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Trends in Monthly Natural Streamflow in Romania and Linkages to Atmospheric Circulation in the North Atlantic

Marius-Victor Birsan[1]

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Abstract Natural and reconstructed monthly streamflow records from 172 river basins in Romania (143 with full records and 29 with less than 10 % missing values) have been analyzed for trends with the nonparametric Mann-Kendall test for the period 1956–2005. The statistical significance of trends was tested for each station on a monthly basis. Changes in the streamflow regime in Romania are demonstrated. The monthly flow presents upward trends from August to January, and predominantly downward trends from February to June. The most important changes are the increasing streamflow trends from September till November, which are well explained by the increase in autumn precipitation. The annual streamflow shows a dependence on latitude, with increasing trends in the northern part, and decreasing in the south. Strong negative correlations between the North Atlantic Oscillation and the mean annual streamflow have been found in western and southern Romania, highlighting the influence of the large-scale atmospheric circulation on Romanian annual streamflow in these areas, as well as the important orographic role of the Carpathian Mountains.

Keywords Natural flow regime · Reconstructed streamflow · Romania · Mann-Kendall · Monthly trends · North Atlantic Oscillation

1 Introduction

Trend analysis of hydroclimatic data is essential for the assessment of the impacts of climate variability and change on the water resources of a region, and necessary for planning

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✉ Marius-Victor Birsan
marius.birsan@gmail.com; marius.birsan@meteoromania.ro

[1] Meteo Romania (National Meteorological Administration), Sos. Bucuresti-Ploiesti 97, 013686 Bucharest, Romania

adaptation strategies (Viviroli et al. 2011). Streamflow integrates the influence of atmospheric variables over a watershed, and it is therefore an interesting variable for evaluating regional climatic changes. Stahl et al. (2010) showed that the regional tendencies found in European streamflow variability were part of a continental-scale pattern of change – with generally upward annual trends in Northern Europe and downward trends in the south –, proved to fit well with the hydrological responses expected from future climatic changes (Stahl et al. 2012). In Romania, previous hydroclimatic studies were focused on changes in precipitation (Busuioc and von Storch 1996; Tomozeiu et al. 2005), temperature (e.g., Rimbu et al. 2014), evapotranspiration (Croitoru et al. 2013), wind speed (Birsan et al. 2013) or snow (Micu 2009), while streamflow variability have only been analyzed for small areas (Stefan et al. 2004; Croitoru and Minea 2014), for mountain basins (Birsan et al. 2012, 2014a), or for a particular season (Ionita et al. 2014; Ionita 2015). This paper presents a 50-year country-wide analysis of monthly streamflow trends in Romania, using not only records from pristine river basins (available almost exclusively in the mountainous areas), but also reconstructed data series of the natural runoff regime, providing a good coverage over the entire country. Linkages with the North Atlantic Oscillation (NAO) are also investigated.

2 Material and Methods

Romania is the largest country in southeastern Europe, having an area of 238 391 km^2. The terrain is fairly equally distributed between mountainous (Carpathians), hilly and lowland territories. Elevation varies from sea level to 2544 m.a.s.l. The climate is continental-temperate with oceanic influences in the central and western parts, continental in the east and Mediterranean in the south (Balteanu et al. 2010). The agricultural land represents 62 % of Romania's territory, while forested areas occupy about one third of the country. The cumulated length of rivers longer than 5 km and with watersheds above 10 km^2 is around 85 000 km. Most of them are tributary to the Danube, which drains 98 % of the Romanian territory. The hydrological regime in Romania (Fig. 1) is generally of rainfall-snowmelt origin, except for the southeastern (Black Sea) area, where it is rainfall-based (Stanescu and Ungureanu 1997). The streamflow variability is influenced by the temperate-continental climate and to a lesser degree by the topography and regional factors, like land-use / land cover, geology, etc. (Ionita et al. 2014).

The data series used in this study (Table 1 – supplementary material) have been provided by the National Institute of Hydrology and Water Management (INHGA). The time series consist in mean monthly natural (−ised) streamflow from 143 gauging stations in Romania (Fig. 2), with continuous records over the study periods, and quality controlled. For a better coverage, 29 stations with less than 10 % missing values have been additionally selected. The naturalised (reconstructed) flow was done by adding / subtracting the monthly quantities altered by the anthropogenic interventions – like water withdrawals or hydropower plants. As a general rule, data series presenting differences greater than 30 % between the measured and reconstructed flows were not considerred.

The analysis was conducted over the period 1956–2005, which allowed a good compromise between the spatial coverage of available data and the record length.

The local significance of trends was analysed with the nonparametric Mann-Kendall (MK) test. The MK test (Mann 1945; Kendall 1975) is a rank-based procedure, especially suitable for non-normally distributed data, data containing outliers and non-linear trends (Salas 1993), therefore being widely used in trend analysis of hydroclimatic variables. The null and the

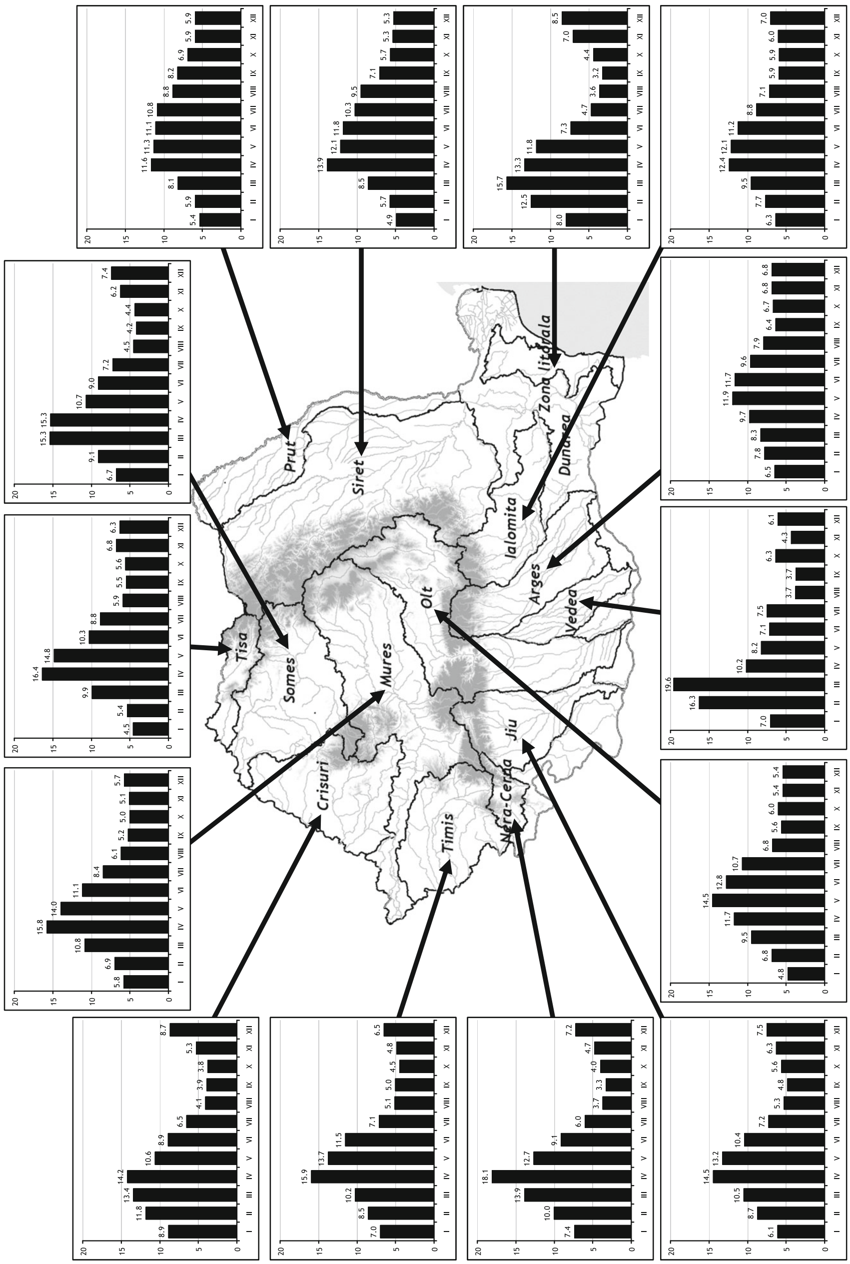

Fig. 1 The monthly hydrological regime in the major Romanian river basins. The monthly values represent the percentages of the annual streamflow. "Zona litorala" denotes the area that drains directly into the Black Sea

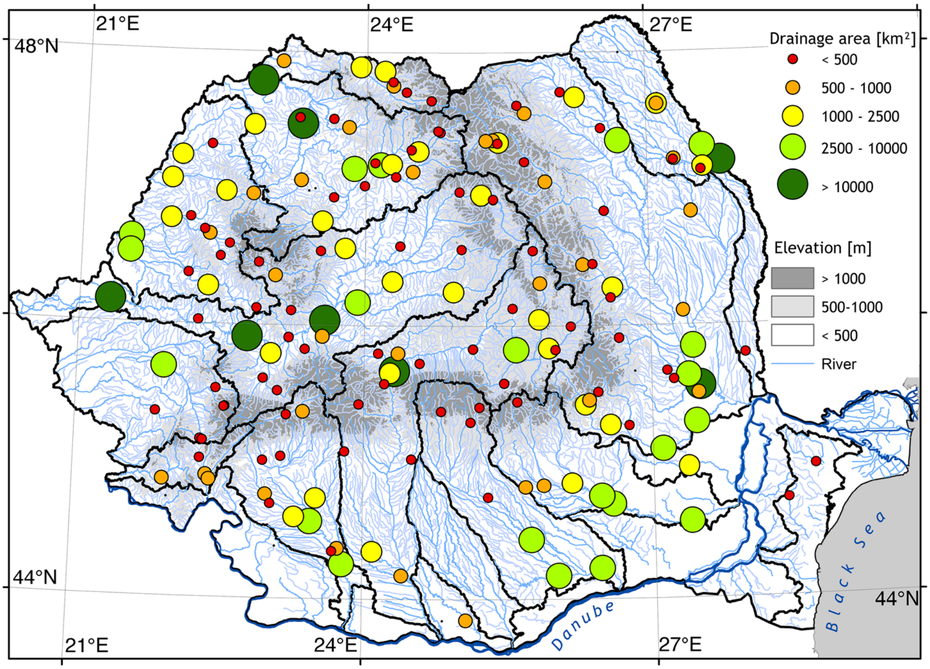

Fig. 2 Location of the 172 gauging stations

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

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

The MK statistic S is:

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

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:

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

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

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

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 variate Z_S is then used for hypothesis testing.

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

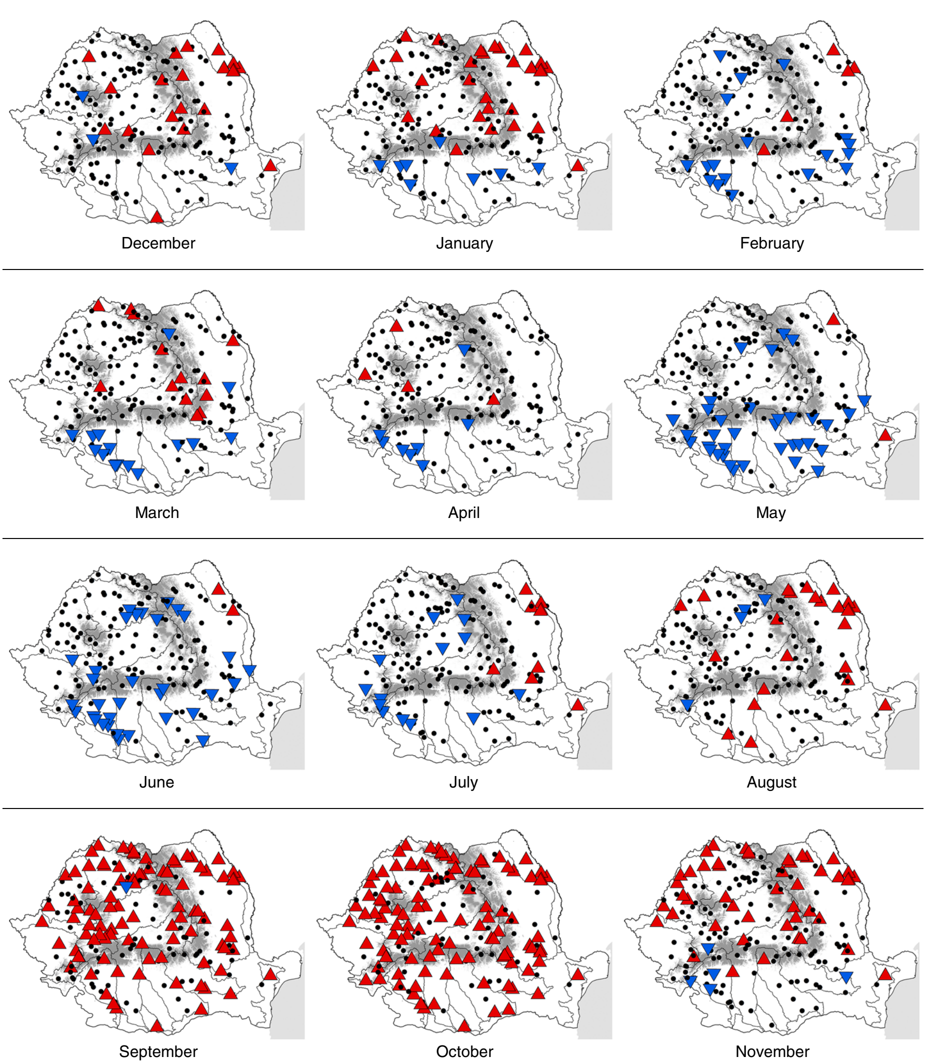

Fig. 3 50-year trends in monthly streamflow (1956–2005); *downward blue triangles* signify decreasing trends, *upward red triangles* denote increasing trends and *black circles* symbolize no trend

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 the significance level was fixed at 10 % (two-tail test).

The NAO index used in this study is Hurrell's PC-based DJFM index (Hurrell and NCAR 2013). The NAO has been shown to influence the winter precipitation and snow cover west of -30°E (Bednorz 2004). Beniston (1997) found the NAO influencing the timing and amount of snow in the Swiss Alps.

Spearman's nonparametric rank-based correlation coefficient rho (Helsel and Hirsch 1992) was used in order to estimate the relationship between the NAO and the mean annual streamflow.

3 Results and Discussion

Mean monthly streamflow shows increasing trends from September to November, predominantly increasing trends in December and January, and decreasing trends from May to June (Fig. 3). The most important results are the upward trends in September and October, which could be directly linked the increase in precipitation that occurred during these months (Busuioc et al. 2010; Cheval et al. 2014a; Dumitrescu et al. 2014; Marin et al. 2014). The upward streamflow trends in December and January – when there is no significant increase in precipitation – are well explained by the increase in winter temperature, which led to a higher percentage of precipitation falling as rain instead of snow, inducing a smaller snowpack (Birsan and Dumitrescu 2014). As a consequence, the snowmelt-induced (early spring) streamflow is decreasing. There is a balanced change in March, with increases in the east and decreases in the west, while in April there is almost no change. Of high importance with respect to water resources management are the decreasing trends from the end of spring till mid-summer, which suggest an increase in water scarcity in southern Romania – an area of high agricultural importance. During this period, the dominant hydrological process responsible for streamflow reduction is the increase in evapotranspiration (Nune et al. 2014). Overall, the monthly streamflow is more sensitive to changes in precipitation – which is increasing in autumn – than to changes in potential evapotranspiration – which is increasing from May to August. Zuo et al. (2014) reached to similar conclusions regarding the streamflow response to climate change.

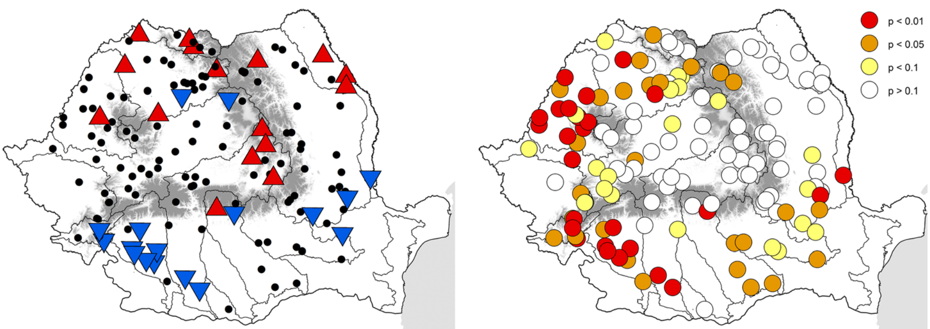

Fig. 4 **a** Annual streamflow trends over 1956–2005; *downward blue triangles* signify decreasing trends, *upward red triangles* denote increasing trends and *black circles* symbolize no trend. **b** Correlations between Hurrell's NAO index DJFM and mean annual streamflow; all significant correlations are negative. Only the 143 stations with full record are presented

The mean annual streamflow (Fig. 4a) presents decreasing trends in the southern half of the country and increasing trends in the northern one. This spatial pattern is in good agreement with the observed changes in precipitation amount over the country for the same time interval (e.g., EEA 2008). Apart from this latitudinal pattern, it is worth mentioning that most of the stations show no significant trend in annual streamflow. Also, the trend results do not show a strong dependence on basin mean altitude or catchment area.

The NAO was proven to influence to some degree the streamflow variability in Europe (Rimbu et al. 2004; Trigo et al. 2004; Kingston et al. 2006; Vicente-Serrano and Cuadrat 2007; Giuntoli et al. 2013), western Iran (Tabari et al. 2013) or Canada (Coulibaly and Burn 2005). The NAO affects the strength of westerly flow and weather patterns in Europe in particular in winter (Wanner et al. 2001; Bojariu and Gimeno 2003). The influence of the North Atlantic on precipitation and temperature in Romania during winter was demonstrated in several papers (e.g., Tomozeiu et al. 2002, 2005; Birsan and Dumitrescu 2014; Busuioc et al. 2014). Cheval et al. (2014b) found that, at country scale, the winter *Standardized Precipitation Index* in Romania had a statistically significant negative correlation with NAO. A high NAO index is associated with positive thermal anomalies and with negative precipitation anomalies in the region (Bojariu and Paliu 2001). Bojariu and Dinu (2007) using monthly data for 1961–2000 found that the NAO positive phase leads to less snowy winter months in Romania, whereas the NAO negative phase increases the probability of snowy winters, suggesting that the diminishing snow depth over the country was related to the tendency toward the positive phase of NAO.

In this study it was found that the NAO index for the extended winter (December-March) shows strong negative correlations with the annual streamflow in western Romania, as well as in the south (Fig. 4b), suggesting that the NAO might be a useful predictor for the annual flow in the above-mentioned regions, and also emphasizing the orographic effect of the Carpathian Mountains on the large-scale atmospheric circulation in the region (e.g., Birsan et al. 2014b), most mountain basins being poorly correlated with the NAO). These results are in agreement with previous findings concerning linkages between NAO and Romanian Streamflow (e.g., Rimbu et al. 2002; Ionita et al. 2014).

4 Conclusions

The study presented a trend analysis of Romanian streamflow using monthly records from 172 gauging stations for a 50-year period. The main findings are summarized below.

(1) There is an obvious change in the hydrological regime in Romania, with predominantly increasing flow from September to January, and predominantly decreasing trends from May till June.
(2) The autumn months show upward trends due to the increasing precipitation amount during this season. The increasing streamflow trends in December and January – in central and northern Romania – can be explained by the increase in temperature, resulting in more precipitation falling as rain than as snow.
(3) Of high importance are the decreasing trends in southern Romania in May and June, pointing to the increasing scarcity of water resources in this important agricultural region, especially in the southwestern area.
(4) The influence of NAO on Romanian climate is well reflected in the annual streamflow in the southern and western regions.

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