982, 1985, 1989; T/P**—no observation 1986–1992, 1994)

No	River	Hydrological station	Abbreviations	Longitude (N°)	Latitude (E°)	Altitude H (m)	Basin area F (km^2)	Data period
1	Velika Morava	Ljubičevski most	VM/LJM	44.58	21.13	73	35,496	1967–2007
2	Velika Morava	Bagrdan	VM/B	44.08	21.19	101	33,446	1967–2007
3	Juzna Morava	Mojsinje	JM/M	43.63	21.48	136	15,390	1961–2007
4	Juzna Morava	Korvingrad	JM/K	43.22	21.84	188	9396	1976–2007
5	Nisava	Niš	N/N	43.32	21.90	188	3870	1961–2007
6	Nisava	Dimitrovgrad	N/D	43.01	22.77	440	482	1966–2007
7	Jerma	Trnski Odorovci	J/TO	42.94	22.63	553	557	1966–1985
8	Visocica	Bracevci	V/B	43.12	22.88	747	227	1965–1986
9	Vlasina	Vlasotince	V/V	42.96	22.13	254	879	1963–2007*
10	Jablanica	Pečenjevce	J/P	43.10	21.91	206	891	1966–1985
11	Veternica	Leskovac	V/L	42.99	21.94	224	500	1961–1990
12	Toplica	Pepeljevac	T/P	43.16	21.31	330	986	1966–2007**
13	Zapadna Morava	Kratovska stena	ZM/KS	43.87	20.12	290	3077	1981–2007
14	Zapadna Morava	Jasika	ZM/J	43.61	21.3	138	14,721	1981–2007
15	Ibar	Raška	I/R	43.29	20.62	392	1036	1988–2007
16	Ibar	Lopatnica Lakat	I/LL	43.65	20.55	225	7818	1988–2007

The abbreviations for the names of hydrological stations appear in the manuscript text

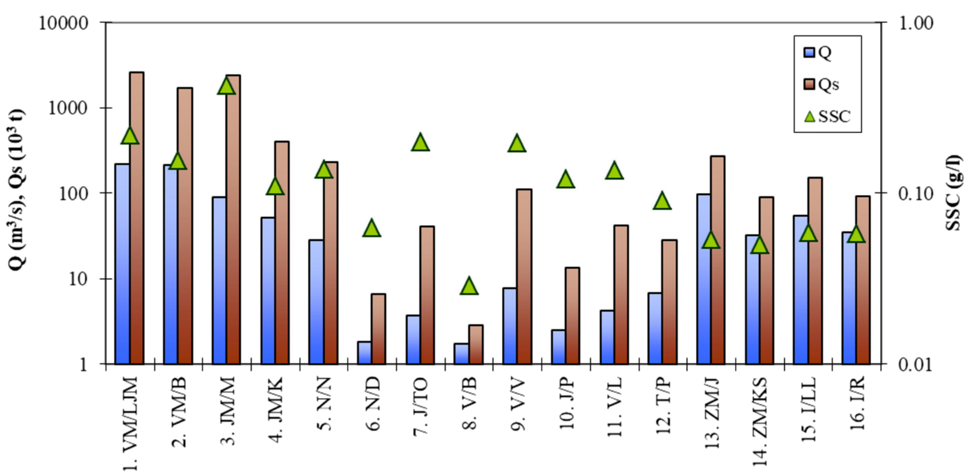

Fig. 2 Average annual water discharge (Q – m^3/s), suspended sediment concentration (SSC – g/l) and suspended sediment load (Qs – 10.^{3} t) at gauging stations

settlements and data on arable land are from statistical yearbooks published by the Statistical Office of the Republic of Serbia (Statistical Office of the Republic of Serbia 2012).

Trend and change-point analysis

The Mann–Kendall test (MK) and Pettitt test are widely applied in hydrological and meteorological data analyses (Zhang et al. 2008; Zhu et al. 2008; Heimann et al. 2011; Panda et al. 2011; Memarian et al. 2012; Gao et al. 2012). A non-parametric MK test was used to analyze trends in precipitation (P), water discharge (Q), suspended sediment concentration (SSC) and suspended sediment load (Qs). The Mann–Kendall test is often used to investigate whether a trend exists in a given time series. This test was initially proposed by Mann (1945) and later improved by Kendall (1975). Based on the confidence level value (α), the Z statistic (Memarian et al. 2012; Gao et al. 2012) was obtained from the MK test. Positive values of Z point to an upward trend and negative values point to a downward trend. The slopes of the Q, SSC, and Qs trends were estimated using the Sen's non-parametric approach.

Identifying change points is one of the most important parts of evaluating the impact of precipitation and human activities on water discharge and suspended sediment load. If an upward or downward trend exists, Pettitt's non-parametric test is used to detect a change point in the data series (Pettitt 1979). The confidence level (α) of Pettitt's test in this study was set to $\alpha = 0.05$.

Double mass curve method—precipitation and human impact identification

Double mass curve (DMC) analysis is a simple and practical method that has been widely used to quantitatively evaluate the impact of change by precipitation and human activities on river discharge and sediment regimes (Walling 2006). The method uses linear regression analysis of precipitation, water discharge and the suspended sediment load time series (Gao et al. 2010, 2011, 2013; Guo et al. 2020; Tian et al. 2016; Zhao et al. 2017; Zhong et al. 2020). It involves a plot of two cumulative parameters for a concurrent time. The results usually manifest as a straight line if the proportionality between those two parameters remains unchanged. The presence of an abrupt change in the slope of the curve indicates the impact of human activities and precipitation. Double mass curves of precipitation vs. water discharge, or precipitation vs. suspended sediment load, were plotted for both before-change and after-change periods to estimate the changes induced by climate variability and human activities. The change points were determined by the Pettitt test.

The impact of human activities and precipitation on sediment load can be calculated using the following equations (Li et al. 2016; Wu et al. 2017; Zhong et al. 2020):

$$\Delta Qs = Qs_{ao} - Qs_{po} \quad (1)$$

where ΔQs is the total change in the annual average suspended sediment load; Qs_{ao} is the observed suspended sediment load in the after-change period; and Qs_{po} is the observed average annual suspended sediment load in the before-change period.

$$\Delta Qs_{human} = Qs_{ao} - Qs_{ac} \quad (2)$$

where ΔQs_{hum} is the change in annual average suspended sediment load caused by human activities, and Qs_{ac} is the calculated suspended sediment load in the after-change period, extrapolated using the regression equation for the before-change period.

$$\Delta Qs_{precipitation} = \Delta Qs - \Delta Qs_{human} \quad (3)$$

where $\Delta Qs_{precipitation}$ is the change in the annual average suspended sediment load caused by precipitation.

The following equations can be used to calculate the contribution of precipitation and human activities to the suspended sediment load:

$$\mu_{precipitation} = \frac{\Delta Qs_{precipitation}}{\Delta Qs} 100\% \quad (4)$$

$$\mu_{human} = \frac{\Delta Qs_{human}}{\Delta Qs} 100\% \quad (5)$$

where $\mu_{precipitation}$ is the contribution rate of precipitation to the suspended sediment change, and μ_{human} is the contribution rate of human activities to the sediment change.

Sediment rating curves

Sediment rating curves (SRC) are based on the relationship between suspended sediment concentration and water discharge so that SSC = *f*(Q), or suspended sediment load and water discharge, thus Qs = *f*(Q) (Jansson 1996). In our study, we used Qs = *f*(Q). These curves are used to understand the dynamics and conditions of suspended sediment transport in rivers. The most common sediment rating curve is a power function (Asselman 2000; Iadanza and Napolitano 2006; Walling 1977):

$$Qs = aQ^b \quad (6)$$

where Qs is the suspended sediment load (*t*); *Q* is the water discharge (m^3/s); and *a* and *b* are the rating coefficients of the sediment rating curve.

The *a* coefficient represents the soil erodibility. High *a* values indicate the availability of weathered sediment in the basin, which can be easily eroded and transported by runoff. The *b* coefficient describes the erosivity of the river, with a high value indicating a strong increase in the erosive power of the river (Asselman 2000, Gao et al. 2017; Morgan 1995; Peters-Kümmerly 1973).

Depopulation index and deagrarization index

The process of deagrarization of rural areas in Serbia is significantly related to the processes of depopulation and senilization of rural settlements (Sibinović 2018). The intensity of the depopulation process was calculated based on indices for each rural settlement separately, according to the formula:

$$Pj = \frac{Nj^1}{Nj^0} 100 \quad (7)$$

where *Pj* is the Depopulation index; Nj^1 is the size of the population in the final year of the study period (2011); and Nj^0 is the size of the population in the initial year of the study period (1961). Based on the obtained results, rural settlements were classified according to the population index: high depopulation $Pj < 10$, medium depopulation $Pj = 10–70$, low depopulation $Pj > 70–100$, population growth $Pj > 100$ (Sibinović et al. 2016).

The intensity of the deagrarization was calculated on the basis of base indices for each rural settlement separately, according to the formula:

$$Aj = \frac{Cj^1}{Cj^0}100 \tag{8}$$

where Aj is the deagrarization index; Cj^1 is the arable area in the final year of the study period (2011); and Cj^0 is the arable area in the initial year of the study period (1961). Based on the results, rural settlements were classified according to the deagrarization index: high deagrarization $Aj < 10$, medium deagrarization $Aj = 10$–70, low deagrarization $Aj > 70$–100, agricultural growth $Aj > 100$ (Sibinović et al. 2016).

Spatial autocorrelation analysis

In order to detect spatial patterns in the distribution of settlements by considering both their locations and associated population and agricultural index values, Moran's I index was used, specifically the local autocorrelation index I_i (O'Sullivan and Unwin 2010). Local indicators of spatial autocorrelation (LISA) statistics provide insight into how the settlements with high and low associated attribute values are clustered, representing the range within which each unit is surrounded by similar high or low values (Anselin 1995).

$$I_i = \frac{x_i - \overline{X}}{S_i^2} \sum_{j=1}^{n} w_{ij}\left(x_j - \overline{X}\right) \tag{9}$$

where x_i is the value of a variable at location i; x_j is the value of a variable at location j; w_{ij} is the weight that determines the relationship between i and j; n is the number of settlements; is the calculated average value of all x values; and S_i is the standard deviation of i, calculated as.

$$S_i^2 = \frac{\sum_{j=1}^{n}\left(x_j - \overline{X}\right)^2}{n-1} \tag{10}$$

In addition, we used bivariate Moran's I to depict the spatial relationship between population (X) and agricultural index (Y):

$$I = \frac{n}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij}\left(x_i - \overline{X}\right)\left(y_i - \overline{Y}\right)}{\sum_i \left(y_i - \overline{Y}\right)} \tag{11}$$

Based on the univariate LISA, the bivariate LISA represents the extension of the standard univariate local autocorrelation indices (Anselin et al. 2010), and it is designed to describe the bivariate spatial autocorrelation between the value of one variable at a location and the averages of a different variable at the neighboring locations. Theoretically, this approach explains how the population index value at a location affects the values of the agricultural index of nearby locations.

All calculations related to local autocorrelation indices were performed using GeoDa open-source software (Anselin 2005).

Results

Spatial variability of suspended sediment load

The results show a large spatial diversity in the transport of Qs in the rivers of Serbia. The average annual suspended sediment load of the rivers ranges from $Qs = 2.9 \times 10^3$ t in the Visočica River to $Qs = 2569 \times 10^3$ t transported to the Danube from the Velika Morava River (Fig. 2). Sediment transport is directly dependent on water discharge (Meybeck et al. 2003). The highest average annual Qs is spatially related to the VM/LJM and VM/B in the Velika Morava and the JM/M station in the Južna Morava, where the largest water discharges were recorded.

In addition to discharge, spatial differences in the transport of suspended sediment can be attributed to a combination of other factors. Besides the basin area, suspended sediment is closely related to other basin characteristics such as topography, climate, lithology, land use, and vegetation cover (De Vente et al. 2007; Vanmaercke et al. 2011). Also, in this case, the highest values of suspended sediment at the three mentioned measuring stations (VM/LJM, VM/B, and JM/M) are the result of the geological characteristics of the terrain. The presence of large amounts of unconsolidated sediments near rivers forms an easily eroded source of sediments. It is an area where the dominant geological features are neogene and alluvial sediments, with significant areas under flysch rocks. Therefore, the average annual values are high and amount to 0.4244 g/l in JM/M, and 0.2173 g/l in VM/LJM, which are the highest values of all the observed rivers. Also, the immediate catchment area of the Velika Morava and the lower course of the Južna Morava, which is characterized by alluvial sediments and neogene sediments, is mainly used for agricultural production, resulting in higher concentrations of suspended sediments and higher erosion rates.

The spatial distribution of trends for the annual water discharge (Q), suspended sediment concentration (SSC) and suspended sediment load (Qs) for the study period were analyzed (Fig. 1). The results of the MK tests for all parameters are presented in Table 2. For Q, decreasing trends were detected in the Južna Morava and most of its tributaries. Statistically decreasing trends of Q were detected in the N/N station at a significant level of $\alpha = 0.01$, then in the N/D and JM/M stations at a significant level of $\alpha = 0.05$, and in the V/V and V/L stations at a significant level of $\alpha = 0.1$. The water discharge at four stations (J/TO, J/P, T/P, ZM/J) shows a slight increasing trend, and a statistically increasing trend

Table 2 Results of Mann–Kendall (MK) test for water discharge (*Q*), suspended sediment concentration (SSC), and suspended sediment load (Qs) at the different river basin

No	River	Hydrological station	Abbrev	Q (m^3/s/year)			SSC (g/l/year)			Qs (10^3 t/year)		
				Z	α	*b*	*Z*	α	*b*	*Z*	α	*b*
1	Velika Morava	Ljubičevski most	VM/LJM	−0.80	/	−0.746	−4.28	***	−0.0096	−4.14	***	−111.09
2	Velika Morava	Bagrdan	VM/B	−1.16	/	−1.050	−5.07	***	−0.0062	−4.23	***	−68.09
3	Juzna Morava	Mojsinje	JM/M	−2.31	*	−0.770	−6.09	***	−0.0144	−5.23	***	−84.69
4	Juzna Morava	Korvingrad	JM/K	−1.57	/	−0.578	−2.09	*	−0.0024	−2.25	*	−13.37
5	Nisava	Niš	N/N	−2.73	**	−0.317	−4.88	***	−0.0050	−5.14	***	−7.58
6	Nisava	Dimitrovgrad	N/D	−2.13	*	−0.021	−3.79	***	−0.0015	−2.70	**	−0.15
7	Jerma	Trnski Odorovci	J/TO	0.68	/	0.046	−5.19	***	−0.0305	−4.00	***	−2.61
8	Visocica	Bracevci	V/B	−1.41	/	−0.023	4.34	***	−0.0023	−3.89	***	−0.23
9	Vlasina	Vlasotince	V/V	−1.95	+	0.064	−5.91	***	−0.0095	−5.04	***	−5.79
10	Jablanica	Pečenjevce	J/P	1.52	/	0.095	−3.21	**	−0.0071	−0.49	/	−0.14
11	Veternica	Leskovac	V/L	−1.77	+	−0.046	−3.23	**	−0.0032	−1.90	+	−0.60
12	Toplica	Pepeljevac	T/P	1.02	/	0.032	−4.18	***	−0.0028	−1.90	+	−0.41
13	Zapadna Morava	Kratovska stena	ZM/J	0.04	/	0.045	−1.63	/	−0.0007	−1.54	/	−5.19
14	Zapadna Morava	Jasika	ZM/KS	−0.25	/	−0.046	−1.29	/	−0.0004	−1.38	/	−1.73
15	Ibar	Raška	I/LL	2.17	*	1.319	−1.46	/	−0.0010	0.55	/	0.90
16	Ibar	Lopatnica Lakat	I/R	2.56	*	1.046	−1.85	+	−0.0008	0.29	/	0.51

α significance level, + α = 0.1, *α = 0.05, **α = 0.01, ***α = 0.001, / no significance; *b* Sen's slope

at a significant level of α = 0.05 was detected only on the Ibar River.

On the other hand, Qs shows a decreasing trend at most stations except I/R and I/LL. Seven stations in the Velika Morava and Južna Morava River basin have highly significant decreasing trends of Qs at a significant level of α = 0.001 and one station showed a decreasing trend at α = 0.01. However, it is important to emphasize that, regardless of the trend of *Q*, decreasing trends of SSC were identified at all stations. The suspended sediment concentration decreased significantly (α = 0.001) at nine stations, two stations showed a downward trend at a significance level of α = 0.01 and one of α = 0.05. Sen's slope curve shows that the average decrease in Qs = 0.14–111 × 10^3 t/year and the average decrease in SSC = 0.0004–0.0305 g/l/year.

It can be concluded that a significant decreasing trends of SSC and Qs were identified at stations on the Velika Morava and Južna Morava and its tributaries. Although the monitoring of suspended sediment was established later, decreasing trends of SSC at all four stations have been identified in the Zapadna Morava and its tributary the Ibar River. On the Ibar River, no significant increased trend of Qs was recorded.

Change points detection and temporal analysis of the suspended sediment load

In this study, three hydrological stations on three rivers, the Velika Morava (VM/LJB), Južna Morava (JM/M) and Nišava (N/N), which have the longest continuous observation period of suspended sediment, were considered in the analysis to evaluate the impact of precipitation and anthropogenic factors on changes in the transport of suspended sediment. The results of the Pettitt test for precipitation (P), water discharge (Q), and suspended sediment load (Qs) are given in Fig. 3. The results for precipitation suggest a significant downward shift only for the N/N station. In the N/N station, 1982 was identified as a transition year for water discharge. In the JM/M station, 1982 was also detected as a transition year for water discharge. No significant sudden shift downwards for water discharge was recorded in the VM/LJM station. The results of the Pettitt test showed that there was a significant sudden downward shift for the research period for the suspended sediment load at all three stations ($p < 0.0001$). As transition years (*T*) for Qs, 1982, 1984, and 1983 for the VM/LJM, JM/M, and N/N river stations, respectively, were identified.

Assessment of the impact of precipitation and human activities on the suspended sediment load

The double-mass curve of Q/Qs versus *P* on both annual scales, along with the linear regression lines are presented in Fig. 4. The water discharge variation was relatively stable. It can be clearly seen that the changing points for Qs were observed in the same periods, which confirmed the results seen in the Pettitt test. The straight line indicates that the relationship between annual Qs and annual P can be assumed to be consistent for the entire period recorded

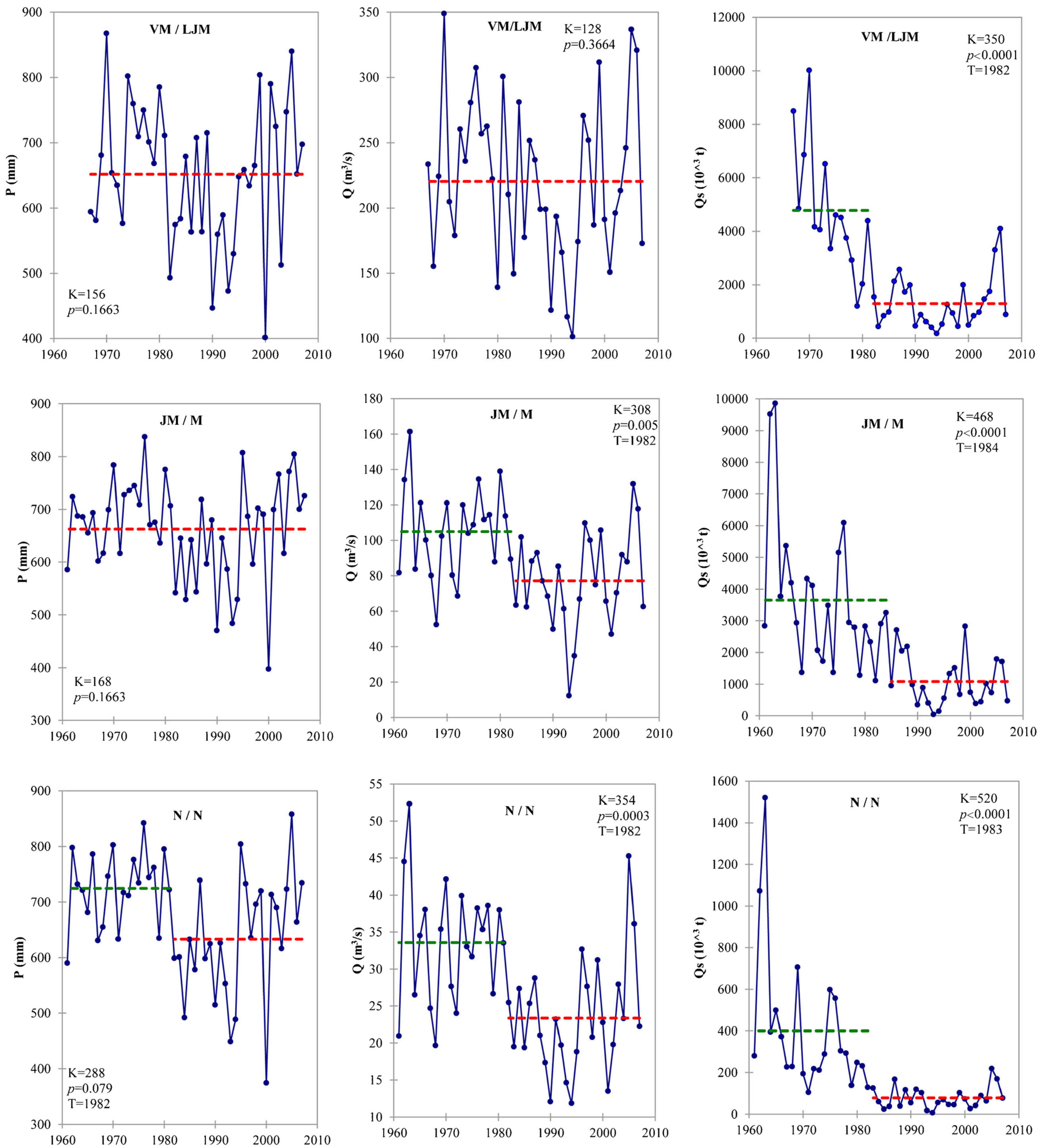

Fig. 3 Observed precipitation (*P*), water discharge (*Q*), and suspended sediment load (Qs) for VM/LJM, JM/M, and N/N station transition year (*T*) detected with Pettitt test (α = 0.05)

from 1961 to 1982, 1961 to 1984, and 1961 to 1983 at the VN/LJM, JM/M, and N/N river stations, respectively. Since the transition year, a change in the slope of the double-mass curve emphasizes a drastic decrease in the Qs of the rivers that cannot be directly linked to precipitation. This reduction reflects the impact of human induced modification in the river basins.

It is evident that the decrease in the cumulative Qs is far bigger than the decrease in the cumulative *Q* in the period after the transition year. Comparative analysis between

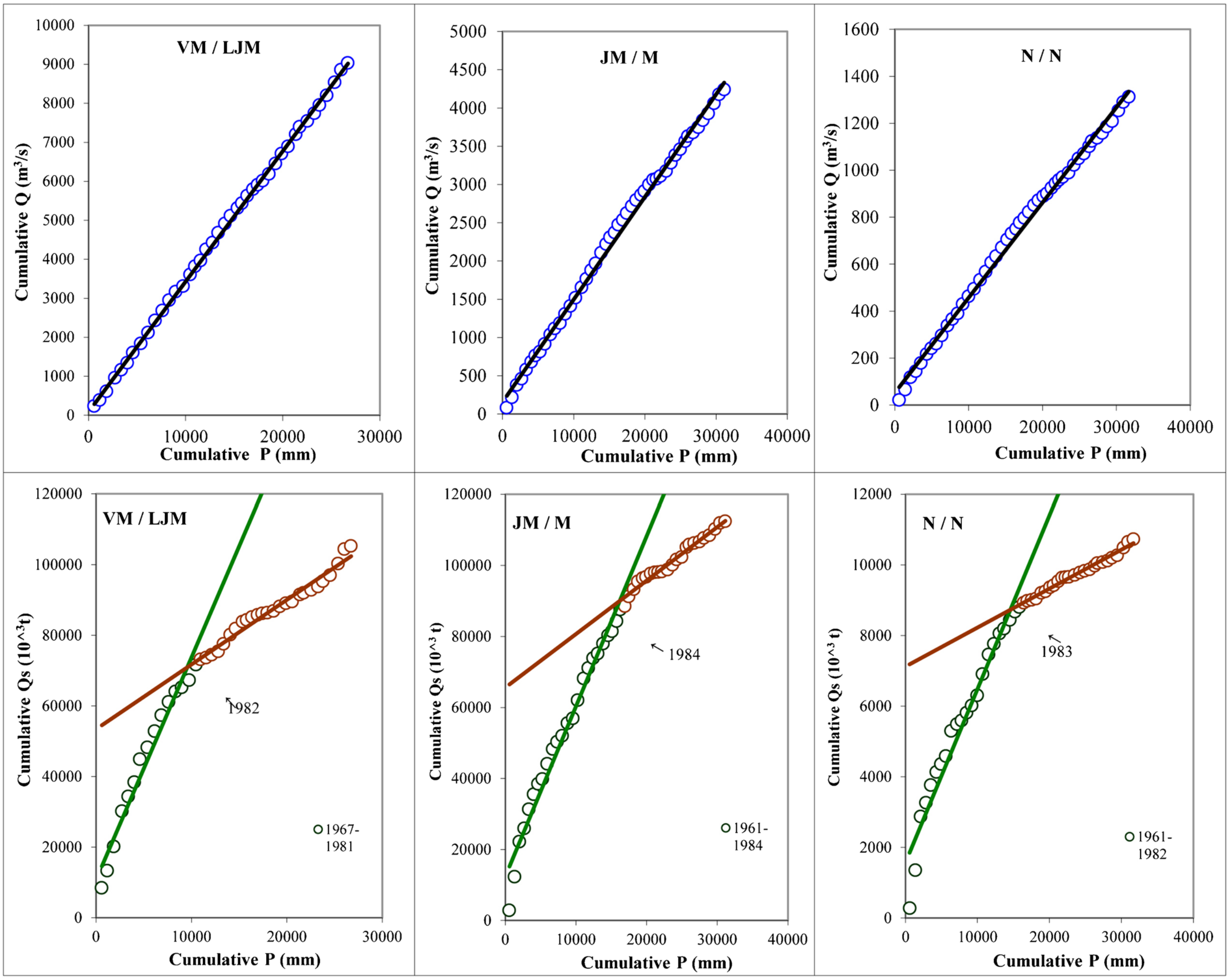

Fig. 4 Double-mass curve analysis of precipitation (*P*), water discharge (*Q*), and precipitation (*P*)-suspended sediment load (Qs) in the VM/LJM, JM/M, and N/N station

extrapolated water discharge (Q_1) and observed cumulative water discharge (Q_2) shows that it decreased by only 2.9%, 8.0%, and 9.6% in the VM/LJM, JM/M, and N/N river stations, respectively (Table 3). On the other hand, the cumulative decrease in Qs was 41.2%, 30.4%, and 37.4% for the same stations (Table 4).

The relative contribution of precipitation and human activities to the variations in the Qs changes are presented in Table 5. The results suggest that human activities play a dominant role in the reduction of Qs in the river basins. The greatest impact of human activities compared to precipitation resulting in a decrease in the Qs was recorded in the Nišava River basin (91.9% versus 8.1%). Precipitation variability resulted in a 10.8% reduction in Qs, and the remaining 89.2% was attributed to a variety of different human activities in the Južna Morava River basin. A similar situation was noted with the Velika Morava River basin (12.3% impact of precipitation versus 87.7% human impact).

The significantly lower impact of precipitation on the decrease in Qs compared to human impact can be explained by a relatively small variation in the time series of precipitation on an annual scale. The results of the MK test are presented in Table 6 for four precipitation parameters: maximum daily preciptitation (PMD), number of annual days of precipitation ˃ 1 mm (*P* ˃ 1 mm), number of annual days of precipitation ˃ 10 mm (*P* ˃ 10 mm), and number of annual rainy days (P_R). Overall, no significant trend was found for most parameters of precipitation series in all three river basins. As shown by the results of the Pettitt test, precipitation did not show any abrupt changing points that were detected in the water discharge and sediment load, except in the Nisava river basin. The greatest changes in this river basin were observed for a decreased P_R ($Z = 3.57$) at a

Table 3 Linear regression equations between cumulative water discharge (Q) and cumulative precipitation (P) for period before transition years

River/station	Regression equation	Q_1 (m³/s)	Q_2 (m³/s)	Q_1–Q_2 (m³/s)	(Q_1–Q_2) × 100/Q_1 (%)
VM/LJM	$\Sigma Q = 0.3549\ \Sigma P - 4.6327$; $R^2 = 0.99$	9300.0	9033.6	266.4	2.9
JM/M	$\Sigma Q = 0.1464\ \Sigma P + 49.041$; $R^2 = 0.99$	4607.5	4239.7	367.8	8.0
N/N	$\Sigma Q = 0.0455\ \Sigma P + 10.511$; $R^2 = 0.99$	1454.4	1312.5	138.9	9.6

ΣQ cumulative water discharge, *ΣP* cumulative precipitation, Q_1 extrapolated cumulative water discharge till 2007, Q_2 observed cumulative water discharge till 2007

Table 4 Linear regression equations between cumulative suspended sediment load (Qs) and cumulative precipitation (P) for period before transition years

River/station	Regression equation	Qs_1 (10^3 t)	Qs_2 (10^3 t)	Qs_1–Qs_2 (10^3 t)	(Qs_1–Qs_2) × 100/Qs_1 (%)
VM/LJM	$\Sigma Qs = 6.2986\ \Sigma P + 10{,}827$; $R^2 = 0.96$	179,138.2	105,328.9	73,809.2	41.2
JM/M	$\Sigma Qs = 4.7943\ \Sigma P + 12{,}398$; $R^2 = 0.98$	161,677.2	112,483.2	49,194.0	30.4
N/N	$\Sigma Qs = 0.4918\ \Sigma P + 1564.3$; $R^2 = 0.96$	17,144.6	10,733.9	6410.6	37.4

ΣQs cumulative suspended sediment load, *ΣP* cumulative precipitation, Qs_1 extrapolated cumulative suspended sediment load till 2007, Qs_2 observed cumulative suspended sediment load till 2007

Table 5 The impact of precipitation and human activity on change of annual suspended sediment

River/station	Periods	Qs_o (10^3 t)	Qs_{ac} (10^3 t)	ΔQs (10^3 t)	ΔQs climate (10^3 t)	ΔQs human (10^3 t)
VM/LJM	Before 1982	4778.9				
	After 1982	1294.1	178,316.9	3484.8 (72.9%)	429.7 (12.3%)	3,055,128.1 (87.7%)
JM/M	Before 1984	3650.0				
	After 1984	1172.5	159,279.2	2408.3 (66.0%)	261.1 (10.8%)	2147.2 (89.2%)
N/N	Before 1983	400.2				
	After 1983	77.2	17,576.9	323.0 (80.7%)	26.2 (8.1%)	296.8 (91.9%)

significant level of $\alpha = 0.01$. The spatial variations for all four parameters show decreasing trends in the three stations: two in the Nišava River basin (Niš and Dimitrovgrad) and one station in the Južna Morava River basin (Vranje). Also, the spatial distribution of stations shows a decreasing trend in the PMD at most stations, and an increasing trend at only two stations.

Impact of human activities on the suspended sediment load

Demographic process

This part of Serbia comprises highly differentiated rural spaces. There are large rural centers located on the development axes of Serbia (such as highway Corridor X), and sparsely populated and underdeveloped villages in the mountainous, peripheral and border areas (Martinović and Ratkaj 2015). Industrialization, agrarian reform, compulsory schooling, and other socio-economic indicators of development were the main attractive factors that caused the accelerated migrations of the population from rural to urban areas (Jeftić 2019). Rural–urban migrations in the second half of the twentieth century caused an intensive process of depopulation of rural settlements (Nikitović et al. 2016), which led to spatial demographic inequality in the settlement system (Lukić 2013). The rural population of the Velika Morava River basin saw a large decrease during the period from 1961 (1,990,270 people) to 2011 (1,251,497 people). The socio-economic change in the rural areas, the integration of non-agricultural industries into urban settlements, and the transfer of agricultural labor to non-agricultural labor all accelerated the urbanization process (Bański 2008; Jordan 2009; Tomić et al. 2010). In the urban area of the Velika Morava River basin, in 1961, there were 602,029 people, only 23% of the total population. In the 2011 census, the urban population in the Velika Morava River basin had risen to 1,350,882 people, accounting for 52% of the total population.

Decades of negative development tendencies have resulted in the spatial redistribution of the population in

Table 6 Mann–Kendall (MK) Z statistics for maximum daily preciptitation (PMD), number of annual days precipitation ˃ 1 mm (P ˃ 1 mm), number of annual days precipitation ˃ 10 mm (P ˃ 10 mm), and number of annual rainy days (PR) in period 1961–2007

River basin	Station	PMD (mm)	P ˃ 1 mm	P ˃ 10 mm	P_R
VM	S.Palanka	0.94	0.53	0.77	1.47
VM	Cuprija	−0.41	0.73	0.56	−0.53
VM	Kraguje-vac	−0.10	0.03	0.36	2.34 *
JM	Vranje	−0.50	−0.72	−1.23	-2.57 *
JM	Leskovac	0.68	1.74+	1.05	0.79
N	Nis	−0.10	−0.04	−0.22	−3.57 **
N	Dimitro-vgrad	−0.35	−0.68	−0.52	−1.12

Ssignificance level of + α = 0.1, *α = 0.05, **α = 0.01

rural areas. According to Fig. 5a, in the area of the Velika Morava basin, 75% of the total number of rural settlements have a high or medium depopulation index. A low population index is presented in 14% of rural settlements, and only 11% of rural settlements record population growth.

Based on the mapped LISA values of population indices, spatial patterns of depopulation clusters can be clearly detected (Fig. 5b). Note that strong depopulation is expressed with quantitatively low values of the depopulation index, and weak depopulation and population growth are expressed with high values of the index. Distinct depopulation clusters (low–low) can be clearly observed. These clusters cover the rural settlements of the Južna Morava River basin. Clusters of low depopulation (high–high), i.e., high values of population growth that cover significantly smaller spatial areas, are also noticeable. These areas include rural settlements in the valleys of the Zapadna Morava and Južna Morava, which are located in the immediate vicinity of large urban centers.

Deagrarization process

The complex dynamics of rural–urban migrations have resulted in intensive demographic aging of the rural population, continuous fragmentation of rural settlements, structural changes in agricultural production, and changes in arable land use. The basic agrarian characteristic of the basin as a whole is the intensive and unplanned reduction of arable land. In the researched territory during the period 1961–2011, the total area under arable land decreased by 36.7% (1961–822,051 ha; 2011–520,213 ha), with the decrease in the area of arable land in the Južna Morava River basin being greater than 70%. Of a total of 2,737 settlements, in 1961 the population of 432 settlements had more than 500 ha of arable land, compared to 217 such settlements in 2011. On the other hand, the 2012 agricultural census recorded 1390 settlements (50.8% of the total number of settlements) had less than 100 ha of arable land (Statistical Office of the Republic of Serbia 2012; McDonagh 2012; Sibinović et al. 2014; Antić et al. 2017; Sibinović 2018).

According to Fig. 6A, a high and medium deagrarization index is present in 68% of rural settlements, 21% have

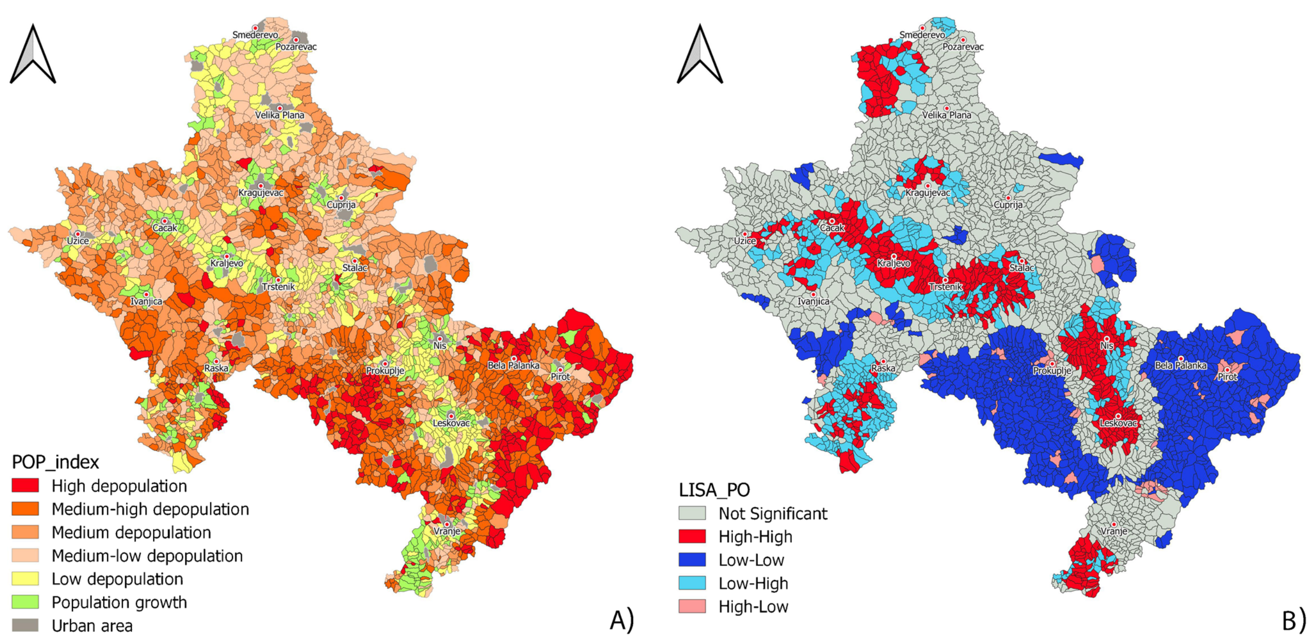

Fig. 5 **A** Index of depopulation in rural area. **B** Univariate LISA clusters map of depopulation index

low a deagrarization index, and only 10% an increase in arable land. The same is true in the case of demographic processes, the mapped agrarian LISA indicators (Fig. 6b) indicate clusters of strong deagrarization (low–low), i.e., low values of the deagrarization index. They are predominantly represented in rural settlements in the Južna Morava River basin. Clusters of low deagrarization and agricultural growth are expressed by high–high clusters. They are dominant in the immediate basin of the Velika Morava, as well as in rural settlements along the valley of the Zapadna Morava, which represent the peri-urban belt of larger city centers.

Relationship between depopulation, the deagrarization process, and suspended sediment

The influence of depopulation on deagrarization is shown through the bivariate LISA indicators (Fig. 7). In the mentioned map, the areas of extreme or dominant reduction of arable land and those of medium reduction of arable land are clearly distinguished. Areas of pronounced depopulation and pronounced deagrarization are shown with Low-Low clusters. The extreme reduction of arable land resulting from high depopulation is most pronounced in the Južna Morava River basin. Rural settlements of this category are characterized by a decrease in population of 77.6% and a decrease in arable land of 75%. The dominant decrease in arable land, typical of certain settlements recording an increase in population (16% increase in population, 51% decrease in arable land), is shown by high–low clusters. Absolute population growth is recorded only in rural settlements concentrated in the peri-urban belt (and suburban settlements), which, by the number of inhabitants and evident transformations in space, have the character of an urban–rural continuum, but are by all other characteristics (extensive agricultural activity, level of communal equipment) of a rural character (Jeftić 2019).

An area with a stagnant population (or population growth) and medium reduced arable land is shown as High-High clusters. The medium reduction of arable land is typical for settlements spatially connected to the immediate catchment area of the Velika Morava, as well as settlements concentrated along the valley of the Zapadna Morava. It covers rural areas in the immediate vicinity of larger urban settlements (the peri-urban belt), due to which there is a stagnant type of depopulation (population decreases slightly) and a relatively low intensity of deagrarization (average reduction of arable land of 17%). There are several factors that caused the appearance of low deagrarization in an area where depopulation was not pronounced. Economic transformation caused an increase in demand for non-agricultural occupations around urban centers (Bański 2008), suburban settlements that make up the peri-urban belt were continuously strongly influenced by urbanization, which led to fragmentation of agricultural holdings (Sibinović et al. 2014), and rural–urban migration caused an increase in the number of inhabitants in suburban settlements, but was not a significant factor in changing the typology of agriculture in those settlements (Kostov and Lingard 2004; McDonagh 2012; Sibinović 2018). The low–high clusters are also clearly visible, and these refer to areas of somewhat more intensive depopulation where there has been a medium decrease in

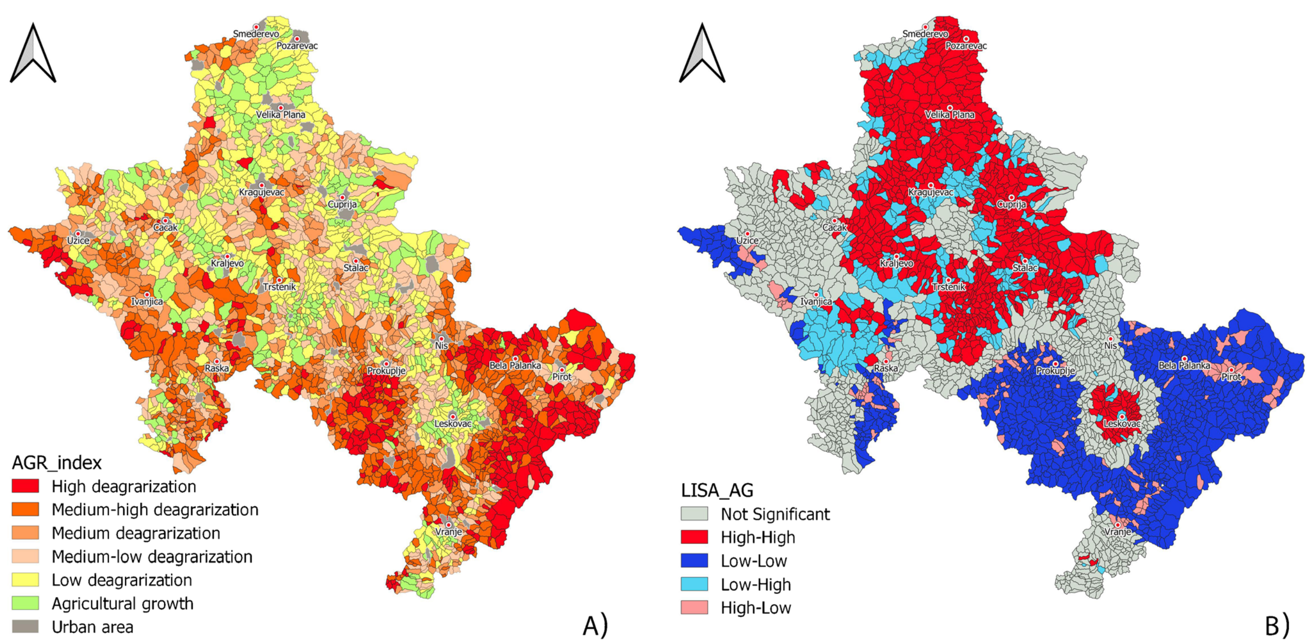

Fig. 6 **A** Index of deagrarization in rural area. **B** Univariate LISA clusters map of deagrarization index

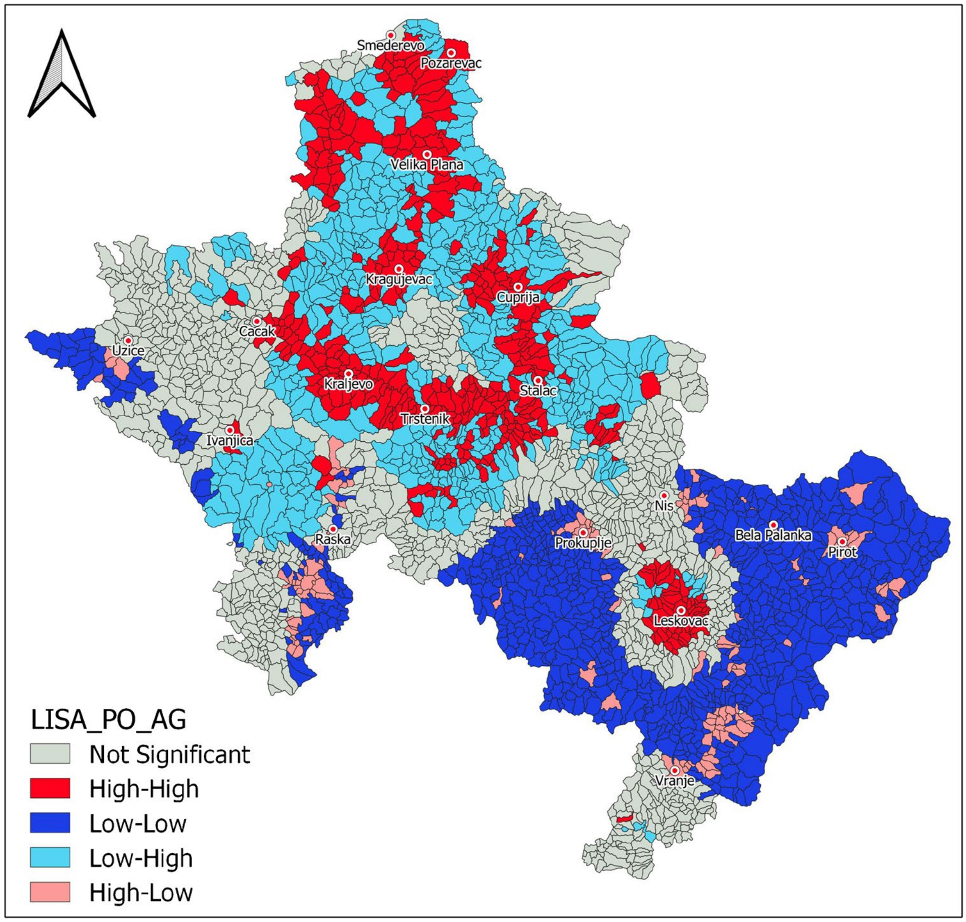

Fig. 7 Bivariate LISA cluster map of depopulation index/deagrarization index

the deagrarization index. These low–high clusters also cover the territory around the peri-urban belt (the rural area in the immediate vicinity of larger urban settlements) which is characterized by a moderate high intensity of depopulation (population reduction over 50%), and medium deagrarization intensity (reduction of arable land by about 25%). The lower decrease of arable land in relation to the depopulation process is a direct consequence of the productive intensification of agriculture under the influence of the agrarian market from the surrounding urban centers (Gatarić 2019).

According to the above analysis, under the influence of various factors relating to urban development, industrial and demographic trends, spatial differentiation in the rural population, and the use of arable land took place, which influenced changes in suspended sediment. The analysis also took into account changes in the average annual and maximum concentrations of suspended sediment as an important parameter for transporting sediment loads, monitoring soil, and water conservation. As can be seen from Fig. 8, there is a positive correlation between the rural population and suspended sediment. As the rural population decreases, the concentration of suspended sediment decreases exponentially. Figure 8 shows that this relationship is most pronounced in the Nišava River basin and Južna Morava River basin, and then in the Velika Morava River basin (coefficient of determination for SSC_{max} $R^2=0.98$, $R^2=0.97$, and $R^2=0.69$, respectively). As can be seen from Fig. 9, the decreasing trend of SSC_{av} and SSC_{max} indicates a significant confidence level of $\alpha=0.001$. The results of the MK test show the most pronounced downward trend in the Južna Morava ($Z=-6.09$ for SSC_{av}, $Z=-5.37$ for SSC_{max}) and its tributary, the Nišava ($Z=-4.88$ for SSC_{av}, $Z=-4.86$ for SSC_{max}), and the Velika Morava ($Z=-4.28$ for SSC_{av}, $Z=-4.36$ for SSC_{max}).

The exponential character of the relationship between suspended sediments and the rural population, as well as the statistically significant trends of decreasing SSC_{av} and SSC_{max}, show that sediment transport is directly related to the anthropogenic activity of the population in rural settlements. The focus of socio-economic development on the urban space has strengthened the emigration of the rural population (Martinović and Ratkaj 2015). Rural areas have experienced the characteristics of a rural exodus since 1960, and the long-term institutional marginalization of the village culminated in the period 1971–1981, when hundreds of thousands of people left agricultural production in the

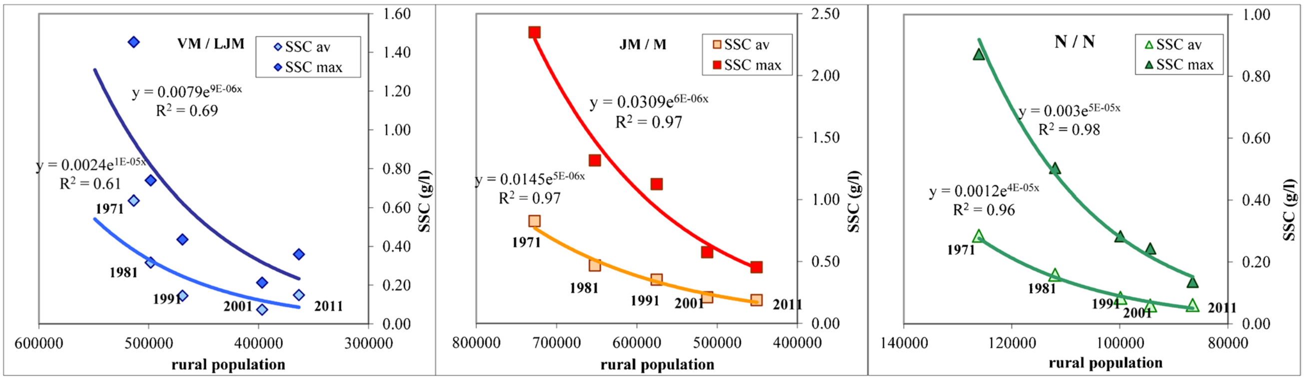

Fig. 8 Relationship between rural population and average annual suspended sediment concentration (SSC_{av}) and maximum suspended sediment concentration (SSC_{max}) for 10-year periods

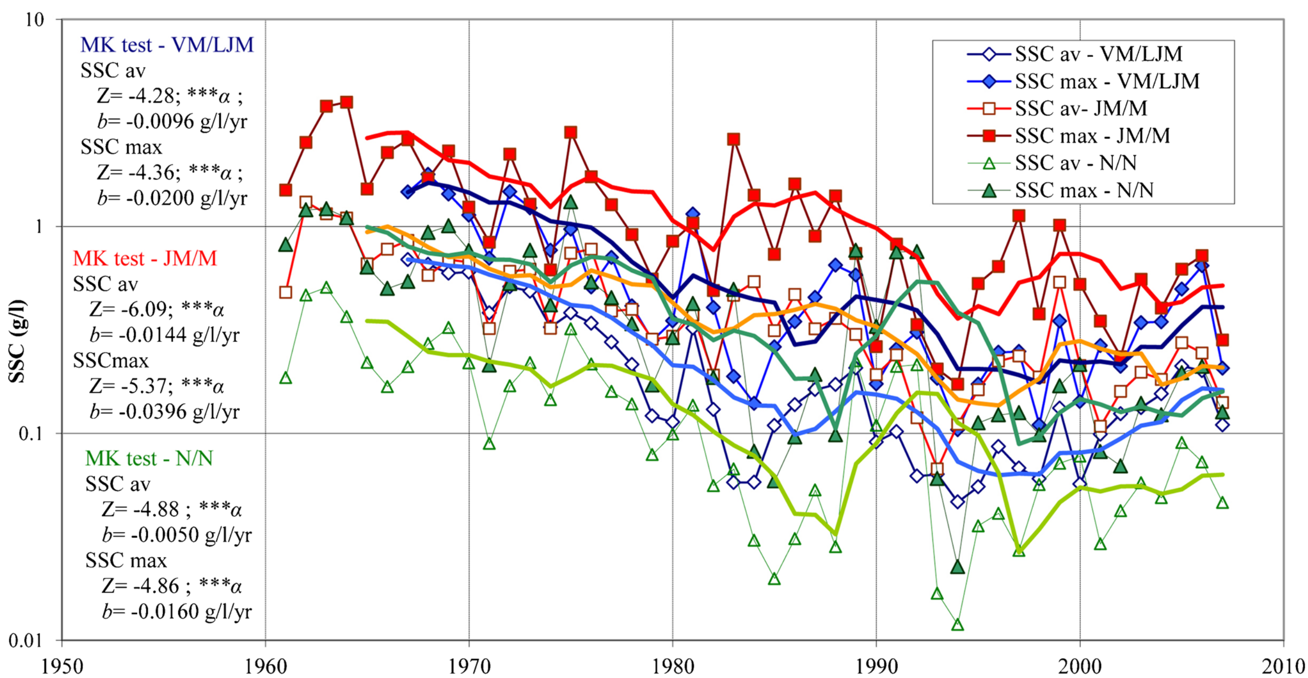

Fig. 9 Temporal change in average annual suspended sediment concentration (SSC_{av}) and maximum suspended sediment concentration (SSC_{max}) in the VM/LJM, JM/M and N/N river station (α—signifience level, $^{***}\alpha = 0.001$, *b*—Sen's slope)

eastern and south-eastern parts of Serbia (Todorović and Drobnjaković 2010). Along with depopulation, there has also been a decrease in the number of households, whereas there has been an increase in the number of settlements with a small population and those without inhabitants (Lukić 2013). This was reflected in the fact that, after 1980, most rural settlements recorded negative rates of natural population growth (Jeftić 2019).

According to the above, as a consequence of industrialization and urbanization, the processes of depopulation and deagrarization in rural areas were most pronounced up until the 1980s, which coincides with the period of sudden changes in the transport of suspended sediment (Fig. 3). As seen in Fig. 10, sediment rating curves for the three rivers were obtained for two periods (before and after the transition year *T*). The regression lines of SRC in the period after *T* are lower in relation to the regression lines in the period up to the 1980s. The values of regression coefficients *a* and *b* for the two periods in the plot are different, which suggests a change in the sediment transport. The decreasing *a* ($a < 1$) in the period after the *T* year implies that the main source area of availability and the accessibility of sediments in the basin were significantly reduced, and sedimentary sediment eroded more slowly and was transported more slowly to the riverbed. Reduced anthropogenic pressure on the soil resulted in lower values of suspended sediment. As indicated in Table 7, the average annual suspended sediment load for the period after *T* is lower by approximately 70–81% compared to the period before *T* (VM/LJM: before *T* Qs = 4779 × 10^3 t, after *T* Qs = 1294 × 10^3 t; JM/M: before *T* Qs = 3650 × 10^3 t, after *T* Qs = 1082 × 10^3 t; N/N: before *T* Qs = 400 × 10^3 t, after *T* Qs = 77 × 10^3 t). Reducing SSC leads to a reduction of the Qs. The average concentration of suspended sediment before *T* for the measuring stations was VM/LJM SSC = 0.4010 g/l, JM/M SSC = 0.6079 g/l and N/N SSC = 0.2167 g/l. The average concentration of suspended sediment after *T* for the same stations was 0.1113 g/l, 0.2328 g/l, and 0.0686 g/l, respectively. Considering the small decrease in precipitation, the results indicate a gradual downward shift after the transition year in response to the sediment reductions induced by human activities.

Soil and water conservation and sediment control programs

In addition to changes in the land use, the adoption of regional and local scale soil and water conservation measures and engineering structures, applied through various conservation programmes, are also influential factors in the sediment load reduction in the Velika Morava River basin.

The erosion and torrent control works (ETCW) in the territory of Serbia started at the end of the nineteenth century, but the more organized work started in 1907 (Kostadinov 2007). The main works refer to torrent control and regulation of the riverbed in the zones of intersections with the railway, designed to protect the railway. Based on the ongoing business policy, i.e., the work performed so far, organizational changes, and methods of financing in the Republic of Serbia, there have been six stages of development and realization of the ETCW in the second half of the twentieth century and the beginning of the twenty-first century. All the works have been classified into two groups (Fig. 11): (1) masonry (including all the construction engineering works made of concrete and masonry in the channel-transverse and longitudinal structures). (2) biological works (including all the areas where biological works were carried out in the watershed, such as afforestation, reclamation, grassing, establishment of orchards, shelterbelts, wattles, coppice reclamation, terracing contour farming, etc.). The largest number of soil and water conservation and sediment control programmes were executed at the end of the 1980s (93% masonry works and 73% biological works). The completed large-scale works

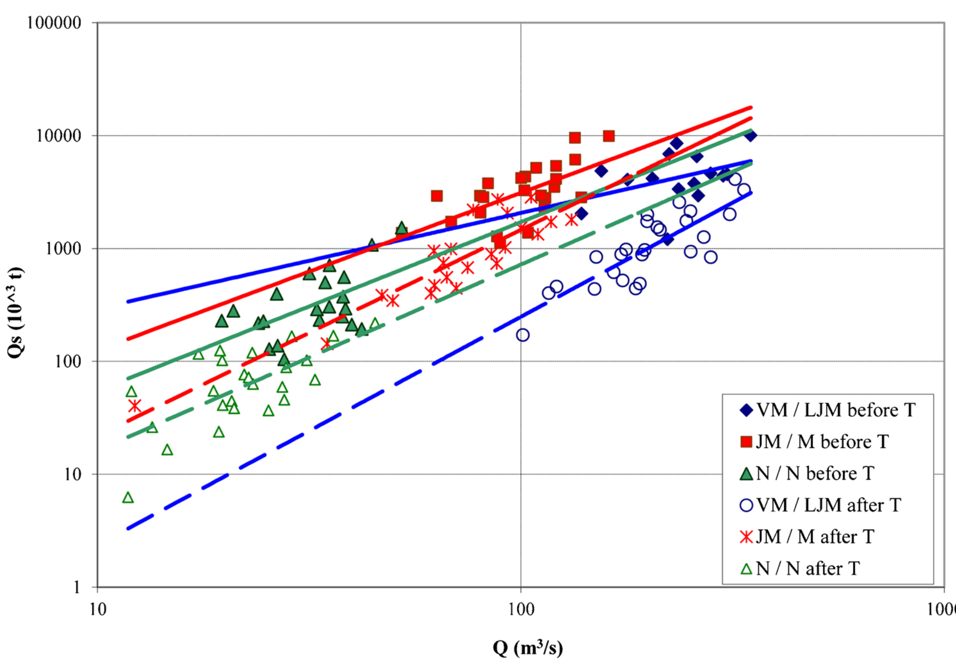

Fig. 10 Decline of the suspended sediment load (Qs) at the VM/LJM, JM/M, and N/N river station. Sediment rating curve before transition year (*T*): VM/LJM – Qs = 41.824 × 10^3Q$^{0.8465}$, R^2 = 0.16; JM/M – Qs = 5.0488 × 10^3Q$^{1.3947}$, R^2 = 0.41; N/N-Qs = 1.7602 × 10^3Q$^{1.4941}$, R^2 = 0.32. Sediment rating curve after transition year (*T*): VM/LJM – Qs = 0.0225 × 10^3Q$^{2.0514}$, R^2 = 0.68; JM/M – Qs = 0.3283 × 10^3Q$^{1.8243}$, R^2 = 0.83; N/N – Qs = 0.3674 × 10^3Q$^{1.6461}$, $R.^2$ = 0.36

Table 7 Results of change analysis for precipitation, water discharge, suspended sediment concentration, and suspended sediment load before and after transition year

River/station	T year	P (mm)		Q (m³/s)		SSC (g/l)		Qs (10^3 t)	
		Before T	After T	Before T	After T	Before T	After T	Before T	After T
VM/LJM	1982	698.2	625.0	240.7	208.6	0.4010	0.1113	4779	1294
JM/M	1984	678.3	646.0	103.1	76.7	0.6079	0.2328	3650	1082
N/N	1983	718.2	634.0	33.2	23.3	0.2167	0.0686	400	77

are in the Južna Morava River, in the region of the Grdelička Klisura gorge (Lukić et al. 2015), where the international railway line Belgrade-Skopje-Athens passes. The largest volume of ETCW works in the Južna Morava River basin was performed on all large tributaries in which suspended sediment was measured, as well as in 137 direct torrent tributaries of the Južna Morava River (Kostadinov et al. 2018; Petković 1995). From 1990 to 2000, due to the political and economic crises and international sanctions, erosion and torrent control works were carried out to a much smaller extent.

Discussion

Many studies have reported that apparently decreasing trends have been identified in sediment loads in many rivers around the world. According to Walling and Fang (2003), historical observations of the annual sediment load for 145 of the most important world rivers indicate a decreased load in 65 of them. Studies have shown that in many rivers, sediment loads have declined by 60–90% over recent decades (Walling 2006; Milliman and Farnsworth 2013). Two key factors influencing sediment load changes are precipitation and human impact. The average contribution rate for human activity of 87.8% for reduction in the sediment discharge in the middle reaches of the Yellow River is significantly higher than the contribution rate for precipitation (12.2%) (Gao et al. 2011). In some parts of the Yellow River basin, the impact of precipitation on the decreasing trend of suspended sediment is 44.5% and the impact of human intervention is 55.4% (Yue et al. 2014), while in the Yanhe River basin, these rates are 34.3% and 65.7%, respectively (Gao et al. 2016). In the Malian River basin, anthropogenic activities significantly reduced the sediment load (78.7%), whereas precipitation changes amounted to 21.3% (Du et al. 2021). In the Wei River basin, precipitation reduces the suspended sediment yield by approximately 3.44% to 5.86%, while human impact varies from 94.14 to 96.56% (Gao et al. 2013). In the catchments of the Loess Plateau, changes in precipitation accounted for 43.5% and 20.2% of the sediment load reduction during 1980–1996 and 1997–2010, whereas human activities contributed 56.5% and 79.8%, for the same time periods (Tian et al. 2016). Predominantly, the reduction in suspended sediment by human activity is caused by two factors: the implementation of soil conservation measures and the effect of constructing reservoirs. For example, Wang et al. (2007) reported that 30% of the reduction in the sediment load in the Yellow River basin area was produced by precipitation changes and 70% by human impact, of which soil conservation practices contributed 40% to the total decrease. Sediment retention within reservoirs accounted for 30% of the total sediment load decrease. Human activities were dominant in sediment reduction, including 44.9% caused by large reservoirs, 1%

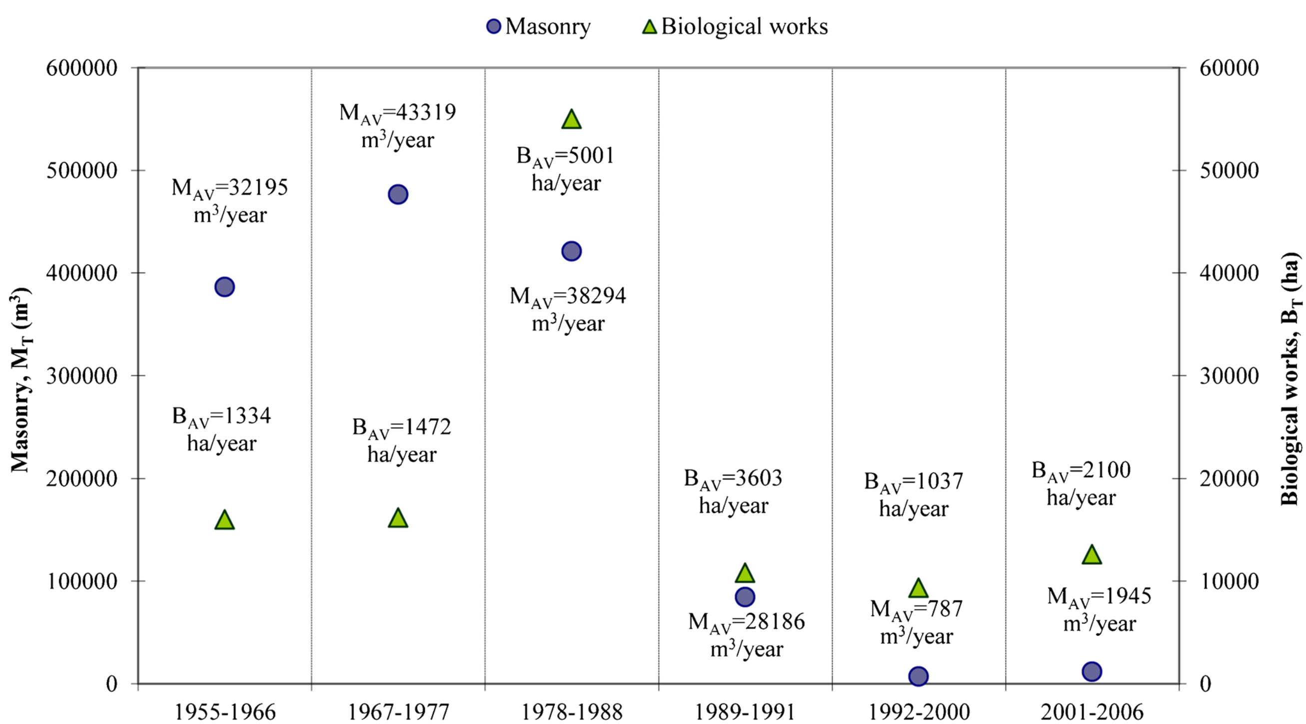

Fig. 11 Erosion and torrent control works in the period 1955–2006 (M_T—total masonry works, m³; M_{AV}—annual average masonry works, m.³/year; B_T—total biological works, ha, B_{AV}—annual average biological work, ha/year)

from increased water consumption and 35% by conservation measures in the Jinsha river Basin (Zhang et al. 2019). Among the tropical rivers, the maximum reduction of 80% in sediment load took place in the Narmada River, due to the construction of a dam (Panda et al. 2011). It was found that climate change was not the main driving force behind the variation in suspended sediment load in the Pearl River basin. However, sediment retention within reservoirs began to play a dominant role following the construction of large dams after 1990, and resulted in a decrease in the suspended sediment load delivered to the ocean (Zhang et al. 2011). On a global scale, Vorosmarty et al. (2003) also reported that the decreasing trends of sediment load in the world's main rivers are mainly caused by the construction of reservoirs and dams.

As quantitatively analyzed above, precipitation also accounts for 8.1–12.3% of the reduction in the suspended sediment load in Serbian rivers. Generally, the annual scale results suggest no significant trend for precipitation in Serbia in the second half of the twentieth century and the beginning of the twenty-first century. Most of the precipitation in the country tends to increase over an annual timescale, with the exception of the central and south-eastern parts (Luković et al. 2014). A previous study showed that precipitation follows a decreasing trend at several stations located along the Nišava River basin and, therefore, indicates a slight tendency toward drier conditions (Tošić and Unkašević 2014). Our study shows that the variations in precipitation in the three river basins that have occurred over the past 47 years are relatively small. Compared to the period before T (transition year), the annual precipitation in the period after *T* in the Velika Morava, Južna Morava and Nišava river basins decreased by 10.5%, 4.8%, and 11.7%, respectively (Table 7). Statistically significant changes in precipitation were registered only in the Nišava river basin. The analysis in our research suggests that intense human activities are the dominant factors leading to noticeable variations in the suspended sediment. The contribution rate for human activities amounts to 87.7–91.9% of the decrease in suspended sediment load. As presented in Fig. 11, various soil and water conservation measures have been implemented since the middle of the twentieth century in the Velika Morava River basin. The soil and water conservation measures cover relatively small areas and have shown an obvious decrease since the 1980s, suggesting limited effects on the sediment load. Compared to the above examples of river basins, in which dam construction and soil and water conservation are the dominant factors causing sediment reduction, in Serbian river basins the decrease in suspended sediment was influenced by an intensive reduction in arable land. In several other studies, similar conclusions were reported. Land use changes have been recognized as the most significant reason for the decreasing trend of the sediment load of river basins. These changes were manifested, above all, as a result of a significant reduction in cultivated land areas (Gusarov 2021; Zhong et al. 2020). Many authors have explained the decrease in arable land by means of different socio-economic factors: economic development and industrial restructuring, migration of the rural population, and urbanization. The results of our study suggest that the basic agrarian characteristic in the rural areas is the process of deagrarization. In the period 1961–2010, a high and medium deagrarization index was present in 68% of rural settlements in the basin. The extreme reduction of arable land in rural areas is a consequence of demographic processes, with the depopulation of rural areas being the main demographic characteristic. According to our research, 75% of rural settlements have a high or medium index of depopulation. Actually, the main reasons for all the changes noted over the last decades in Serbia are a combination of social, economic, and political factors. First of all, the decrease in cultivated areas was directly dependent on the population decline. The rural areas in Serbia have been affected by long-term migration in recent decades. The main internal migration flows have been in the same direction for decades, following patterns of socio-economic development (Lukić 2022). With the adjustment of economic development and industrial structure, and the rapid development of industry, a large portion of the rural labor force has migrated to cities, promoting the process of urbanization, gradually reducing agricultural demand, and also reducing the use of arable land (Martinović and Ratkaj 2015). In that context, the dynamics of the internal migration and distribution of the population in the regional and sub regional level has been directed to larger urban centers along the centrally positioned Danube-Morava corridor, and from rural to urban settlements (Lukić 2013). Peripheral rural areas, mainly located in south Serbia, have shown the deepest multifaceted decline, and are represented by areas effected with extreme depopulation, population aging, economic shrinkage and insufficient infrastructural supply (Gajic et al. 2021). The complex dynamics of socio-economic processes have resulted in the continued fragmentation of rural settlements and structural changes in agricultural production (Stojanović 2022). Demographic research has shown that rural areas have experienced characteristics of rural exodus, followed by depopulation and deagrarization processes, which were most pronounced in the period leading up to the 1980s (Martinović and Ratkaj 2015; Nikitović 2016), and this coincides with a period of sudden changes in the transport of suspended sediment. A significant change in land use observed in the Velika Morava basin, through the abandonment of arable land due to the depopulation process, was accompanied by significant impacts on soil erosion and sediment transport. Changes in the regime and transport of sediments, presented through the sediment rating curve, showed lower regression lines for the periods after the transition years than the period before the transition years. The results show that the values of the average annual suspended sediment load are approximately 70–81% lower.

Conclusion

This study analyzed changes in the suspended sediment loads in the Velika Morava River basin from 1961 to 2007 and analyzed the influence of precipitation and human activities on suspended sediment transport. Trend analysis shows a significant decrease in the suspended sediment concentration and sediment load at stations on the Velika Morava River and the Južna Morava River and its tributaries. The changes in sediment load were predominantly impacted by the human activities. The main reason for the reduction in suspended sediment is the extreme reduction of arable land in rural areas. The extreme reduction of arable land is the direct result of long-term depopulation, which has been characteristic of most of Serbian rural settlements over the last six decades. Spatial patterns of depopulation and deagrarization clusters clearly demonstrated that the study area is dominated by settlements with a high or medium depopulation index and deagrarization index. Bivariate spatial autocorrelation analysis showed a high reduction of arable land resulting from extreme depopulation. It can be concluded that the decrease in the suspended sediment is positively correlated to the reduction ratio of the rural population. The decrease in suspended sediment occurred against the background of widespread agricultural degradation in arable land due to socio-economic transformations of rural areas in Serbia over the last few decades. The changes in sediment regimes were also influenced by different soil and water conservation and sediment control programs in the period from the middle of the twentieth century to the beginning of the twenty-first century.

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Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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