

## **ANALYSIS OF TEMPERATURE, PRECIPITATION AND POTENTIAL EVAPOTRANSPIRATION TRENDS IN SOUTHERN OLTENIA IN THE CONTEXT OF CLIMATE CHANGE**

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### **ABSTRACT:**

The analysis of a territory's climate trends are currently major research interests, as this is a viable method for identifying changes in climatic parameters against the background of global climate change, which at the same time can provide basic support for environmental system adjustments. The present study aims to identify the temporal trends of the main climate parameters (temperature, precipitation and potential evapotranspiration) in southern Oltenia, based on climate data provided by five regional weather stations (Drobeta Turnu Severin, Calafat, Craiova, Bechet and Turnu Măgurele). The analysis covers the 1961 - 2009 period, and the nonparametric Mann-Kendall test was used as trend quantification method. The entire study was conducted on three temporal analysis scales – annual, seasonal (spring, summer, autumn and winter) and monthly. The results showed specificities for each climatic parameter on each of the three temporal scales. For the average temperature, trends are mainly upward on annual and seasonal scales (generally statistically significant), except for autumn, when a slight cooling trend lacking statistical significance was found. The same general pattern was identified for evapotranspiration, save for the fact that autumn's negative trends are statistically relevant. For rainfall, while trends are generally decreasing annually and seasonally, except for autumn (characterized by positive trends), its dynamics status is uncertain as a result of the general lack of statistical significance. The monthly regime analysis revealed visibly more pronounced trend dynamics for all three climatic parameters.

*Key-words: Southern Oltenia, Climate change, Climate parameters, Trends, Mann-Kendall.*

### **1. INTRODUCTION**

Presently, there is an increasingly global research concern with climate change-related issues, which is currently one of the most critical global environmental changes of the Anthropocene (Steffen et al, 2011). A large share of the studies on climate change are presently directed towards the analysis of the key climate parameters' variability, which influences Earth's biophysical processes, i.e. temperature, rainfall and evapotranspiration.

In the last century (1906-2005), the mean global temperature increased by approximately 0.74 °C (IPCC, 2007; Sayemuzzaman, Jha & Mekonnen, 2014), and the process can be divided into two main phases – 1910-1940 (warming by 0.35 °C) and 1970-up to present day, during which a notably higher warming rate is being recorded (0.55 °C) (IPCC, 2007). Although a general climate warming phenomenon can therefore be noticed worldwide, there are certain regional differences in terms of magnitude (global warming is particularly noticeable at high latitudes in the Northern Hemisphere, over land regions). Among the most important planetary-scale consequences, tipping points stand out (global warming effect autoacceleration mechanisms), e.g. the ongoing polar ice cap melting (albedo changes due to the disappearance of ice) (Callaghan et al, 2011; Lenton, 2012).

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Rainfall has a much higher spatial variability, and the changes are related to certain specificities such as quantity, precipitation type, intensity and frequency. While many of the planetary regions have been affected by significant precipitation rate decreases (southern Europe, Africa and Asia, the Sahel), there are regions where rainfall rates have increased over recent decades (IPCC, 2007). Northern Eurasia, northern North America, southern South America and East Africa are the most visible examples for liquid precipitation gain, which is largely a consequence of global climate warming (atmospheric water vapour amount increase). Therefore, a major current change of this parameter is related to the precipitation type (as snow falls behind liquid precipitation, especially in the northern regions which are more heavily affected by temperature rise), with preeminent consequences on environmental systems such as hydrological systems (Hodgkins, Dudley & Huntington, 2003; Stewart, Cayan, & Dettinger, 2005; Bîrsan et al, 2014; Mitof & Prăvălie, 2014).

Evapotranspiration is the third most important climate parameter, following temperature and precipitation, and plays an essential role in mass and energy flows between the atmospheric and terrestrial systems (Thomas, 2000; Croitoru et al, 2013). There are numerous global regions affected by this parameter's intensification, e.g. Mediterranean region (Chaouche et al, 2010; Espadafor et al, 2011) and Middle East (Tabari & Marofi, 2011; Tabari, Nikbakht & Hosseinzadeh Talaei, 2012). Although evapotranspiration is largely influenced by temperature, it was observed that, contrary to global warming, its values decreased in recent decades in many areas in the USA, India, Thailand, Australia, New Zealand and China (IPCC, 2007). The decreasing trends are due to a complex series of reasons, generally of anthropogenic nature. For instance, it is highly likely that the evapotranspiration decrease in China be due to the sunshine duration decrease resulting from the amplification of pollution and aerosols in the atmosphere, and that of the cloud cover (IPCC, 2007).

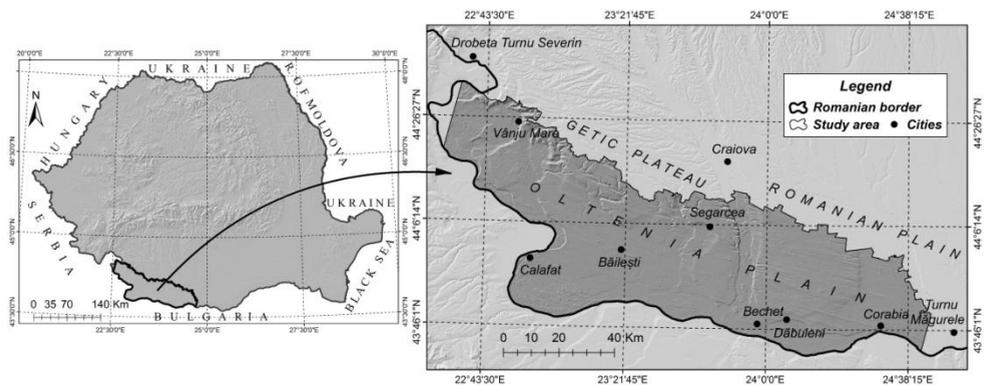
In Romania, studies have shown that the three climatic parameters have undergone significant changes over the past half-century, with notable seasonal differences. Temperature had an overall increasing trend in winter, spring and summer, and a mild decreasing one in autumn (Busuioc et al, 2009). Rainfall generally decreased in winter and spring, and increased in many regions of the country in summer and especially in autumn (Busuioc et al, 2009). Evapotranspiration had a general increase in all seasons except for autumn, when most of the weather stations recorded lower values (Croitoru et al, 2013).

This paper aims to identify spatial and temporal trends of the three climate parameters between 1961 and 2009 in southern Oltenia with the Mann-Kendall method, which is widely used in the international literature focusing on climate variability. This study is relevant both in terms of climatic context (as the region has been subjected to intense climate aridization over the past decades due to the changes in the parameters' regimes) (Prăvălie, 2013a), and in terms of methodology, as it tries to perform a more detailed climatic trend analysis (such as those made at a monthly scale), compared to other country-wide studies.

## 2. DATA AND METHODS

The study area covers southern Oltenia, situated in south-western Romania (**Fig. 1**), and is delimited by the Danube in the west and south, by Olt River in the east, and by the Getic Plateau in the north. It consists of 113 administrative-territorial units and, geographically, the study area mostly overlaps the Oltenia Plain, except for its north-

western region which corresponds to a piedmont area (Getic Plateau). Climatically, the region is subjected to oceanic and Mediterranean influences, which cause higher temperatures and rainfall amounts compared to other regions in southern Romania. Considering the values provided by regional weather stations, mean multiannual temperatures range between 11 and 12 °C, while average multiannual rainfall amounts approximately fall in the 500-650 mm interval (1961-2009 period).



**Fig. 1** Location of the study area, southern Oltenia, in Romania.

For climate trend analysis, this paper used climate data such as mean monthly and annual temperatures (°C), and monthly and annual amounts of rainfall (mm) and potential evapotranspiration (mm), and the analysed period covers a 49 year-range (1961-2009). The temperature and precipitation data were provided by five regional weather stations situated in the area of the respective cities (Drobeta Turnu Severin, Calafat, Craiova, Bechet and Turnu Măgurele) (**Fig. 1**), and were obtained through the ECA&D platform (Klein Tank et al, 2002), for the Drobeta Turnu Severin, Craiova and Turnu Măgurele stations, and from the National Meteorology Administration (NMA, 2014), for the remaining two stations. Based on monthly temperature values, potential evapotranspiration (PET) was computed by Thornthwaite's method (Thornthwaite, 1948), which has produced satisfactory results for Romanian territories (Păltineanu et al, 2007), although it does have certain limitations related to the fact that it only makes use of the temperature parameter.

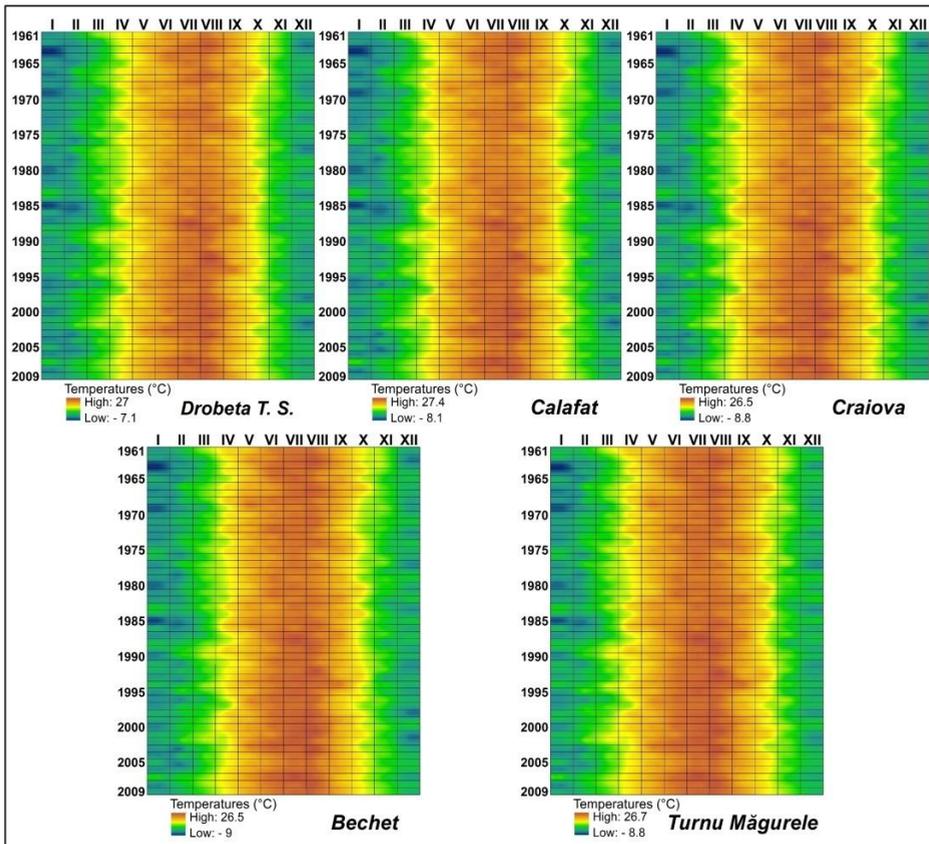
Based on the climate data collected from the five weather stations, annual, seasonal and monthly temporal trends were quantified for the 1961-2009 period. This analysis entailed the use of the Mann-Kendall nonparametric test through the Excel MAKESENS application, developed by the Finnish Meteorological Institute (Salmi et al, 2002). The test operates with four trend statistical significance thresholds, namely  $\alpha = 0.001$ ,  $\alpha = 0.01$ ,  $\alpha = 0.05$  and  $\alpha = 0.1$ . For the graphical analysis of climate data, the vectorized grid method was used in GIS environment (Cheval, Baciu & Breza, 2003), adapted for the present study through the *Spline* point grid data interpolation method (Prăvălie, Sîrodoev & Peptenatu, 2014). Also, Office Excel was used for trend graphical rendering. The analysis of these graphs is important because it provides additional information (compared to the table values obtained by applying the Mann-Kendall statistical test) on the trend dynamics interval throughout the analyzed period.

It is important however to note that between table trends and graphic trends there may be certain discrepancies, in some cases (for stationary trends or those close to stationarity), which is due to the slope trend computation algorithm of the Mann-Kendall test.

### 3. RESULTS AND DISCUSSIONS

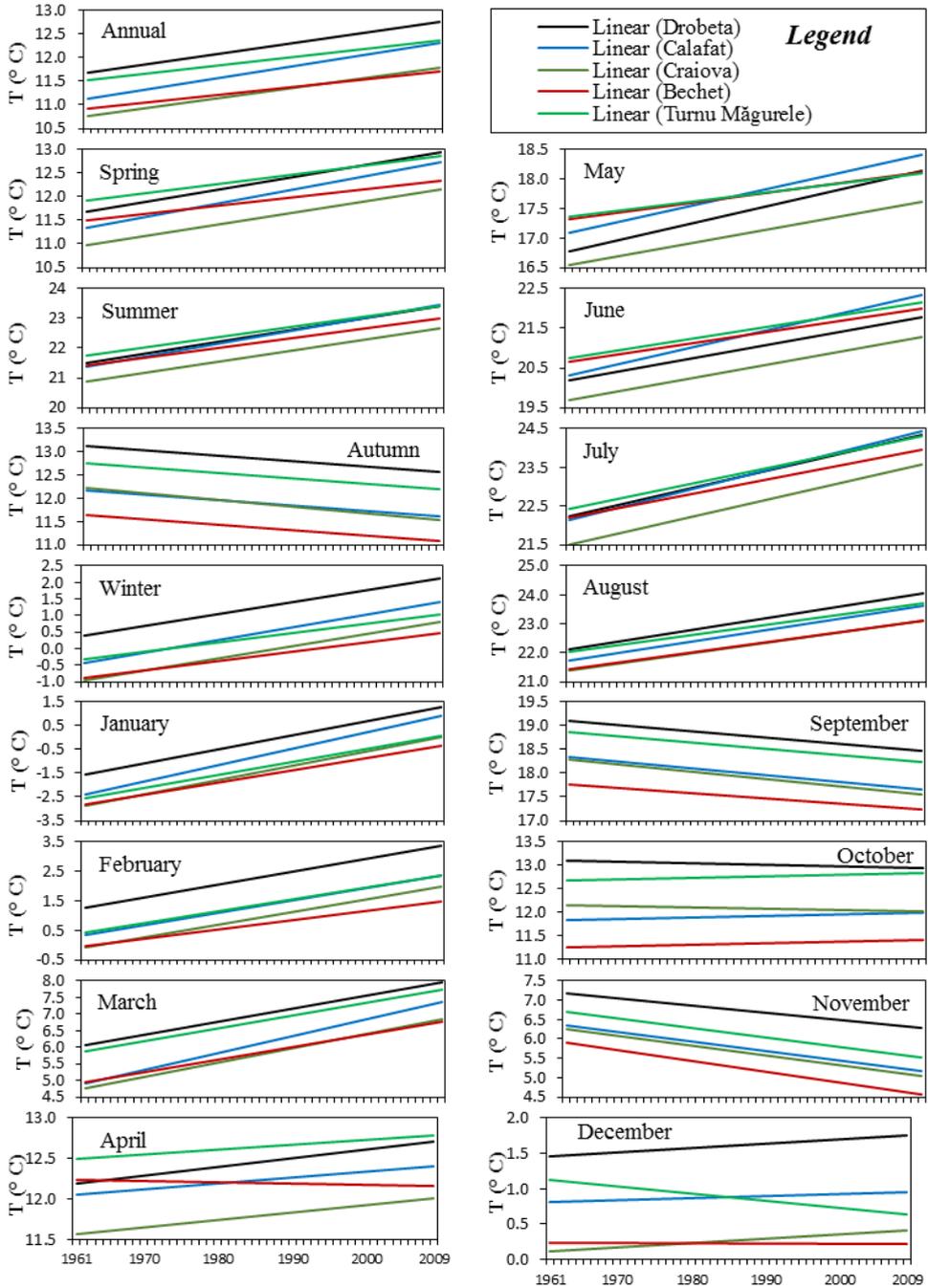
#### Temperature trends

Upon analysis of the vectorized grid method results, an overall temperature increase can be noticed over the last five decades at all five weather stations in southern Oltenia (**Fig. 2**). This is particularly apparent after 1980 (even more so after 1990), which marks a climate warming acceleration, as can be seen from the higher temperatures recorded especially during summer months (**Fig. 2**). Therefore, this thermal intensification, observed primarily during high biological activity periods, constituted the premises for the degradation of natural components in the study area, e.g. forest ecosystems (Prăvălie, Sîrodoev & Peptenatu, 2014).



**Fig. 2** Interannual variations (1961-2009 period) of the mean monthly temperatures ( $^{\circ}\text{C}$ ), recorded at the five weather stations from southern Oltenia.

By placing this parameter's regional dynamics in a global context, it can be stated that the study region's status is consistent with the general planetary-scale climate warming, a phenomenon which has accelerated especially after the seventh and eighth decades of the twentieth century (IPCC, 2007). For a concrete quantification of mean temperature changes, thermal regime dynamics were analysed (in terms of trends) on annual, seasonal and monthly bases. The Mann-Kendall test results evinced particular situations for each analysis scale and, in many cases, for each analysed meteorological station.



**Fig. 3** Temperature (T) trends at annual, seasonal and monthly scales, recorded at the five weather stations from southern Oltenia.

**Table 1. Temperature trend characteristics (resulting from the Mann-Kendall test) at annual, seasonal and monthly scales, at the five weather stations from southern Oltenia.**

Temporal scale	Mann-Kendall test	Temperature (° C)					
		Drobeta T.S.	Calafat	Craiova	Bechet	Turnu Măgurele	
ANNUAL	<i>Sen's slope (yr)</i>	0.022***	0.024**	0.021**	0.016*	0.019*	
	<i>Sen's slope (49 yr)</i>	1.1	1.2	1.0	0.8	0.9	
SEASONAL	SPRING	<i>Sen's slope (yr)</i>	0.027*	0.032*	0.027*	0.020	0.021
	<i>Sen's slope (49 yr)</i>	1.3	1.6	1.3	1.0	1.0	
SUMMER	<i>Sen's slope (yr)</i>	0.041***	0.041***	0.038***	0.032**	0.035***	
	<i>Sen's slope (49 yr)</i>	2.0	2.0	1.8	1.6	1.7	
AUTUMN	<i>Sen's slope (yr)</i>	-0.012	-0.013	-0.012	-0.011	-0.008	
	<i>Sen's slope (49 yr)</i>	-0.6	-0.7	-0.6	-0.5	-0.4	
WINTER	<i>Sen's slope (yr)</i>	0.032*	0.033*	0.033*	0.021+	0.021	
	<i>Sen's slope (49 yr)</i>	1.6	1.6	1.6	1.0	1.1	
MONTHLY	January	<i>Sen's slope (yr)</i>	0.05+	0.05+	0.05	0.033	0.04
	<i>Sen's slope (49 yr)</i>	2.5	2.5	2.5	1.6	2.0	
February	<i>Sen's slope (yr)</i>	0.056+	0.05	0.05	0.048	0.046	
	<i>Sen's slope (49 yr)</i>	2.7	2.5	2.5	2.4	2.2	
March	<i>Sen's slope (yr)</i>	0.041	0.056*	0.044*	0.038+	0.039+	
	<i>Sen's slope (49 yr)</i>	2.0	2.7	2.2	1.8	1.9	
April	<i>Sen's slope (yr)</i>	0.013	0.009	0.012	0.000	0.009	
	<i>Sen's slope (49 yr)</i>	0.7	0.4	0.6	0.0	0.4	
May	<i>Sen's slope (yr)</i>	0.031*	0.033*	0.023	0.019	0.017	
	<i>Sen's slope (49 yr)</i>	1.5	1.6	1.1	0.9	0.8	
June	<i>Sen's slope (yr)</i>	0.036**	0.043**	0.038**	0.033*	0.033**	
	<i>Sen's slope (49 yr)</i>	1.8	2.1	1.9	1.6	1.6	
July	<i>Sen's slope (yr)</i>	0.043***	0.043***	0.039**	0.032**	0.033***	
	<i>Sen's slope (49 yr)</i>	2.1	2.1	1.9	1.6	1.6	
August	<i>Sen's slope (yr)</i>	0.043*	0.041*	0.036*	0.034*	0.036*	
	<i>Sen's slope (49 yr)</i>	2.1	2.0	1.8	1.7	1.7	
September	<i>Sen's slope (yr)</i>	-0.017	-0.021	-0.021	-0.013	-0.018	
	<i>Sen's slope (49 yr)</i>	-0.8	-1.0	-1.1	-0.6	-0.9	
October	<i>Sen's slope (yr)</i>	0.000	0.007	0.003	0.008	0.006	
	<i>Sen's slope (49 yr)</i>	0.0	0.3	0.2	0.4	0.3	
November	<i>Sen's slope (yr)</i>	-0.021	-0.025	-0.022	-0.027	-0.020	
	<i>Sen's slope (49 yr)</i>	-1.0	-1.2	-1.1	-1.3	-1.0	
December	<i>Sen's slope (yr)</i>	0.008	0.006	0.013	0.003	-0.005	
	<i>Sen's slope (49 yr)</i>	0.4	0.3	0.7	0.2	-0.3	

Note: “+”, “\*”, “\*\*” and “\*\*\*” indicate significance at  $\alpha = 0.1, 0.05, 0.01$  and  $0.001$  level, respectively; the values without these symbols indicate lack of statistical significance.

Annually, in the 1961-2009 reference period, upward trends were recorded at all five weather stations, statistically significant in all instances (with a significance level ranging from 0.05 to 0.001) (**Fig. 3, Table 1**). The Calafat, Drobeta and Craiova stations are the most representative for the amplified annual thermal regime, given the high rates of temperature increase (with annual intensification values ranging from 0.21 to 0.24 °C, and with a total increase over the entire 49-year period of more than 1 °C) (**Table 1**).

Seasonally, there are certain specificities for each season, related to both temporal trend recorded values, and to their level of statistical confidence. In spring, while positive trends were found at all stations (**Fig. 3**), only three were statistically significant (Drobeta, Calafat and Craiova), where higher warming rates were identified (more than 1 °C throughout the study period) compared to the other two stations (**Table 1**). This is due to the months of March and May, as April does not influence temperature evolution in this

season (trends are almost stationary at all five stations, and are not statistically significant). Interestingly, March has the highest statistical confidence level out of the three spring months, and also has the maximum monthly warming rate recorded at the weather stations in the study region (Bechet station, where the warming rate over the 49 years amounted to 2.7 °C, which was found in only one other instance – in February, at the Drobeta station) (**Table 1**).

Summer is the season with the most obvious climate warming, as the positive trends (statistically significant at high thresholds in all cases, i.e.  $\alpha$  - 0.01 and 0.001) recorded high warming rates (between 1.6 – 2 °C) over the 49 years (**Fig. 3, Table 1**). While the highest monthly warming values are found in July and August, all three summer months generally show high thermal rates, at high statistical significance thresholds (**Table 1**).

Autumn is an exception to the entire seasonal context due to decreasing thermal trends (**Fig. 3**). While all stations detected variable climate cooling in this season, the cooling rates did not have high values (they ranged between -0.4 and -0.7 °C / 49 years) and lacked statistical significance at all weather stations (**Table 1**). This season's trend specificity is due to September and November (cooling rates over 49 years generally exceed 1 °C), as October is an exception (while slope values are positive, they are stationary or very close to being stationary); however, none of the monthly trends is statistically significant (**Table 1**).

In winter, all stations recorded increasing trends (statistically significant, with one exception – Turnu Măgurele station), with annual rates ranging from 0.021 to 0.033 °C, and rates over 49 years falling in the 1 - 1.6 °C interval (**Fig. 3, Table 1**). January and February had the greatest influence on the overall warming of the entire season (warming rates / 49 generally exceeding 2 °C, with a 2.7 °C peak at Drobeta station, in February), while December trends are almost stationary, or even negative (at Turnu Măgurele).

Therefore, the trends identified in this region of south-western Romania are consistent with the overall nation-scale temperature change pattern. A general nation-wide climate warming was noticed in spring, summer and winter (especially outside of Carpathian regions), and a slight cooling in autumn (lacking statistical significance, however) (Busuioc et al, 2010), which resembles this case study's results.

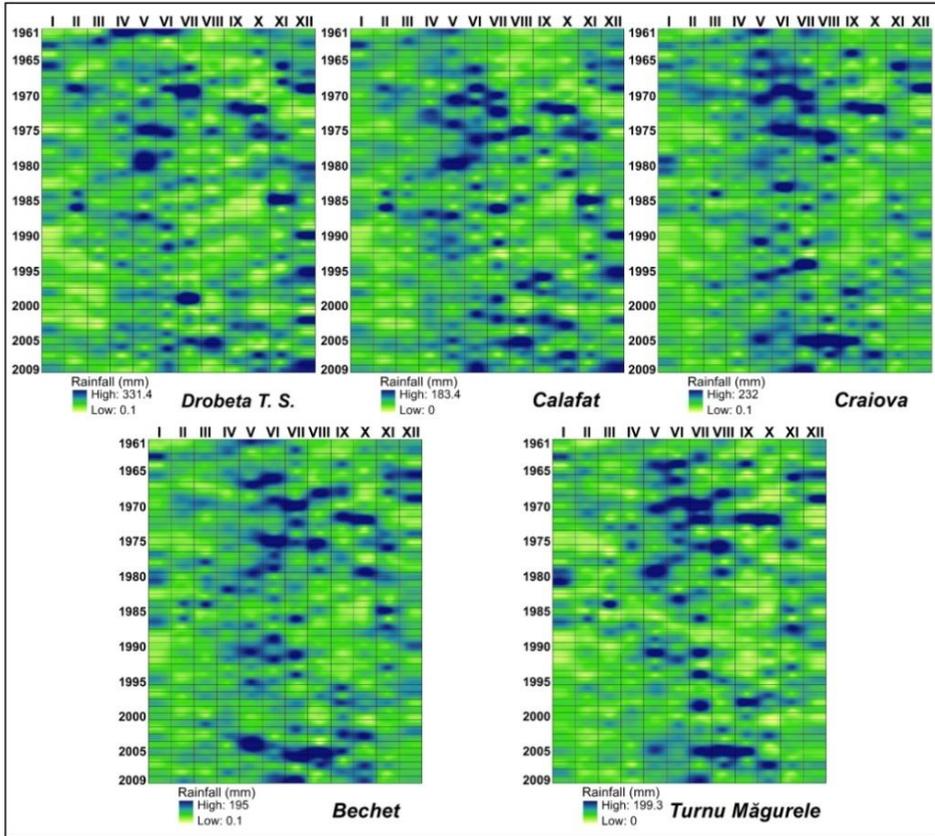
One of the main causes of these temperature dynamics in Romania is related to the frequency and intensity amplification of high altitude anticyclone structures in recent decades, a phenomenon which has led to the increase of air temperature at 850 mb (and, implicitly, of that in the lower troposphere, near ground level) in winter, spring and summer, while autumn had conflicting trends due to the decrease of these structures' frequency at this particular atmospheric altitude (Busuioc et al, 2009).

Another important cause is linked to the North Atlantic Oscillation mechanism (NAO), specifically to the positive phase of the phenomenon, the intensification of which has led to an accelerated climate warming over recent decades, especially in the extra-Carpathian regions of Romania, where the study area is located (Busuioc et al, 2009).

### **Precipitation trends**

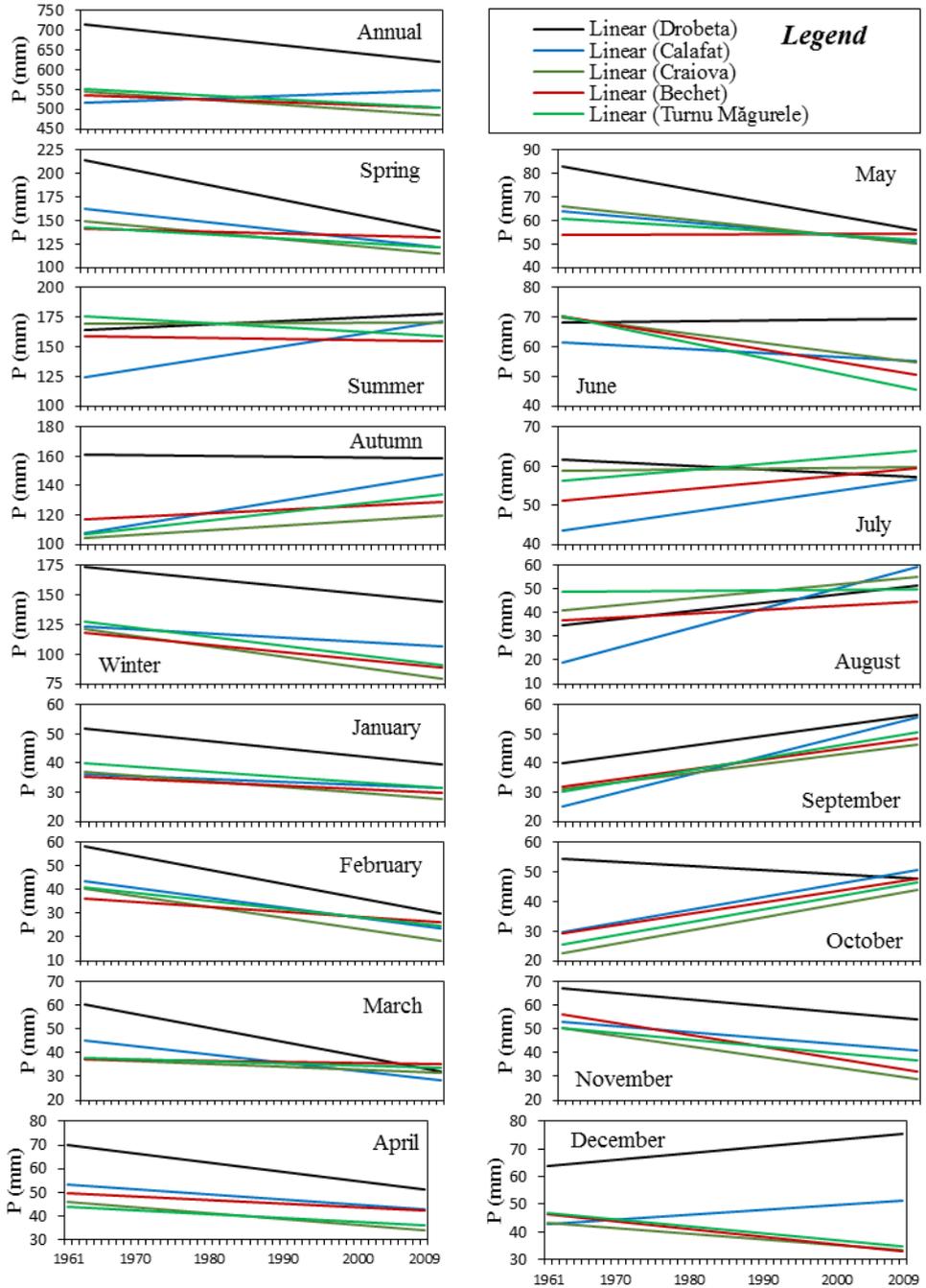
Upon analysis of the overall rainfall regime dynamics, the vectorized grid results revealed a general decrease in precipitation amounts, especially after 1980, at all five weather stations (**Fig. 4**). Thus, a general decrease can be noticed especially during biologically active periods (April-October), which caused, for this climatic parameter as well, an acceleration of climatic stress on natural components (e.g. forests) over the past decades (Prăvălie, Sîrodoev & Peptenatu, 2014).

Regarding the trend statistical, while results indicated specificities for each temporal regime (annual, seasonal and monthly), it was found that this parameter generally shows uncertain dynamics, with trends lacking statistical significance in most of the analysed cases. Annually, trends indicated a general decrease (lacking statistical significance) of rainfall amounts (at all stations, except for Calafat), with annual rates ranging from -0.5 to -1.6 mm, or from -24 to -76 mm when considering the 49-year rate (**Fig. 5**, **Table 2**).



**Fig. 4** Interannual variations (1961-2009 period) of the monthly amounts of rainfall (mm), recorded at the five weather stations from southern Oltenia.

Seasonally, the spring season is generally characterized by the most apparent decreases in precipitation amounts (**Fig. 5**), which come close to -70 mm over the entire analysed period for the Drobeta Turnu Severin station. While it is the only season showing statistical significance, it only does so at Drobeta and Calafat stations (**Table 2**). Spring's status is due to the months of March and May, as March is the only spring month with a statistically significant decrease rate (the highest was recorded at the Drobeta station, but with a minimum significance level) (**Table 2**).



**Fig. 5** Precipitation (P) trends at annual, seasonal and monthly scales, recorded at the five weather stations from southern Oltenia.

**Table 2. Precipitation trend characteristics (resulting from the Mann-Kendall test) at annual, seasonal and monthly scales, at the five weather stations from southern Oltenia.**

Temporal scale	Mann-Kendall test	Precipitation (mm)					
		Drobeta T.S.	Calafat	Craiova	Bechet	Turnu Măgurele	
ANNUAL	<i>Sen's slope (yr)</i>	-1.553	0.756	-1.388	-0.483	-0.856	
	<i>Sen's slope (49 yr)</i>	-76.1	37.0	-68.0	-23.7	-41.9	
SEASONAL	SPRING	<i>Sen's slope (yr)</i>	-1.401*	-0.952*	-0.751	-0.182	-0.417
		<i>Sen's slope (49 yr)</i>	-68.7	-46.6	-36.8	-8.9	-20.4
	SUMMER	<i>Sen's slope (yr)</i>	0.015	1.049	-0.146	-0.170	-0.154
		<i>Sen's slope (49 yr)</i>	0.7	51.4	-7.2	-8.3	-7.5
	AUTUMN	<i>Sen's slope (yr)</i>	0.069	0.775	0.600	0.323	0.746
		<i>Sen's slope (49 yr)</i>	3.4	38.0	29.4	15.8	36.6
	WINTER	<i>Sen's slope (yr)</i>	-0.628	-0.324	-0.346	-0.423	-0.395
		<i>Sen's slope (49 yr)</i>	-30.7	-15.9	-16.9	-20.7	-19.4
MONTHLY	January	<i>Sen's slope (yr)</i>	-0.100	-0.081	0.010	0.036	0.064
		<i>Sen's slope (49 yr)</i>	-4.9	-4.0	0.5	1.8	3.1
	February	<i>Sen's slope (yr)</i>	-0.568+	-0.415+	-0.365+	-0.185	-0.300
		<i>Sen's slope (49 yr)</i>	-27.8	-20.4	-17.9	-9.0	-14.7
	March	<i>Sen's slope (yr)</i>	-0.543+	-0.360	-0.053	-0.072	-0.008
		<i>Sen's slope (49 yr)</i>	-26.6	-17.7	-2.6	-3.5	-0.4
	April	<i>Sen's slope (yr)</i>	-0.142	-0.210	-0.290	-0.172	-0.149
		<i>Sen's slope (49 yr)</i>	-7.0	-10.3	-14.2	-8.4	-7.3
	May	<i>Sen's slope (yr)</i>	-0.540	-0.265	-0.323	-0.110	-0.160
		<i>Sen's slope (49 yr)</i>	-26.5	-13.0	-15.9	-5.4	-7.9
	June	<i>Sen's slope (yr)</i>	0.180	-0.028	-0.132	-0.227	-0.314
		<i>Sen's slope (49 yr)</i>	8.8	-1.4	-6.5	-11.1	-15.4
	July	<i>Sen's slope (yr)</i>	-0.200	0.322	-0.225	0.112	0.147
		<i>Sen's slope (49 yr)</i>	-9.8	15.8	-11.0	5.5	7.2
	August	<i>Sen's slope (yr)</i>	0.064	0.693*	-0.087	-0.105	-0.112
		<i>Sen's slope (49 yr)</i>	3.1	34.0	-4.3	-5.1	-5.5
	September	<i>Sen's slope (yr)</i>	0.451	0.532*	0.301	0.307	0.426
		<i>Sen's slope (49 yr)</i>	22.1	26.1	14.7	15.0	20.9
	October	<i>Sen's slope (yr)</i>	-0.002	0.364	0.412+	0.446	0.426
		<i>Sen's slope (49 yr)</i>	-0.1	17.8	20.2	21.8	20.9
	November	<i>Sen's slope (yr)</i>	-0.244	-0.195	-0.348+	-0.420	-0.244
		<i>Sen's slope (49 yr)</i>	-11.9	-9.5	-17.0	-20.6	-12.0
	December	<i>Sen's slope (yr)</i>	-0.063	0.087	0.028+	-0.137	-0.111
		<i>Sen's slope (49 yr)</i>	-3.1	4.3	1.3	-6.7	-5.4

Note: "+", "\*", "\*\*" and "\*\*\*" indicate significance at  $\alpha = 0.1, 0.05, 0.01$  and  $0.001$  level, respectively; the values without these symbols indicate lack of statistical significance.

In summer, in three of the five cases, slightly decreasing precipitation trends were detected (Craiova, Bechet and Turnu Măgurele), while at the Drobeta and Calafat stations positive trends were identified (evident at Calafat, with a rate of 51.4 mm / 49 years); however, all instances lacked statistical significance. In the three summer months, trend slope values are generally relatively low, except for August, at the Calafat station (**Fig. 5, Table 2**), where a pronounced variability rate was recorded, the only statistically significant one out of all summer months.

Autumn represents a particular case in the rainfall seasonal variability analysis, as it is the only season with precipitation amount increases recorded at all the weather stations. Although these increases are evident (in terms of trend slope value) in four of the five cases (except for the Drobeta station, which has an almost stationary trend) (**Fig. 5**), none of the stations shows statistically significant trends. While the largest contribution to precipitation

increase, typical for this season, is attributed to the months of September and October (as November is characterized by contrary, negative trends, statistically significant only at the Craiova station), the two months do not generally show statistical significance (except for the Calafat station in September, and Craiova in October) (**Table 2**).

Winter trend analysis reveals declines at all five weather stations, with rates ranging from -15.9 to -30.7 mm over the 49 years (**Table 2**). This situation is due for the most part to February, which is characterized by high trend slope values, statistically significant (at a minimal threshold of  $\alpha = 0.1$ ) at three of the five weather stations in the study region (**Table 2**).

By placing this analysis in the general precipitation dynamics context over the past five decades in Romania, a certain level of similarity can be noticed between results for this climatic parameter as well. Therefore, nationally, an overall precipitation decrease was recorded in winter, spring and, partially, in summer, while in autumn significant increases were detected over large areas, of which the most pronounced were found in south-eastern and north-western regions of Romania (Busuioc et al, 2009; Busuioc et al, 2010). However, regardless of the trends identified nationally or regionally (such as this study), an important feature of precipitation is related to the temporal variability's uncertainty, which means that, in Romania at least, it is generally difficult to detect clear, statistically significant trends of temporal and spatial changes for this climatic parameter.

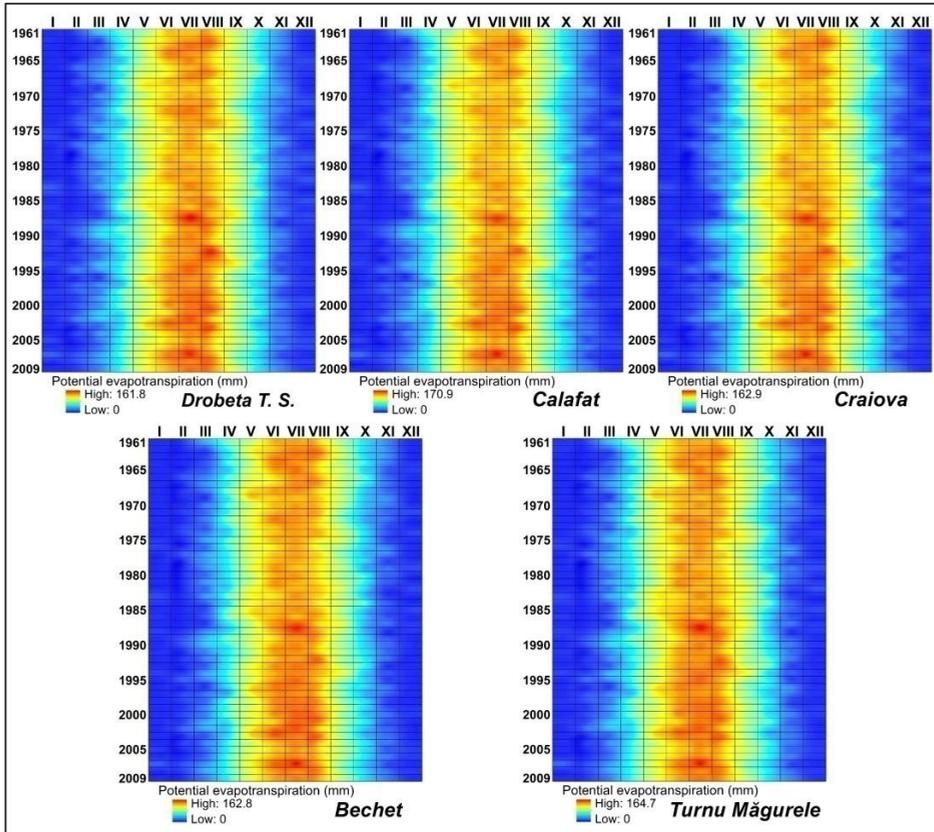
Regarding the causes of these dynamics in recent decades, they are related to the general increase in the frequency of anticyclonic structures over Romanian territory in winter, spring and summer, which determined an overall rainfall amount decrease, as well as an amplification of cyclonic structures in autumn, thus causing a precipitation increase in this season (Busuioc et al, 2010). A particular situation can be noticed in summer, when in addition to the amplified anticyclonic structures which played an essential role in reducing rainfall over large areas in Romania, there was also an increase in the specific humidity of air at 850 mb, responsible for precipitation increase in numerous regions throughout the country (Busuioc et al, 2009). This study's results' status, in terms of summer trends (precipitation decreases and increases) (**Table 2**), can be explained by these contrary effects mechanisms of rainfall regimes. Other causes may be related to oscillations of the NAO index, the positive phase of which, having accelerated after 1980, caused declines in precipitation amounts in Romania in certain times of the year, e.g. winter season (Tomozeiu, Stefan, & Busuioc, 2005), which means it is very likely for this phenomenon to have influenced rainfall variability in the analysed region in south-western Romania, at least in this season.

### **Potential evapotranspiration trends**

The overall assessment of the temporal dynamics of this study's last parameter reveals a value increase roughly after 1985, especially in the warm season (the grid method indicated obviously higher PET values mainly in July and August) (**Fig. 6**). This is largely influenced by temperature dynamics, given the methodology for computing potential evapotranspiration.

A detailed three-scale trend analysis revealed peculiarities for this parameter as well. Annually, the five weather stations recorded apparent upward PET rate trends (high and very high statistical confidence thresholds) ranging from 0.68 to 0.92 mm / year, or from 33.3 to 45.2 mm / 49 years (**Fig. 7, Table 3**). Seasonally, it can be noticed that spring is characterized by relatively low variability rates (increase), reaching up to a maximum of 13.8 mm / 49 years at Calafat station. However, one of this season's main features is having

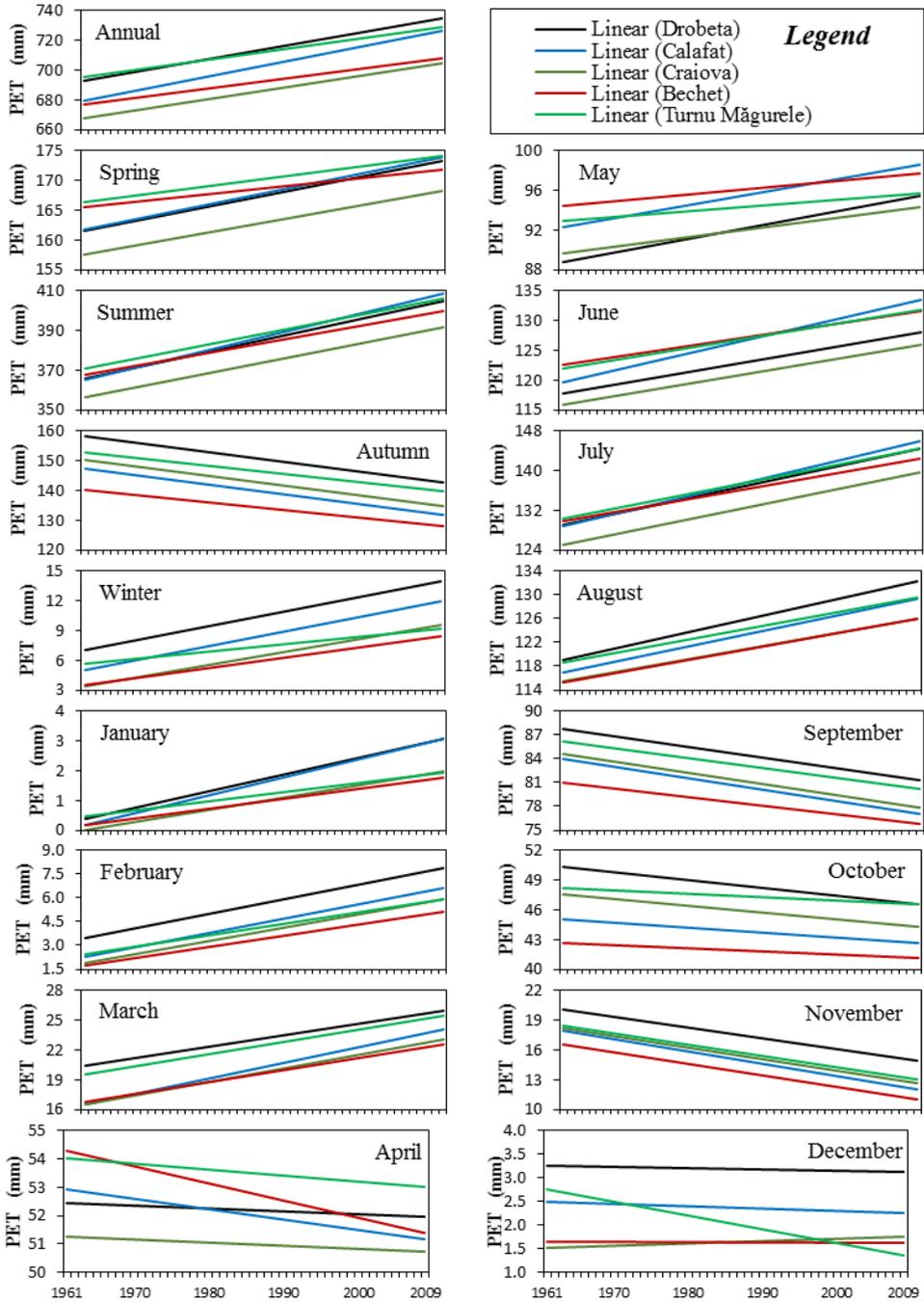
the lowest rate statistical confidence level (**Table 3**). Its rate values are mainly due to March (**Fig. 7, Table 3**), which generally had the highest trend slope values, but with lack of statistical significance (except for Calafat station in this month, April and May lacked statistical significance in all considered cases).



**Fig. 6** Interannual variations (1961-2009 period) of the monthly amounts of potential evapotranspiration (mm), recorded at the five weather stations from southern Oltenia.

Summer is characterized by clear PET value increasing trends, ranging from 31.9 to 42.5 mm / 49 years, with a high degree of statistical confidence for all weather stations (**Table 3**). Although PET increase values show statistical significance for all summer months, July is the most evident by having both the highest positive rates, and the highest degree of statistical significance.

Autumn is an exception, similarly to the temperature parameter, due to the negative trends it recorded. These trends have relatively constant values, given that the rate interval is limited, and ranges from -12 to -18 mm over the 49 years (**Table 3**). Also, statistical significance is found in all cases, and falls in the  $\alpha$  range 0.1 - 0.01. Of all autumn months, September stands out, due to the higher trend slope values, and the statistical confidence found at all five weather stations (**Table 3**).



**Fig. 7** Potential evapotranspiration (PET) trends at annual, seasonal and monthly scales, recorded at the five weather stations from southern Oltenia.

**Table 3. Potential evapotranspiration trend characteristics (resulting from the Mann-Kendall test) at annual, seasonal and monthly scales, at the five weather stations from southern Oltenia.**

Temporal scale	Mann-Kendall test	Potential evapotranspiration (mm)					
		Drobeta T.S.	Calafat	Craiova	Bechet	Turnu Măgurele	
ANNUAL	<i>Sen's slope (yr)</i>	0.854***	0.922***	0.850**	0.765**	0.681**	
	<i>Sen's slope (49 yr)</i>	41.9	45.2	41.6	37.5	33.3	
SEASONAL	SPRING	<i>Sen's slope (yr)</i>	0.267+	0.282+	0.254+	0.155	0.201
	<i>Sen's slope (49 yr)</i>	13.1	13.8	12.5	7.6	9.9	
SUMMER	<i>Sen's slope (yr)</i>	0.867***	0.828***	0.721***	0.651**	0.740***	
	<i>Sen's slope (49 yr)</i>	42.5	40.6	35.3	31.9	36.2	
AUTUMN	<i>Sen's slope (yr)</i>	-0.367**	-0.373*	-0.329*	-0.271+	-0.251+	
	<i>Sen's slope (49 yr)</i>	-18.0	-18.3	-16.1	-13.3	-12.3	
WINTER	<i>Sen's slope (yr)</i>	0.151*	0.146*	0.122*	0.101*	0.054	
	<i>Sen's slope (49 yr)</i>	7.4	7.2	6.0	4.9	2.7	
MONTHLY	January	<i>Sen's slope (yr)</i>	0.000	0.000	0.000	0.000	0.000
	<i>Sen's slope (49 yr)</i>	0.0	0.0	0.0	0.0	0.0	
February	<i>Sen's slope (yr)</i>	0.075	0.000	0.006+	0.008+	0.007	
	<i>Sen's slope (49 yr)</i>	3.7	0.0	0.3	0.4	0.4	
March	<i>Sen's slope (yr)</i>	0.110	0.164+	0.140	0.120	0.125	
	<i>Sen's slope (49 yr)</i>	5.4	8.1	6.9	5.9	6.1	
April	<i>Sen's slope (yr)</i>	-0.002	-0.010	0.017	-0.041	-0.015	
	<i>Sen's slope (49 yr)</i>	-0.1	-0.5	0.8	-2.0	-0.8	
May	<i>Sen's slope (yr)</i>	0.149	0.164	0.100	0.119	0.073	
	<i>Sen's slope (49 yr)</i>	7.3	8.0	4.9	5.8	3.6	
June	<i>Sen's slope (yr)</i>	0.259*	0.299**	0.249*	0.191*	0.225*	
	<i>Sen's slope (49 yr)</i>	12.7	14.7	12.2	9.3	11.0	
July	<i>Sen's slope (yr)</i>	0.299***	0.306***	0.246**	0.213**	0.237***	
	<i>Sen's slope (49 yr)</i>	14.7	15.0	12.1	10.5	11.6	
August	<i>Sen's slope (yr)</i>	0.274*	0.251*	0.242*	0.213*	0.240*	
	<i>Sen's slope (49 yr)</i>	13.4	12.3	11.9	10.5	11.7	
September	<i>Sen's slope (yr)</i>	-0.147+	-0.173*	-0.157*	-0.125+	-0.141*	
	<i>Sen's slope (49 yr)</i>	-7.2	-8.5	-7.7	-6.1	-6.9	
October	<i>Sen's slope (yr)</i>	-0.065	-0.038	-0.052	-0.013	-0.010	
	<i>Sen's slope (49 yr)</i>	-3.2	-1.8	-2.6	-0.6	-0.5	
November	<i>Sen's slope (yr)</i>	-0.104+	-0.116+	-0.093	-0.118	-0.107	
	<i>Sen's slope (49 yr)</i>	-5.1	-5.7	-4.5	-5.8	-5.2	
December	<i>Sen's slope (yr)</i>	0.000	0.000	0.000	0.000	0.000	
	<i>Sen's slope (49 yr)</i>	0.0	0.0	0.0	0.0	0.0	

Note: "+", "\*", "\*\*" and "\*\*\*" indicate significance at  $\alpha = 0.1, 0.05, 0.01$  and  $0.001$  level, respectively; the values without these symbols indicate lack of statistical significance.

The last season, winter, has slight increasing PET trends (Fig. 7), with rate values which did not exceed 7.4 mm over the entire period (but generally statistically significant). This season's trends are due solely to February, as the other two months were stationary (Table 3).

Following this parameter's trend assessment and analysis, it can be stated that the results are generally in accordance with certain country-wide studies (Croitoru et al, 2013), which detected an overall increase in PET values both annually and seasonally, except for autumn, similarly to the present study. However, in some cases certain differences arise from potential evapotranspiration values obtained through different computation methods. For the country-wide analysis made in Romania (Croitoru et al, 2013), trend results were obtained based on PET values computed with the FAO Penman-Monteith method (Allen et al, 1998), which is widely used in specialized studies - this is the main cause for any

potential discrepancies (especially with regard to statistical significance and, in very few cases, to trend type) between the two studies. Moreover, upon analysis of this parameter's entire temporal dynamics and after having compared the results to rainfall variation, it can be noticed that potential evapotranspiration trends generally showed clearly higher rates, which means that the climatic water deficit has increased over the five-decade study period. Autumn is an exception, as this season is representative for the excess climatic water recorded between 1961 and 2009, which resulted from increased rainfall amounts and lower evapotranspiration rates.

With regard to agricultural systems, as their dependence on climatic conditions has increased significantly over recent decades, against the background of the general collapse of irrigation systems (Prăvălie, 2013b), the climatic water deficit had a real impact on the fluctuations (decrease) of agricultural yields (Bălteanu et al, 2013). Upon a separate analysis of evapotranspiration, it was found that the general increasing trend of the 1961-2009 period had an indirect impact on yield decline for southern Oltenia's main crops (wheat, corn, sunflower), by influencing (decreasing) groundwater levels (Prăvălie, Peptenatu & Sîrodoev, 2013a). The ecological component is noteworthy as well, as it has also been subjected to climate change-induced pressure. For instance, forest ecosystems have degraded (withering) due to the region's climate aridization (especially during summer months), against the background of temperature rise (and implicitly potential evapotranspiration increase) and rainfall decrease (Prăvălie, Sîrodoev & Peptenatu, 2013b; Prăvălie, Sîrodoev & Peptenatu, 2014).

#### 4. CONCLUSIONS

The present study aims to thoroughly analyse the dynamics (annual, seasonal and monthly) of the main climatic parameters (mean temperatures, and precipitation and potential evapotranspiration amounts) in south-western Romania, between 1961 and 2009. To this end, climate data provided by five regional weather stations were analysed using the Mann-Kendall statistical test as main trend quantification and analysis method. The results revealed the following features of each climate parameter's dynamics:

- the mean annual temperature had positive annual and seasonal trends (statistically significant for the most part), except for autumn (cooling trends ranging from 0.4 to 0.7 °C / 49 years, lacking statistical significance); while annual warming rates / 49 years were roughly situated around 1 °C, seasonal values were twice as high, e.g. summer (2 °C / 49 years or close to this threshold for all weather stations); almost all monthly instances had positive trends (statistically significant especially in summer months), except for September and November, characterized by decreasing temperatures;

- while rainfall had more acute dynamics, the identified trends show uncertainty due to the general lack of statistical significance; an overall decrease was observed in precipitation annually (with a maximum value of 76 mm / 49 years) and seasonally (the maximum value close to -70 mm / 49 was recorded in spring), except for autumn (increase rates of up to 38 mm / 49 years) and, in part, summer (increases in two cases, with a maximum value of 51 mm / 49 years); monthly, generally negative trends were recorded, with clear exceptions in January, July, September and October (months with increasing trends at at least three out of five analysed weather stations);

- the last parameter, potential evapotranspiration, had relatively similar dynamics to temperature; the trends identified between 1961 and 2009 are positive annually and seasonally (except for autumn), and are generally statistically significant (the annual regime

and summer are the most representative for high and very high levels of statistical confidence); in terms of PET increase rates, it was found that, in some cases, they exceeded 40 mm / 49 years both annually and seasonally (summer); monthly, mostly positive trends were observed, except for April, September, October and November, representative for negative trends, but also except for December and January, which had stationary trends.

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