Pregledni rad/Review paper
Primljen/Received: 21. 3. 2019.
Prihvaćen/Accepted: 6. 6. 2019.

ANALYSIS OF THE MONTHLY AND ANNUAL FLOWS OF THE CETINA RIVER AT THE TISNE STINE 1 GAUGING STATION

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Abstract: A basic statistical data analysis and trend analysis were performed for the flows recorded at the Tisne Stine 1 gauging station on the Cetina River. The analysis was carried out using the linear and nonlinear regression, Mann-Kendall test, and the so-called RAPS method.

Keywords: Cetina, river basin, karst, Tisne Stine 1 gauging station, flows, regression analysis, Mann-Kendall test, RAPS, trend

ANALIZA MJESEČNIH I GODIŠNJIH PROTOKA RIJEKE CETINE NA VODOMJERNOJ POSTAJI TISNE STINE 1

Sažetak:U radu je izvršena osnovna statistička analiza te analiza trenda za protoke zabilježene na vodomjernoj postaji Tisne Stine 1 na rijeci Cetini. Analiza je provedena metodama linearne i nelinearne regresije, Mann-Kendall testom te primjenom tzv. RAPS metode.

Ključne riječi: Cetina, sliv, krš, vodomjerna postaja Tisne Stine 1, protoci, regresijska analiza, Mann-Kendall test, RAPS, trend

1. Introduction

The Tisne Stine 1 gauging station is the most downstream station at the Cetina River that is unaffected by the Adriatic Sea backwaters. The distance from the mouth is 6.6 km, and the zero level is at 1.198 m a.s.l. The station has at its disposal a series of measurement data from 1966 to 2018.

Based on the flow data recorded at the Tisne Stine 1 gauging station, a trend test analysis was conducted. The values of mean daily flows for the period from 1967 to 2017 were analyzed. Along with mean daily flows, minimum, mean and maximum monthly and annual flows are presented.

Figure 1. The geographical position of the Tisne Stine 1 gauging station1

Figure 2. The Tisne Stine 1 gauging station2

2. The main characteristics of the Cetina River catchment area

The Cetina River is part of the Adriatic basin and represents the largest river of the Split-Dalmatia County. It is 105 kilometers long with a catchment area of 4,090 km^2. From the source (Figure 3) in the town of Vrlika (Šibenik-Knin County), it flows through different geographic units, which characterize its course. It ends at its mouth in the town of Omiš (Figure 4), immediately before which the Tisne Stine 1 gauging station is located. Cetina rises from five springs at the foot of the Dinara mountain, between the peaks of Gnjat (1,809 m) and Dinara (1,831 m), at 380 meters above sea level near the village of the same name, Cetina. The main source is over a hundred meters deep lake, and it has been established that he source is connected with Buško Blato and Livanjsko polje.

The river course is determined by various valleys, poljes and plateaus. The Svilaja mountain extends from the source on its rights side, and on the left side is Dinara followed by Kamešnica. In its upper course it flows through several poljes: Cetinsko, Koljansko, Ribaričko and Sinjsko. The flat upper course of the Cetina River ends in the town of Trilj. In its lower course, up to Zadvarje, it is deeply cut into a karst plateau, resulting in the canyon appearance. In this area, the course features a few waterfalls and river rapids, which are also an important tourist factor. The lower course is followed by the Mosor mountain, and the last kilometers have an exceptionally attractive navigable section due to the large width of the riverbed. At the mouth, the Cetina River is fed by the submarine spring known as Vrulja.

Figure 3. Source of the Cetina River3

Figure 4. Mouth of the Cetina River4

3. The methodology of work

The methodology of work includes a description of mathematical formulations used for data analysis. The basic statistical concepts and methods from numerical mathematics are also described. Particular attention is focused on methods for identifying the existing trend.

3.1. Mann-Kendall trend test

The Mann-Kendall test is used to statistically evaluate the presence of a trend of an observed variable over a given period of time. The trend can be rising or falling, which means that the variable is consistently increasing or decreasing over time. The MK test can be used instead of a parametric linear regression test, which is based on the assumption that residuals of the approximation line follow a normal distribution. The MK test does not require the assumption of normal distribution, i.e., it represents a nonparametric test.

The MK test does not require the measurements to follow a normal distribution or the trend, if present, to be linear, but it requires the assumption of independence (Gilbert, 1987). In order to satisfy the assumption of independence, the time step between the measurements must be large enough. This ensures the absence of correlation between measurements at different times. The MK test tests whether to reject the hypothesis (H_0) or to accept the alternative one (H_1).

3.2. The RAPS method

The RAPS (Rescaled Adjusted Partial Sums) method is often used to detect and quantify trends and fluctuations in time series. A graphical view of RAPS reveals subperiods with similar characteristics, multiple trends, sudden jumps or drops of values, irregular fluctuations, existence of periodicity in analyzed time series, etc. (Bonacci, 2010). The expression for calculation of RAPS values:

$$RAPS_k = \sum_{t=1}^{k} \frac{Y_t - \bar{Y}}{S_y} \quad (1)$$

where:
S_y - is the standard deviation,
n - the number of data of the time series,
$\bar{Y}$ - mean of the observed times series.

4. Analysis of results

Data for analysis were obtained from DHMZ in the period from 1967 to 2017 at the level of mean daily flows. Trend analysis was carried out for the observed period, based on the available data, using the Mann-Kendall trend test, linear and nonlinear regression analysis and the RAPS method.

4.1. Data processing

The available data (67 - 17) were obtained at the level of mean daily flows, averaged on a monthly and annual basis and presented in the form of a hydrograph. The flow duration curve for the Tisne Stine 1 gauging station was created and shown.

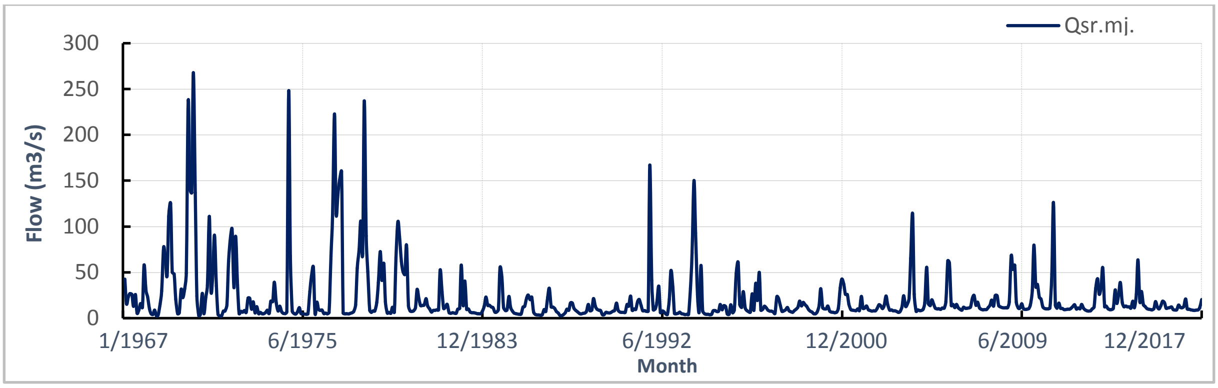

Figure 5. Hydrograph for the period 1967 - 2017

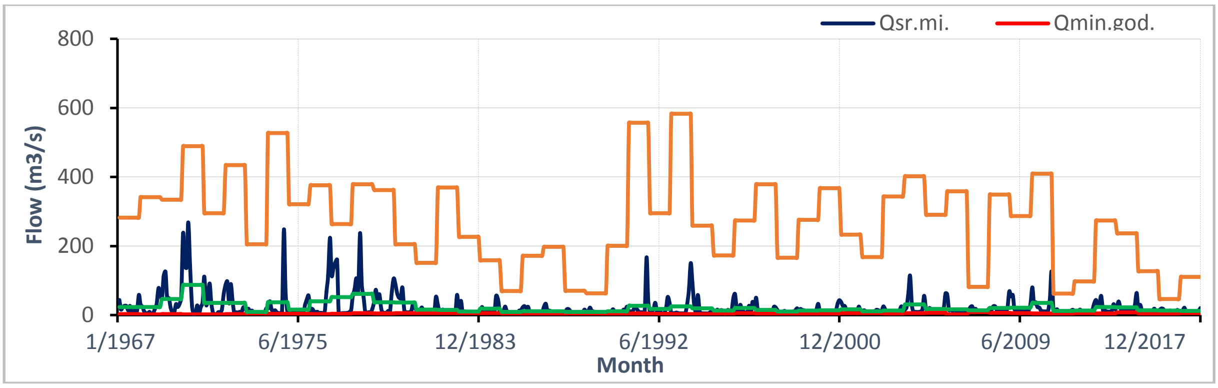

Figure 6. Min, max and mean annual flows

Some years with considerably larger flows, such as 1970, 1974, 1976 and 1978, are noticeable for the observed period. Larger flows were also registered in 1991, 1993, 2004 and 2011.

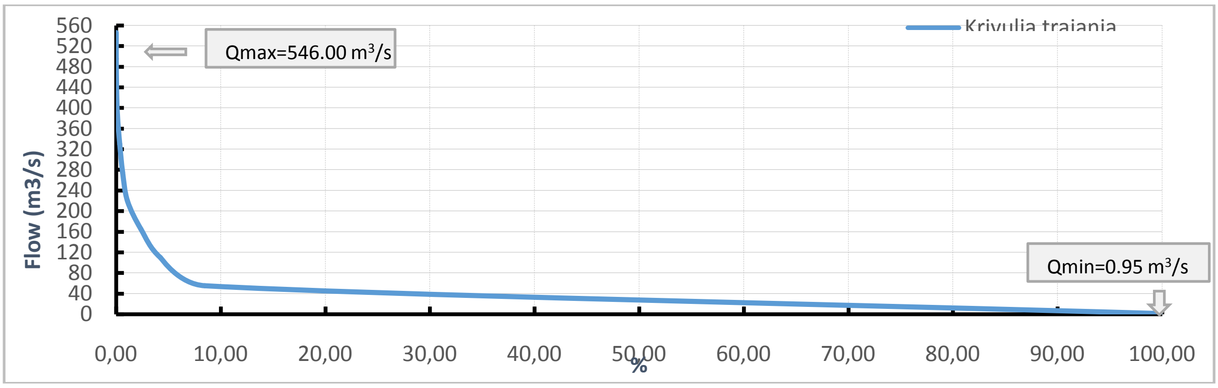

Figure 7. Duration curve (Žugaj, 2011)

4.2. Mann-Kendall trend test

Trend analysis was performed for the data set at the level of mean daily flows using the Mann-Kendall trend test. Before conducting the test, it is necessary to check the persistence of periodicity for the given data set, or to check the seasonal character of data. The procedure is necessary in order to determine the possible persistence of periodicity, and in that case a seasonal Mann-Kendall trend test, which takes into account seasonal character of data, is used.

4.2.1. Periodicity analysis

The initial step in determining the existence of seasonal character of data is to create a correlogram. Then the coefficients of autocorrelation R (τ) are calculated, based on the mean value and variance for the corresponding time stepτ. The next step is to check the persistence of periodicity. The assumption of the analysis is that the autocorrelation coefficient follows a normal distribution (Ross, 2007). This procedure defines the null hypothesis for the given significance level α. If all the data are within the confidence interval, the zero hypothesis is accepted, otherwise it is rejected. The calculation results are presented graphically (Figure 8) and tabularly (Table 1).

Table 1. Calculation results, Tisne Stine 1

N	τ	μ	$\sigma^2 * N$	α	$z_{\alpha/2}$	B_1	B_2
18628	100	21,9159	34304456,02	0,05	-1,96	-0,0144	0,0144

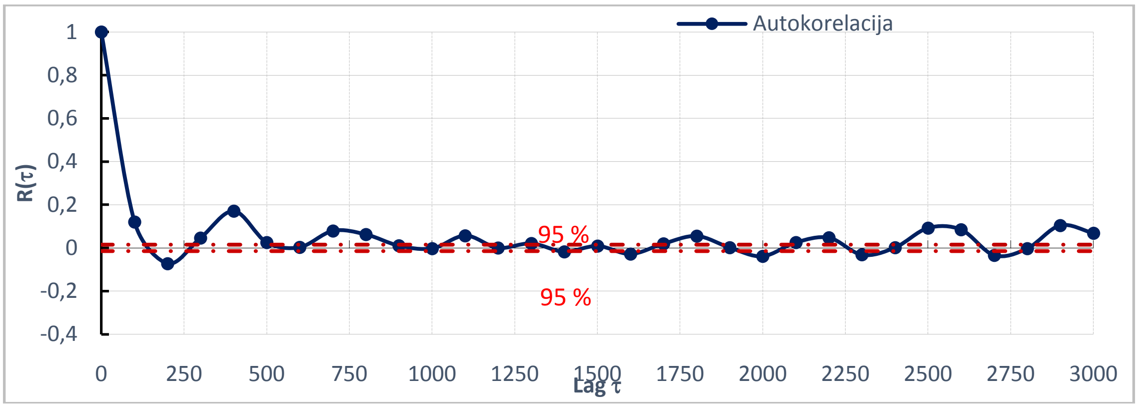

Figure 8. Correlogram (Hrvatske vode, 2008)

The results show that a significant part of the autocorrelation coefficient value is outside the 95% confidence interval and it can be concluded that the data are periodic, or of a seasonal character. The zero hypothesis is rejected in favor of the alternative one, with the given coefficient of significance α.

4.2.2. Seasonal Mann-Kendall test

The previous analysis established the presence of periodicity, or the existence of seasonal character, and so the seasonal Mann-Kendall trend test was used.

The initial step is to divide data into 12 classes (months), which meets the condition of data independence (Hrelja, 2007). The treated data are presented graphically in figures (Figure 9) in the form of a hydrograph. Each class is defined by the sign of all n (n-1)/2 differences, and indicator function calculated for each difference. The next step is to perform calculation of the Mann-Kendall statistics Si for the i^{th} month, and the corresponding variances Var (Si), which are summed. The last step is to calculate the Mann-Kendall test statistics ZMK according to the expression, and to present the obtained calculation results (Table 2).

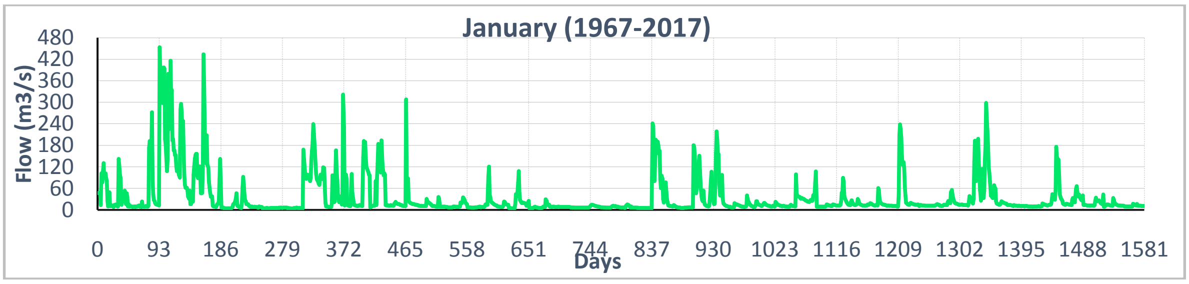

Figure 9: Calculation results (demonstration example for January)

Table 2. Calculation results of the MK test statistics

i	S_i	$Var(S_i)$		S'	Var(S')
1	38836	4.39E+08		2652853	5.00E+09
2	2169	3.33E+08			
3	52282	4.39E+08		Z_{MK}	
4	-28137	3.98E+08		37.518	
5	152710	4.39E+08			
6	389219	3.98E+08			
7	639081	4.39E+08			
8	603812	4.39E+08			
9	325643	3.98E+08			
10	211594	4.39E+08			
11	174580	3.98E+08			
12	91064	4.39E+08			

The conducted calculation results in a positive value of MK test statistics, which implies a rising trend. Then the null hypothesis is tested H_0: there is no trend against the alternative hypothesis H_1: there is a rising trend with the corresponding significance level α. A two-tailed Z-test was selected. The analysis results are presented tabularly (Table 3).

Table 3. Hypothesis testing

α	Z_{MK}		$Z_{(1-\alpha)/2}$
0,05	37,51766	>	1,96

Since $Z_{MK} > Z_{1-\alpha/2}$, the null hypothesis H_0 is rejected, and the alternative hypothesis H_1 is accepted. From the conducted analysis for the data set at the level of mean daily flows, it can be concluded that there is a rising trend.

4.3. Linear and nonlinear regression analysis

Regression analysis is a parametric method for determining trends. Two regression analysis models, linear and polynomial, are created for known flow data in this chapter. Each model is presented graphically with corresponding parameters and their characteristics. Trend analysis was performed for the data at the level of mean daily, monthly and annual flows and minimum and maximum annual flows. The averaged flows on a monthly and annual basis result in an increased correlation coefficient. A disadvantage is the loss of extreme values, which reduces the accuracy of the assessment. For a large number of data, the correlation coefficient assumes a small value and as such indicates low accuracy of the selected model. The polynomial model better describes the data set, and unlike the linear one shows the trend for multiple periods (Dunn, 2005). Any increase of polynomial degree results in an increase of correlation coefficient, but up to a certain limit.

A small value of correlation coefficient calls into question the validity of the model. For this reason, validity analysis was performed for each model. The hypothesis is tested H_0:r=0: there is no correlation between data, against the alternative hypothesis H_1:r≠0: or a correlation is present, at the significance level of α=5 %. A two-tailed Z-test was selected. Validity analysis was performed for coefficients of both linear and polynomial model.

Analyses were conducted for mean daily, monthly flows, and minimum, mean and maximum annual flows. The analysis results are illustrated for maximum annual flow graphically in the form of a hydrograph with the corresponding trend line for the values and in table form with corresponding calculated parameters.

4.3.1. Maximum annual flows

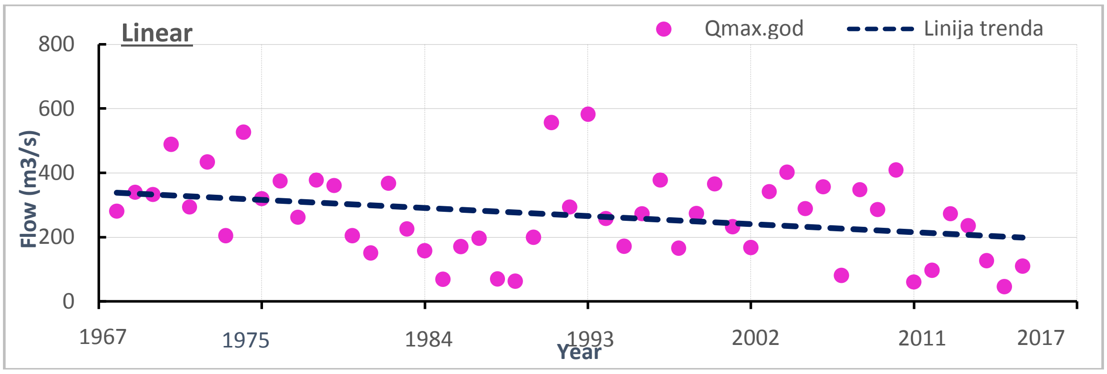

Figure 10. Linear model for maximum annual flows

Table 4. Polynomial model parameters

Line equation	y = -2.795x + 341.029								
Line slope	y' = 2.795								
r	r^2	$\hat{\sigma}$	n	Coefficients		s_{coef}	$\lvert z_n \rvert$		$Z_{(1-\alpha)/2}$
0.315	0.099	126.670	51	a	-2.795	1.205	2.319	>	1.96
				r	0.315	0.136	2.319	>	1.96

The linear model for maximum annual flows contains 51 data. It describes 9.9 % of data. Testing of the hypotheses for the slope and correlation coefficients shows that the test statistics are greater than the limit ones (Table 4). The negative value of the line slope shows a downward trend, or a decrease in the value of flow in the observed period of 43%; 2.941 m^3/s annually (Figure 10).

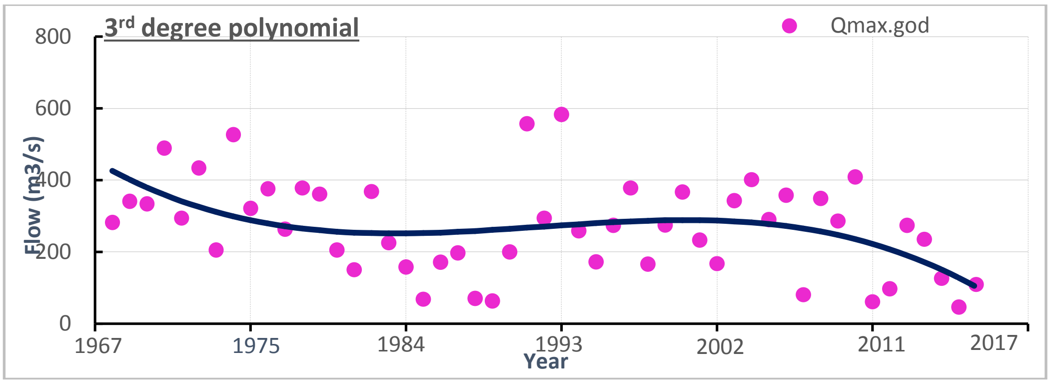

Figure 11. Polynomial model for maximum annual flows

Table 5. Polynomial model parameters

Curve equation	Y = - 0.016x3 + 1.209x2 - 27.87x + 452.524										
Curve slope	Y = - 0.048x2 + 2.418x - 27.87x										
r		**r^2**				**$\hat{\sigma}$**			**n**		
0.434		0.189				122.728			51		
Coefficients		S_{coef}	$\|z_n\|$		$Z_{(1-\alpha)/2}$	Coefficients		S_{coef}	$\|z_n\|$		$Z_{(1-\alpha)/2}$
a_1	-0.016	0.007	2.277	>	1.96	**a_3**	-27.870	12.225	2.280	>	1.96
a_2	1.210	0.543	2.226	>	1.96	**r**	0.434	0.129	3.375	>	1.96

A 3rd degree polynomial, which describes 18.9 % of data, was selected for the polynomial model. By testing the hypotheses, it was found that test statistics are greater than the limit value for all coefficients (Table 5). The model results presented in the diagram (Figure 11) result in decreases of flow: 39% in the period 1967 - 1984 and 67% in the period 2002 - 2017. A not very significant increase of flow occurs in the period 1984-2002 in the amount of 13%.

4.4. The RAPS method

Through the analysis using the linear and nonlinear regression methods, the polynomial model showed certain rising and falling oscillations of flow. The results were verified using the RAPS method. Mean annual flows for the period 1967 - 2017 were used for the analysis.

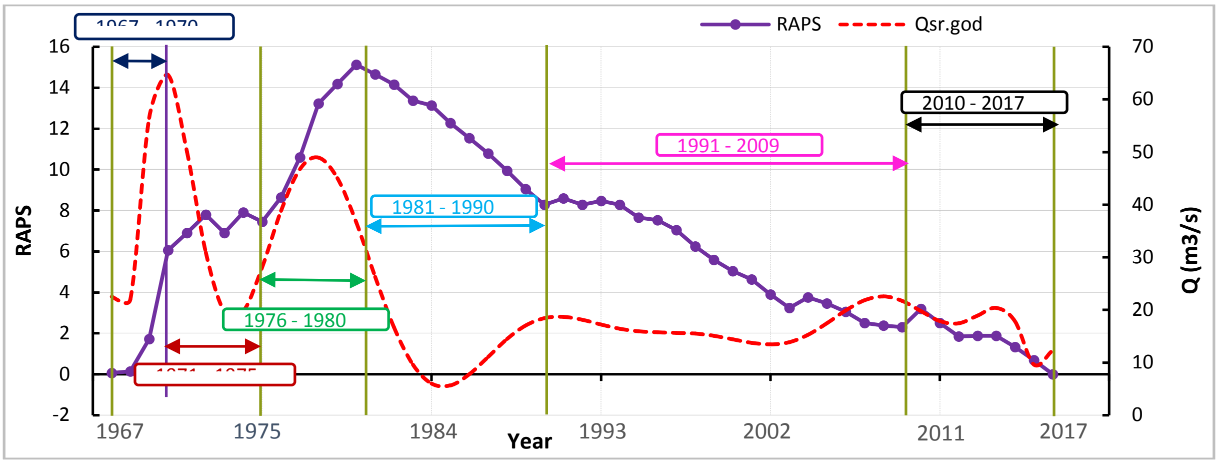

Figure 12. RAPS method for mean annual flows

The results of the method indicated certain subperiods of sudden flow changes and subperiods of similar characteristics. The obtained results are presented in Figure 12, with presented trend line for the polynomial model $Q_{mean/yr}$ (Figure 12). The results obtained in this way can be compared using the nonlinear regression method and RAPS method. The time series is divided into 6 subperiods in chronological order: 1967 - 1970; 1971 - 1975; 1976 - 1980; 1981 - 1990; 1991 - 2009; 2010 - 2017. Based on the division, it can be observed that the trend line of the polynomial model can be approximately described by the RAPS curve. The subperiods with falling trend line, or falling flows, are: 1967 – 1968; 1970 – 1974; 1978 – 1985; 1991 – 2002; 2008 – 2011; 2014 – 2016. The subperiods with rising trend line or rising flows are: 1968 – 1970; 1974 – 1978; 1985 – 1991; 2002 – 2008; 2011 – 2014; 2016 – 2017.

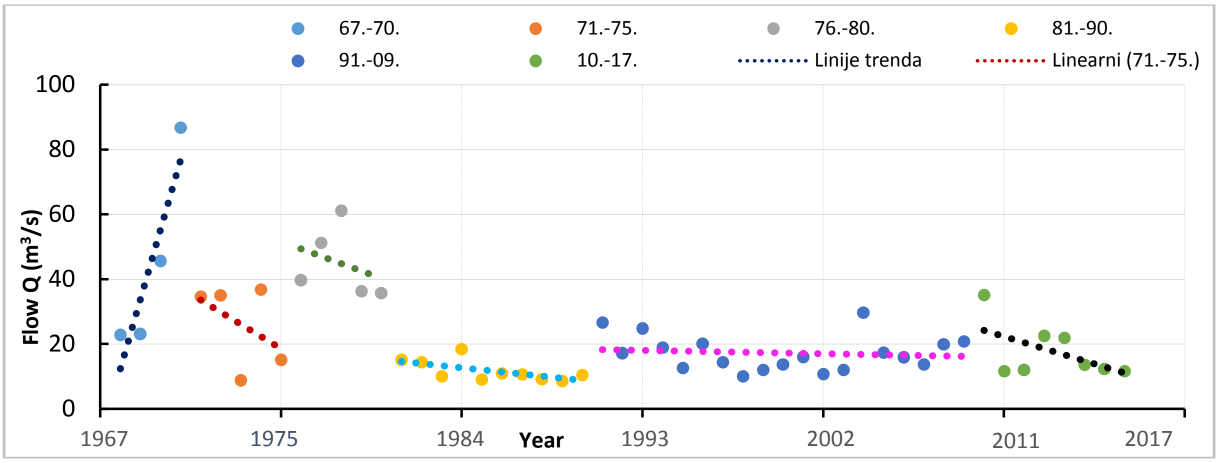

Figure 13. The linear model for seven subperiods for mean annual flows

In order to obtain a better insight into the data, a graphical view of linear regression model with the corresponding trend line was made for each subperiod (Figure 13). The model parameters and analysis results are also presented in table form (Table 6), from which it can be concluded that the linear model does not describe the data set for the following subperiods: 1971 - 1975; 1976 - 1980; 1991 - 2009; 2010 - 2017, i.e., the values of test statistics are lower than the limit value. For the subperiods: 1967 – 1970; 1981 – 1990, the model shows the presence of a trend.

Table 6. Linear model parameters for the seven periods, Tisne Stine 1

Year	Line equation	r	r^2	б	n	a			r		
						$\lvert z_n \rvert$		$Z_{(1-\alpha)/2}$	$\lvert z_n \rvert$		$Z_{(1-\alpha)/2}$
67-70	y = 21.45x - 9.05	0.92	0.85	14.47	4	3.31	>	1.96	3.31	>	1.96
71-75	y = - 3.74x + 52.3	0.45	0.20	13.56	5	0.87	<	1.96	0.87	<	1.96
76-80	y = - 2.72x + 72.1	0.33	0.11	12.03	5	0.60	<	1.96	0.60	<	1.96
81-90	y = - 0.65x + 24.54	0.62	0.38	2.68	10	2.22	>	1.96	2.22	<	1.96
91-09	y =- 0.11 x + 21.15	0.12	0.01	5.58	19	0.49	<	1.96	0.49	<	1.96
10-17	y =- 1.86 + 106.27	0.54	0.30	7.63	8	1.59	<	1.96	1.59	<	1.96

For the subperiod 1967 - 1970 the model shows a rise in flow of 86% and for the subperiod 1981 - 1990 a fall of 44%. Unfitness of the model for the subperiods 71 - 75; 76 - 78; 91 - 09 and 10 - 17 can be explained by the high variability of the small number of data. This resulted in a very low correlation coefficient and the model did not show the presence of a statistically significant trend.

The subperiod 1967 - 1970 gives a similar rise in flow as in the polynomial model. The subperiod of fall in flow 1981 - 1990 gives results different from the polynomial one. For the subperiod defined by the RAPS curve, the linear model shows a fall in flow while the polynomial model for the same subperiod includes both fall and rise.

5. Conclusion

In this paper, the objective was to present and compare the trend analysis results obtained by the selected methods. The conducted analysis of the three methods showed different but also similar results.

The first method, the Mann-Kendall trend test, based on the obtained results, showed stability of the rising trend for the observed period 1967 - 2017. The advantage of the test is that it takes into account the seasonal character of data, which considerably affects the trend analysis in the regression methods.

The next method, regression, provides a more detailed insight into flow behavior over the observed period. Linear models showed a falling trend of 67 %, which is contrary to the Mann-Kendall test. The obtained correlation coefficient is the lowest for the model of mean daily flows (r=0.158), while for mean monthly flows it is somewhat higher (r=0.212), and is the highest for mean annual flows (r=0.452). The polynomial model showed periods of alternating fall and rise of flow, which can be explained in two stages. The first stage covers the period up to 1980, during which the construction of HPP Zakučac was in progress, resulting in the occurrence of significantly higher flows. The second stage from 1980, when HPP was constructed, represents a period without significant changes in flow, which can be explained as a result of the commissioning of HPP

The RAPS method resulted in a view of subperiods as in the polynomial model for $Q_{mean/yr}$. Similarities in the behavior of the models are indicative of the accuracy of the conducted regression analysis, which resulted in a downward trend.

Considering that one of the models showed a falling trend, and the other showed a rising trend, one may point to the accuracy of the methods. The fact of falling trend, as a result of the regression method, can be explained as the consequence of the construction of HPP Zakučac. Still, a somewhat more precise trend analysis is shown by the Mann-Kendall test, which accounts for the seasonal character of data and correlates them, thereby providing more reliable results, while the regression one is based on the trend prediction with respect to the model that best describes the data, which often results in errors.

6. References

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