Application of revised innovative trend analysis in lower Drava River

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Received: 17 April 2021 / Accepted: 26 January 2022 / Published online: 11 April 2022
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Abstract
Changes in the streamflow pattern raise a plethora of implications on the morphological, economic, social, and cultural aspects of an entire river basin. Trend analysis of hydrological time series is the most common method to identify these changes. Several methods have been proposed to identify the trends in time series. In the present study, Mann–Kendall (MK), innovative trend analysis (ITA), and revised innovative trend analysis (RITA) were used to identify the trend in discharge and sediment load at two gauging sites of the lower Drava River Basin, during 1988–2017 with an objective to compare and understand the limitations of these methods. Innovative trend analysis provided greater visualization of the trend of different magnitude of discharges and sediment load as compared to Mann–Kendall test. However, it was observed that due to certain assumptions, ITA produced significant trends when the trends were insignificant. The significance of trends obtained from RITA was in close agreement with the Mann–Kendall test. In this regard, the method of determining the significance of trend in ITA needs to be rechecked and revised.

Keywords Trend analysis · Drava River · Mann–Kendall test · Innovative trend analysis

Introduction
River systems and their management have remained a challenging task especially in the present scenario when flow of river is highly influenced by climate change (Prudhomme and Davies 2009; Aiyelokun et al. 2021). Significant alteration in discharge and sediment load in various rivers has been observed all over the world (Millimen and Meade 1983; Milliman et al. 2008; Cong et al. 2009; Wilby 2005; Vansteenkiste et al. 2013; Juahir et al. 2010; Myronidis et al. 2018; Zakwan and Ara 2019; Zakwan 2018 and Abeysingha et al. 2020).

Alteration in flow regime of river directly affects the hydraulic and hydropower projects associated with the river. In this regard, numerous studies have been conducted to assess the trends in streamflow and sediment yield all over the world (Wilby 2005; Haktanir and Citakoglu 2015; Ragetti et al. 2016; Elouissi et al. 2017; Bhatta et al. 2019; Didovets et al. 2019; Benzater et al. 2019; Budhathoki et al. 2020; Fan et al. 2020).

Walling and Fang (2003) and Milliman et al. (2008) analyzed the sediment and discharge data, respectively, of over 100 streams from different regions of the world and observed that a significant trend exists in most of the cases. Rivers of central Japan experienced a significant decline in sediment load over last few decades; however, discharge did not exhibit any remarkable trend (Siakeu et al. 2004). On the other hand, Debar River Basin showed significant increase in flood flows over the years (Sharafati and Pezeshki 2020). Peng et al. (2020) reported a significant decline in sediment yield in Yangtze River Basin, China. Van Binh et al. (2020) observed a decline in sediment load in Vietnamese Mekong Delta resulting from anthropogenic reasons.

To identify the temporal variation in flow and sediment transport characteristics of river Mann–Kendall test has been widely used (Alley1988; Moraes et al. 1998; Aziz and Burn 2006; Hamed 2008; Zakwan and Ara 2019). In recent times,
innovative trend analysis has been proposed to analyze trend in hydrological time series (Şen 2012; Kisi and Ay 2014; Elouissi et al. 2016; Şen 2017; Khazaei et al. 2019; Wang et al. 2019 and Marak et al. 2020; Citakoglu and Minarecioglu 2021). Wang et al. (2019) reported that in many cases where insignificant trend was detected from Mann–Kendall test, but innovative trend analysis detected significant trend. However, Serinaldi et al. (2020) and Alashan (2020) asserted that the assumption of taking standard deviation of two parts of time series equal in innovative trend analysis may lead to incorrect identification of trends.

Mann–Kendall is the most widely used trend analysis method among the hydrologists, but this method lacks in providing any physical or visual understanding of trend. Although most of the scientist around the world agree that ITA provides better visualization of available trends, still some ambiguity exist around the significance of trend obtained through ITA (Zakwan and Ahmad 2021). In this regard, the objective of present study is twofold: (i) to realize the capabilities of innovative trend analysis and revised innovative trend analysis with respect to Mann–Kendall test and (ii) to identify the trends in discharge and sediment load in lower Drava River for the period 1988–2017. Drava River being extensively utilized for hydropower potential, any significant alteration in the flow or sediment transport characteristic of Drava River would influence the hydropower potential of the river. In this regard, it becomes imperative to analyze the trends in discharge and suspended sediment concentration. Further, the significance of trend in various hydrological variables calls for actions; therefore, discrepancy in the significance of trend obtained from different methods needs to be analyzed and compared; with this objective, the trend significance obtained from the three methods was compared.

**Materials and methods**

**Study area**

The Drava River flows through five countries (Italy, Austria, Slovenia, Croatia, Hungary). It is the fourth largest and longest tributary, which connects the Alps with the Danube and the Black Sea (Fig. 1) (Schwarz 2019). The Drava River is 749 km long, and the catchment area of the river basin is 41.238 km². In the Danube River, the hydrological

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**Fig. 1** Drava River Basin
and sedimentological regime is greatly affected by the Alps. Its hydrological regime is typical glacial with the highest water discharges in late spring and summer and lowest water levels during the winter period. In the recent period, deviations from these characteristics occurred because of climate changes. The Drava River Basin comprises the following three major geological units (Lóczy 2019): (1) the Austro alpine Nappe System; (2) the South alpine Nappe System; and (3) the south western margin of the Pannonian (Carpathian) Basin (ICPDR 2021).

The upper part of the river course (about 424 km long) is heavily regulated. The regulation of the Drava River and canalization were increased paying attention from the beginning of the nineteenth century to the middle of the twentieth century. Because of this reason, its ecological status has deteriorated. There are 23 dams and reservoirs with hydropower plants on the Drava River.

Several catastrophic floods have occurred in 1925, 1965, 1966, and 1972 during the last 100 years. The 435 km of dykes was the result of the reconstructed and improved facility for flood protection. The lower part of the river course (about 325 km long) hosts some of the last free-flowing river sections in Europe. The highly endangered part of the lower Drava River is the most downstream section (about 20 km upstream from the mouth in the Danube River), which is influenced by the Danube River (Tadić and Brleković 2019).

The lower part of the Drava River watercourse downstream, from the Mura River firth to the Donji Miholjac city, is a border river between Hungary and Croatia. The Drava River Basin in Croatia covers 7015 km², which is 12% of the Croatian territory. Channel morphology and typology of the Drava River are characterized with straight type in the upstream part until the mouth of the Mura River. Downstream of the Mura River confluence is characterized by the transitional braided and the meandering type. Regarding the land cover/land use, the basin is covered by (1) forests (45.8%); (2) agriculture fields (28.7%); (3) natural grasslands (9.0%); and (4) sparse vegetation (3.9%).

The Drava River and Pannonian Basin have been altered by various anthropogenic activities, especially during the last about 200 years (Fig. 2) (Croatian Hydrocarbon Agency 2021). In the natural state, the lowland Drava River was full of meanders, which supported natural processes of sediment erosion and deposition. Since the mid-nineteenth century, the massive engineering works continuously affected the Drava and Mura rivers. At the same

![Fig. 2 Location of the Pannonian Basin](https://www.azu.hr/en/exploration-and-production/geological-overview-onshore/)
time, the Drava River course had been used for massive gravel and sand sediment excavation. The massive gravel and sand sediment intensified in recent time.

The response of the river on the natural changes as well as direct and indirect human impacts varies, along the different reaches of the river, depending on the geological setting, equilibrium state, and sensitivity of the reach. The most important direct human impacts on the lower Drava River watercourse are (1) artificial cut-offs; (2) construction of groins; and (3) construction of dams and reservoirs. The artificial cut-offs on the Drava River had increased its slope, which resulted in channel deepening and destabilization of the river banks (Schwarz 2019; Tadić and Brleković 2019).

The greatest disturbance on the hydrology and morphology of the Drava was caused by dams and reservoirs built since the beginning of the twentieth century. The last and the most downstream hydropower plant Dubrava in Croatia started in operation in 1989. As it operates in peak hours, due to this fact, the downstream water level changes about 1.5 m during a day and results in the mini flood-waves which will get lower towards downstream.

Any river and its environment are deeply interconnected. In this process, sediment transport plays a crucial role. Sediment transport along the course of the river is one of the serious problems of water management and basin environmental sustainability. Suspended sediment contains inorganic soil particles, foods, habitats, organic materials, microorganisms, seeds, eggs, and contaminants that will be transported throughout the river (Droppo 2001).

The lower Drava has been regulated with embankments and channels (Bonacci and Oskoruš 2010; 2019). There are great environmental values with unique assemblages of flora and fauna and several endemic species in the middle and lower of the basin in spite of these changes in flow regulation. In this study, the lower Drava River section two gauging stations (Botovo and Donji Miholjac) were analyzed (Fig. 3). Their data are provided by the Croatian Meteorological and Hydrological Service. The Botovo and Donji Miholjac profiles are located 28 km and 178 km downstream from the Dubrava dam. Their main characteristics are given in Table 1. The difference of mean annual discharges between the two stations was small since there were no large tributaries between Botovo and Donji Miholjac.

The hydrological and channel parameters of the lower Drava River change continuously that influence the environmental and social processes in the whole lower Drava River Basin. It needs to know that the lower Drava River is far-from-equilibrium state, which can be triggered for many different problems.

It is an urgent requirement of observing and evaluating the long-term effects of hydropower plants and interrupted sediment continuum as well as the changing hydrographical conditions for flood and river management.

In the present study, trend analysis of long-term discharge and suspended sediment concentration has been performed at Botovo and Donji Miholjac gauging sites of Drava River. Suspended sediment concentration data was used over the suspended sediment load data to minimize the impact of trend in discharge as suspended sediment load is itself a product of suspended sediment concentration and discharge. Before performing the trend test, all the data set were subjected to Von-Neumann (VN) independence, Wald-Wolfowitz’s (WW) stationarity, and Mann–Whitney’s (MW) homogeneity test.

Von-Neumann (VN) test

Von-Neumann (VN) test statistics can be determined as (Hakタンir and Citakoglu 2014):

\[
Q = \frac{1}{n} \sum_{i=1}^{n-1} (x_{i+1} - x_i)^2
\]

(1)

where \(x_i\) is the \(i\)th observation and \(\bar{x}\) is the average of the series. The test statistic is compared with the standard values for given confidence level to declare the independence of data.

Wald-Wolfowitz’s (WW) stationarity test

Wald-Wolfowitz’s (WW) stationarity test statistics can be determined as follows (Rao and Hamed 2019):

\[
R = \sum_{i=1}^{n-1} x_i x_{i+1} + x_1 x_n
\]

(2)

\[
\text{var}(R) = \frac{(s_2^2 - s_4)}{n - 1} - \frac{1}{R^2} + \frac{(s_4^4 - 4s_2^2s_2 + 4s_2s_4 + s_2^2 - 2s_4)}{(n - 1)(n - 2)}
\]

(3)

\[
u = \frac{(R - \bar{R})}{\text{var}(R)^{0.5}}
\]

(4)

\(s_{2r} = mn_r\) where \(m_r\) is the \(r\)th moment about origin.

The \(u\) statistics is compared with the standard values for given confidence level to assure stationarity of data.

Mann–Whitney’s (MW) homogeneity test

Mann–Whitney’s statistics is utilized to assure that all the data in time series follow single probability distribution.
Initially, the data is divided into two equal halves such that $p \leq q$ ($p + q = n$), then the actual data set is ranked in ascending order, and finally sum of the ranks ($R_1$ and $R_2$) for the two halves is calculated (Rao and Hamed 2019). Thereafter compare minimum of the following statistics with the standard table for given confidence level to determine homogeneity of data.

$$U_1 = pq + 0.5p(p + 1) - R_1$$  \hspace{1cm} (5)$$

$$U_2 = pq + 0.5q(q + 1) - R_2$$  \hspace{1cm} (6)$$

Table 1 Main characteristics of the two analysed gauging stations from the years 1988–2017

| Station       | Basin (km²) | Elevation (m.a.s.l.) | Coordinates                  | $Q_{\text{average}}$ (m³/s) |
|---------------|-------------|----------------------|------------------------------|-----------------------------|
| Botovo        | 31,038      | 121.55               | 46° 14′ 33.2″ N 16° 56′ 25.1″ E | 510                         |
| Donji Miholjac| 37,142      | 88.57                | 45° 46′ 29.1″ N 18° 10′ 20.8″ E | 537                         |

Fig. 3 Location of the gauging stations Botovo and Donji Miholjac
$R_1$ is the sum of rank of first half and $R_2$ is the sum of rank of second half.

The trend analysis was performed using Mann–Kendall, Innovative trend test, and modified Innovative trend test.

**Mann–Kendall test**

Mann–Kendall test (Mann 1945 and Kendall 1975) is a statistical test widely used for the analysis of time series. The null hypothesis $H_0$ assumes that there is no trend, and this is tested against the alternative hypothesis $H_1$, which assumes that there is a trend. For $x_i$ and $x_j$ as two subsets of data where $i = 1, 2, 3, \ldots, n-1$ and $j = i + 1, i + 2, i + 3, \ldots, n$,

The Mann–Kendall $S$ Statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i)$$  \hspace{1cm} (7)

The variance ($\sigma^2$) for the $S$-statistic is defined by:

$$\sigma^2 = \frac{[n(n-1)(2n+5)]}{18}$$  \hspace{1cm} (9)

The standard test statistic $Z_s$ is calculated as follows:

$$Z_s = \frac{S-1}{\sigma} \text{ for } S > 0$$

$$Z_s = \frac{0}{\sigma} \text{ for } S = 0$$

$$Z_s = \frac{S+1}{\sigma} \text{ for } S < 0$$  \hspace{1cm} (10)

If $|Z_s|$ is greater than $Z_{\alpha/2}$, where $\alpha$ represents the chosen significance level (5% with $Z_{0.025} = 1.96$) then the null hypothesis is invalid implying that the trend is significant.

Depending on the autocorrelation, autocorrelation correction may be required before applying the Mann–Kendall test. So, the limits of autocorrelation of all the time series were checked at defined significance level according to the formula (Yue et al. 2002):

$$\frac{-1 - f(c) \sqrt{n - 2}}{n - 1} \leq r \leq \frac{-1 + f(c) \sqrt{n - 2}}{n - 1}$$  \hspace{1cm} (11)

where $r$ is lag-1 correlation and $f(c)$ is function of confidence probability.

**Innovative trend analysis (ITA)**

Şen (2012) proposed the innovative trend analysis; in this trend analysis method, available time series is divided into two equal halves. The average of both the time series is calculated as $\bar{Y}_1$ and $\bar{Y}_2$. The two parts of the time series are then arranged in ascending order. Later a plot is prepared with first half of time series $x$-axis and second half series on $y$-axis as shown in Fig. 2. Relative position of scatter point with respect to trendless (1:1) line demarcates the trend as shown in Fig. 4. The points above and below the trendless line indicate increasing and decreasing trend, respectively, while the points lying on the 1:1 line represent no trend. The major advantage of this plot is that from a single plot one can understand the trends of low magnitude, moderate magnitude, and high magnitude events. For instance, Fig. 4 shows that low magnitude events are trendless, while the moderate magnitude falls below the trendless line and represents decline in magnitude of moderate magnitude events. However, the significance of trend cannot be determined from the plot and can only be determined based on confidence limit.

The magnitude of trend may be calculated as:

$$s = \frac{2(\bar{Y}_2 - \bar{Y}_1)}{n}$$  \hspace{1cm} (12)

Critical trend ($Z_s$) can be calculated as:

$$Z_s = \frac{s}{\sigma_s}$$  \hspace{1cm} (13)

$$\sigma_s = \text{standard deviation of trend values.}$$

$$\sigma_s = \frac{8\sigma^2(1 - \rho_{Y_2,Y_1})}{n^3}$$  \hspace{1cm} (14)

where $\rho_{Y_2,Y_1} = \text{cross correlation coefficient of averages of two halves given by:}$

$$\rho_{Y_2,Y_1} = \frac{E(\bar{X}\bar{Y}) - E(X)E(Y)}{\sigma_x\sigma_y}$$  \hspace{1cm} (15)

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**Fig. 4** Graphical representation of innovative trend analysis (Zakwan and Ahmad 2021)
Revised innovative trend analysis

In the recent past several researchers, including Wang et al. (2019), Serinaldi et al. (2020), and Alashan (2020) observed that due to assumption of equal variance of two half of the series ($\sigma_x = \sigma_y$) in ITA, significant trends were identified while the trends were actually insignificant. In this regard, the confidence interval of innovative trend analysis was modified by removing the equity condition of the variance of two half of the series. So, the Eq. (13) is modified as:

$$\sigma_x^2 = \frac{4(\sigma_x + \sigma_y - 2\rho_{xy})}{n^2} \quad (16)$$

Thereafter, the modified confidence limit is calculated according to the Eq. (13).

Results and discussion

On testing the time series data, it is observed that more than about 98%, 88%, and 93% of the time series were homogeneous, stationary, and independent as shown in Table 2.

Table 3 represents the trend analysis of minimum, maximum, average discharge, and average sediment load of two gauging sites in the lower Drava River Basin. Table 3 also represents the significance of trend. Tables 4 and 5 represent the trends of monthly sediment load and discharge at Botovo and Donji Miholjac, respectively.

A perusal of Table 3 reveals that minimum, maximum, and average discharge at both the gauging sites are insignificant according to Mann–Kendall test and revised innovative trend test. Similarly, average sediment load at both sites represents insignificant trends. However, ITA represents significant trend in average discharge at both the gauging sites and annual average sediment load at Botovo. The insignificance of trends of minimum and maximum discharge indicates that the magnitude of extreme events (floods and droughts) has not altered significantly in the region unlike many rivers in the world which are experiencing significant increase in the magnitude and frequency of extreme events. Figure 5 represent the trends in maximum and minimum discharges at Botovo and Donji Miholjac according to ITA. The ITA plot for maximum discharge at Botovo represents that most of the points plot below 45º line indicating a decline in maximum discharge which is also reflected by negative trend obtained for Botovo through ITA (refer to Table 3). The maximum discharge trend plot at Donji Miholjac, shows points both above and below the trendless line; however, the difference in slope of two series indicates insignificant negative trend. On the other hand for minimum discharge plot, most of the points plot above the 45º line, indicating an increase in minimum discharge at both the gauging sites which is also reflected in terms of positive trend obtained through ITA (refer to Table 3).

The need for applying modified Mann–Kendall test arises if the autocorrelation of the time series is not within suggested limits (Salas et al. 1980; Hamed and Rao 1998; Yue et al. 2002). It was observed that autocorrelation for all the time series except sediment load time series for February at Donji Miholjac was within the prescribed limits. So, the modified Mann–Kendall test was not performed for these time series. Moreover, when sediment load time series for February at Donji Miholjac was subjected to modified Mann–Kendall test, its trend remained insignificant just like the results of Mann–Kendall test.

According to Mann–Kendall test and revised innovative trend test, monthly discharges and sediment load at Botovo represent insignificant trend at 95% confidence level as shown in Table 4. Similarly, at Donji Miholjac (Table 5), according to Mann–Kendall test and revised innovative trend, no significant trend exists, but ITA represents several significant trends. Şen (2012) claimed that power of Mann–Kendall is low and it fails to recognize several trends that are significant and proposed the application of ITA method for trend analysis. However, as suggested by Wang et al. (2019) and Alashan (2020), the presence of high Type I in ITA leads to misinterpretation of significance of trends. Variance equity ($\sigma_x = \sigma_y$) was recognized as one of the major reasons for it. On the other hand, when variance equity condition was aborted from the test (RITA), the power of the test to recognize the trend reduced considerably. For example, in September month, the trend of sediment load at Botovo is significant at 1% significance level according to Mann–Kendall test, but, according to RITA, it is insignificant. Similarly, according to Mann–Kendall test, sediment load of January and discharge of February at Donji Miholjac are significant at 1% significance level, but according to RITA, the trends are insignificant.

Earlier, Zhu et al. (2019) identified 1981 as the change point in discharge and sediment load mainly due to development of hydropower plants. No new hydropower plants came in operation since 1989, and much variation in sediment and flow was observed in this period. Tamás (2019) also pointed towards the role of hydropower projects in the variation of sediment load at Botovo and Donji Miholjac. Bonacci and Oskoruš (2010) also reported a significant decline in water level, sediment load, and discharge in late nineteenth century resulting from construction of reservoirs in Drava River Basin. As already mentioned during the study period (1987–2017), no major hydraulic construction has taken place on the river, and as such no major alteration has in hydrological characteristics has been observed, hinting
| Data        | Botovo          |                     | Donji Miholjac       |                     |
|-------------|-----------------|---------------------|----------------------|---------------------|
|             | Discharge       | Sediment load       | Discharge            | Sediment load       |
|             | V–N (independent) | WW (stationary) | M-W (homogeneous) | V–N (independent) | WW (stationary) | M-W (homogeneous) |
| January     | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| February    | Yes             | No                  | Yes                  | No                 | Yes            |
| March       | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| April       | Yes             | No                  | Yes                  | Yes                | Yes            |
| May         | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| June        | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| July        | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| August      | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| September   | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| October     | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| November    | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| December    | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| Annual Avg  | Yes             | Yes                 | Yes                  | Yes                | Yes            |
| Annual Min  | Yes             | No                  | -                    | Yes                | Yes            |
| Annual Max  | Yes             | Yes                 | -                    | Yes                | Yes            |
Table 3  Trends of discharge and sediment load at Botovo and Donji Miholjac

| Gauging sites | Quantity                  | Trend | Significance |
|---------------|---------------------------|-------|--------------|
|               |                           | MK    | ITA | RITA | MK | ITA | RITA | MK | ITA | RITA |
| Botovo        | Annual maximum discharge  | −0.11 | −3.83| −3.83 | No | No | No   |
|               | Annual minimum discharge  | 0.27  | 1.87 | 1.87  | No | No | No   |
|               | Average annual discharge  | 0.32  | 0.88 | 0.88  | No | Yes| No   |
|               | Average annual sediment load | 0.39 | 6.57 | 6.57  | No | Yes| No   |
| Donji Miholjac| Annual maximum discharge  | −0.41 | −1.40| −1.40 | No | No | No   |
|               | Annual minimum discharge  | 1.38  | 1.47 | 1.47  | No | No | No   |
|               | Average annual discharge  | 0.07  | 0.33 | 0.33  | No | Yes| No   |
|               | Average annual sediment load | −0.07 | −5.04| −5.04 | No | No | No   |

Table 4  Trends of monthly discharge and sediment load at Botovo

| Month       | Discharge | Significance | Sediment load | Significance |
|-------------|-----------|--------------|---------------|--------------|
|             | Trend     | MK | ITA | RITA | Trend | MK | ITA | RITA | MK | ITA | RITA |
| January     | 0.29      | 0.08 | 0.08 | No | No | No   | 0.21 | −0.27 | −0.27 | No | No | No   |
| February    | 1.46      | 4.78 | 4.78 | No | Yes| No   | 1.25 | 19.76 | 19.76 | No | Yes| No   |
| March       | 1.36      | 4.71 | 4.71 | No | Yes| No   | 0.82 | 8.45  | 8.45  | No | No | No   |
| April       | 0.00      | 2.27 | 2.27 | No | Yes| No   | −0.18| −2.07 | −2.07 | No | No | No   |
| May         | −0.07     | −0.08| −0.08| No | No | No   | 0.07 | 14.53 | 14.53 | No | No | No   |
| June        | −0.25     | 1.19 | 1.19 | No | Yes| No   | −0.46| 8.68  | 8.68  | No | No | No   |
| July        | −1.21     | −3.25| −3.25| No | Yes| No   | −0.50| −5.54 | −5.54 | No | No | No   |
| August      | 1.68      | 2.04 | 2.04 | No | Yes| No   | 0.79 | 19.48 | 19.48 | No | No | No   |
| September   | 1.43      | 5.38 | 5.38 | No | Yes| No   | 1.78 | 34.40 | 34.40 | No | Yes| No   |
| October     | −0.11     | −4.15| −4.15| No | Yes| No   | −0.18| −10.10 | −10.10| No | No | No   |
| November    | 0.64      | −1.63| −1.63| No | No | No   | 0.00 | −0.63 | −0.63 | No | No | No   |
| December    | 0.39      | −0.81| −0.81| No | No | No   | 0.32 | 2.19  | 2.19  | No | No | No   |

Table 5  Trends of monthly discharge and sediment load at Donji Miholjac

| Month       | Discharge | Significance | Sediment load | Significance |
|-------------|-----------|--------------|---------------|--------------|
|             | Trend     | MK | ITA | RITA | Trend | MK | ITA | RITA | MK | ITA | RITA |
| January     | 0.43      | −1.34| −1.34| No | Yes| No   | −1.82| −12.57 | −12.57| No | Yes| No   |
| February    | 1.82      | 4.25 | 4.25 | No | No | No   | −0.11| 5.95   | 5.95 | No | Yes| No   |
| March       | 1.43      | 4.86 | 4.86 | No | Yes| No   | −0.96| −4.66  | −4.66 | No | Yes| No   |
| April       | −0.14     | 2.34 | 2.34 | No | No | No   | −1.57| −20.08 | −20.08| No | Yes| No   |
| May         | −0.14     | −0.55| −0.55| No | No | No   | 0.32 | −10.82 | −10.82| No | Yes| No   |
| June        | 0.00      | 1.11 | 1.11 | No | No | No   | −0.04| 1.56   | 1.56 | No | No | No   |
| July        | −1.43     | −3.26| −3.26| No | No | No   | −1.43| −13.47 | −13.47| No | Yes| No   |
| August      | 1.11      | 1.35 | 1.35 | No | Yes| No   | 0.79 | 18.62 | 18.62 | No | Yes| No   |
| September   | 1.00      | 4.75 | 4.75 | No | Yes| No   | 0.96 | 10.14 | 10.14 | No | Yes| No   |
| October     | −0.14     | −4.68| −4.68| No | Yes| No   | −0.64| 17.24  | 17.24 | No | Yes| No   |
| November    | 0.36      | −2.23| −2.23| No | No | No   | 0.04 | −16.15 | −16.15| No | Yes| No   |
| December    | 0.11      | −2.68| −2.68| No | No | No   | −1.03| −1.72  | −1.72 | No | No | No   |
Conclusion

Temporal variation in discharge and suspended sediment load was assessed using Mann–Kendall, innovative trend test, and revised innovative trend test at two gauging sites, Botovo and Donji Miholjac, of Drava River for the period 1988–2017. Almost all the time series used in the present study were found to be independent, homogenous, and stationary. It was observed that during this period, there has been no significant alteration in flow and suspended sediment load at annual as well as monthly level in the lower Drava River Basin. Results of trend analysis would be useful in forecasting the hydrological characteristics which can be used as an input to determine reservoir sedimentation and water availability in the region. The trends in annual maximum discharge and annual minimum discharge were insignificant at both the gauging sites indicating frequency of extreme events is not increasing in the region. The Drava River Basin is one of the most hydraulically exploited basins of the world which has experienced lot of alteration in its hydrological characteristics leading to continual decline in discharge and sediment load in the past. The last major hydraulic construction in the region was during the late 1980s, since that no major hydraulic construction has taken place on the river and as such no major alteration has in hydrological characteristics has been observed, hinting towards the strong impact of hydraulic construction on the lower Drava River Basin.

ITA plots provided an additional benefit of visual display of trend in comparison to traditional Mann–Kendall test; however, ITA plots are not sufficient to determine the significance of trend and the significance of trend cannot be assured by mere visualization of plot until determined mathematically. While the trends obtained by Mann–Kendall and RITA were insignificant at 95% significance level, in some cases, ITA represented significant trend which may be mainly attributed to the assumption of variance equity condition in ITA. Removal of variance equity condition of ITA as done in RITA reduced the power of ITA considerably as a result the trends that were significant at 1% significance level in accordance with Mann–Kendall test were found insignificant in accordance with RITA. In this regard, the assumption of variance equity in ITA needs to be rechecked after applying to more data sets in future studies so that the additional benefit of visual availability of trends can be utilized with greater confidence and reliability.

Author contribution Mohammad Zakwan: Project administration, Conceptualization, Writing-original draft, Software, Formal analysis.
Visualization. Quoc Bao Pham: Formal analysis, Visualization. Data curation, Writing, Review and editing, Supervision. Ognjen Bonacci: Writing, Review, Editing. Bojan Đurin: Review, Editing, Writing.

Data availability The data that support the findings of this study are available from the corresponding author, [Quoc Bao Pham, quoc_bao.pham@us.edu.pl], upon reasonable request.

 Declarations

 Ethics approval Not applicable.
 Consent to participate Not applicable.
 Consent to publish Not applicable.

 Competing interests The authors declare no competing interests.

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