CENTENNIAL TRENDS IN PRECIPITATION, AIR TEMPERATURE, EVAPOTRANSPIRATION AND WATER BALANCE OVER ROMANIA FROM OBSERVATIONAL DATA (1924–2023)

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Abstract. While climate variability in Romania since 1961 is well documented, studies spanning on longer periods are few, and use either modelled, or sparse observational data. This paper presents the 100-year trends in precipitation, air temperature (average, minimum and maximum), monthly air temperature range, potential evapotranspiration and water balance over Romania using data from 156 weather stations. The recently released, freely available RoCliHom dataset has been used for this purpose. Trend analysis was conducted with the nonparametric Mann-Kendall test, as it allows a direct comparison with the vast majority of previous studies on climatic changes in Romania. Our results indicate that, since 1924, air temperature had increased over the entire country in all months except autumn, showing that the warming signal has been consistent over the 100-year period. In contrast, annual precipitation amount looks stable at most stations, while 28% show increasing trends. Monthly temperature range had mostly decreased. Potential evapotranspiration has increased in winter, spring and especially in summer, when all stations present upward trends. Water balance had declined in August at almost half of the stations. Generally, the patterns of change are clear, without mixed trends (*i.e.*, trends showing opposite signs for the same variable). Trend magnitudes of annual precipitation and air temperature are strongly correlated (p-value < 0.001) with elevation.

Key words: weather station data; potential evapotranspiration; Hargreaves-Samani; extreme temperature; monthly data; Mann-Kendall; Southeastern Europe.

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1. INTRODUCTION

Romania has experienced a country-wide increase in average air temperatures over the past decades with warming trends most pronounced in summer and winter [1]. There is also evidence of more frequent, intense, and prolonged heat waves [2, 3]. Precipitation extremes show both regional and seasonal variation, with notable increases in the frequency of very wet days during autumn and longer dry spells in summer. The wind speed shows decreasing trends since 1961 at seasonal and annual scales [4, 5] diminishing its effect on evapotranspiration. Also, the snowpack duration has been decreasing within the same period [6, 7]. These climatic changes have been accompanied by irregular shifts in daily precipitation extremes and significant anomalies in both temperature and precipitation patterns [8–12]. These well-documented significant changes had affected the natural river flow regime [13], plant phenology [14–19] and human comfort [20]. However, the vast majority of the aforementioned studies focused on periods starting from the second half of the last century, or used data from only few stations. Here we present a 100-year trend analysis of monthly precipitation amount, air temperature (monthly average, minimum and maximum), potential evapotranspiration and water balance using observational data from 156 meteorological stations (Fig. 1) from a new, high-quality dataset.

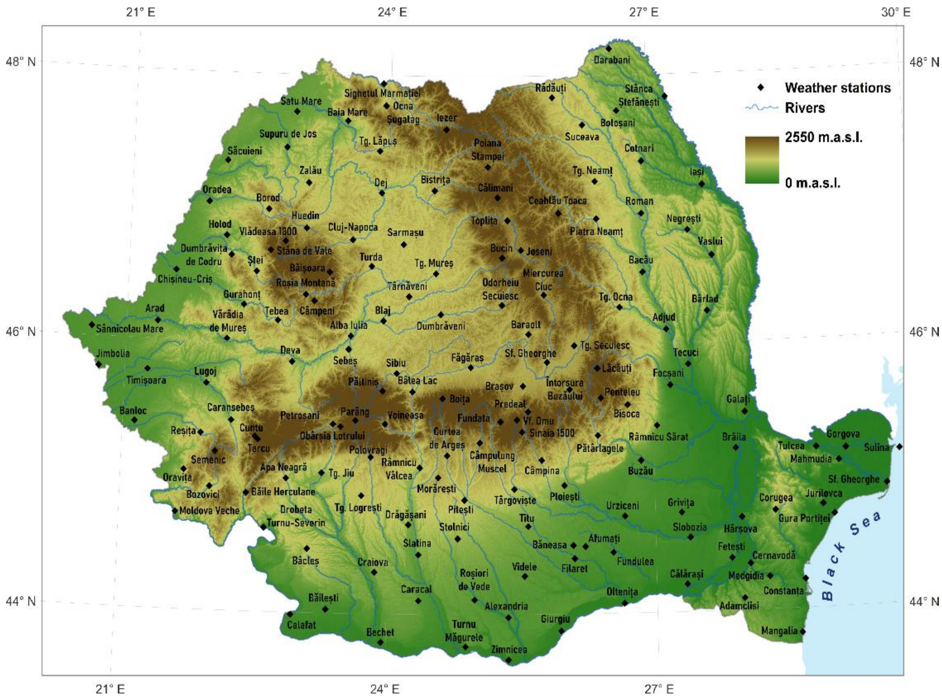

Fig. 1 – Spatial distribution of the 156 weather stations.

2. DATA AND METHODS

RoCliHom (Romanian Climate Homogenized Dataset) [21, 22] is a station-based, homogenized dataset of precipitation and air temperature (mean, minimum and maximum) over the Romanian territory, covering the period 1901–2023. The homogenization of the dataset was done in several steps (including quality control and breakpoint detection), in order to eliminate non-climatic biases. It also addressed some historical inconsistencies related to changes in measurement instruments, methodology or station relocations. We decided to conduct the trend analysis over the 1924–2023 period, as there is a lack of original data measurements in previous years, due to the disruption of weather observations during the First World War.

The following parameters were tested for 100-year trends:

- monthly precipitation amount;
- monthly mean, minimum and maximum air temperature;
- monthly air temperature range;
- monthly potential evapotranspiration, using the Hargreaves-Samani formula [23];
- monthly water balance, *i.e.*, the difference between monthly precipitation and monthly potential evapotranspiration.

The statistical significance of trends was analysed with the nonparametric Mann-Kendall (MK) test [24, 25], which is is a rank-based procedure appropriate for non-normally distributed data, time series with outliers and non-linear trends [26]. The significance level was fixed at 10% (two-tailed test). The null and the alternative hypothesis of the MK test for a trend in the random variable x are:

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

The MK statistic S is calculated as:

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

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; sgn() is the sign function:

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

For large n, the distribution of S can be well approximated by a normal distribution 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 (*i.e.*, observations that have the same value), with t_i denoting the number of ties of extent i. The standard normal variate Z_S is then used for hypothesis testing

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

The null hypothesis is rejected at significance level *a* if $|Z| > Z_{\alpha/2}$ (two-tail test), where $Z_{\alpha/2}$ is the value of the standard normal distribution with an exceedance probability *a*/2. In the present study, the significance level was fixed at 10%.

The trend magnitude was computed using the nonparametric Sen's slope estimator, which is a robust method for estimating quasi-linear trends, also being less affected by non-normal data and outliers [26]. This approach consists in computing slopes for all the pairs of points and then using the median of these slopes as an estimate of the overall slope.

3. RESULTS AND DISCUSSION

Trend results revealed significant climatic changes within the 100-year period of study. A summary is shown in Table 1.

Table 1

Summary of the monthly trend results. Numbers represent percentages of statistically-significant trends out of the total number of stations. Values below 10 are in grey

Climatic variable	Trend	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Precipitation	Up	11	11	0	31	2	0	6	20	0	28	1	1
	Down	1	6	5	1	1	3	3	1	12	0	1	3
Mean air temperature	Up	92	99	99	94	35	83	100	100	100	1	14	6
	Down	0	0	0	0	0	0	0	0	0	0	0	0
Minimum air temperature	Up	96	100	100	99	84	89	99	98	99	91	88	13
	Down	0	0	0	0	0	0	0	0	0	0	0	0
Maximum air temperature	Up	92	94	100	90	15	13	95	56	98	0	13	14
	Down	0	0	0	0	0	0	0	0	0	0	1	0
Air temperature range	Up	10	4	12	4	0	1	2	2	4	0	0	6
	Down	22	49	17	18	15	26	37	53	31	85	45	9
Potential evapotranspiration	Up	65	32	80	85	35	83	100	100	100	1	14	7
	Down	0	0	0	0	0	0	0	0	0	0	0	0
Water balance	Up	6	6	0	2	0	0	0	3	0	15	0	1
	Down	3	6	12	1	1	6	13	6	47	0	4	6

Annual precipitation has increased at 28% of the stations, in northern, western and southeastern areas of the country (Fig. 2), but without a clear spatial pattern. All statistically-significant trends are upward. However, most stations show no statistically-significant trend. The average magnitude of annual precipitation increase is 5 mm per decade. There is a strong positive correlation (p-value < 0.001) between trend magnitude and elevation.

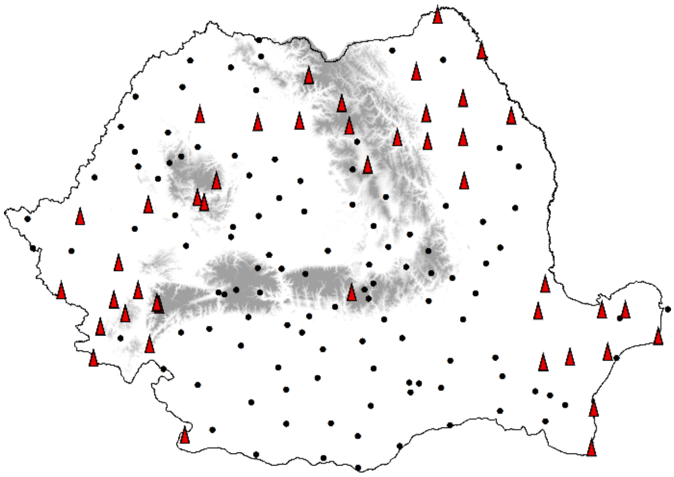

Fig. 2 – Trends in annual precipitation over Romania (1924-2023). Statistically-significant increasing trends are symbolized with red triangles. Black points denote stations with no trend.

Monthly precipitation show increases in March (at 31% of the stations), July (20%) and September (28%), while in August the precipitation amount is decreasing at 12% of the stations, in the intra-Carpathian and northeastern areas (Fig. 3).

Annual air temperature presents statistically-significant increasing trends at all stations, the average annual temperature increasing by 0.155°C per decade. The slope of temperature increase has a strong negative correlation (p-value < 0.001) with elevation. At monthly scale, mean air temperature has increased over the entire Romanian territory in all winter, spring and summer months (Fig. 4). Autumn is the only season that had remain stable in this respect. Minimum temperature present increasing trends in September (91% of the stations) and October (88%). Clearly, the minimum air temperature shows more statistically-significant increases that the maximum air temperature – especially in April, May, September and October.

Monthly air temperature range presents predominantly decreasing trends (Fig. 5), suggesting that the minimum temperature has increased at a faster rate than maximum temperature, as found in most studies worldwide [27, 28].

Potential evapotranspiration has a pattern similar to air temperature, showing exclusively increasing trends over large areas in winter and spring, and over the entire country in all summer months (Fig. 6).

Water ballance seems rather stable in all months except August (Fig. 7), when 47% of the stations show statistically-significant decreases. This decline might have affected the ripening of grapevine and of some important autumn crops. The increase in precipitation in June, July and September seems to compensate for the effect of rising temperatures on water balance. At the same time, the lack of increasing precipitation trends in August determines the decline in water balance in this month.

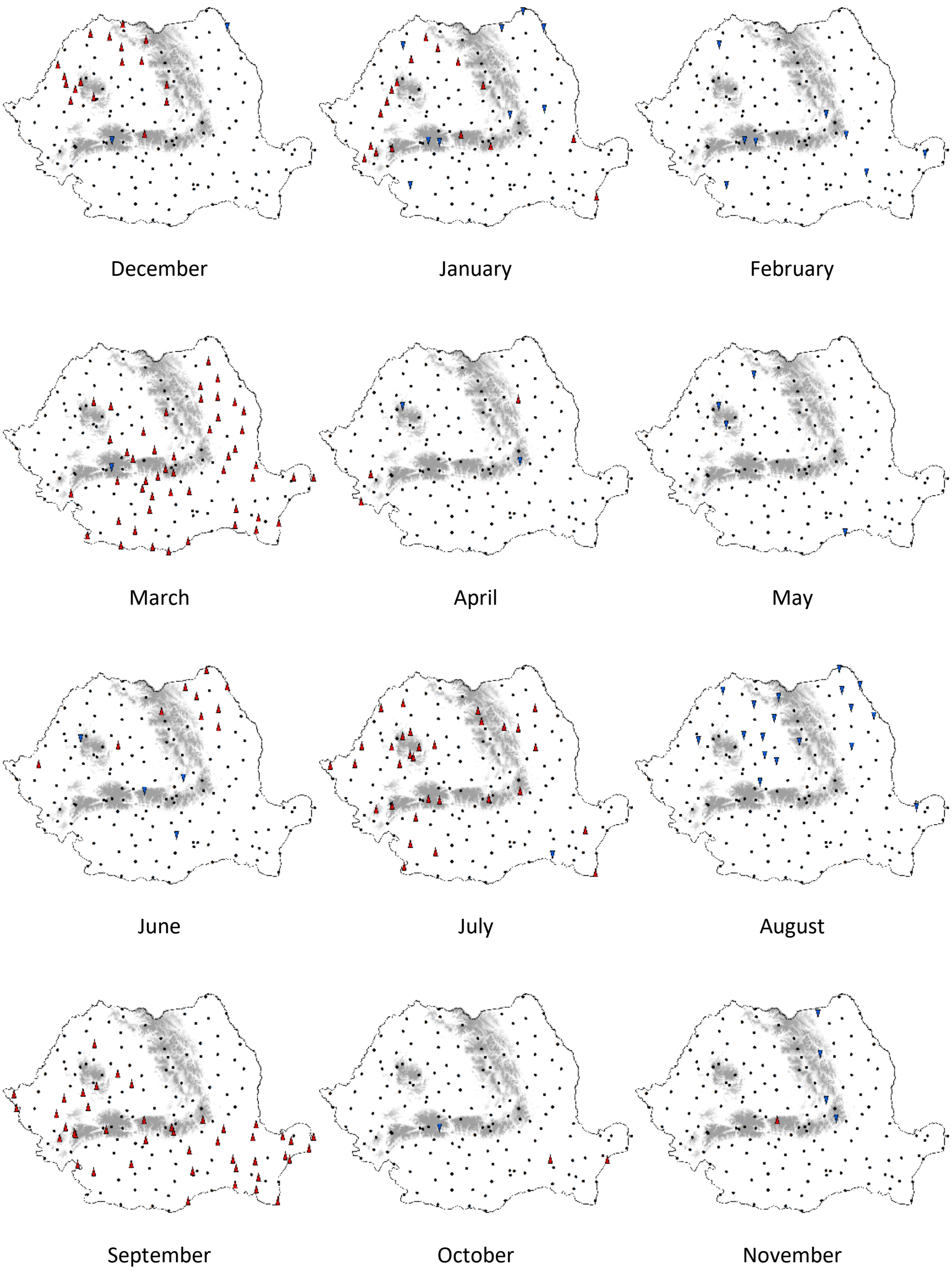

Fig. 3 – Monthly trends in precipitation over Romania for the period 1924–2023.
Increasing (decreasing) trends are symbolized with red (blue) triangles.
Black points denote no statistically-significant trend.

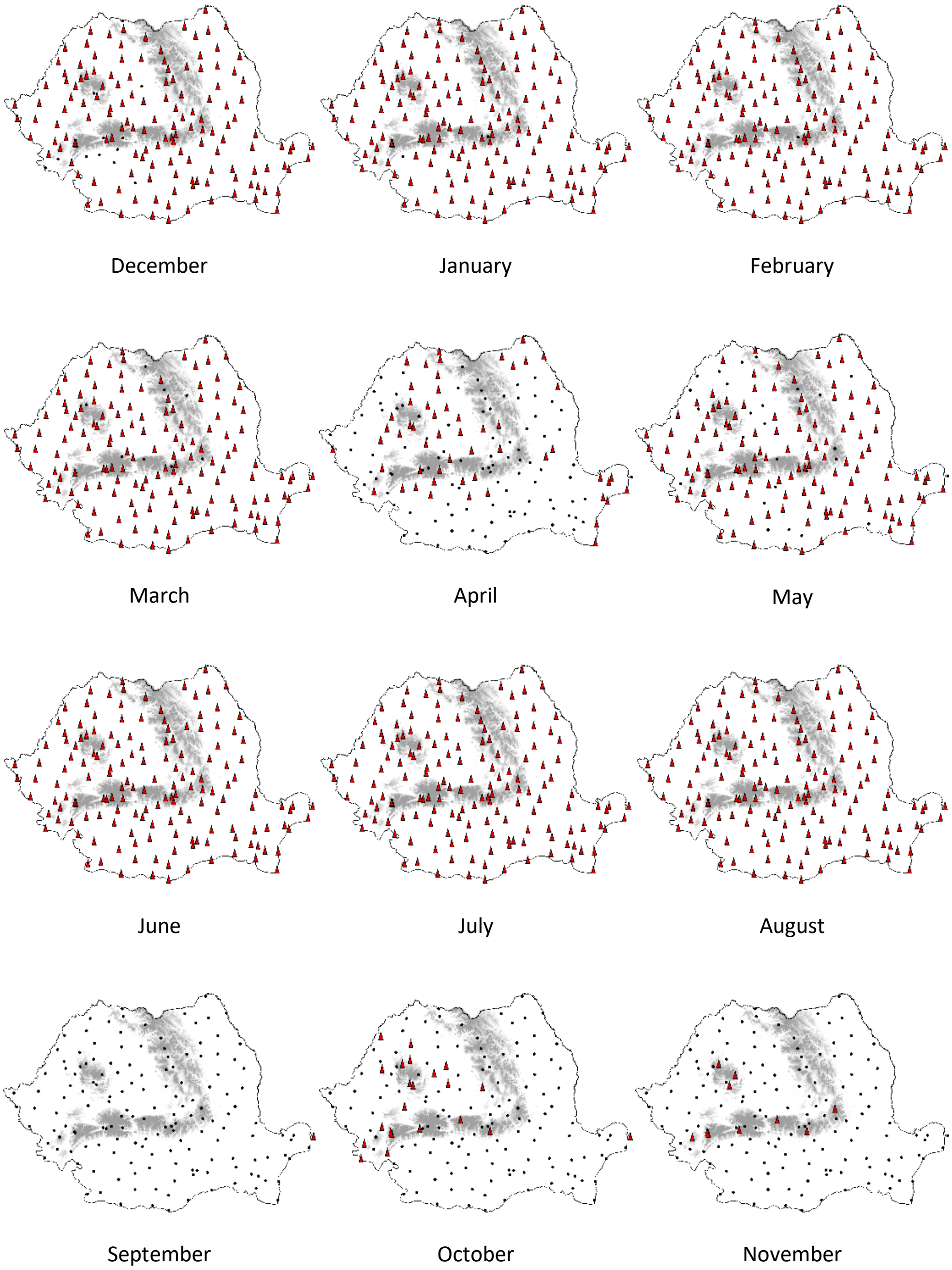

Fig. 4 – Trends in mean monthly air temperature over Romania (1924–2023). Increasing trends are symbolized with red triangles. Black points denote stations with no statistically-significant trend.

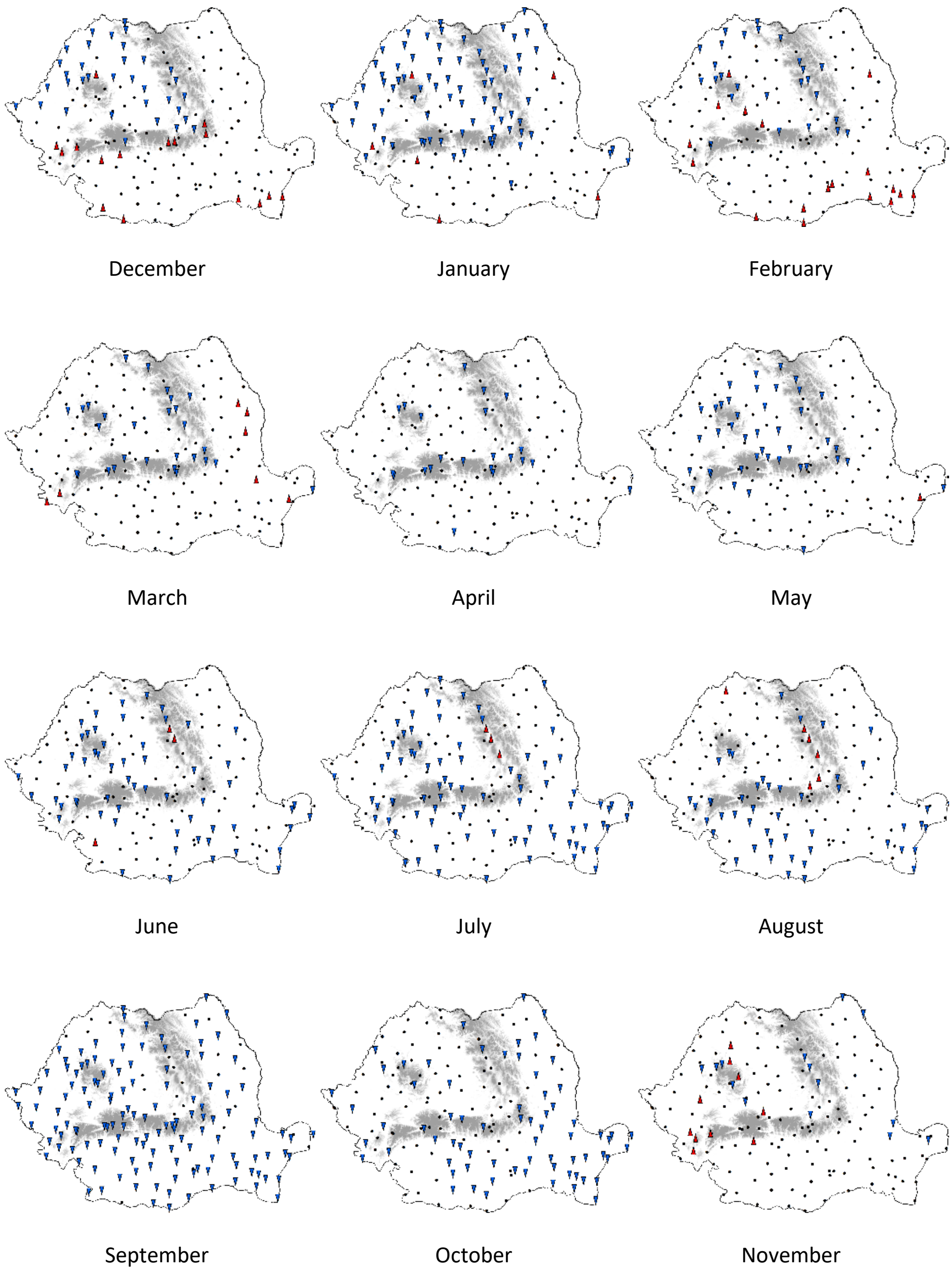

Fig. 5 – Trends in monthly air temperature range over Romania (1924–2023).
Increasing (decreasing) trends are symbolized with red (blue) triangles.
Black points denote no significant trend.

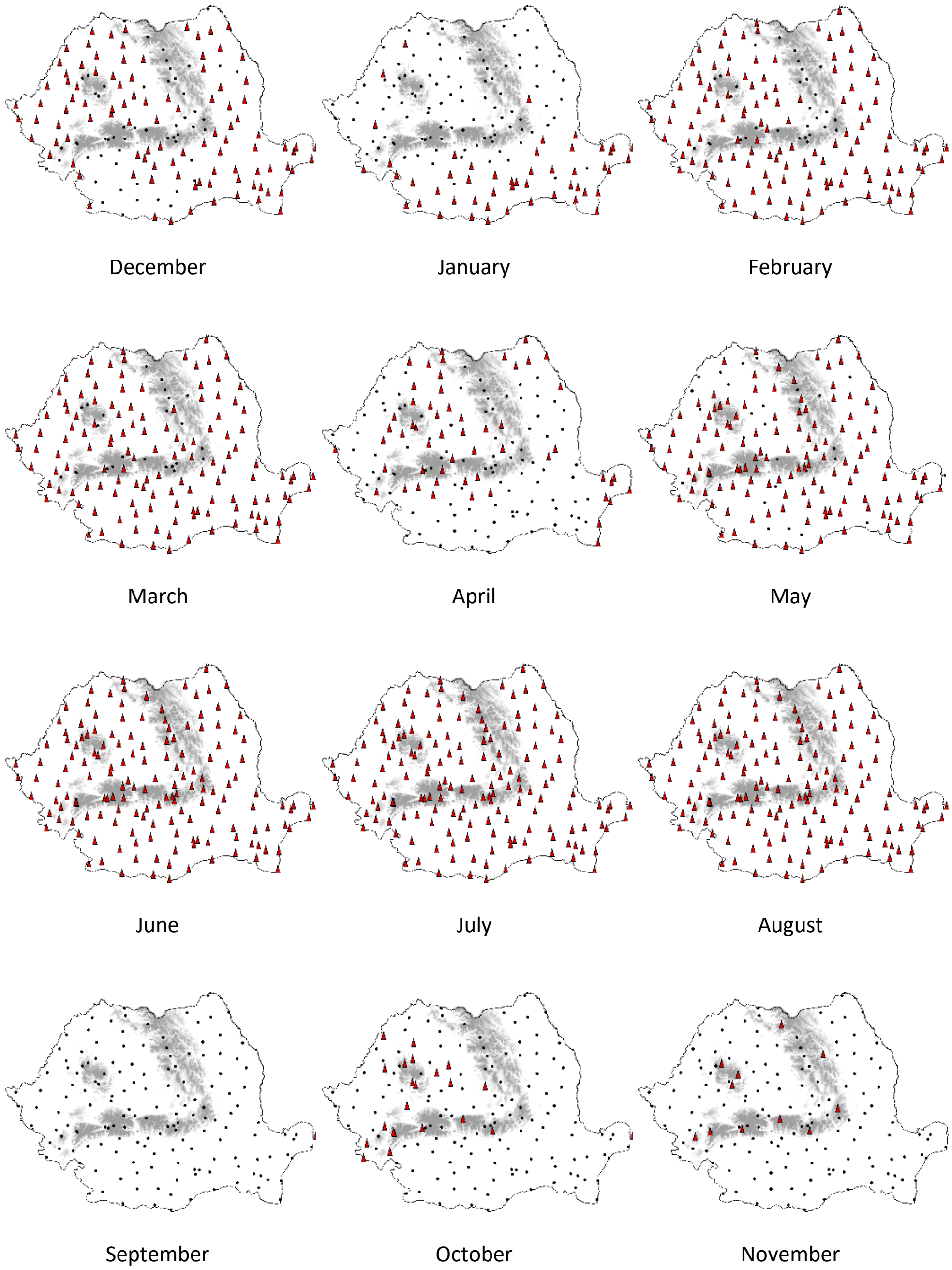

Fig. 6 – Trends in monthly potential evapotranspiration over Romania (1924–2023). Increasing trends are symbolized with red triangles. Black dots symbolize no statistically-significant trend.

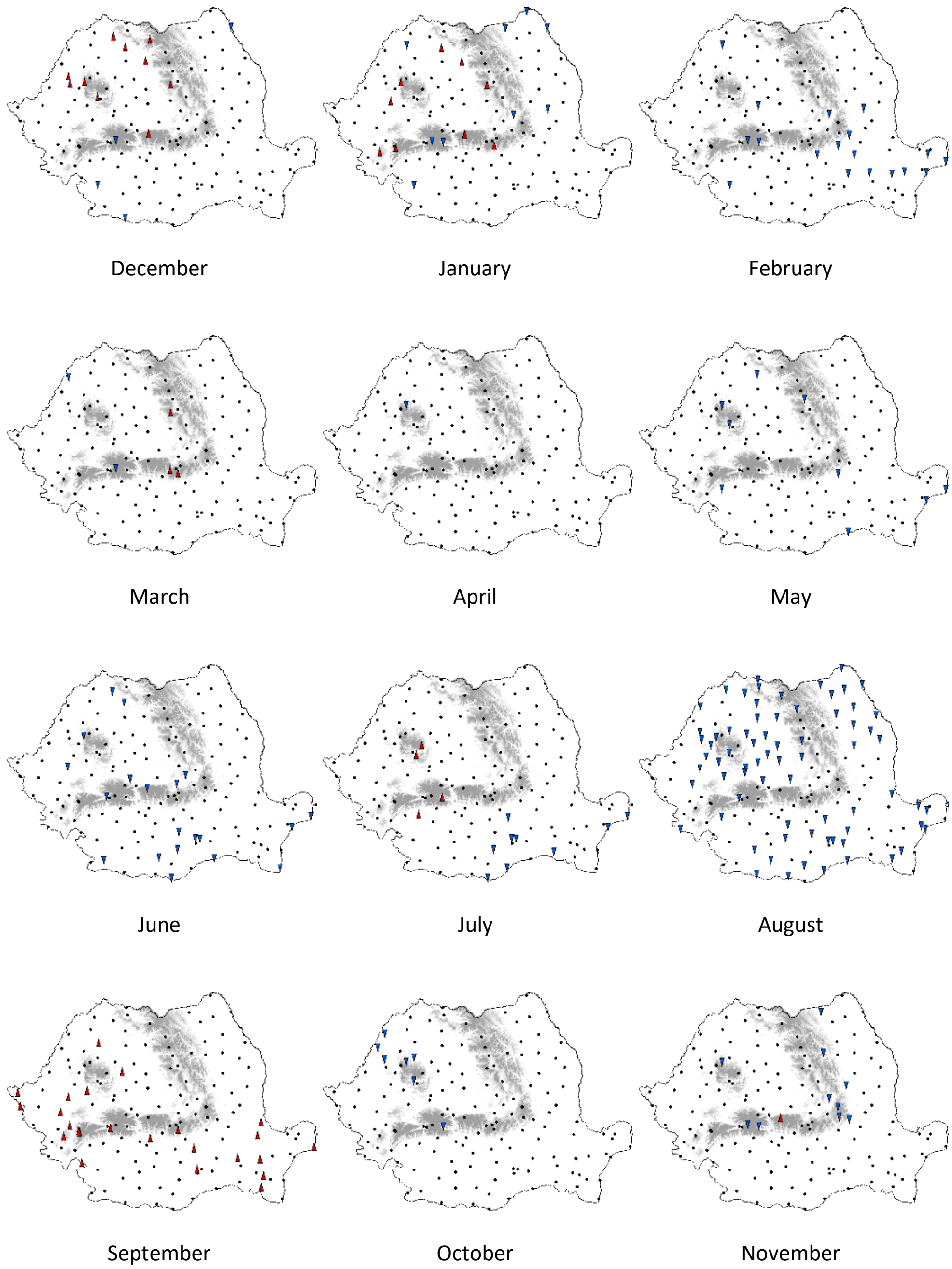

Fig. 7 – Trends in monthly water balance over Romania (1924–2023).
Increasing (decreasing) trends are symbolized with red (blue) triangles;
black dots symbolize no statistically-significant trend.

The results are generally in good agreement with previous findings on climatic changes in the region [29–31], and in contrast with some findings of precipitation decline since 1961. Most of these long-term changes in the regional climate (especially precipitation, temperature, and frequency of extreme events) were demonstrated to be (partly) caused by changes in large-scale atmospheric circulation [32–36].

4. CONCLUSIONS

We presented a 100-year trend analysis of several climatic variable over Romania using monthly data from 156 weather stations. The main findings are:

- an increase in mean monthly air temperature over the entire country in winter, spring and summer, with minimum temperature increasing in all seasons;
- a similar increase in potential evapotranspiration in winter, spring, and especially summer (with all stations presenting upward trends);
- an increase in annual precipitation at 28% of the locations, indicating no significant changes in annual precipitation amount, as most stations show no trend;
- a stable water balance in all months except August.

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