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RECENT TRENDS IN STREAMFLOW IN ROMANIA (1976–2005)

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Abstract. Mean monthly streamflow from 51 hydrometric stations corresponding to undisturbed independent Romanian watersheds, were analysed for trends with the Mann-Kendall nonparametric test for a period of 30 years (1976-2005). We found substantial changes in seasonality, with more than half of the stations presenting decreasing trends at the end of spring and in the early summer streamflow; from April to July the trends are exclusively downward, while during autumn, the streamflow is increasing. No change has been found for August and December. In February and March the trends are mixed and their percentage is rather low (under 20%). On annual basis only the downward trends are statistically significant.

Key words: streamflow trends, Mann-Kendall, climate change, Romania.

1. INTRODUCTION

The detection of trends in hydroclimatic data, in particular precipitation, temperature and streamflow, is essential for the assessment of the impacts of climate variability and change on the water resources of a region. Comprehensive studies on streamflow trends and their spatial patterns have first been conducted in the U.S. [1], suggesting a general increase in low streamflow, and later in Canada [2, 3]. In Europe, a large number of trend studies has been carried out since 2005 at national or regional scales in Switzerland [4–7], Slovakia [8, 9], France [10], Czech Republic [11], Nordic countries [12], Spain [13, 14] and Iceland [15, 16]. In 2010, Stahl *et al.* showed that the regional tendencies found in European streamflow variability were part of coherent patterns of change, which covered a much larger region. The broad, continental-scale patterns of change prove to fit well with the hydrological responses expected from future climatic changes [17]. Similar studies have recently been conducted for several regions in China [18–20] and Malaysia [21]. The global aspects of changes in freshwater discharge are presented by Dai *et al.* [22] and Jones [23].

In Romania, previous studies at country level have focused on changes in precipitation [24, 25], temperature [26], or cyclonic activity [27], while seasonal trends in streamflow have only been done for small areas [28–30]. The paper presents a first, brief analysis of mean monthly streamflow trends in Romania.

2. DATA AND PERIOD OF STUDY

The data used in this study belongs to the National Institute of Hydrology and Water Management (INHGA). The time series consist in mean monthly natural streamflow of 51 gauging stations in Romania, with continuous records over the 30 year study period, and quality controlled.

The related watersheds are not affected by major anthropogenic influences (like water withdrawals for hydropower or other water-use purposes) and can be considered independent in space: spatial independence for two stations located along the same river was ensured by always choosing the upstream station; in very few cases – with substantial increase in drainage area between the stations – a downstream station was additionally selected.

The river basins have an average drainage area of 223 km^2, with the mean river basin elevation ranging from 139 to 1658 m.a.s.l.

The analysis was conducted for the period 1976–2005, on monthly, seasonal and annual basis.

3. METHODOLOGY

The local significance of trends has been analysed with the nonparametric Mann-Kendall (MK) test for the annual, seasonal and monthly average streamflow. The MK test is a rank-based procedure, especially suitable for non-normally distributed data, data containing outliers and non-linear trends [31].

The null and the alternative hypothesis of the MK test for trend in the random variable x are:

$$\begin{cases} H_0: & \Pr(x \;\; > x_i) = 0.5 \;, \quad j > i \\ H_A: & \Pr(x \;\; < x_i) \neq 0.5 \;, \quad \text{(two-sided test)} \end{cases} \tag{1}$$

The Mann-Kendall statistic S is calculated as

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right), \tag{2}$$

where x_j and x_k are the data values in years j and k, respectively, with $j > k$, n is the total number of years and sgn() is the sign function:

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 \text{ , if } x_j - x_k > 0 \\ 0 \text{ , if } x_j - x_k = 0 \\ -1 \text{ , if } x_j - x_k < 0. \end{cases} \tag{3}$$

The distribution of S can be well approximated by a normal distribution for large n, with mean zero and standard deviation given by:

$$\sigma_S = \sqrt{\frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)(2i+5)}{18}}. \quad (4)$$

Equation (4) gives the standard deviation of S with the correction for ties in data, with t_i denoting the number of ties of extent i. The standard normal variable Z_S is then used for hypothesis testing.

$$Z_S = \begin{cases} \frac{S-1}{\sigma_S} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma_S} & \text{if } S < 0. \end{cases} \quad (5)$$

For a two-tailed test, the null hypothesis is rejected at significance level α if $|Z| > Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability $\alpha/2$. In the present analysis we chose a 10% significance level (two-tail test).

4. RESULTS AND CONCLUSIONS

The Mann-Kendall trend test applied to monthly streamflow data revealed substantial changes in the natural hydrological regime in Romania (Fig. 1).

The most important changes happen in June, where over 60% of the stations present decreasing trends. From April to July the trends are exclusively downward, while during autumn the streamflow is increasing. In February and March the trends are mixed and their percentage is rather low (under 20%). August and December show no trends.

On a seasonal basis (Fig. 2), the streamflow is decreasing for 20% of the stations in spring and summer, while during autumn there is an increase for 9% of the stations. Winter presents the highest percentage of trends from all seasons (due to January and February): 18% upward trends and 6% downward. However, most stations show no trends – indicating a stable seasonal regime.

Trends in annual streamflow are exclusively decreasing for 13% of the stations, suggesting a possible future water resources scarcity.

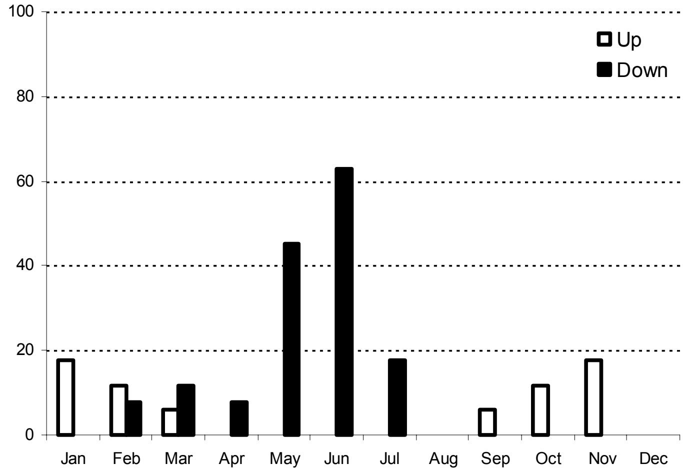

Fig. 1 – The percentage of stations exhibiting monthly trends at 10% significance level (two-tail test).

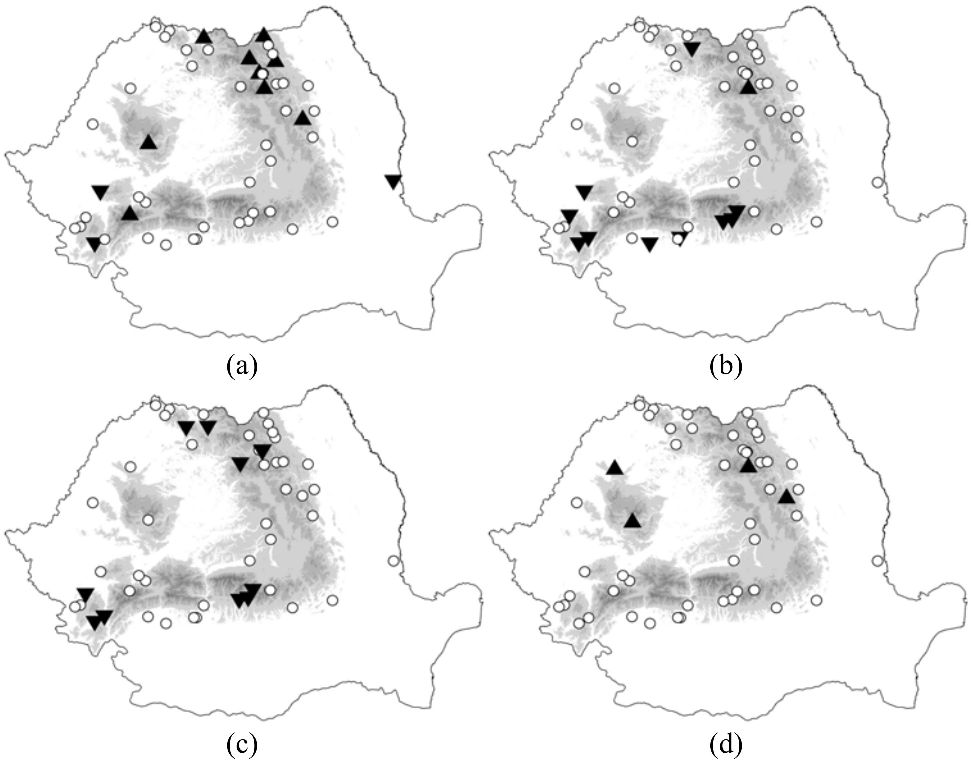

Fig. 2 – Significant trends at 10% level (two-tailed test) for: a) winter DJF; b) spring MAM; c) summer JJA; d) autumn SON. Significant increasing (decreasing) trends are shown with upward (downward) arrows; stations presenting no significant trend are marked circles.

The results are in agreement with the previous studies on climatic variables in Romania [24–26, 32–34]. The increase in winter temperature [35] could justify the positive trends in winter flow, with an earlier timing of the snowmelt-induced streamflow and also generating a higher percentage of liquid precipitation (*i.e.*, precipitation falling as rain instead of snow).

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