STREAMFLOW AND SUSPENDED SEDIMENT LOAD TRENDS IN TROTUȘ DRAINAGE BASIN: GEOMORPHIC IMPLICATIONS

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Abstract. The research focusing on the trends of the streamflow and suspended sediment, as well as on the controls involved in these changes, are currently topics of significant interest in fluvial geomorphology. In this context, the aim of this study is to analyze the trends of the streamflow discharge and the sediment load based on a geomorphological approach of the relations between the two variables. These trends were assessed based on three testing methods frequently employed in hydro-geomorphological studies (Mann–Kendall trend test, Şen's slope estimator and the innovative trend method) applied on data from 10 gauging stations located on major tributaries of Trotuș River. Results reveal an overall downward trend of the mean annual streamflow and an increasing trend of the mean annual suspended sediment load. Whereas the decreasing streamflow trend was linked to the diminishing precipitation amounts, the upward trend of suspended sediment load was related to the changes occurring within river channels as a result of flood events.

1. INTRODUCTION

Rivers are regarded as major links between continents and oceans and play a crucial role in the manifestation of geological, geomorphic, hydrological, biological and chemical processes occurring at the surface of the crust (Milliman and Meade, 1983; Walling and Fang, 2003). In the last half century fluvial systems were severely disrupted due to anthropogenic activities (e.g. land use / land cover changes within drainage basins, river channel regularization, dam construction, gravel mining etc.) and climate changes. Anthropogenic activities are believed to have disrupted to a significant degree the spatial and temporal evolution of water resources pertaining to more than half of the major fluvial systems on Earth (Liu et al. 2005). Moreover, the global hydrological cycle was

also affected by climate changes, primarily through the shifts occurring in precipitation and temperature regimes, which further interfere with the streamflow discharge (Vorosmarty et al. 2000). Consequently, either an increase or a decrease were documented in the streamflow and the sediment regime in close correlation with the disturbances occurring in the basin (Zhao et al. 2014). Therefore, research tackling the trends of streamflow discharge and sediment load in certain drainage basins is often addressed in hydrogeomorphological studies (Guo et al. 2018; Dey and Mishra, 2017). These studies are of great relevance both scientifically and practically especially in the fields of water resources management, flood protection and the rivers management (Barnett et al. 2005).

The studies focusing on the analysis of streamflow change trends are much more numerous compared to those addressing the shifts of the sediment load. The latter were more numerous for rivers from Asia, and China in particular. In Europe the tendencies of the streamflow are largely in line with precipitation trends, with decreasing values in southern and eastern Europe and increasing values in the north (Stahl et al. 2010, 2012). In Romania the publications pertaining to this category focused either on streamflow discharge trends in certain drainage basins (Rîmbu et al. 2002, 2004; Croitoru and Minea, 2015; Minea and Chelariu, 2020), or at national scale (Bîrsan et al. 2012, 2014, 2015; Ioniță et al. 2014; Ioniță, 2015). The trends of the suspended sediment load were studied mainly in connection with the construction of large dams. The analysis of long sediment load data series for 145 rivers across the planet revealed that in more than 50% of cases this parameter is declining (Walling and Fang, 2003). The sediment load decreased significantly in Europe in the past half century (Milliman, 2001). In Romania Rădoane et al. (2013) documented an upward trend of the sediment load in the central and northern parts of Siret drainage basin as opposed to a downward trend in the southern sector (particularly in Buzău drainage basin). Correlative studies between streamflow and sediment load trends are infrequent, as are investigations focusing on catchments, which are the fundamental units for interpreting landform dynamics (Rădoane et al. 2006). Similarly, few studies carried out in Romania looked into the factors controlling the variation of sediment loads.

This article is focused on the analysis of streamflow and sediment load trends between 1994 and 2017 at 10 gauging stations located on the main tributaries of Trotuș River.

Several approaches are available in the literature to assess the trends of hydrological variables. The most commonly used are the Mann–Kendall (MK) trend test and Şen's slope estimator (ŞSE) (Ali et al. 2019). Recently, the innovative trend analysis (ITA) or innovative trend method (ITM) introduced by

Şen (2012, 2017) (Ali and Abubaker, 2019) is used more frequently. The study aims to analyse the trends of streamflow discharge and sediment load based on a correlative approach of the two hydrological variables. Moreover, we attempted to identify the controls responsible for the variation of the sediment load. The objectives of this study include: (i) detecting the trends and shifts occurring in the streamflow and sediment load regimes at the 10 gauging stations; (ii) identifying the potential controls which have likely led to changes in the sediment flow.

2. DATA AND METHODS

2.1. Study area

The analysis of streamflow and sediment load trends was carried out based on the data recorded at the gauging stations located on the following tributaries of river Trotuș: Valea Rece, Sulța, Ciobănuș, Asău, Uz, Dofteana, Slănic, Oituz, Cașin and Tazlău (Figure 1). The main characteristics of drainage basins upstream of the gauging stations are shown in Table 1.

Table 1. Main characteristics of the drainage basins at the gauging stations

No.	River	Gauging station	Distance from river mouth (km)	Data regarding the drainage basin		Gauging station elevation (m)
				Area (km ²)	Mean elevation (m)	
1	Valea Rece	Valea Rece	1	120	1145	790
2	Sulța	Sulța	1	116	1041	551
3	Ciobănuș	Ciobănuș	1	135	1052	475
4	Asău	Asău	2	204	951	430
5	Uz	Valea Uzului	22	150	1070	628
6	Dofteana	Dofteana	0.4	110	735	301
7	Slănic	Cireșoaia	7	105	775	340
8	Oituz	Ferăstrău	19	267	810	300
9	Cașin	Haloș	18	220	717	298
10	Tazlău	Helegiu	14	998	520	209

The resistance to erosion of the geological substrate differs depending on the types of rock outcropping in these basins: thus, erosion resistant rocks are prevalent in basins such as Valea Rece, Sulța, Ciobănuș, Asău, Uz and Oituz (upper and mid basins), and Cașin (upper basin); moderately resistant rocks are dominant in Dofteana and Slănic basins; and rocks with low resistance are prevalent in basins such as Tazlău, Oituz (lower basin) and Cașin (mid and lower basins) (Dumitriu, 2014). Consequently, the most significant sediment yields were documented in basins whereby the rock resistance to erosion is low. These basins are also under the influence of strong anthropogenic intervention (Dumitriu et al. 2017). Gravel bed channels are typical for all 10 investigated

streams (Dumitriu, 2007; Rădoane et al. 2006). With the exception of Tazlău and Valea Rece basins, within the remaining basins the forested area accounts for more than 75% of the total basin area.

Figure 1. Location of the study area in Romania and location of gauging stations within Troțuș drainage basin

2.2. Data sources

The data regarding streamflow (Q), and suspended sediment load (SSL) from 1994 to 2017 are provided by the “Romanian Waters” National Administration - Siret Water Branch, which manages the ten gauging stations included in this study. These data were examined statistically and were further used for the integrated analysis of streamflow and sediment load changes throughout the investigated time frame.

2.3. Methods

In this study, three types of trend methods were applied for testing. The non-parametric MK trend test was used to examine the occurrence of monotonic increasing or decreasing trends. The $\hat{S}SE$ method was applied in order to estimate the real slope of the linear trend. The ITM method was used to check the possible trends in Q and SSL data (Kiři et al. 2018).

2.3.1. Mann–Kendall test

The MK test was the most frequently used for assessing trends in hydroclimatic studies (Ali et al. 2019).

The MK test is applied in the situations where it is assumed that the values of the x_i temporal data series conform to the following model:

$$x_i = f(ti) + \varepsilon_i \quad (1)$$

where $f(ti)$ is a continuous monotonic time dependent function and ε_i is residuals which are assumed to be from the same distribution having zero mean. Therefore, it is expected that the distribution's variance should be constant in time.

The aim is to test the null hypothesis of no trend, the null hypothesis (H_0), *i.e.* the data x_i is randomly ordered in time, versus the alternative hypothesis (H_1) where an upward or downward monotonic trends exist. Hence, two statistics might be computed depending on the data length, the S statistics provided by Gilbert (1987) and the Z statistics. S test is utilized for the time series having data points less than 10, whereas normal approximation is utilized for the time series having 10 or more data points (n) (Kışı et al. 2018).

The Mann-Kendall test statistic S can be computed using the following formula:

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^n \text{sgn}(x_k - x_j) \quad (2)$$

In the above formula x_j and x_k are the data values at times j and k , $j > k$, respectively, and

$$\text{sgn}(x_k - x_j) = \begin{cases} +1 & \text{when } (x_k - x_j) > 0 \\ 0 & \text{when } (x_k - x_j) = 0 \\ -1 & \text{when } (x_k - x_j) < 0 \end{cases} \quad (3)$$

The variance of S is estimated as:

$$\text{VAR}(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^q t_p(t_p-1)(2t_p+5)}{18} \quad (4)$$

where q denotes the number of tied groups and t_p represents the number of data values in the q^{th} set.

The standardized test static for the MK test (Z) can be calculated, as shown in Eq. (5):

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad (5)$$

The sign of Z indicates the direction of the trend. The negative value of Z indicates a decreasing trend and positive value of Z indicates a increasing trend. Testing trends is performed at the specific α significance level. In this study, $\alpha = 0.05$ was used. At the 5 % significance level, the null hypothesis of no trend is rejected if $Z > 1.96$. The significance of the change in annual Q and SSL was estimated using the MK test.

Data were processed using an Excel macro named Makesens created by Salmi et al. (2002).

2.3.2. Estimation of magnitude of change

The Sen's slope method (Sen, 1968) was used for the estimation of the change in annual Q and SSL for the period 1994-2017. The Sen's slope (β) is calculated as the median of all the slopes estimated between all the successive data points of a river flow time series (x_i) as (Ali et al. 2019):

$$\beta = \text{median} \left[\frac{\Delta y}{\Delta t} \right] \quad (6)$$

where, Δy is the change in Q or SSL due to the change in time, Δt , between two subsequent Q or SSL data. The Sen's slope is a non-parametric method which has been found highly reliable for estimation of change over time (Da Silva et al. 2015).

2.3.3. Innovative trend method

Innovative trend method (ITM) was first introduced by Şen (2012). In this method, data are equally divided into two segments between first dates to the last date. Both segments are arranged in ascending order and presented in the X and Y -axis. The first segment ($x_i : i = 1, 2, \dots, n/2$) is presented in the horizontal axis while the second segment ($x_j : j = n/2 + 1, n/2 + 2, \dots, n$) is presented in vertical axis in the Cartesian coordinate system. A bisector line at 1:1 (45°) divides the diagram into two equal triangles. The upper triangle represents an increasing trend, while a lower one indicates a decreasing trend. If the points are concentrated along the median line, they do not indicate any trend. For the estimation of the trend, the S_{ITM} statistic is computed as follows (Şen, 2017):

$$S_{ITM} = \frac{2(\bar{x}_i - \bar{x}_j)}{n} \quad (7)$$

where S_{ITM} is the slope base on the ITM method, n is the sample size, $\bar{x}_i$ and $\bar{x}_j$ are the mean value of the first and second half of the series, respectively.

The standard deviation of sampling slope is calculated as:

$$\sigma_s = \frac{2\sqrt{2}}{n\sqrt{n}} \sigma \sqrt{1 - \rho_{xixj}} \quad (8)$$

where σ_s is the standard deviation of sampling slope; σ is the standard deviation of whole data series; and ρ_{xixj} is the crosscorrelation coefficient between the ascendingly sorted two halves' arithmetic averages.

The confidence limits (upper and lower) of the trend slope at α level of significance are expressed using the following expression:

$$CL_{1-\alpha} = 0 \pm s\sigma_s \quad (9)$$

where CL is the upper and lower confidence limits at α level of significance; σ_s is the standard deviation of sampling slope; and s is the slope value. The null hypothesis (H_0) is such that there is no trend in the time series, and alternate hypothesis (H_1) is such that there is a trend in the time series. Thus, in a two-sided condition, the H_0 and H_1 are tested at $\alpha = 5\%$ with $Z = \pm 1.96$. If $\pm s > \pm CL_{1-\alpha}$, then H_0 is rejected and H_1 is accepted. A positive (negative) value of s indicates an increasing (decreasing) trend in the time series (Malik et al. 2019). In this study, the significance of the change in annual Q and SSL was estimated using ITM.

The statistical relation between SSL and Q , also known as the sediment rating curve, is typically determined using the power function (Asselman, 2000):

$$SSL = aQ^b \quad (10)$$

where SSL is the rate of the suspended sediment load; a – regression coefficient; b – regression exponent.

3. RESULTS AND DISCUSSION

In order to acquire a better understanding and perform an accurate analysis of streamflow and sediment load regimes during the studied time frame we used the descriptive statistics of data series characteristic for the two variables (Table 2). The data analysis revealed that the investigated basins can be ranked into three categories: (i) basins under 200 km² in area, with average streamflow discharge below 2 m³/s and maximum streamflow below 100 m³/s (with the exception of Asău and Dofteana). This category includes basins from the upper and midcourse (upstream of Târgu Ocna); (ii) basins ranging between 200 and 300 km² in area, with average multiannual streamflow values between 2 and 3 m³/s and maximum streamflow values higher than 300 m³/s. This class comprises the basins of rivers Oituz and Cașin; (iii) Tazlău basin, with an area of ca. 1000

km² and a multiannual streamflow averaging at ca. 7 m³/s, whereas the maximum streamflow in the studied period reached 1556 m³/s.

Table 2. Descriptive statistics of annual discharge (1994–2017) and suspended sediment load at study gauging stations

River	Gauging station	Statistical parameters	Q _{mean} (m ³ /s)	Q _{max} (m ³ /s)	SSL _{mean} (kg/s)	SSL _{max} (kg/s)
Valea Rece	Valea Rece	Mean	1.3	20.7		
		Standard Dev.	0.4	19.7		
		Kurtosis	0.0	4.1		
		Skewness	0.9	2.2		
		Minimum	0.7	5.6		
		Maximum	2.4	78.1		
Sulța	Sulța	Mean	1.0	16.1		
		Standard Dev.	0.3	18.6		
		Kurtosis	1.2	3.8		
		Skewness	0.9	2.2		
		Minimum	0.6	3.0		
		Maximum	1.8	71.2		
Ciobănuș	Ciobănuș	Mean	0.9	15.0		
		Standard Dev.	0.3	12.8		
		Kurtosis	0.1	2.7		
		Skewness	0.2	1.8		
		Minimum	0.2	3.4		
		Maximum	1.6	52.6		
Asău	Asău	Mean	1.8	29.5	1.7	91.9
		Standard Dev.	0.7	38.1	1.2	82.7
		Kurtosis	1.1	18.3	-0.2	7.1
		Skewness	1.2	4.1	0.8	2.2
		Minimum	1.1	8.3	0.2	3.5
		Maximum	3.7	198.0	4.5	394.0
Uz	Valea Uzului	Mean	1.4	21.7	0.7	42.4
		Standard Dev.	0.6	13.0	0.7	56.6
		Kurtosis	0.5	3.1	0.3	12.0
		Skewness	0.6	1.6	1.2	3.1
		Minimum	0.5	6.2	0.04	1.7
		Maximum	3.0	62.5	2.4	272.0
Dofteana	Dofteana	Mean	0.9	29.7		
		Standard Dev.	0.4	31.7		
		Kurtosis	3.8	5.5		
		Skewness	1.6	2.3		
		Minimum	0.4	5.4		
		Maximum	2.1	138.0		
Slănic	Cireșoaia	Mean	1.1	23.5		
		Standard Dev.	0.3	22.3		
		Kurtosis	-0.2	4.8		
		Skewness	0.6	2.1		
		Minimum	0.6	4.7		
		Maximum	1.8	98.8		

Oituz	Ferăstrău	Mean	2.7	47.7	1.2	124.7
		Standard Dev.	0.9	36.3	1.3	206.5
		Kurtosis	0.1	3.6	6.9	17.5
		Skewness	0.7	1.7	2.5	4.0
		Minimum	1.5	9.8	0.3	4.0
		Maximum	5.0	311.0	5.8	1030.0
Cașin	Haloș	Mean	2.1	81.2		
		Standard Dev.	0.8	101.2		
		Kurtosis	1.4	5.0		
		Skewness	1.1	2.2		
		Minimum	0.9	8.9		
		Maximum	4.4	419.0		
Tazlău	Helegiu	Mean	6.4	279.6	5.3	1671.1
		Standard Dev.	2.9	407.6	5.4	4030.0
		Kurtosis	0.4	5.7	5.4	19.7
		Skewness	1.0	2.5	2.3	4.3
		Minimum	3.1	18.6	0.5	16.8
		Maximum	13.8	1556.0	23.6	19800.0

3.1. River flow trends

The MK trend test was applied for the data series of the average annual streamflow values at all gauging stations comprised in the study. The tests were applied for confidence intervals of 90%, 95% and 99%. The results yielded by this approach are shown in Table 3 and reveal negative (decreasing) trends at all stations, with the sole exception of Helegiu gage on river Tazlău, where a positive (increasing) trend was documented.

Table 3. Mann–Kendall test and Sen’s slope statistics of mean annual discharge

Gauging station	Mann–Kendall test		Sen’s slope	Trend
	Z	P-value		
Valea Rece	-1.91	0.06	-0.02	Downward
Sulța	-0.52	0.60	-0.01	Downward
Ciobănuș	-0.32	0.63	-0.01	Downward
Asău	-1.07	0.29	-0.02	Downward
Valea Uzului	-1.27	0.21	-0.03	Downward
Dofteana	-0.52	0.60	-0.01	Downward
Cireșoaia	-1.07	0.29	-0.01	Downward
Ferăstrău	-0.77	0.44	-0.03	Downward
Haloș	-0.27	0.78	-0.01	Downward
Helegiu	0.97	0.33	0.05	Upward

The results of Sen’s trend test are also shown in Table 3 (column 3) and reveal the same decreasing trend of streamflow discharge, with the exception of Helegiu (Tazlău) gauging station where the trend was upward. The downward slope is not steep, and the documented trend is a slow progressive decrease. However, more abrupt downward trends were observed at Valea Rece, Asău, Uz

and Oituz gauging stations. The upward trend recorded at Helegiu gage is more evident compared to the decreasing trends observed at the other 9 stations (Figure 2).

Figure 2. Annual time series and trend statistics of annual streamflow during 1994–2017

The results yielded by ITM are similar to the ones generated by the MK and $\text{\text{SSE}}$ tests only in the case of mean multiannual streamflow discharge. The maximum annual streamflow differs in terms of trends (Table 4, Figure 3). Thus, the downward trend of the maximum streamflow was documented solely in the case of tributaries from the mid part of Trotuș drainage basin (Ciobănuș, Asău and Valea Uzului). By contrast, evident upward trends for the maximum

streamflow were observed at Haloș and Helegiu gauging stations. At stations pertaining to the latter category the increasing trend of maximum streamflow was in fact characteristic only for median and upper classes, whereas at most gages the lower classes of maximum streamflow showed no visible trend or a slow decrease.

Table 4. The results of innovative trend analysis on mean and maximum annual discharge

Gauging station	Variables	Slope (s)	σ	$\overline{\rho\bar{y}_1\bar{y}_2}$	σ_s	Upper CL	Lower CL
Valea Rece	Qmean	-0.02*	0.45	0.811	0.005	0.01	-0.01
	Qmax	1.10*	19.67	0.850	0.18	0.36	-0.36
Sulța	Qmean	-0.02*	0.30	0.958	0.001	0.003	-0.003
	Qmax	0.18	18.57	0.804	0.20	0.39	-0.39
Ciobănuș	Qmean	-0.01	0.35	0.893	0.003	0.01	-0.01
	Qmax	-0.56*	12.76	0.914	0.09	0.18	-0.18
Asău	Qmean	-0.03*	0.66	0.936	0.004	0.01	-0.01
	Qmax	-1.34*	38.08	0.859	0.34	0.67	-0.67
Valea Uzului	Qmean	-0.02*	0.61	0.959	0.00	0.01	-0.01
	Qmax	-0.15	12.99	0.920	0.09	0.17	-0.17
Dofteana	Qmean	-0.02*	0.37	0.959	0.002	0.004	0.00
	Qmax	1.20*	31.69	0.773	0.36	0.71	-0.71
Cireșoaia	Qmean	-0.02*	0.32	0.930	0.002	0.004	-0.004
	Qmax	1.31*	22.32	0.974	0.09	0.17	-0.17
Ferăstrău	Qmean	-0.04*	0.94	0.963	0.004	0.01	-0.01
	Qmax	0.97	36.30	0.659	0.51	1.00	-1.00
Haloș	Qmean	-0.03*	0.81	0.978	0.003	0.01	-0.01
	Qmax	6.01*	101.24	0.920	0.69	1.35	-1.35
Helegiu	Qmean	0.02	2.88	0.963	0.01	0.03	-0.03
	Qmax	12.00*	407.65	0.908	2.97	5.83	-5.83

*Statistically significant at $\alpha = 5\%$ (critical $Z = \pm 1.96$)

The downward trend of streamflow discharge can be related to the increasing trend of temperature and the diminishing amounts of precipitation (Kahya and Kalayci, 2004; Da Silva et al. 2015). The current state of Trotuș drainage basin is very well correlated with the data provided by Rădoane et al. (2013) regarding the annual trend of precipitation between 1950 and 2010 at 29 gauging stations within Siret drainage basin. The precipitation trend was estimated based on the b coefficient (the slope) of the linear regression. Depending on its value, the following trends were delineated: positive ($b > 0.5$), relatively stationary ($0.5 < b < -0.5$) and negative ($b < -0.5$) trend. This method was employed in other climatological studies in Romania, as well (Apostol, 2000; Busuioc et al. 2010). In the case of Trotuș drainage basin (with the exception of river Tazlău) values below -0.5 are prevalent, which indicates a downward trend in precipitation, which further explains the decreasing trend of streamflow discharge. In Tazlău drainage basin the b coefficient is higher than 0,

Figure 3. The results of ITM for mean and maximum annual discharge

which points to an upward trend of the streamflow. As regards the trend of the maximum streamflow, the correlation between the former and extreme precipitation is good (Croitoru et al., 2016). The downward trend of maximum streamflow discharge at gauging stations from the mid part of the drainage basin can be attributed to the ‘shade’ effect manifested in relation to the extreme precipitation generated by Atlantic (in western and central Romania) and Mediterranean (in eastern Romania) cyclones (Apostol, 2008; Dobri et al., 2017). At Helegiu and Haloș stations, both located in the area affected by extreme rainfall generated by Mediterranean cyclones, the upward trend of maximum streamflow is evident.

Minea and Chelariu (2020) reveal that the same general downward trend of mean multiannual streamflow is maintained in eastern Romania.

3.2. Annual trends of suspended sediment load

The trends of the suspended sediment load determined using the MK and SSE tests are shown in Table 5. Unlike the streamflow discharge, the data indicate an upward trend at all stations (Figure 4).

Table 5. Mann–Kendall test and Sen’s slope statistics of mean annual suspended sediment load

Gauging station	Mann–Kendall test		Sen’s slope	Trend
	Z	P-value		
Asău	1.66	0.10	0.07	Upward
Valea Uzului	3.35	0.00	0.04	Upward
Ferăstrău	2.01	0.04	0.03	Upward
Helegiu	0.87	0.39	0.07	Upward

Similar results were yielded by ITM (Table 6, Figure 5). Statistically significant increases were documented at Asău and Valea Uzului gauging stations, which could indicate that the rise is more evident when the area of the drainage basins located upstream of the gages is smaller in size. In the case of Ferăstrău and Helegiu gauging stations, which monitor the hydrological effects across larger basins, the SSL increase was more moderate. The maximum annual suspended sediment load are diminishing only in the case of Asău River, whereas at the remaining gages the upward trends are more or less marked.

Figure 4. Annual time series and trend statistics of SSL during 1994–2017

Table 6. The results of innovative trend analysis on mean and maximum annual suspended sediment load

Gauging station	Variables	Slope (s)	σ	$\rho\bar{y}_1\bar{y}_2$	σ_s	Upper CL	Lower CL
Asău	SSLmean	0.03*	1.25	0.969	0.01	0.01	-0.01
	SSLmax	-1.00	82.66	0.836	0.80	1.58	-1.58
Valea Uzului	SSLmean	0.05*	0.75	0.725	0.01	0.02	-0.02
	SSLmax	1.11	56.58	0.628	0.83	1.63	-1.63
Ferăstrău	SSLmean	0.001	1.27	0.850	0.01	0.02	-0.02
	SSLmax	4.40	206.46	0.741	2.53	4.96	-4.96
Helegiu	SSLmean	0.01	5.42	0.983	0.02	0.03	-0.03
	SSLmax	167.83*	4029.96	0.997	4.98	9.76	-9.76

*Statistically significant at $\alpha = 5\%$ (critical $Z = \pm 1.96$)

The increasing trend of the suspended sediment load (SSL) was also documented by Rădoane et al. (2013). The authors took into account the data from the gauging stations located on river Trotuș (Lunca de sus, Goioasa, Târgu Ocna and Vrânceni).

Figure 5. The results of ITM for Q_{mean} and SSL_{mean} : (a) Asău; (b) Valea Uzului; (c) Ferăstrău; (d) Helegiu.

3.3. Correlations between Q and SSL

The studies carried out in the last half century revealed that the trend of the sediment flow is directly related to the anthropogenic impact (e.g. dam construction, land use/land cover changes, mining and gravel mining from channel beds, soil erosion control etc.) and climate changes. Some shifts (either anthropogenic or climatic) resulted in increasing sediment yields, whereas others (including mainly the construction of dams) led to a decrease in the sediment flow. In many instances it proves difficult to clearly distinguish between the causes (anthropogenic or climatic) which have determined either a rise or a drop in the sediment flow (Walling and Fang, 2003).

At gauging stations located on the main tributaries of Trotuș River the main general trends documented by this study were the decreasing Q and increasing SSL. The correlations between Q and SSL trends (Figure 6) indicate that at the stations where the area of the monitored basin is small (Valea Uzului, Asău) the correlation coefficients (R^2) are below 0.500, due to the fact that SSL trends reflect the Q trends to a much lower extent. In the case of larger drainage basins, the correlation coefficients have values higher than 0.005, which indicates that Q and SSL are more closely related.

Figure 6. Correlation between Q and SSL

The downward Q trend at the ten gauging stations of the study area can be linked to the decreasing precipitation trend in the area of Trotuș drainage basin. However, the question remains whether the increasing SSL trend can be attributed to climate changes or to the anthropogenic impact?

The anthropogenic impact of the last two decades in the basins investigated in this study cannot explain the upward trend of SSL. The only anthropogenic intervention which could have resulted in a SSL increase is deforestation. However, the scale of forest removal in these basins (Rădoane et al. 2013) could not have influenced the SSL trend to this extent. In many scientific publications (mostly Romanian) the increasing streamflow and sediment load values are attributed to deforestation, albeit without presenting conclusive evidence to this support this hypothesis. Several studies show that in some instances forest logging does not lead to a rise of SSL (Arismendi et al. 2017; Hatten et al. 2018), whereas others reveal that deforestation can result in significant SSL increase of 3 up to 12 times (Beschta, 1978; Grant and Wolff, 1991). *"The variability in response to forest harvesting may be due, in part, to the multitude of variables that influence suspended sediment yields. For example, catchment lithology, physiography, land cover, land use, and hydrologic conditions may all impact suspended sediment"* (Bywater-Reyes et al. 2018).

In our view, the stages of the reversal of SSL trend after 1989 were the following: the first stage was characterized by a general upward trend of the maximum streamflow under the direct influence of the increasing magnitude of extreme precipitation; the second stage was marked by the onset of river channel adjustments triggered by flood events (Dumitriu, 2016; 2018). These channel changes (widening, aggradation, degradation) resulted in the availability of sediment sources within the channel which further reflected in the sediment regime; in the current stage, the same streamflow discharge transports larger amounts of sediment. All these changes define the upward trend of SSL. To sum up, climate changes strongly influenced geomorphic processes occurring in river channels, which contributed to the overall increasing trend of SSL.

4. Conclusions

This study set out to analyze from a geomorphic viewpoint the trends of the streamflow and sediment load characteristic for the major tributaries of river Trotuș. Three methods for trend testing were under scrutiny: Mann–Kendall trend test, Sen's slope estimator and the innovative trend method. The results yielded by the three approaches attest that the general trend (between 1994 and 2017) of the mean annual streamflow is downward, whereas the maximum annual streamflow is increasing. These trends were linked to the diminishing of

mean annual precipitation, as well as to the increasing magnitude of extreme precipitation. Depending on the location of investigated basins, some exceptions to this overall trends occur due to the amounts of precipitation generated by Atlantic and Mediterranean cyclones. The suspended sediment load had an upward trend at all gauging stations of the study area, which is likely related to the changes occurring in channel beds as a result of major flood events. These shifts led to an increase in the availability of new sediment sources within the channels and thus to a rise in the sediment transport.

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