Anomalies and trends of high river flow under temperate climatic conditions in north-eastern Romania

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ABSTRACT

Regional water resource management plans include various scenarios related to the anomalies and trends of hydro-climatic parameters. Two methods are used for the identification of the anomalies and trends associated with high flow (annual and seasonal) of the rivers in Eastern Romania, namely the quantile perturbation method (QPM) and the partial trend method (PMT). These methods were selected due to the fact that they are suitable for data sets which do not rely on restrictive statistical assumption as common parametric and nonparametric trend tests do. For six of the nine stations analyzed, the decreasing trend in high extremes for annual high flow based on the PTM is the same as the annual trend obtained with the QPM. Using the PI index (associated with PTM) for the estimation of trend intensity, values between \(-2.280\) and \(-9.015\) m\(^3\)/s were calculated for the decreasing trend of the annual high flow and between \(+1.633\) m\(^3\)/s (in autumn) and \(-9.940\) m\(^3\)/s (in summer) for the seasonal high flow. The results obtained on the anomalies and trends of high river flow may represent a starting point in the analysis of the evolution of water resources and their effective management.

Key words | anomalies, Eastern Romania, high flow quantile perturbation method, magnitudes, partial trend method, trends

INTRODUCTION

The identification of the anomalies and trends in the temporal variations of water elements becomes increasingly relevant, given the growing global effects of climate change. Modifications occurring at the hydro-climatic level can trigger significant changes in hydrological parameters, which later reflect in the evolution of water resources and social development at a regional level (Chen et al. 2006; Wei et al. 2018). In this context, research has been carried out on anomalies of the extreme values of atmospheric precipitation (Tabari & Hosseinizadeh Talaei 2011; Hu et al. 2012; Kassian et al. 2016; Wu et al. 2018) and river flow (Tabari et al. 2017). The statistical methods used most frequently in the determination of trends are the Mann-Kendall test, Sen’s slope linear regression (Bürger 2017) or Monte Carlo method (Yang et al. 2017). Trend identification is generally carried out based on mean and extreme seasonal and annual value sets for climatic and hydrological parameters. These methods were used to analyze the response to climate change of meteorological (Djebou & Singh 2016; Shrestha et al. 2017) or hydrological parameters (Feng et al. 2011; Taye et al. 2015; Molina & Zazo 2017) or to assess the impact on underground water resources (Taylor et al. 2012; Pathak & Dodamani 2019). Recent scientific research suggests new statistical approaches (Willems 2013) and graphs (Kisi & Ay 2014) for the identification of anomalies in relation to past events (mean and extreme), such as the quantile perturbation method (QPM) and trend-based ones, such as the partial trend method (PMT).
The QPM was used to identify the anomalies of hydro-meteorological extremes (Nyeko-Ogiramoi et al. 2015), while the PTM, developed by Şen (2012), suggests the graphic and statistical identification of trends and has also been widely used (Sonali & Nagesh-Kumar 2013). Previous studies carried out on north-eastern part of Romania have estimated the general trends of various hydro-climatic parameters using statistical approaches based on the Mann-Kendall test and Sen’s slope linear regression (Dumitrescu et al. 2015; Croitoru et al. 2018). The region has witnessed significant changes in climatic (Croitoru et al. 2016; Prăvălie et al. 2018), hydrological (Bîrsan et al. 2014) and hydrogeological parameters (Minea & Croitoru 2015, 2017a) as a result of regional climate changes.

To continue and complete this research direction, in the present study, the two aforementioned graphical methods were selected (QPM and PTM) due to their suitability for data sets that do not rely on the restrictive statistical assumption, as in the case of common parametric and non-parametric trend tests. The main objective of the study is, therefore, the application of the methods in question so as to identify the anomalies and trends of high river flow under temperate-continental climatic conditions, which, in turn, is a starting point in the analysis of the evolution of water resources and their effective management.

### DATA AND METHODS

#### Study area

The identification of anomalies in groundwater level variation was based on data from nine hydrometric stations in Eastern Romania (Figure 1). The region analyzed, covering an area of over 20,000 km², is characterized by a temperate-continental climate, with maximum temperature and precipitation values in summer (June and July, respectively), and minimum values recorded during the winter season (in February).

The mean annual temperature increases from 7–8 °C, in the north, to 9–10 °C, in the south. The annual amount of precipitation decreases from 620 mm in the north to 480 mm in the south. In winter, precipitation is mainly solid and most of it is preserved as snow cover until spring because of frequent negative temperatures, which vary from −4 to −6 °C, in the north, to −2 to −3 °C, in the south (Sandu et al. 2008). The statistical analyses carried out on data sets regarding seasonal and annual mean temperatures have indicated positive trends for temperature and precipitation in spring and autumn, and decreasing precipitation levels during winter (Croitoru & Minea 2015).

#### Data

The statistical analyses were conducted on five data sets with high flow values (four seasonal and one annual) for each hydrometric station employed. All the hydrological data sets were derived from monthly high river flow values. The main criterion employed in the selection of hydrometric stations was their location within the hydrographic basins. Stations located in the upper basin were generally chosen, given the reduced anthropogenic influence, so as to better highlight the natural features of the rivers in question. Seven of the nine hydrometric stations selected do meet this criterion. For the remaining two stations (Barlad and Oancea), located within lower basins, the monthly high flow values reconstituted for the natural flow regime of the rivers Barlad and Prut, respectively, provided by the Prut-Siret branch of the Romanian Waters Administration, were used. The detection of anomalies and trends was carried out only on the series with no gap in data sets over the 1955–2010 period.

#### Methods

##### Quantile perturbation method

This method highlights changes in quantiles at the level of temporal subseries compared to the entire time span analyzed. The QPM was applied to monthly high river flows and the three largest high flow values for each season and year were considered the threshold in the present study (Onyutha & Willems 2015). The first important step in the analysis of anomalies through the QPM lies in the selection of an appropriate subseries. Given the length of the data string (56 years) and the analyses performed on the same type of hydrological parameters, 10 years for the moving window were chosen (Tabari et al. 2017). This moving
Figure 1 | Study region and position of hydrological gauging stations.
window was glided 1 year further starting with the first value from the data string.

A confidence threshold of 95% was established using the nonparametric bootstrap method based on the full series of data (Ntegeka & Willems 2008).

Given that the analyses are based on temporal data subseries, the following work hypotheses must be taken into account (Willems 2015): (i) If the interval between two consecutive oscillations identified (either minimum or maximum) is greater than the length of the subseries analyzed, the previous one is considered independent; (ii) If anomalies above or below a certain threshold occurred; and (iii) If maximum and minimum oscillations of anomalies are recorded within the same time span at several neighboring hydrometric stations, the previous one is regarded as significant. The results were illustrated on the same graph so as to allow the identification of intervals with significant anomalies.

**Partial trend method**

This method can be applied to various extreme values of hydro-climatic parameters, given that the former display significant serial correlations at least in the case of short-memory basins (Sen 2017). Its application is facilitated by the fact that the comparative analysis of data series (high or low extremes) can be carried out without statistical assumptions (Dabanli et al. 2016).

The first stage of the PTM involves the separation of the data string into two equal subseries in ascending order. Within the second stage, the series are plotted into a two-dimensional Cartesian coordinate system as scatter points and compared against the 1:1 line (median line). The points that are located above the median line on this graphic representation constitute increasing trends, while those located below represent decreasing trends. If the points are concentrated along the median line, they do not indicate any trend. Sen (2017) suggests the following formula for calculating the slope of a trend:

\[ s = \frac{2(\bar{y}_2 - \bar{y}_1)}{n} \]

where \( s \) is the slope of the trend, \( \bar{y}_1, \bar{y}_2 \) are the averages of the first and second series, and \( n \) is the total number of data.

To apply this method, the confidence limit (CL\( \sigma_s \)) of the trend slope must be taken into account. This can be expressed with the formula:

\[ CL\sigma_s = \bar{X}\sigma_s \pm \sigma_{\sigma_{os}} \] \( \sqrt{n_{os}} \)

where \( \bar{X}\sigma_s \) is mean of \( \sigma_s \) series, \( \alpha \) is the value for confidence level, \( \sigma_{\sigma_{os}} \) is the standard deviation of the slope standard deviation values, and \( n_{os} \) is the number of standard deviation slopes values obtained. For this study, the statistical significance level for \( \alpha \) was selected at 5% (Figure 2). When slope values fall outside the lower and upper confidence limit, the alternative hypothesis is adopted. On this assumption, we can consider that it is a trend in analyzed data (Yes in Table 2). The type of trend is given by the slope sign, if it is negative, the type of trend is decreasing; if it is positive, the type of trend is increasing and if the slope is equal with 0, there is no trend.

On a similar note, Wu & Qian (2017) suggest an index (PI) for the estimation of overall trend magnitude:

\[ PI = \frac{1}{n} \sum_{i=1}^{n} 10 \left( \frac{y_i - \bar{x}}{\bar{x}} \right) \]

where PI refers to overall trend magnitude, \( x_i \) is the \( i \)th value of the first-ordered subseries, \( y_i \) is the \( i \)th value of the second-ordered subseries, and \( \bar{x} \) is the average of \( x_i \).

In the present study, trend analysis for the 1955–2010 interval was based on the extraction of two subseries with data spanning 28 years each, namely 1955–1982 and 1983–2010. Dividing the data into two subseries allows us to evaluate the changes for the entire data series not only focus on the extreme quantiles.

**RESULTS AND DISCUSSION**

Trend dynamics at the level of annual series (Figure 3) emphasizes a consistent decreasing trend for most stations starting with the mid-1970s. This significant negative anomaly, with an anomaly factor between 1.2 and 1.6, was recorded at five stations. The constant decreasing trend after the mid-1970s, for six of the nine stations analyzed,
can be associated with a reduction of the volume of precipitation identified for this region by Tomozeiu et al. (2000) between 1975 and 1995.

Two of the hydrometric stations (Manoleasa and Bacesti) exhibited an increase in anomaly trend between 1983 and 1995, and only one station (Iasi) is characterized by a significant positive anomaly trend in recent years. The maximum statistically significant positive anomaly has an anomaly factor of 2.91 and was recorded at the Bacesti station in 1977, while the maximum statistically significant negative anomaly value is 0.31 and was recorded at the Codaesti station in 2007, as a result of the severe drought of 2000 and 2007 (Minea & Croitoru 2017b). The strongest positive anomalies were recorded at Codaesti, and the strongest negative anomalies were noted at Nicolae Balcescu.

The dynamics of anomalies for the seasonal series displays the same oscillations as in the case of the annual series for five of the nine stations analyzed. As expected, the statistically significant positive seasonal values are far higher than the annual ones, reaching an anomaly factor of 4.94 at the Nicolae Balcescu station in the summer of 1977 or 4.84 at Codaesti in the summer of 1978. The statistically significant negative seasonal values registered drop to an anomaly factor of 0.15 at the Nicolae Balcescu and Codaesti stations in the winter of 1995.
An oscillatory-type pattern during the winter season was noticed at all nine stations, with different anomaly amplitudes. This model, that was observed for the winter season, highlights the oscillatory dynamics of the volume of water from rainfall with an important impact in water management (Zelenáková et al. 2017a). The period before 1975 was marked by negative anomalies. Between 1975 and 1990 there were high positive anomalies, followed between 1990 and 1995 by a period with very low negative anomalies (Figure 4). From 1995
to 2005, another period with positive anomalies was noted, which continued until recently in the case of only four stations (Nicolae Balcescu, Targu Frumos, Iasi and Codaesti).

Between 1970 and 1980, positive anomalies were registered at all hydrometric stations during spring, when the hydrological regime of rivers is influenced by the melting of the snow layer (Apostol & Sfica 2013). For the stations...
located in the northern part of the region (Dorohoi and Manoleasa), the positive anomalies extend into the early 1990s. Most stations display a decreasing trend for anomalies throughout recent decades, with the exception of Oancea, where positive anomalies were registered between 1990 and 2006.

For six of the nine stations in question, the summer season is characterized by strong positive anomalies between 1970 and 1980. Furthermore, it is during this season that the highest positive values of the anomaly factor are recorded at all six stations, varying between 2.29 at the Dorohoi station, in 1975, and 4.94 at the Nicolae Bălcescu station, in 1977. At the Manoleasa station, the highest values of the positive anomalies of the summer season were recorded between 1980 and 1990, a similar cycle of positive anomalies having been recorded at the Dorohoi and Iaşi stations. Throughout the past two decades, seven of the nine stations have exhibited a decreasing trend for anomalies, with a slight tendency toward a return to positive anomalies over the past 5 years.

For two of the nine stations analyzed (Targu Frumos and Iaşi), the highest anomaly values were recorded during the autumn season from 1995 to 2005. Between 1990 and 2000, an increasing trend during this season has been noted for eight of the nine stations, the exception being Oancea. The anomaly regime for this season is, generally speaking, rather oscillatory, without significant patterns.

The PTM was applied to the same sets of seasonal and annual data. The detailed analysis based on the formulas associated with this method has revealed that eight of the nine stations exhibit a decreasing trend for the annual high flow values (Table 1). The slopes of these decreasing trends vary between $-1.301\text{ m}^3/\text{s per decade (at Dorohoi)}$ and $-0.334\text{ m}^3/\text{s per decade (at Iaşi)}$, and the magnitude of the decreasing trends as shown by the PI index (Table 2) indicates that decreasing values vary between $-2.280$ and $-9.015\text{ m}^3/\text{s}$ at the level of annual high flow.

In the case of one station (Targu Frumos), the PI has a positive value for the annual high flow ($+0.728$). For six of the nine stations, the decreasing trend in high extremes for annual high flow based on the PTM is the same with the annual trend obtained using the QPM.

The patterns of the annual flows series as revealed by the PTM are different from those of the monthly ones (Figures 5 and 6).

During the winter season, positive trends were noted for four stations from the northern and central parts of the region (Dorohoi, Manoleasa, Târgu Frumos and Iaşi), with PI values between 0.165 and 0.390 m$^3$/s.

The remaining five stations exhibited negative trends, yet with values significantly lower (between 25 and 50%) than the annual ones. These trends were also observed in different precipitation studies in Central and Eastern Europe (Zelenáková 2017b). In spring, when the melting of snow occurs and there is high spring flow in the hydrological regime of all rivers in the region (Minea 2012), decreasing trends for high flow values were noted at all stations. The values of the slopes depicting negative trends vary between $-0.007\text{ m}^3/\text{s per decade (at Iaşi station and} -3.569\text{ m}^3/\text{s per decade (at Oancea station. The intensity of the decreasing trend during this season is characterized by values lower than the annual ones (between 25 and 90%) for eight stations. It is only in the case of Oancea station that the intensity of the decreasing trend exceeds the annual value by 9%.

The same decreasing trend was recorded at eight stations during the summer season, with slopes between $-0.075\text{ m}^3/\text{s per decade at Dorohoi and} -1.958\text{ m}^3/\text{s per decade at Oancea. In summer, the values of the intensity of the decreasing trend are, for eight of the nine stations, lower than the annual ones (between 16 and 67%). Only at Iaşi station does the decreasing trend of the summer season exceed the annual value (by 147%). The decreasing trend in high extremes in the summer season based on the PTM is in good relation with the annual trend obtained using the same method, on the one hand, and with the QPM, on the other. This confirms the increasing trends of drought periods observed in the Mediterranean basin (Sousa et al. 2011) and for Eastern Europe (Croitoru et al. 2013) with the effect on the volume of water from rainfall that reaches the hydrographical network.

During the autumn season, only four stations (Nicolae Bălcescu, Băceştii, Codaesţi and Oancea) display decreasing trends, with slopes between $-0.032\text{ m}^3/\text{s per decade at Nicolae Bălcescu and} -0.516\text{ m}^3/\text{s per decade at Oancea. The magnitude of the decreasing trend at these stations
Table 1 | Results obtained using the formulas associated with PTM and type of trends established for each hydrometric station

| Name of station | River | Type of data | Annual | Winter | Spring | Summer | Autumn |
|-----------------|-------|--------------|--------|--------|--------|--------|--------|
| Dorohoi         | Jijia | Slope, $s$   | –1.301 | 0.017  | –0.336 | –0.075 | 0.150  |
|                 |       | Intercept, $a$ | 107.478| 12.360 | 36.944 | 24.744 | 5.532  |
|                 |       | Standard deviation, $\sigma$ | 61.460 | 15.112 | 28.711 | 34.243 | 10.958 |
|                 |       | Correlation, $\rho$ | 0.935  | 0.956  | 0.964  | 0.836  | 0.958  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.106  | 0.020  | 0.035  | 0.072  | 0.015  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Decreasing | Increasing | Decreasing | Decreasing | Increasing |
| Manoleasa       | Volovat | Slope, $s$ | –0.516 | 0.004  | –0.041 | –0.116 | 0.012  |
|                 |       | Intercept, $a$ | 25.056 | 1.077  | 4.751  | 6.209  | 2.427  |
|                 |       | Standard deviation, $\sigma$ | 17.508 | 1.628  | 7.152  | 8.243  | 3.972  |
|                 |       | Correlation, $\rho$ | 0.973  | 0.959  | 0.811  | 0.891  | 0.948  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.021  | 0.008  | 0.025  | 0.024  | 0.019  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Decreasing | Increasing | Decreasing | Decreasing | Increasing |
| Nicolae Balcescu | Miletin | Slope, $s$ | –0.678 | –0.028 | –0.123 | –0.165 | –0.032 |
|                 |       | Intercept, $a$ | 24.532 | 2.105  | 9.115  | 6.168  | 24.82  |
|                 |       | Standard deviation, $\sigma$ | 18.103 | 1.907  | 12.356 | 11.565 | 3.686  |
|                 |       | Correlation, $\rho$ | 0.978  | 0.968  | 0.943  | 0.962  | 0.885  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.021  | 0.008  | 0.025  | 0.024  | 0.019  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Decreasing | Decreasing | Decreasing | Decreasing | Decreasing |
| Targu Frumos    | Bahluet | Slope, $s$ | 0.117  | 0.007  | –0.076 | 0.002  | 0.027  |
|                 |       | Intercept, $a$ | 14.965 | 0.518  | 5.977  | 5.324  | 0.135  |
|                 |       | Standard deviation, $\sigma$ | 19.753 | 1.585  | 5.324  | 12.714 | 2.023  |
|                 |       | Correlation, $\rho$ | 0.942  | 0.959  | 0.931  | 0.895  | 0.880  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.068  | 0.007  | 0.024  | 0.011  | 0.005  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Increasing | Increasing | Decreasing | Increasing | Increasing |
| Iasi            | Vamesoaia | Slope, $s$ | –0.334 | 0.003  | –0.007 | –0.153 | 0.014  |
|                 |       | Intercept, $a$ | 18.306 | 0.204  | 1.760  | 1.996  | 0.280  |
|                 |       | Standard deviation, $\sigma$ | 15.126 | 0.363  | 3.333  | 9.197  | 1.517  |
|                 |       | Correlation, $\rho$ | 0.887  | 0.938  | 0.931  | 0.912  | 0.920  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.057  | 0.001  | 0.011  | 0.030  | 0.005  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Decreasing | Increasing | Decreasing | Increasing | Increasing |
| Bacesti         | Barlad | Slope, $s$ | –0.704 | –0.045 | –0.243 | –0.142 | –0.004 |
|                 |       | Intercept, $a$ | 39.543 | 3.518  | 14.679 | 9.494  | 3.007  |
|                 |       | Standard deviation, $\sigma$ | 26.115 | 2.997  | 12.058 | 12.903 | 4.503  |
|                 |       | Correlation, $\rho$ | 0.942  | 0.959  | 0.939  | 0.891  | 0.795  |
|                 |       | Slope standard deviation, $\sigma_s$ | 0.043  | 0.004  | 0.020  | 0.031  | 0.014  |
|                 |       | Hypothesis | $H_a$  | $H_a$  | $H_a$  | $H_a$  | $H_a$  |
|                 |       | Decision | Yes    | Yes    | Yes    | Yes    | Yes    |
|                 |       | Type of trends | Decreasing | Decreasing | Decreasing | Decreasing | Decreasing |

(continued)
ranges from −0.240 m³/s at Bâcești to −6.389 m³/s at Codaești. The remaining five stations exhibit increasing trends for high flow in autumn, with slopes between 0.012 m³/s per decade at Manoleasa and 0.150 m³/s per decade at Dorohoi. The greatest magnitude for the increase in high flow during this season was recorded at Dorohoi station (1.633 m³/s).

## Table 1 | continued

| Name of station | River | Type of data | Annual | Winter | Spring | Summer | Autumn |
|-----------------|-------|--------------|--------|--------|--------|--------|--------|
| Codaești        | Vaslui | Slope, s     | −0.978 | −0.222 | −0.282 | −0.198 | −0.046 |
|                 |       | Intercept, a | 54.667 | 2.018  | 17.089 | 12.650 | 2.813  |
|                 |       | Standard deviation, σ | 28.010 | 3.037  | 14.037 | 15.053 | 4.777  |
|                 |       | Correlation, ρ | 0.981 | 0.963  | 0.930  | 0.951  | 0.866  |
|                 |       | Slope standard deviation, σs | 0.028 | 0.004  | 0.022  | 0.024  | 0.013  |
|                 |       | Hypothesis | H_a  | H_a  | H_a  | H_a  | H_a  |
|                 |       | Decision | Yes | Yes | Yes | Yes | Yes |
|                 |       | Type of trends | Decreasing | Decreasing | Decreasing | Decreasing | Decreasing |
| Barlad          | Barlad | Slope, s     | −0.656 | −0.083 | −0.261 | −0.138 | 0.056  |
|                 |       | Intercept, a | 58.180 | 8.109  | 22.688 | 16.985 | 5.697  |
|                 |       | Standard deviation, σ | 35.056 | 6.387  | 16.089 | 22.843 | 7.722  |
|                 |       | Correlation, ρ | 0.944 | 0.958  | 0.976  | 0.911  | 0.908  |
|                 |       | Slope standard deviation, σs | 0.054 | 0.008  | 0.017  | 0.045  | 0.014  |
|                 |       | Hypothesis | H_a  | H_a  | H_a  | H_a  | H_a  |
|                 |       | Decision | Yes | Yes | Yes | Yes | Yes |
|                 |       | Type of trends | Decreasing | Decreasing | Decreasing | Decreasing | Increasing |
| Oancea          | Prut   | Slope, s     | −0.658 | −0.354 | −3.369 | −1.958 | 0.516  |
|                 |       | Intercept, a | 421.773 | 91.057 | 281.078 | 255.822 | 120.761 |
|                 |       | Standard deviation, σ | 185.862 | 62.264 | 134.823 | 170.035 | 82.095 |
|                 |       | Correlation, ρ | 0.964 | 0.912  | 0.899  | 0.884  | 0.960  |
|                 |       | Slope standard deviation, σs | 0.444 | 0.159  | 0.380  | 0.492  | 0.148  |
|                 |       | Hypothesis | H_a  | H_a  | H_a  | H_a  | H_a  |
|                 |       | Decision | Yes | Yes | Yes | Yes | Yes |
|                 |       | Type of trends | Decreasing | Decreasing | Decreasing | Decreasing | Decreasing |

## Table 2 | The magnitude of overall annual and seasonal high flow trends according to the PI index

| Name of station | River | Annual | Winter | Spring | Summer | Autumn |
|-----------------|-------|--------|--------|--------|--------|--------|
| Dorohoi         | Jijia | −3.445 | 0.256  | −1.897 | −0.978 | 1.633  |
| Manoleasa       | Volovat | −5.421 | 0.165  | −1.116 | −3.725 | 0.163  |
| Nicolae Balcescu | Miletit | −6.277 | −2.870 | −4.475 | −3.978 | −2.839 |
| Targu Frumos    | Bahlue | 0.728  | 0.390  | −3.014 | 0.131  | 1.082  |
| Iasi            | Vamesoia | −4.039 | 0.190  | −2.476 | −9.940 | 0.224  |
| Bacești         | Barlad | −9.015 | −2.854 | −6.910 | −5.026 | −0.240 |
| Codaești        | Vasluiț | −8.773 | −3.855 | −6.886 | −5.976 | −6.848 |
| Barlad          | Barlad | −2.494 | −1.908 | −2.481 | −0.587 | 0.369  |
| Oancea          | Prut  | −2.280 | −0.465 | −2.495 | −0.748 | −0.484 |

## CONCLUSIONS

The main conclusions derived from the analysis of high flow anomalies exhibited by rivers in Eastern Romania are the following:

1. The QPM has indicated that six out of nine stations analyzed exhibit a general decreasing trend of river flow...
extremes, which can be associated with the general trends indicated, based on the climate changes identified in the region.

2. For eight of the nine stations, the PTM has revealed a negative trend for annual high extreme flow, with significant intensity values. The same negative anomalies were noted during the spring and summer seasons, but with smaller slopes and intensities. In autumn, 55% of the stations analyzed exhibited significant positive trends and intensities.

3. Both methods (the QPM and the PTM) can be used in the analysis of the anomalies and trends displayed by rivers under temperate climatic conditions. If zero flow is not recorded, these methods can also be applied for low extremes for seasonal and annual series and other hydro-meteorological variables.

Numerous studies highlight the importance of considering local natural conditions when developing analysis models for climatic change. Earlier snowmelt, shorter snow season or longer rainfall seasons are only some of the features of the thermo-hydric regime of a region which can substantially alter the hydro-climatic parameters and, therefore, lead to faulty interpretations. The results obtained by applying the QPM and the PTM to large time spans have proved that the two methods can be
Figure 6 | Trend analysis of seasonal high flow based on the PTM.
used to assess how extreme values change across seasons. Furthermore, these results can be used for developing current and future management plans for local and regional water resources.

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