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UNIVERSITATEA TEHNICA "GHEORGHE ASACHI" DIN IASI

„BABEŞ-BOLYAI" UNIVERSITY OF CLUJ-NAPOCA

Faculty of Environmental Science and Engineering

STUDIES REGARDING RECENT CLIMATE CHANGES IN NORTHEASTERN ROMANIA

- THE SUMMARY OF THE THESIS -

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The **"DOCTORAL STUDIES FOR EUROPEAN PERFORMANCES IN RESEARCH INOVATION (CUANTUMDOC)"** project POSDRU/107/1.5/S/79407, is a strategic project which has as general objective „*The implementation of the managerial, research and educational strategies for the improvement of the initial training of the future researchers through doctoral studies program, according to the Bologna process, by the development of the research specific proficiency, but also of some other common outcomes: research management, linguistic and communication skills, scientific documentation, elaboration, publication and scientific communication, modern ITC equipment utilisation, entrepreneurship transfer of the research results. The human capital development for research and inovation will contribute to long-term doctoral training at European Union level with interdisciplinary concern. The PhD students financial support will provide their participation to national doctoral programs, as well as the research internship in European Union universities and research institutes. The project main objective is the training of a young researcher adapted to the new economic and technological environment having theoretical, practical, economic and managerial knowledge, which will be able to promote the sustainable development and the environmental protection principles.* "

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CONTENTS

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Introduction

In the last years, climate changes have become a subject of great topical interest worldwide. This problem worries the scientific community, as it could have a major impact on natural and social systems at local, regional and national scales. The increase of mean and extreme temperature over the last century has been largely demonstrated in many studies focused on different regions of the world (Frich et al., 2002; Klein Tank şi Konnen, 2003; Vinnikov şi Grody, 2003; del Rio et al., 2005; Vincent et al., 2005; Moberg et al., 2006; IPCC 2007; El Kenawy et al., 2011; del Rio et al., 2012). One of the most significant consequences of the identified global warming would be an increase in the magnitude and frequency of extreme precipitation events generated by increased atmospheric moisture levels, thunderstorm activity, and large scale storm activity (Sen Roy şi Balling, 2004). Global warming and changes in precipitation are facts that have numerous negative impacts on society and ecosystems. Among the adverse effects caused by changes in these two climatic elements are: heat stress of a higher intensity which will lead to a higher frequency of death and specific diseases caused by high temperatures and increased vulnerability of plants, increased extreme hydrological events such as floods and droughts, events that have a profound impact on the economy, especially in developing countries, where agriculture plays a major role (Choi et al., 2009; Radinović şi Ćurić, 2012; Wang et al., 2012), as is the case of Romania.

For a better understanding of climate change, in the following lines will define climate and climate change as they were formulated by the World Meteorological Organization (WMO, 2002).

Climate is generally defined as the average state of the atmosphere for a long period of time and generally for a specified geographical region, whose expansion area can vary from a certain place, till the entire globe (WMO, 2002; Sandu et al., 2008).

Climate change is defined as a significant change in climate attributed directly or indirectly to human activity which, in addition to natural climate variability, is observed over comparable time periods (WMO, 2002).

The definition adopted by the United Nations Framework Convention on Climate Change (UNFCCC) focuses only on the human activity that alters the composition of the global atmosphere and excludes other human activity effects such as changes in the land surface. Sometimes the term "climate change" is used to include all climate variability, which can lead to considerable confusion. Climate has variability on all time and space scales and will always be changing.

The main purpose of this study is to identify recent climate changes in northeastern Romania across 50 years (1961-2010).

1. Geographical location and boundaries of the studied area

For this study, the northeastern Romania was considered (Figure 1). The studied area covers the administrative territory of four counties: Botoşani, Iaşi, Neamţ and Suceava and has an area of 24911 km^2. The study region is bordered on the north by Ukraine, on the east by Republic of Moldova, on the south by Bacău and Vaslui counties and on the west by Harghita, Mureş, Bistriţa-Năsăud and Maramureş counties. The altitude decreases from west to east from mountainous area of Eastern Carpathians to Eastern part of the Moldavian Tableland. The climate of this region is temperate-continental with a more pronounced continental character in the east and moderate character westward.

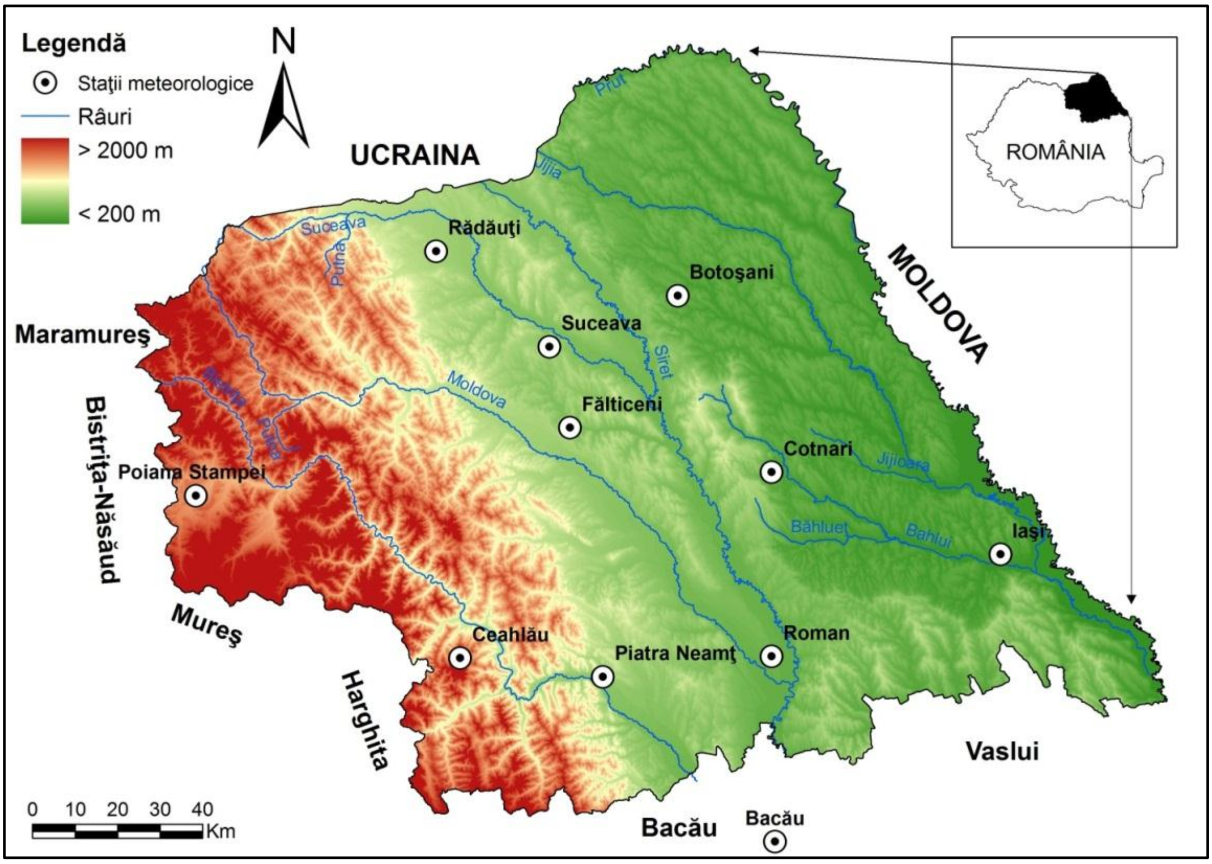


Figure 1. The studied area and the location of the weather stations considered

2. Data and methods

2.1. Data

Data recorded at ten weather stations in Northeastern Romania were used for the present study. The stations are uniform distributed: three of them are located in plain area, five in hilly regions and two in mountainous area of Eastern Carpathians area as shown in Figure 1 and Table 1. For a detailed analysis on temperature and precipitation extremes were used data from a 11th station (Bacău), as support station, located outside the analyzed area, at about 17 km south of it.

Table 1. Geographical coordinates of the weather stations considered

Weather station[a]	**Latitude (N)**	**Longitude (E)**	**Altitude (m)**
Bacău	46°31’	26°54’	184
Botoşani	47°44’	26°39’	161
Ceahlău	46°59’	25°57’	1897
Cotnari	47°22’	26°56’	289
Fălticeni	47°28’	26°18’	348
Iaşi	47°10’	27°38’	102
Piatra Neamţ	46°55’	26°24’	314
Poiana Stampei	47°20’	25°08’	923
Rădăuţi	47°50’	25°54’	389
Roman	46°58’	26°55’	216
Suceava	47°38’	26°15’	350

[a]Weather stations are ranged in alphabetical order

The datasets cover a 50 years period (1961-2010) and they were provided by Romanian National Meteorology Administration (ANM) and ECA&D database (Klein Tank et al., 2002). The period of 50 years was chosen in order to avoid as much as possible the inhomogeneities due to non-climatic factors. Ceahlău station began recordings in 1964 therefore its data series is only 47 years long.

Digital Elevation Model (DEM) data were provided by geo-spatial project (http://earth.unibuc.ro/download/datele-srtm90-reproiectate-in-stereo70) and is based on SRTM model (Shuttle Radar Topography Mission), which represents the best global source of altimetry data.

In order to find connections between trends in mean air temperature and precipitation, and trends in the principal circulation patterns which influences the northeastern part of Romania, we used monthly indices of East Atlantic Pattern (EA), North Atlantic Oscillation (NAO), East Atlantic/Western Russia (EW), Scandinavia Pattern (SC), and Polar/Eurasian pattern (PO), provided by the National Oceanic and Atmospheric Administration Climate Prediction Center (http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml).

2.2. Methods

To illustrate the spatial distribution of climatic elements and phenomena whose territorial variation is very closely related to the altitude was used a well-known method in the literature – Detrended Krigind which is considered to be the most appropriate method for climatic interpolation (Patriche, 2009).

For those parameters in which the coefficient of correlation in relation to altitude were not high enough, the spatial distribution was made by the Ordinary Kriging interpolation method.

As a general rule in testing data for homogeneity the more tests are used, the more accurate are the results. Therefore, the precipitation data have been tested for homogeneity with four tests: Pettitt test – PET (Pettitt, 1979), Standard Normal Homogeneity Test – SNH (Alexandersson, 1986), Buishand Range test – BHR (Buishand, 1982) and Von Neumann Ratio test – VON (Von Neumann, 1941). The first three ones, under the alternative hypothesis, assume that a break in the data series is present and allow identifying the time at which the shift occurs. The VON test assumes, under the alternative hypothesis, the series is not randomly distributed and not allow detecting the time at which the change occurs (it gives no information on the moment of the break).

Also, before performing a detailed analysis of temperature and precipitation extremes, data were tested for their homogeneity using five tests: SNH (Alexandersson, 1986), BHR (Buishand, 1982), PET (Pettitt, 1979), VON (von Neumann, 1941) and Penalized Maximal F - PMF test (Wang, 2008).

To detect and estimate trends in the time series of monthly, seasonal, annual and other time-scales values of climatic parameters we used the non-parametric Mann-Kendall test for the trend (Mann 1945; Kendall 1975) and Sen's non-parametric method for the magnitude of the trend (Gilbert, 1987). Calculations were performed using the Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimator), developed by researcher of the Finnish Meteorological Institute (Salmi et al., 2002). The Mann-Kendall test is applicable to the detection of a monotonic trend of a time series. Sen's method uses a linear model to estimate the slope of the trend, and the variance of the residuals should be constant in time. The procedure offer many advantages: missing values are allowed and data needed are not conferrable to any particular distribution; single data errors or outliers do not significantly affect Sen's method. In Romania these methods were previously used with success in detecting trends in climatic data sets (Micu and Micu, 2006; Micu, 2009; Croitoru et al., 2012b; Piticar and Ristoiu, 2012).

The conditional (or partial) Mann-Kendall test was applied to check whether the trend in the time series of temperature and precipitation are determined by the trends in teleconnection indices (Libiseller and Grimvall, 2002).

In order to quantify the changes in aridity and evapotranspiration in the study area we used the De Martonne aridity index and Penman-Monteith method (Allen et al., 1998).

Other statistical methods used were: absolute and relative frequency, correlation coefficient etc.

3. Changes in the evolution of climatic elements

3.1. Changes in mean air temperature

3.1.1. Homogeneity tests

The homogeneity of the annual temperature time series for the period 1961-2010 has been tested. Change points appeared, particularly in the late 1980s or 1990s. In Table 2, the annual results of the Pettitt, Standard Normal Homogeneity Test (SNHT), the Buishand range and the Neumann tests applied to temperature data are shown.

Table 2. Results of the homogeneity tests for mean annual temperature in northeastern Romania (1961-2010)

Station	PET	SNH	BHR	VON
Botoşani	391*** 1988[1]	14.587*** 1988	13.542*** 1988	1.406*
Ceahlău	329** 1995	11.869** 1995	11.277** 1995	1.65
Cotnari	354** 1988	14.266*** 1998	12.681*** 1988	1.343**
Fălticeni	385*** 1988	16.542*** 1998	14.101*** 1988	1.160***
Iaşi	356** 1988	13.146** 1988	12.856*** 1988	1.432*
Piatra Neamţ	317** 1988	10.747** 1998	11.086** 1988	1.527*
Poiana Stampei	460*** 1988	19.920** 1998	14.249*** 1988	1.322*
Rădăuţi	412*** 1988	16.703*** 1988	14.491*** 1988	1.183***
Roman	370*** 1988	15.426*** 1998	13.087*** 1988	1.381*
Suceava	414*** 1988	16.992*** 1988	14.615*** 1988	1.239**

*Significant at 0.05 level, ** significant 0.01 level, *** significant 0.001 level.

[1]The year at which the change occurred (break year)

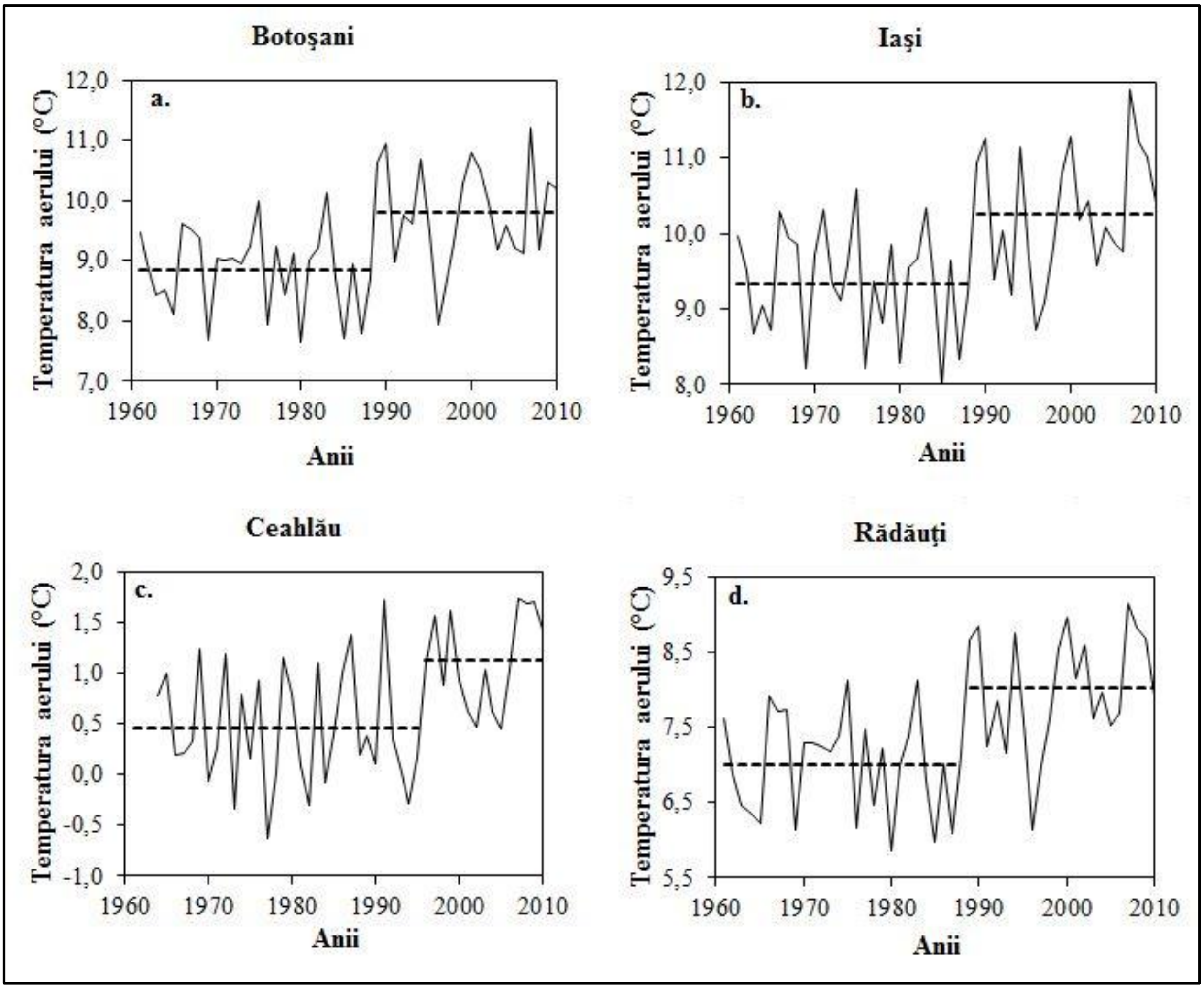


Figura 2. The change points detected in temperature series at Botoşani, Iaşi, Ceahlău, Rădăuţi and Rădăuţi stations over the period 1961-2010

Examples of change points detected for annual temperature data in Northeastern Romania are presented in Figure 2a, b, c and d, along with the mean of the two sub-intervals.

The annual results of the Pettitt, SNHT and the Buishand range tests applied to temperature data series show that the change points were detected at 1988, 1995 and 1998. Two of the tests (the Pettitt and the Buishand tests) show the 1988 shift point as the year at which the change occurs at all stations except Ceahlău station, where shift point was in 1995. According to SNHT the 1988 is the change point for Botoşani, Iaşi Rădăuţi and Suceava, 1995 for Ceahlău and 1998 for Cotnari, Fălticeni, Piatra Neamţ, Poiana Stampei and Roman stations. All the change points are significant at 0.01 and 0.001 levels of α.

The significant values of the Von Neumann test indicates that the series is not randomly distributed at all stations except Ceahlău station where α has a value greater than 0.05 and the result is not significant.

The 1988 change point in temperature data as the year at which the change occurs at most stations over Northeastern Romania coincides with the same year in which a significant change point in air temperature was identified in Northern and Central Europe (Donnelly et al., 2009).

Hari et al. (2006) found out that a change point has also been reported in 1988 for air and water temperature in the Alpine region. These change points have been attributed to a shift in the NAO into its present extended positive phase (Hari et al., 2006; Donnelly et al., 2009). It was demonstrated in several works (Beaugrand, 2004; Fealy & Sweeney, 2005; Donnelly et al., 2009) that there is evidence that a major change in atmospheric variability occurred in the North Atlantic region at that time which was associated with an abrupt increase in temperature and an increased occurrence of westerly winds.

3.1.2. Air temperature trend

Annual mean air temperature has increased during the study period by 0.16 - 0.33°C/decade over the northeastern part of Romania (Table 3 and Figure 3a). According to the Mann-Kendall test, the trend is statistically significant at all stations on the α = 0.05 level.

Table 3. Slopes for air temperature (°C/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0,05 level.

Perioada	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	**0.93**	0.06	**0.87**	**0.80**	0.50	**0.88**	**0.64**	**0.80**	**0.64**	**0.79**
F	0.56	-0.04	**0.72**	**0.68**	0.43	0.50	0.44	0.63	0.55	0.59
M	0.45	-0.15	**0.62**	**0.64**	0.43	**0.58**	**0.40**	**0.54**	**0.55**	0.50
A	0.00	0.17	0.16	0.18	0.04	-0.03	0.27	0.21	0.14	0.20
M	0.23	0.20	0.25	0.30	0.17	0.18	**0.31**	0.27	0.27	0.25
J	0.24	**0.33**	**0.29**	**0.38**	0.21	0.14	**0.50**	**0.33**	**0.33**	**0.33**
J	**0.44**	**0.57**	**0.49**	**0.52**	**0.41**	**0.24**	**0.52**	**0.51**	**0.49**	**0.50**
A	0.23	**0.50**	**0.34**	**0.43**	**0.25**	0.25	**0.53**	**0.45**	**0.38**	**0.44**
S	-0.18	0.00	-0.12	-0.01	-0.10	-0.27	0.00	-0.04	-0.05	-0.05
O	0.00	0.17	0.09	0.15	0.06	-0.06	0.26	0.07	0.06	0.08
N	-0.25	0.20	-0.17	-0.20	-0.26	-0.29	-0.05	-0.08	-0.09	-0.09
D	0.21	0.00	0.21	0.24	0.13	0.23	0.27	0.20	0.08	0.23
Winter	0.45	0.01	**0.66**	**0.52**	0.33	**0.47**	**0.30**	**0.53**	**0.44**	**0.54**
Spring	0.23	0.10	**0.33**	**0.39**	0.22	0.29	**0.33**	**0.36**	**0.33**	**0.33**
Summer	**0.27**	**0.44**	**0.36**	**0.42**	**0.28**	**0.18**	**0.49**	**0.40**	**0.36**	**0.39**
Autumn	-0.08	0.09	-0.04	-0.02	-0.07	-0.18	0.07	0.00	0.00	0.03
Annual	**0.23**	**0.16**	**0.27**	**0.30**	**0.25**	**0.20**	**0.33**	**0.29**	**0.23**	**0.27**

The warming has not been equal throughout a year. The highest increase in air temperature was typical for summer season (0.18 - 0.49°C/decade) indicating generalized positive slopes in the study area statistically significant at the level α = 0.05 at all stations. A remarkable warming has been identified also in winter (0.01 - 0.66°C/decade), statistically significant at 7 weather stations.

During the spring season the time series revealed a moderate warming with values of 0.10 - 0.39°C/decade.

On the other hand, slight decreases were found for autumn season (between -0.02 and -0.18°C/decade) for 5 locations, but they were statistically insignificant.

On a monthly time-scale, it was observed that the most important increase of mean air temperatures was specific to summer months (June, July, August), especially to July where values are statistically significant for all stations. For January, February and March, the values also indicate an increasing trend statistically significant for the most of the time series. For May only a one station (Poiana Stampei) have experienced a significant positive trend. No statistically significant trends for the rest of the year were observed. Few data series reveal negative trends, but they are all statistically insignificant.

The spatial distribution of trends is presented in Figure 3.

These findings are similar to those presented in previous studies for this region (Piticar and Ristoiu, 2012), and for other regions of Romania (Busuioc et al., 2010; Croitoru et al., 2012b).

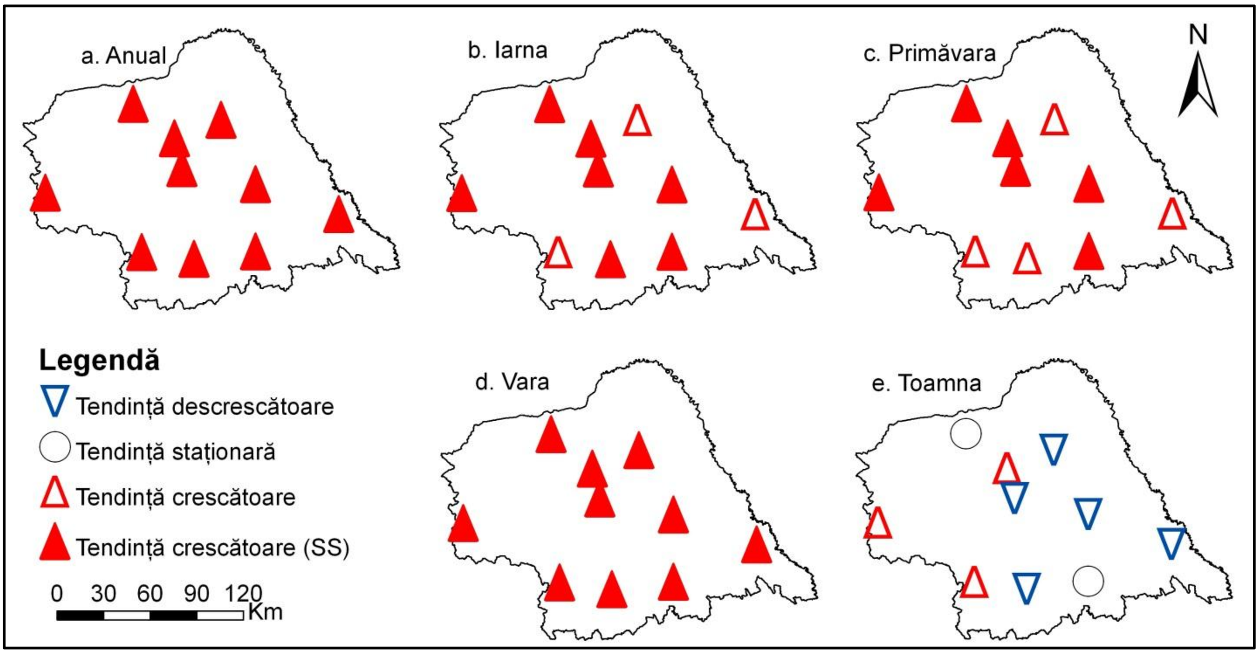


Figure 3. Spatial distribution of air temperature trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.1.3. The influence of changes in circulation patterns on changes in temperature

The analysis of the dependence between the atmospheric circulation teleconnection patterns and temperature and precipitation variability in northeastern Romania was made based on conditional Mann-Kendall test (Table 4). The table lists the teleconnection patterns showing which trends are significantly related to the trends in air temperature or precipitation in the corresponding month or period. When taking into account the time series of those teleconnection indices within the conditional Mann-Kendall test, it shows when statistically significant trends in temperature or precipitation disappear.

The results of the conditional Mann-Kendall test indicate that the warming in January is connected with the trends in the EA and NAO indices. The correlation coefficient is the highest for NAO (0.58), while in the case of EA is only 0.39 (Piticar and Ristoiu, 2013b). The negative trends in the PO teleconnection index in February, March and May have shown a significant influence on changes in temperature. Warming in summer months can be explained by the negative trends in the EW and SC teleconnection indices in June and August, negative trends in the NAO in June, and positive trends in the EA in July and August. The highest correlation has been detected for EA teleconnection index – 0.52. This finding is in accordance with other studies made on Romania (Tomozeiu et al., 2002; Croitoru et al., 2012b).

Table 4. Trends of circulation patterns which are significantly related to air temperature trends in northeastern Romania (1961-2010)

Perioada	Temperatura aerului
I	EA, NAO
F	PO-
M	PO-
A	
M	PO-
I	EW*-, SC*-, NAO-
I	**EA***
A	**EA*,** EW*-, SC*-
S	
O	
N	
D	
Iarna	EA, NAO, PO*-
Primăvara	EA, PO*-
Vara	**EA*,** EW*-,
Toamna	
Anual	**EA*,** EW*-, PO*-, SC*-

Note: Bold abbreviation – the trend is significant in all stations; "-" – a negative relationship, * - the index describes a significant part of the trend, but not entirely

The warming in winter is connected with positive trends in EA and NAO, and negative trend in PO. Temperature increase during spring is influenced by the positive trend in EA, and negative trend in PO teleconnection indices. The significant increase in air temperature in summer series is influenced by the positive trend in EA and negative trend in EW teleconnection indices, but the warming process may be only partly explained this way.

Some teleconnection indices have a trend also in the annual data sets (EA, EW, PO, SC), that may have caused the annual increasing trend of air temperature.

3.1.4. Changes in daily extreme temperatures

The increase of mean temperature over the last century has been largely demonstrated in many studies focused on different regions of the world. Although changes in the mean values of the climate variables have a bearing on the long-term climatic conditions, the changes in the extremes of the variables can have far-reaching economic and social consequences. Thus, recently, many efforts have been made to estimate not only changes in mean temperature series, but also changes in the frequency, intensity, and duration of extreme events (El Kenawy et al., 2011, Croitoru and Piticar, 2013).

In Romania a great part of the previous studies on observed changes were focused mainly on the mean temperature rather than on the extremes (Micu and Micu, 2006; Micu, 2009, Busuioc et al., 2010; Croitoru et al., 2012a, Croitoru et al., 2012b, Piticar and Ristoiu, 2012).

3.1.4.1. Methods

For this study, we employed a set of 20 indicators relating to hot, cold and variability in extreme temperatures using daily temperature data from 4 weather stations across 50 years (1961-2010).

The calculations of indices were made with RClimDex software developed by Byron Gleason at NCDC (National Climate Data Center) of NOAA (*National Oceanic and Atmospheric Administration)* (Zhang and Yang; 2004). Their brief description is available in Table 5.

3.1.4.2. Results and discussions

When analyzing the intensity of increasing and decreasing trends, three degrees were defined:

- high increasing/decreasing trends (large triangle in Figures 3, 5, and 7): >/<4.000 days/decade for SU25, TR30, TRD35, TR20, TN90p, TX90p, ID0, FD0, FN10, TN10p, TX10p, GSL, and ±0.601 to ±0.900 °C/decade for TXn, TXx, TNx, TNn, Txmean, TNmean,DTR, and ETR;

- moderate increasing/decreasing (medium triangle in Figures 3, 5, and 7): ±2.001 to ±4.000 days/decade, for SU25, TR30, TRD35, TR20, TN90p, TX90p, ID0, FD0, FN10, TN10p, TX10p, GSL, and ±0.301 to ±0.600 °C/decade for TXn, TXx, TNx, TNn, TXmean, TNmean, DTR and ETR;

- low increasing/decreasing (little triangle in Figures 3, 5, and 7): ±0.001 to ±2.000 days/decade for SU25, TR30, TRD35, TR20, TN90p, TX90p, ID0, FD0, FN10, TN10p, TX10p, GSL, and ±0.001 to ±0.300 °C/decade TXn, TXx, TNx, TNn, TXmean, TNmean, DTR, and ETR.

Table 5. List of the ETCCDMI climate indices used in this study (after Zhang and Yang, 2004, completed)

ID	Indicator name	Definitions	UNITS
Hot extremes			
SU25	Summer days	Annual count when TX (daily maximum)>25ºC	Days
TR20	Tropical nights	Annual count when TN (daily minimum)>20ºC	Days
TR30	Tropical days	Annual count when TX(daily maximum)>30ºC	Days
HD35	Hot days	Annual count when TX (daily maximum)>35ºC	Days
TN90p	Warm nights	Percentage of days when TN>90th percentile	Days
TX90p	Warm days	Percentage of days when TX>90th percentile	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temperature	ºC
TXn	Min Tmax	Monthly minimum value of daily maximum temperature	ºC
TX mean	Mean Tmax	Monthly mean value of daily maximum temperature	ºC
WD	Warmest day	Annual highest maximum temperature	ºC
Cold extremes			
FD0	Frost days	Annual count when TN (daily minimum)<0ºC	Days
ID0	Ice days	Annual count when TX (daily maximum)<0ºC	Days
FN-10	Frost nights	Annual count when TN (daily minimum)<-10ºC	Days
TN10p	Cool nights	Percentage of days when TN<10th percentile	Days
TX10p	Cool days	Percentage of days when TX<10th percentile	Days
TNx	Max Tmin	Monthly maximum value of daily minimum temperature	ºC
TNn	Min Tmin	Monthly minimum value of daily minimum temperature	ºC
TNmean	Mean Tmin	Monthly mean value of daily minimum temperature (TN)	ºC
CD	Coldest night	Annual lowest minimum temperature	ºC
Variability extremes			
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
ETR	Intra-annual extreme temperature range	Difference between the highest TX and the lowest TN in a year	ºC
GSL	Growing season Length	Annual count between first span of at least 6 days with TG>5ºC and the first occurrence after 1st July of at least 6 consecutive days with TG<5ºC	Days

3.1.4.2.1. Changes in hot extremes

The hot extremes analysis in the considered area indicates general positive trends (Table 6 and Figure 4). This finding demonstrates that temperature during summer months increased more rapidly in the daytime than that related to nighttime for the same months.

For hot extremes indices, the highest slopes were found for SU25 and TRD30 with overall average around 3.9, respectively 2.9 days/decade (Table 6 and Figure 5).

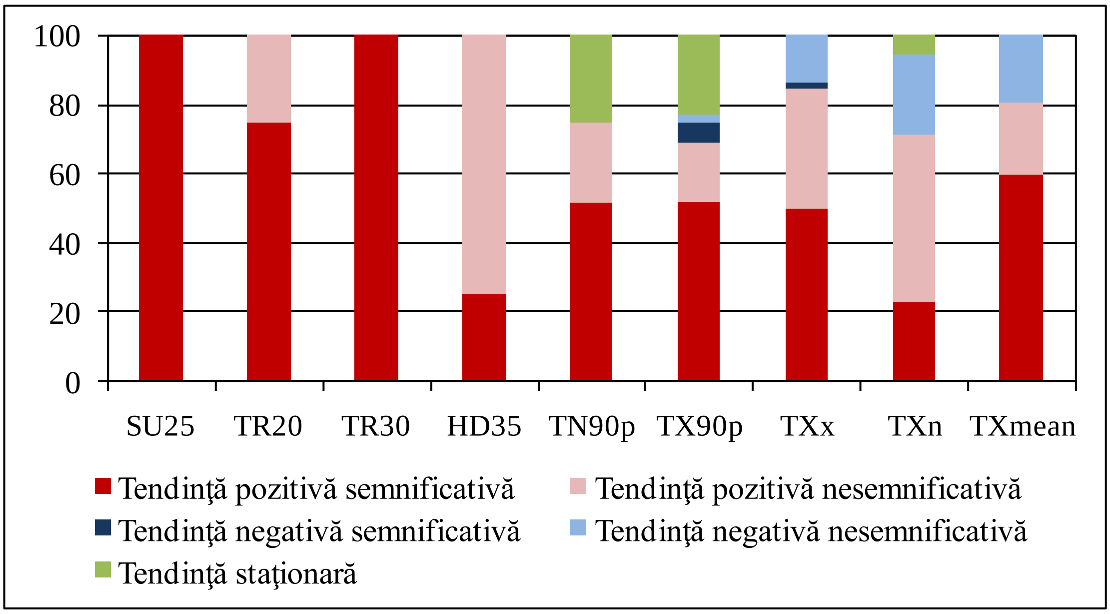


Figure 4. Frequency of trend types of hot extreme indices in northeastern Romania (1961-2010)

Table 6. Slopes for the hot extreme indices calculated for annual data series in northeastern Romania (1961-2010). In the case of indices calculated for each month and for annual, only the annual value is presented in the table

Station	SU25	TR20	TR30	HD35	TN90p	TX90p	TXx	TXn	TXmean
	Slope								
	Days/decade				% of days/decade		°C/decade		
Suceava	**3.261**[a]	0.050	**1.538**	0.110	**2.407**	**1.539**	**0.375**	-0.133	**0.296**
Botoşani	**3.571**	**0.260**	**2.857**	0.410	**1.300**	**1.257**	**0.462**	-0.282	**0.290**
Iaşi	**3.571**	**0.580**	**3.514**	**0.910**	**1.509**	**1.232**	**0.583**	-0.133	**0.239**
Bacău	**5.000**	**0.260**	**3.784**	0.500	**1.380**	**1.646**	**0.605**	0.000	**0.308**
Average	3.851	0.288	2.923	0.483	1.649	1.419	0.506	-0.137	0.283

[a]Values in bold are statistically significant slopes at α = 0.1

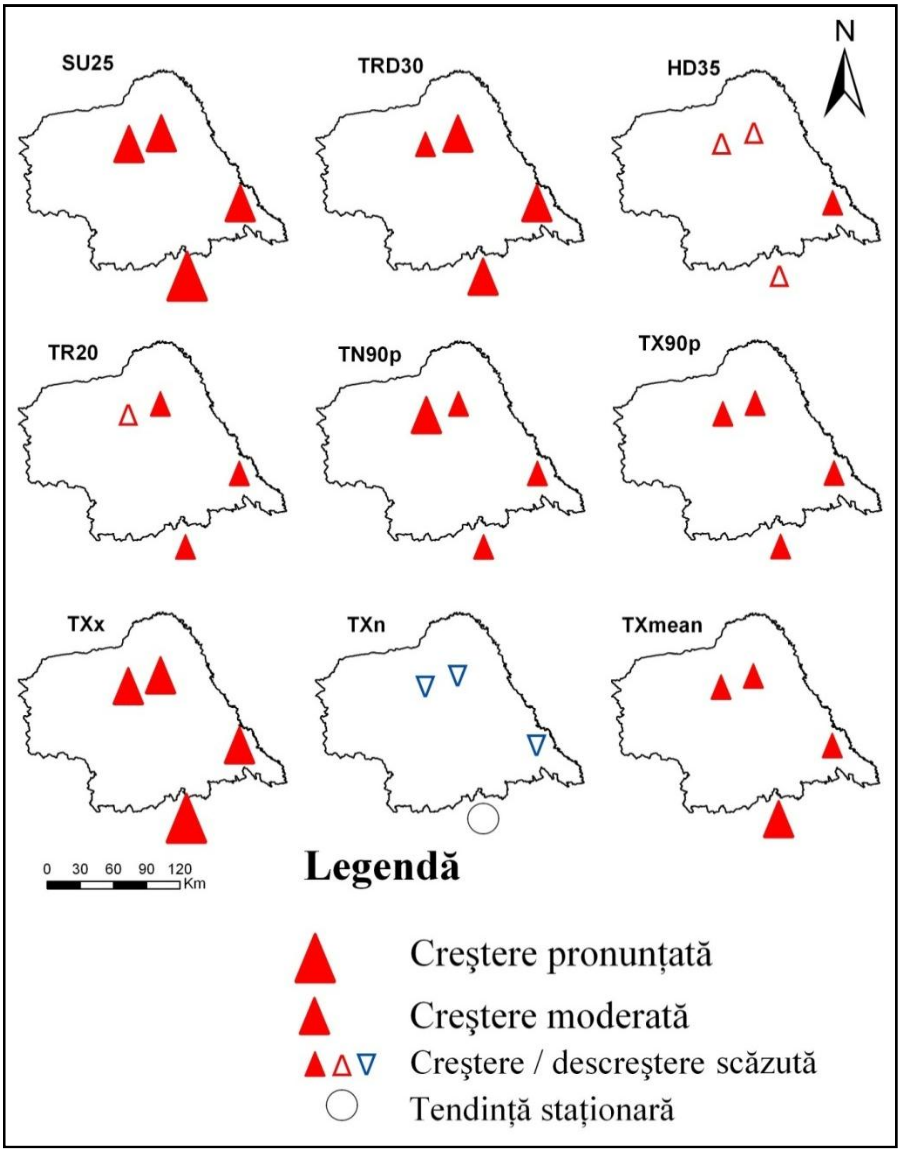


Figure 5. Spatial distribution and intensity of hot extreme indices trends in northeastern Romania (1961-2010). The fully symbol shapes are statistically significant slopes and empty symbol shapes are statistically insignificant slopes

3.1.4.2.2. Changes in cold extremes

Generally, the negative trends are more specific for these indices, especially for those computed based on a fixed threshold and percentile-based indices: frost days (FD0), frost nights (FN-10), ice days (ID0), cool nights (TN10p), and cool days (TX10p) (Table 7 and Figure 6). The positive trends have very low frequency for these indices, which is an important evidence for warming during winter time. The indices based on extreme minimum temperature records (TNx, TNn, and TNmean) also indicate, by their high frequency of positive trends, a warming process through the analyzed 50 years period.

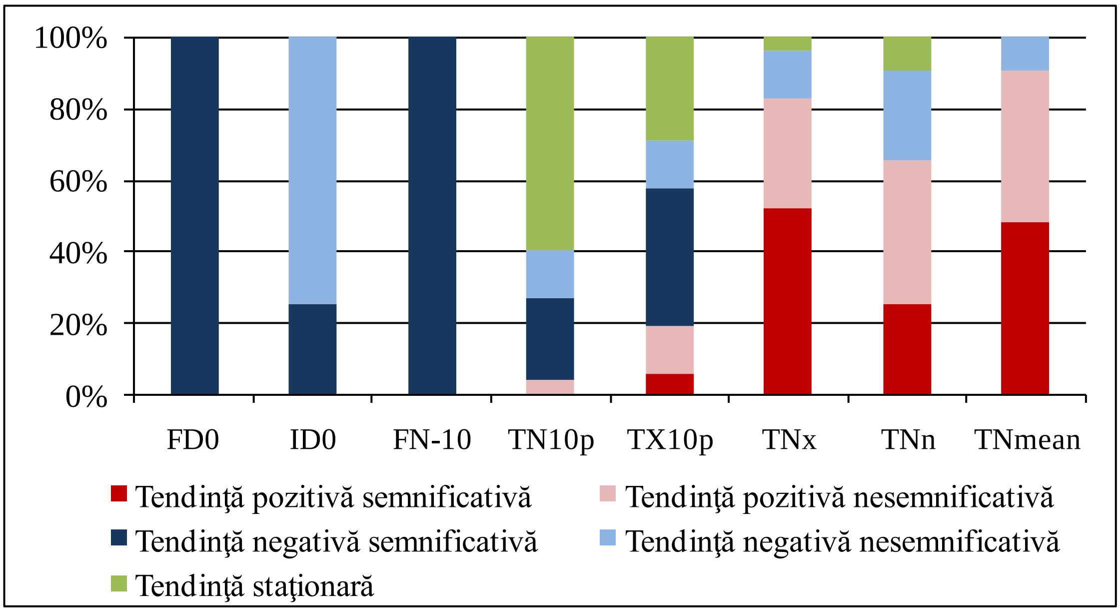


Figure 6. Frequency of trend types of cold extreme indices in northeastern Romania (1961-2010)

Table 7. Slopes for the cold extreme indices calculated for annual data series in northeastern Romania (1961-2010). In the case of indices calculated for each month and for annual, only the annual value is presented in the table

Station	FD0	ID0	FN-10	TN10p	TX10p	TNx	TNn	TNmean
	Slope							
	Days/decade			% of days/decade		°C/decade		
Suceava	**-4.762**[a]	**-3.333**	**-3.333**	**-1.172**	**-0.630**	**0.379**	-0.056	**0.314**
Botoșani	**-2.778**	-2.121	**-2.000**	**-0.605**	**-0.781**	**0.286**	-0.333	**0.172**
Iași	**-3.274**	-1.111	**-2.069**	**-0.887**	**-0.910**	**0.351**	0.060	**0.226**
Bacău	**-3.571**	-1.765	**-2.083**	**-0.806**	**-0.752**	**0.243**	0.000	**0.220**
Average	-3.596	-2.083	-2.371	-0.868	-0.768	0.315	-0.082	0.233

[a]Values in bold are statistically significant slopes at $\alpha = 0.1$

From the point of view of the spatial pattern all the indices based on a fixed threshold and percentile have recorded, generally statistically significant decreasing slopes at all stations analyzed (Figure 7).

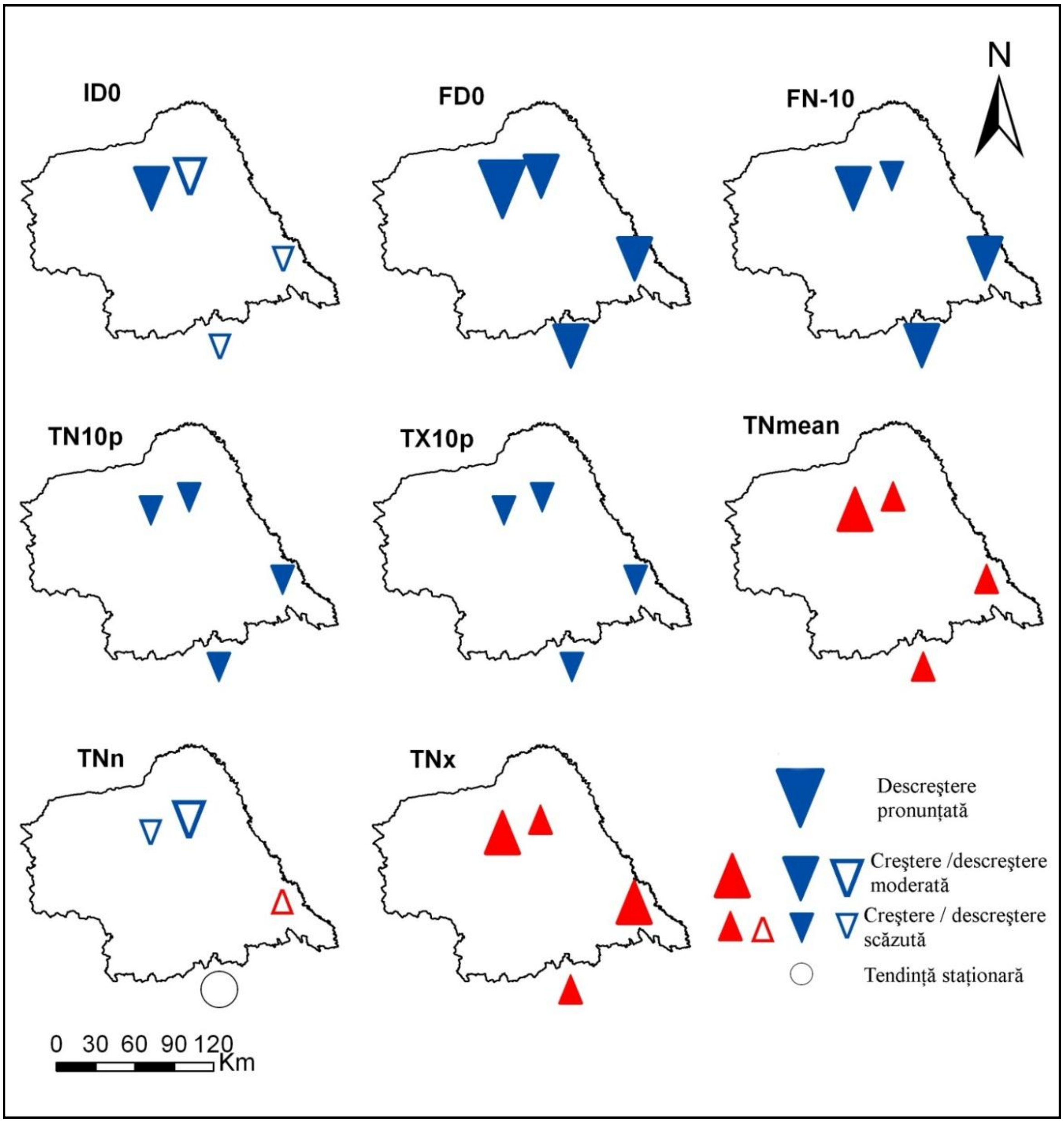


Figure 7. Spatial distribution and intensity of cold extreme indices trends in northeastern Romania (1961-2010). The fully symbol shapes are statistically significant slopes and empty symbol shapes are statistically insignificant slopes

Compared to other extra-Carpathians regions the trends of the same indices and for the same period (1961-2010) are similar (Croitoru and Piticar, 2013). The only notable difference is that the number of frost nights (FN-10) showed decreasing slopes statistically significant only in the northeastern Romania, while in other extra-Carpathian regions they were insignificant or stationary (Croitoru and Piticar, 2013).

3.1.4.2.3. Changes in variability indices

In northeastern Romania the intensity of increasing amplitude in terms of temperature is higher for daily than for annual values (Table 8 and Figure 8). The trend of the growing season length (GSL) is increasing, with an average value of 3 days/decade, the largest increase being recorded at Botoșani station (4 days/decade). Because the extra-Carpathian regions of northeastern Romania include significant agricultural areas, the evolution of this indicator is very important both for agriculture managers and farmers in order to adopt appropriate measures to mitigate the impact of global warming on crops and to ensure the food security of this region.

Table 8. Slopes for the variability indices calculated for annual data series in northeastern Romania (1961-2010). In the case of indices calculated for each month and for annual, only the annual value is presented in the table

Station	DTR	ETR	GSL
	Slope		
	°C/decade		Days/decade
Suceava	0,020	0,033	2,308
Botoșani	**0,137**[a]	0,081	4,000
Iași	0,061	0,075	3,015
Bacău	0,104	0,062	2,500
Average	0,081	0,063	2,956

[a]Values in bold are statistically significant slopes at α = 0.1

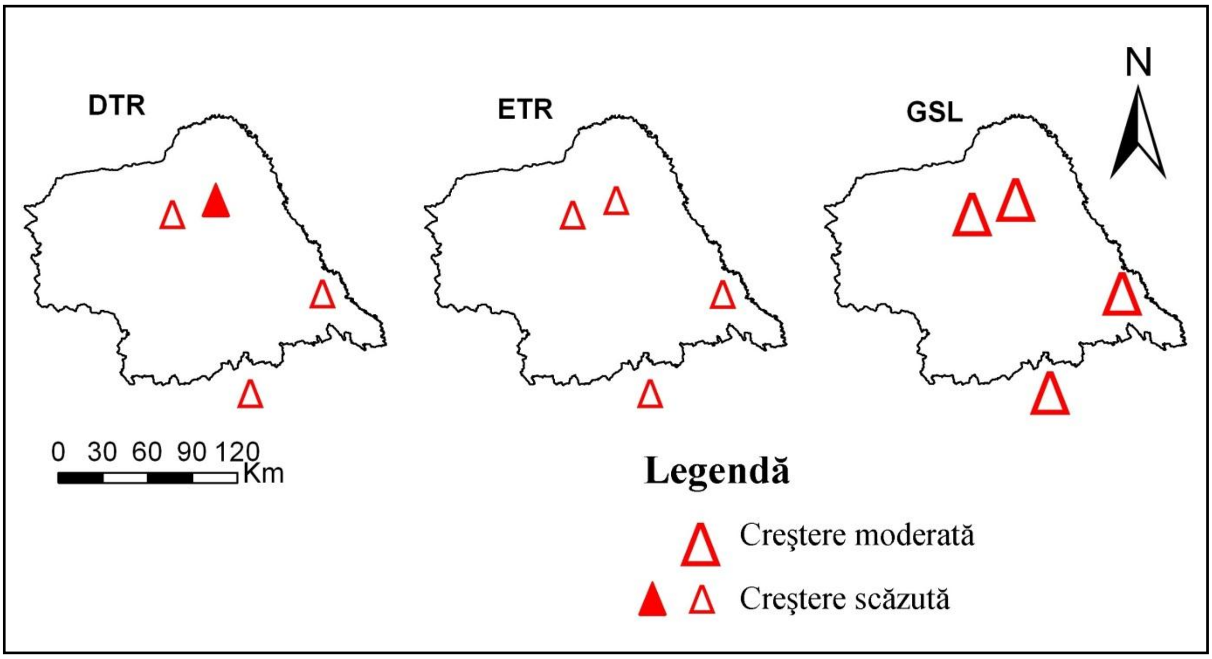


Figure 8. Spatial distribution and intensity of variability extreme indices trends in northeastern Romania (1961-2010). The fully symbol shapes are statistically significant slopes and empty symbol shapes are statistically insignificant slopes

3.2. Changes in precipitation

3.2.1. Homogeneity tests

The results of the homogeneity tests indicate that the data series of precipitation amounts are homogenous. Only few statistically significant change points have been identified in data from Ceahlău, Rădăuţi, and Suceava stations (Fig. 9a, b, c). Since these stations haven't been relocated and no changes have been made in the observation program over the analyzed period (1961-2010), we consider that the change points have rather natural causes (Piticar şi Ristoiu, 2013a).

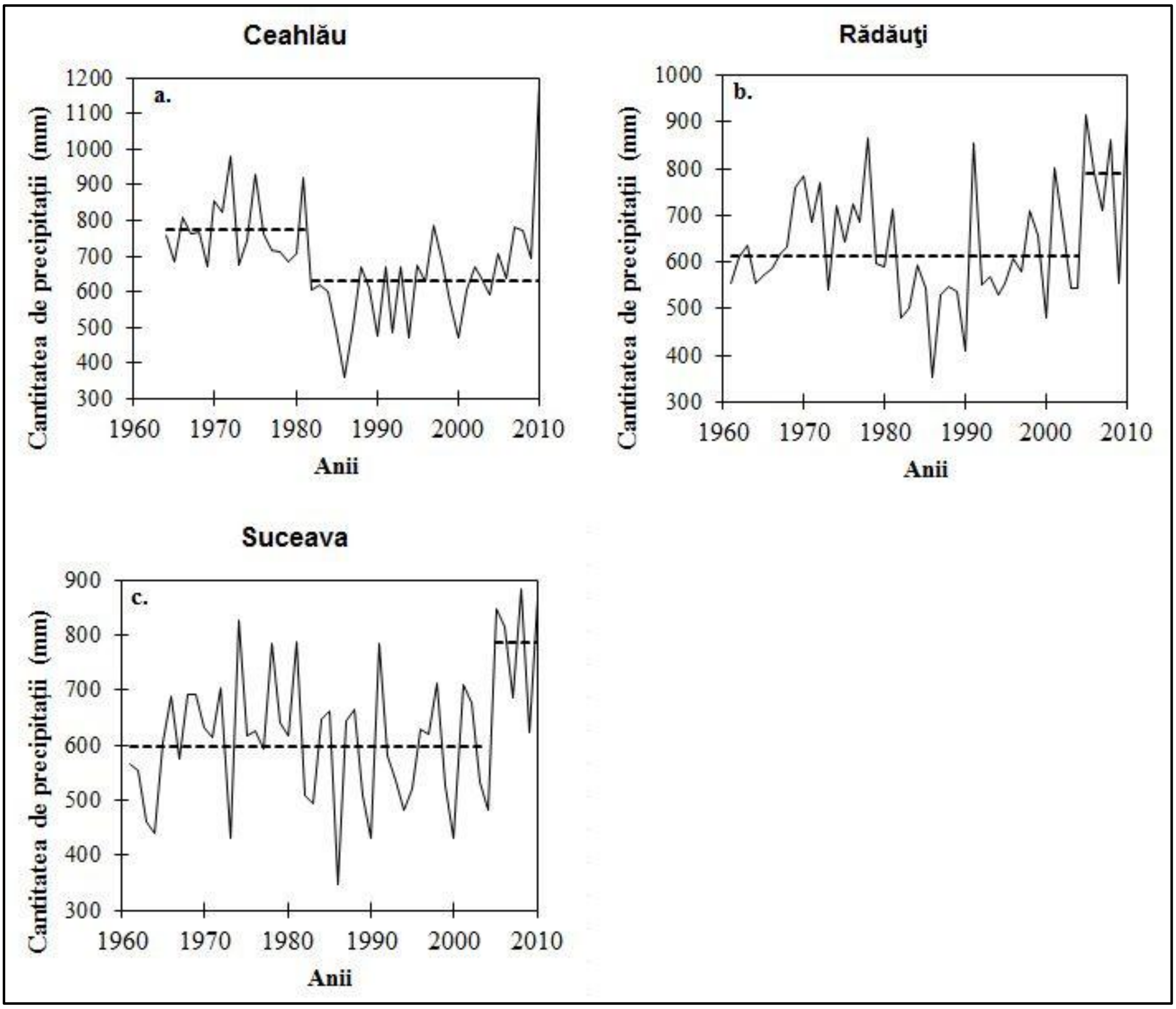


Figure 9. The change points detected in precipitation series at Ceahlău, Rădăuţi and Suceava stations over the period 1961-2010

3.2.2. Trends in precipitation amounts

According to the results of Mann-Kendall test combined with Sen's slope (Table 9 and Figure 10a), annual time series indicate an increasing trend of precipitation amounts at 8 weather stations (5.40 – 18.21 mm/decade), but this increase is not statistically significant. Decreasing slopes are specific only at Iaşi and Ceahlău stations, but the trends are significant only at Ceahlău (-27.23 mm/decade).

From seasonal point of view, the most important increase in precipitation amount was recorded in summer and autumn, but the trend was statistically significant only in the case of Roman station in autumn (Table 9 and Figure 10d, e).

In winter and spring, the decreasing trends are dominant over the analyzed area, but these trends were not statistically significant, excepting Ceahlău station (Table 9 and Figure 10b, c).

Table 9. Slopes for the precipitation amounts (mm/decade) in northeastern Romania over the period 1961-2010. Values in bold are statistically significant at $\alpha = 0.05$.

Period	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra-Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	-1,07	**-5,05**	-0,43	-1,67	-0,50	-0,19	-0,68	-0,94	-0,73	-0,43
F	-0,67	**-8,52**	-0,71	-0,69	-2,59	0,62	-0,30	0,11	0,14	-0,03
M	-1,18	-2,17	-0,14	0,00	-0,35	1,56	1,42	-1,55	-0,29	-0,25
A	-0,56	-2,91	0,23	0,86	-2,77	0,32	-0,33	-1,10	0,63	0,02
M	-1,18	-4,57	-2,17	-4,82	-3,13	-3,13	-0,54	-2,43	1,18	-3,40
J	-5,31	0,28	3,60	0,76	-4,88	-3,58	-2,73	-0,56	-0,39	-0,85
J	4,58	1,45	0,59	3,42	-1,03	2,85	-3,76	0,52	4,87	6,09
A	1,83	8,14	1,97	2,30	1,07	1,00	2,59	4,00	2,56	4,08
S	5,00	2,16	3,40	2,99	1,67	5,19	5,55	4,43	4,81	3,76
O	**5,64**	0,33	**5,08**	4,34	**5,43**	**4,27**	1,61	4,00	**5,46**	**5,00**
N	-0,36	**-4,19**	0,46	-1,93	-0,20	-1,38	-1,08	-0,81	0,63	-1,08
D	0,00	**-4,86**	0,99	0,30	0,43	1,89	-1,63	0,21	1,13	0,56
Winter	-3,43	**-20,71**	-2,53	-3,08	-5,42	2,56	-4,45	-1,27	-1,06	-1,26
Spring	-3,92	**-11,25**	-2,33	-4,99	-6,83	-1,37	2,28	-3,59	0,96	-2,00
Summer	8,77	11,90	6,00	15,03	-6,47	0,59	-1,65	6,26	10,71	12,30
Autumn	10,68	-1,13	9,56	5,93	7,95	6,87	4,51	8,15	**10,40**	6,42
Annual	12,32	**-27,23**	14,53	11,69	-11,02	11,42	7,26	5,40	14,79	18,21

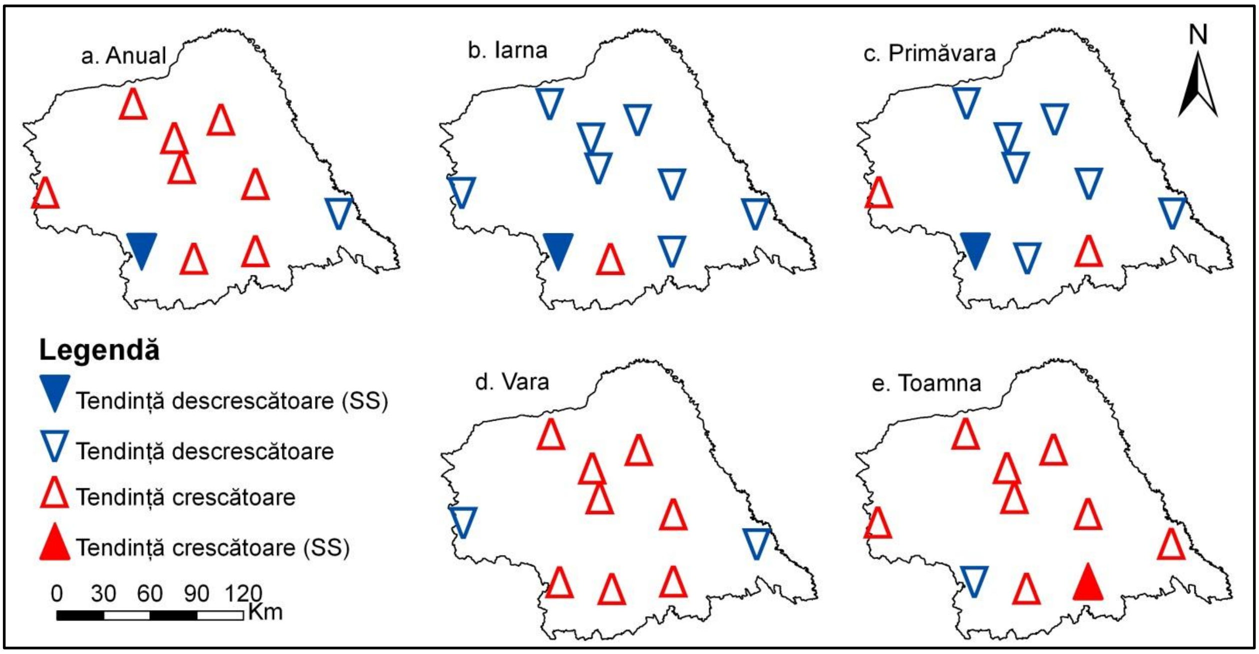


Figure 10. Spatial distribution of precipitation amount trends in northeastern Romania (1961-2010); SS – statistically significant at α = 0.05.

3.2.3. The influence of changes in circulation patterns on changes in precipitation

The analysis of the dependence between the atmospheric circulation teleconnection patterns and precipitation variability in northeastern Romania was made based on conditional Mann-Kendall test (Table 10). The table lists the teleconnection patterns showing which trends are significantly related to the trends in precipitation in the corresponding month or period. When taking into account the time series of those teleconnection indices within the conditional Mann-Kendall test, it shows when statistically significant trends in precipitation disappear.

The connection between precipitation and the circulation indices is remarkably low. This is caused by strong influence of local factors on precipitation fields (Jaagus 2006). Yet, some connections were found. The negative trend in precipitation recorded in January was found to be connected with positive trend in NAO index, which causes below-average precipitation over southern and central Europe. An increase in precipitation in October is significantly related with negative trends in the EW and NAO indices, but the increase can only partly be explained this way. The positive trend in EA teleconnection index in December causes a decrease in precipitation trend for western stations (Ceahlău, Poiana Stampei) located at higher elevations and more exposed to the direct influence of general air mass movements than the other stations. The influence of EA pattern was identified also in spring and annual time series.

Table 10. Trends of circulation patterns which are significantly related to precipitation trends in northeastern Romania. Bold abbreviation – the trend is significant in all stations; “-” – a negative relationship, * - the index describes a significant part of the trend, but not entirely

Period	Precipitation
J	NAO-
F	
M	
A	
M	
J	
J	
A	
S	
O	EW-*, NAO-*
N	
D	EA-
Winter	
Spring	EA-, PO
Summer	
Autumn	EW-
Annual	EA-, PO, SC

3.2.4. Changes in daily precipitation extremes indices

The extreme precipitation events usually generate extreme hydrological events like floods or drought having strong potential impact on national economy especially in case of the developing countries where agriculture is the main income and subsistence source (Radinović şi Ćurić, 2012; Wang et al., 2012).

This analysis aims to identify whether the climate in the considered area is getting more extreme in terms of precipitation by determining the spatial and temporal variability of annual series trends in extreme precipitation indices for northeastern Romania over a period of 50 years, by using 13 extreme precipitation indices.

3.2.4.1. Methods

3.2.4.1.1. Extreme precipitation indices

In this analysis, we employed a set of 13 indices related to extreme precipitation (Table 11). The indices were chosen primarily for the assessment of many aspects 205 in relation to the changing regional climate, including changes in the intensity and frequency of precipitation events. Thus, they can represent events that occur several times per season or year giving them more robust statistical properties than measures of extremes, which are far enough into the tails of the distribution so as not to be observed during some years (Alexander et al., 2006).

Table 11. ETCCDMI precipitation-related extreme indices used (după Zhang and Feng, 2004, completed)

Acronym	**Name of the index**	**Description**	**Unit**
R0.1	Number of precipitation days	Annual number of days with more than 0.1 mm/day	days
R5	Moderate precipitation days	Annual number of days with more than 5 mm/day	days
R10	Number of heavy precipitation days	Annual number of days with more than 10 mm/day	days
R20	Number of very heavy precipitation days	Annual number of days with more than 20 mm/day	days
R30	Number of extremely heavy precipitation days	Annual number of days when precipitation ≥ 30 mm[a]	days
CDD	Consecutive dry[b] days	Annual maximum number of consecutive days with RR<1mm	days
CWD	Consecutive wet[c] days	Annual maximum number of consecutive days with RR ≥ 1mm	days
R95p	Very wet days	Annual total PRCP when RR>95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR>99th percentile	mm
Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
Rx5days	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days in the year	mm
PRCPTOT	Annual total wet-day precipitation	Annual total amount of precipitation cumulated in wet days	mm

Note: [a] - 30 mm was the threshold defined by the authors; [b] - dry days are those days when the amount recorded was < 1 mm; [c] - wet days are those days when the amount recorded was ≥ 1 mm.

All the indices were calculated by employing RClimDex software (Zhang and Feng, 2004; Wang and Feng, 2010) following methodologies established by Zhang and Feng (2004). Then, the resulting series were analyzed through their trends.

3.2.4.1.2. Trends calculation

The slopes of the annual and monthly trends of the climate indices were computed by linear least square method. The procedure was implemented in RClimDex software and the slopes as well as their statistical significance are issued as output of the software together with indices series.

Even though the Mann-Kendall test combined with Sen's slope estimator is very commonly used in climatic studies (Zhang et al., 2005; Choi et al., 2009, Croitoru et al., 2013b, Piticar and Ristoiu, 2012), in the case of extreme precipitation indices we preferred to use the least squares method because of the way of calculating the slope, which is very sensitive to data sets with many similar values (Croitoru et al., 2013a).

We have chosen for the analysis of precipitation extreme indices the α level equal to 0.1 and the trends identified at that level are considered 'significant'. Also we used the level α = 0.05 and slopes found significant at this level will be considered 'strong significant'.

3.2.4.2. Results and discussions

Figures 11 and 12 gives an overview of trend results for each and for all of the investigated indicators. The number of significant trends was expressed as a percentage of all examined cases.

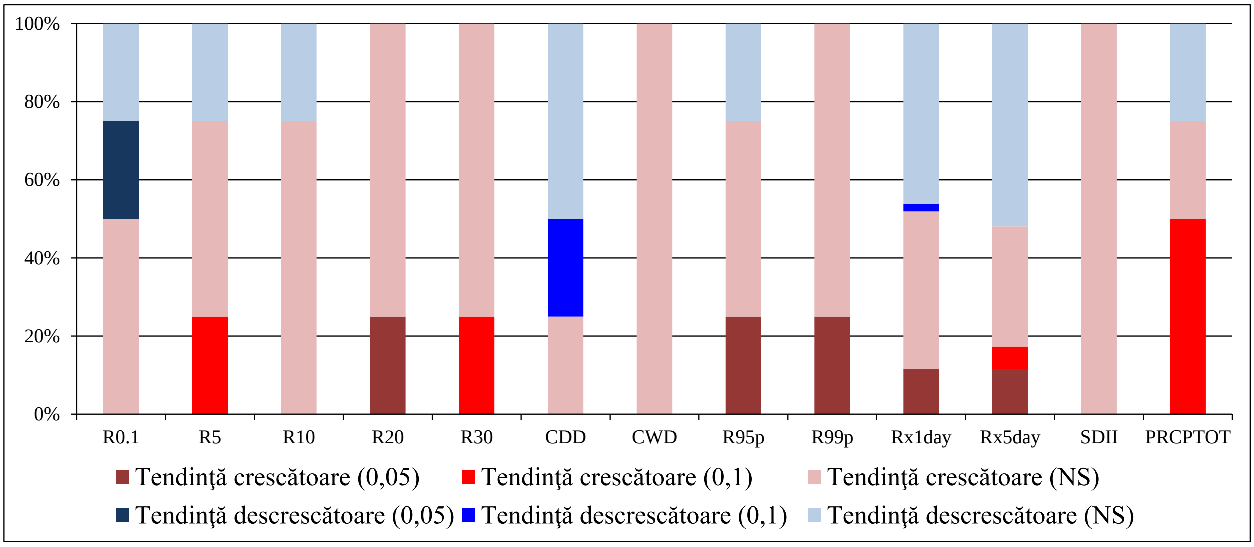
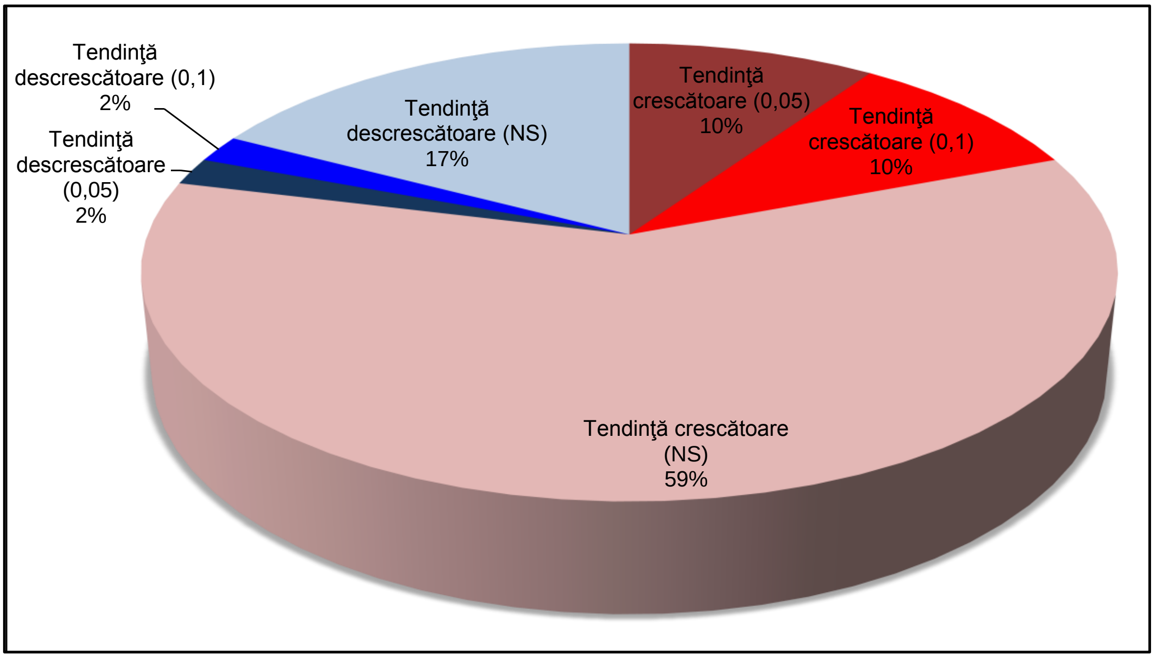


Figure 11. Frequency of different trend types in extreme precipitation indices (1961-2010). NS – statistically insignificant; 0.1 – statistically significant at α level = 0.1; 0.05 – statistically significant at α level = 0.05.

We found a general increase in the precipitation indices. These results are in consent to other studies that previously have asserted that there have been increases in extreme precipitation indices when averaged across the globe or regional scale (Alexander et al., 2006).



Figue 12. Generalized trends of the extreme precipitation indices in northeastern Romania (1961-2010). NS – statistically insignificant; 0.1 – statistically significant at α level = 0.1; 0.05 – statistically significant at α level = 0.05.

In analyzed area, for the great majority of indices, the negative slopes are more specific to the eastern part of the country, while increasing trends are specific for the rest of the territory under consideration (figures 13-15).

In terms of statistical significance, the results are similar with those revealed for other regions in Central and Eastern Europe, like Southern Poland and central-eastern Germany (Lupikasza et al., 2011), where, usually less than 20 % of the trends were found significant (α = 0.1).

The observed increase in the frequency of occurrence and intensity of short-term heavy rainfall events could be attributed to global warming that could enhance the surface evaporation and increase the moisture holding capacity in the atmosphere, resulting in higher chance of the occurrence of heavy rainfall events (IPCC, 2007; Croitoru et al., 2013a).

Precipitation extremes indices slope values are shown in Table 12.

The explanation of most upward trends in extreme precipitation indices could be attributed to the location of all stations near the four large cities (Bacău, Botoşani, Iaşi, and Suceava), if we consider the fact that urbanization can influence changes in precipitation (Wong et al., 2011). Few previous studies have suggested that the "urban heat island" effect can induce more precipitation in the urban areas (Chow, 1986; Sheperd et al., 2002; Dixon and Mote, 2003).

The attribution to local urbanization could be supported by the decreasing trends of precipitation from Ceahlău station located far from large cities (Piticar and Ristoiu, 2013a).

Table 12. Slopes of the extreme precipitation indices in northeastern Romania (1961-2010). Slopes are computed per decade.

Indices	Bacău	Botoşani	Iaşi	Suceava
R0.1	1,91	1,91	-2,96**	-0,03
R5	0,28	0,23	-0,41	1,34*
R10	0,8	0,62	-0,41	0,6
R20	0,55**	0,28	0,12	0,4
R30	0,22	0,2	0,06	0,30*
CDD	-1,39*	0,24	-1,14	-0,15
CDW	0,21	0,24	0,12	0,1
R95p	15,93**	4,82	-0,28	13,44
R99p	10,92**	0,37	0,6	3,44
Rx1d	4,55**	2,38	-3,5	1,78
Rx5d	6,29**	3,78*	-2,71	4,03
SDII	0,11	0,06	0,04	0,13
PRECPTOT	22,60*	12,82	-10,23	20,72*

*Statistically significant trend;

**Strong statistically significant trend

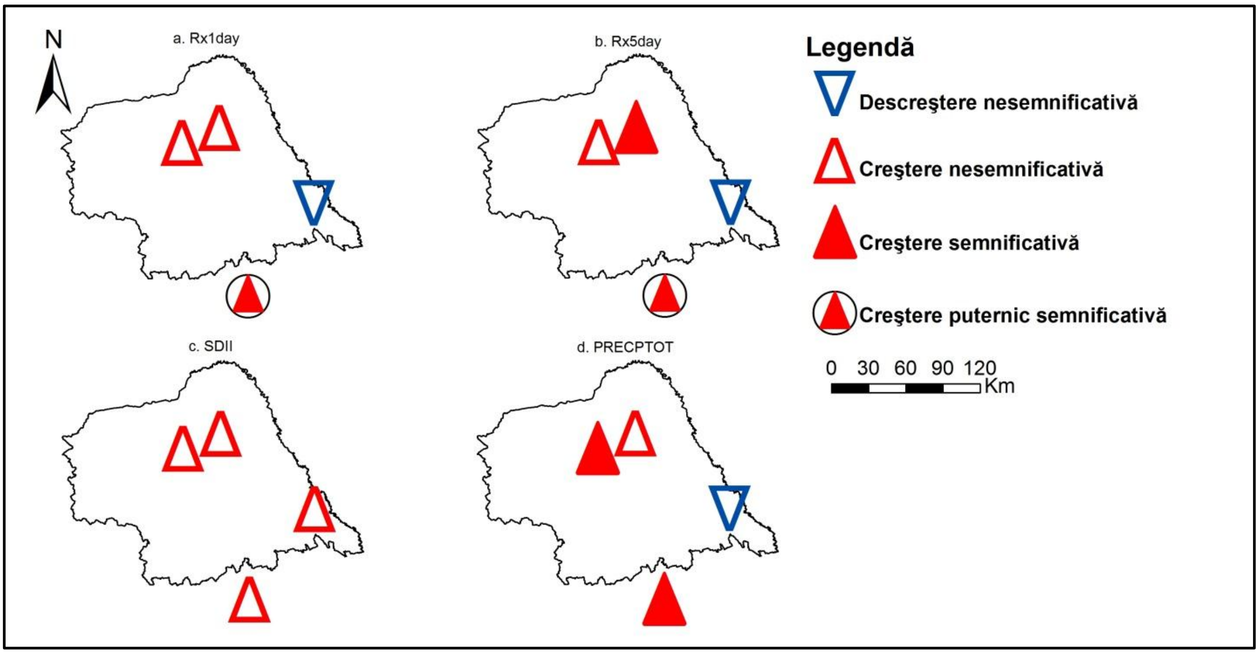


Figure 13. Spatial distribution of trends identified in non-thresholds indices in northeastern Romania (1961-2010)

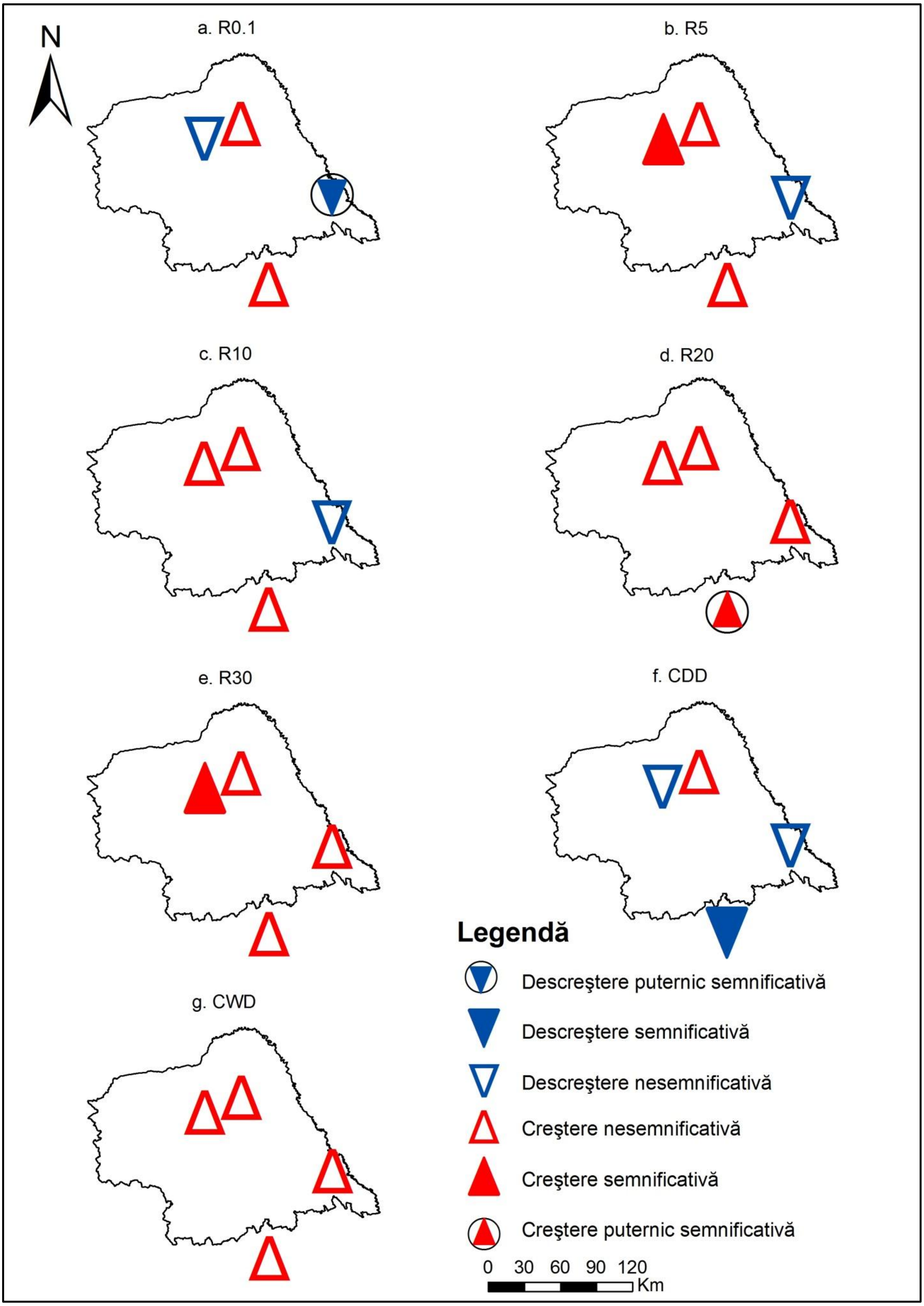


Figure 14. Spatial distribution of trends identified in indices based on fixed thresholds in northeastern Romania (1961-2010)

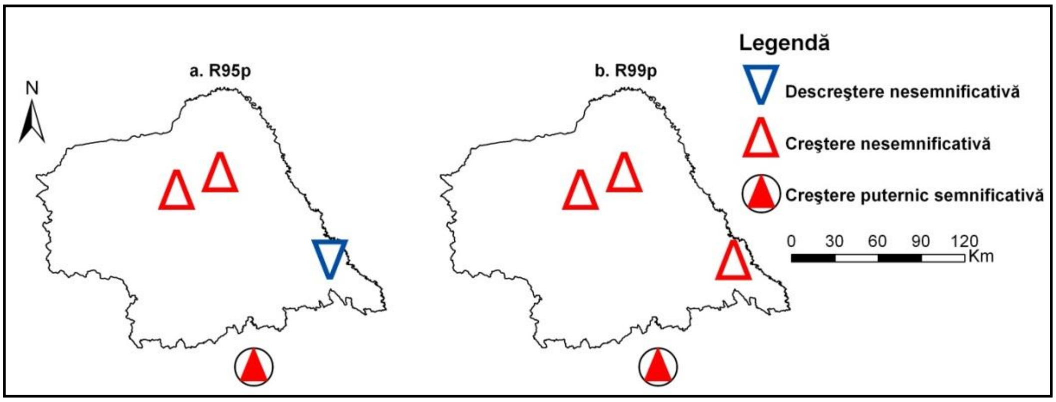


Figure 15. Spatial distribution of trends identified in indices based on station-related thresholds in northeastern Romania (1961-2010)

3.2.5. Changes in snowfall and snow cover

Changes in snowfall and snow cover are presented in tables 13-15 and figures 16-18.

Table 13. Slopes for snowfall days (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level.

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
O	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
N	0,29	-0,50	0,33	0,00	0,49	0,00	0,00	0,00	0,00	0,22
D	-0,65	-0,87	0,00	-0,53	0,00	0,00	**-2,22**	**-1,11**	**-1,03**	**-1,00**
J	**-1,11**	-0,77	0,00	-1,33	-0,53	-0,48	**-1,20**	**-1,25**	**-1,48**	-0,65
F	-0,87	-1,20	0,00	-1,08	-0,38	-0,48	**-1,92**	-0,79	**-1,43**	-0,72
M	-0,63	-0,77	0,00	-0,83	-1,00	-0,54	-1,02	**-1,11**	**-1,00**	-0,72
Winter	**-3,60**	**-3,10**	0,42	**-3,57**	-1,43	-0,30	**-5,97**	**-3,87**	**-4,00**	**-2,62**
Cold semester	**-4,12**	**-4,55**	0,71	**-3,33**	-1,88	-0,32	**-7,27**	**-4,58**	**-5,00**	**-3,10**
Annual	**-3,75**	**-7,22**	0,72	-2,31	-1,79	-1,11	**-7,76**	**-4,58**	**-5,00**	**-3,33**

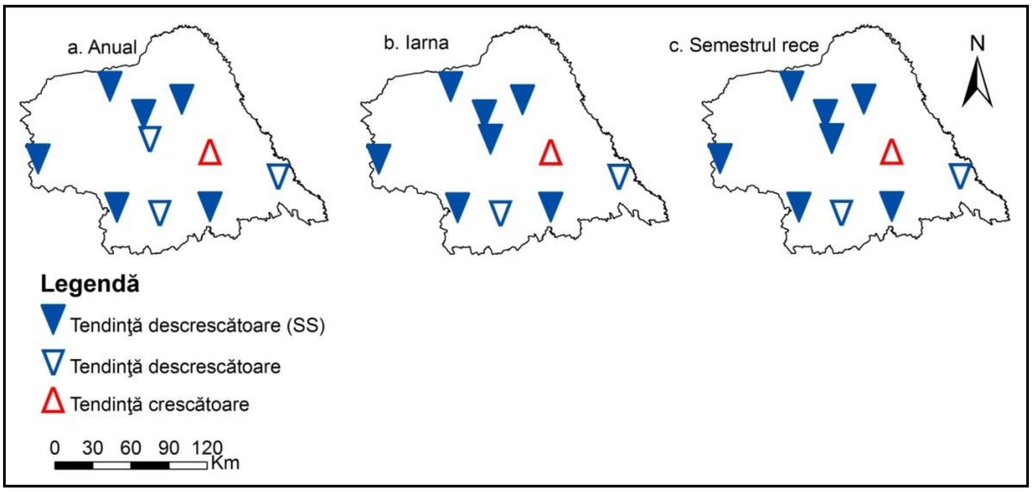


Figure 16. Spatial distribution of snowfall days trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 14. Slopes for snow cover days (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level.

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
O	0,00	0,77	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
N	0,48	0,00	**0,56**	0,00	**0,30**	0,00	0,83	0,24	0,00	0,29
D	0,30	0,00	0,65	1,18	0,67	0,29	0,00	0,32	0,00	0,23
J	-1,48	0,00	-1,52	**-2,70**	-0,83	-0,91	**0,01**	-0,56	**-1,11**	-0,87
F	-0,77	0,00	-0,83	-0,65	-0,81	0,00	0,00	-0,45	-1,58	-0,34
M	0,00	**0,02**	0,00	-1,82	-1,00	0,00	0,00	-1,11	**-1,25**	-0,95
Winter	-3,57	0,00	-2,31	-3,94	-2,50	-1,49	-1,57	-2,08	-3,64	-1,61
Cold sem.	-3,85	1,76	-2,86	-4,29	-2,50	-1,81	-1,49	-2,09	-4,86	-1,47
Annual	-3,00	4,44	-2,70	-2,00	-2,50	0,00	-2,94	-2,50	**-5,00**	-2,50

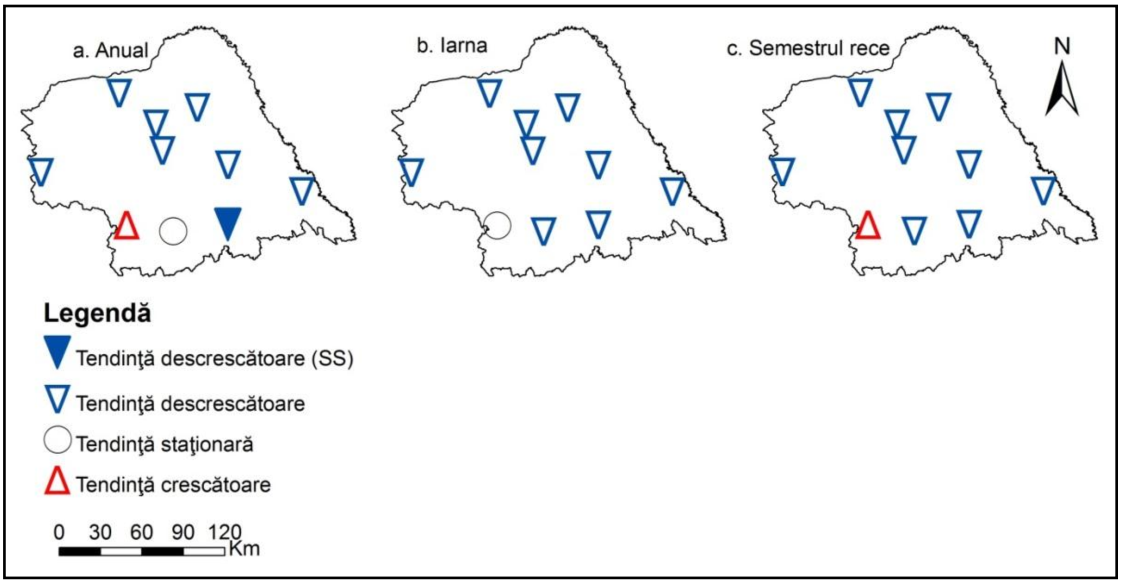


Figure 17. Spatial distribution of snow cover days trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 15. Slopes for snow cover depth (cm/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level.

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
O	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
N	0,00	0,71	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
D	0,00	0,42	0,00	0,70	0,00	0,50	-1,82	0,00	0,00	0,00
I	-0,87	2,83	0,00	0,00	0,00	1,00	-2,16	-0,53	-0,47	0,00
F	**-1,46**	5,94	-0,59	0,00	-0,31	0,00	-2,63	-1,07	**-1,25**	-0,70
M	0,00	**8,00**	0,00	0,00	0,00	0,00	-1,33	**-0,56**	0,00	-0,42
Iarna	**-0,83**	3,03	-0,12	0,58	-0,40	0,67	-1,98	-0,67	-0,80	-0,33
Sem. rece	**-0,71**	2,74	-0,21	0,24	-0,26	0,13	-1,10	-0,58	**-0,56**	-0,37
Anual	**-0,31**	**2,50**	0,00	0,10	-0,02	0,00	-0,63	-0,28	**-0,27**	-0,12

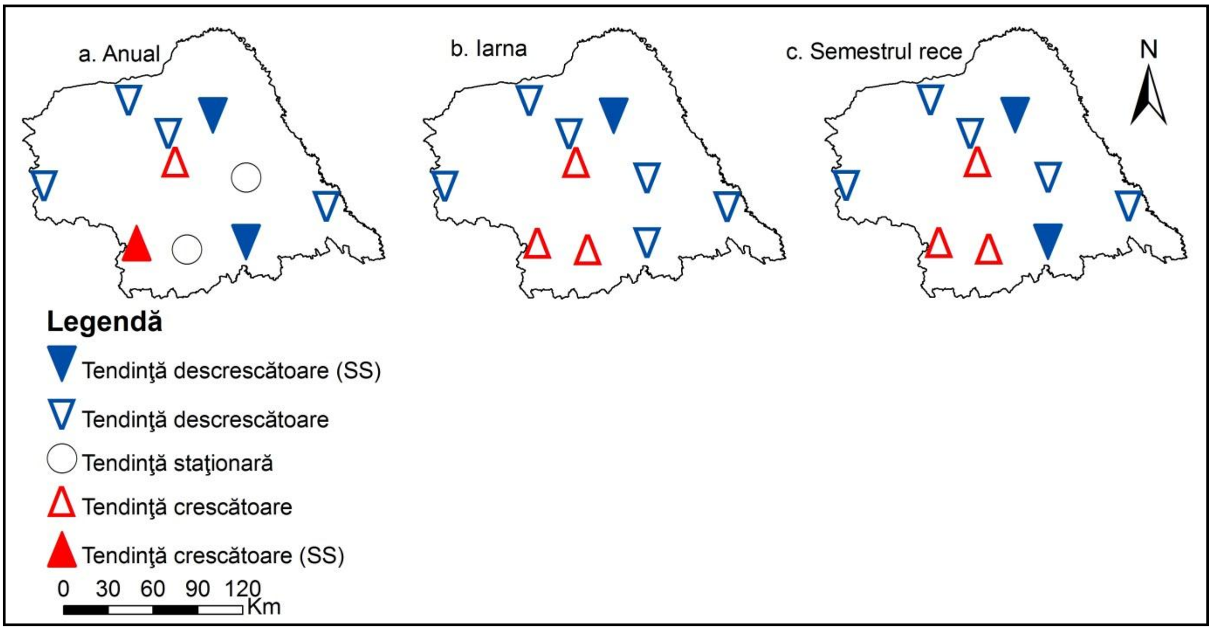


Figure 18. Spatial distribution of snow cover depth trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.3. Changes in cloudiness

Changes in total cloud cover are presented in Table 16 and Figure 19.

Table 16. Slopes for total cloud cover (thents/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	0,12	0,12	0,15	0,10	0,12	-0,17	-0,05	0,05	0,00	0,09
F	-0,03	-0,05	0,00	-0,11	**-0,18**	-0,24	**-0,20**	-0,16	-0,21	-0,12
M	0,00	0,15	0,11	-0,06	-0,10	-0,19	-0,15	-0,08	-0,12	-0,11
A	0,08	-0,05	**0,23**	0,00	0,00	-0,02	-0,18	0,03	0,00	-0,07
M	-0,06	**-0,18**	0,13	-0,18	-0,17	**-0,27**	**-0,27**	-0,09	**-0,24**	-0,13
J	0,17	-0,13	0,20	0,04	0,03	-0,08	**-0,35**	0,06	0,00	0,00
J	0,10	-0,11	0,15	-0,07	0,00	-0,09	**-0,38**	0,00	-0,06	-0,05
A	0,14	-0,15	**0,24**	0,00	0,00	0,00	**-0,38**	0,05	0,00	0,00
S	**0,29**	0,13	**0,35**	**0,25**	0,21	0,15	-0,17	0,22	0,23	0,19
O	**0,27**	0,20	**0,30**	0,20	0,17	0,08	-0,09	0,14	0,13	0,16
N	0,00	-0,07	0,03	-0,04	-0,06	**-0,25**	**-0,30**	-0,10	-0,09	-0,16
D	0,04	-0,17	0,11	0,00	0,00	-0,17	**-0,38**	-0,04	-0,08	0,00
Winter	0,00	-0,02	0,08	-0,02	-0,04	**-0,21**	**-0,24**	-0,08	-0,11	-0,04
Spring	0,00	-0,03	**0,14**	-0,06	-0,09	**-0,17**	**-0,20**	-0,06	**-0,15**	**-0,13**
Summer	**0,14**	-0,13	**0,18**	-0,01	-0,03	-0,08	**-0,38**	0,03	-0,02	-0,04
Autumn	**0,18**	0,06	**0,24**	0,13	0,09	0,00	**-0,20**	0,08	0,12	0,07
Annual	**0,07**	-0,02	**0,16**	0,02	-0,01	**-0,11**	**-0,29**	0,00	-0,03	-0,02

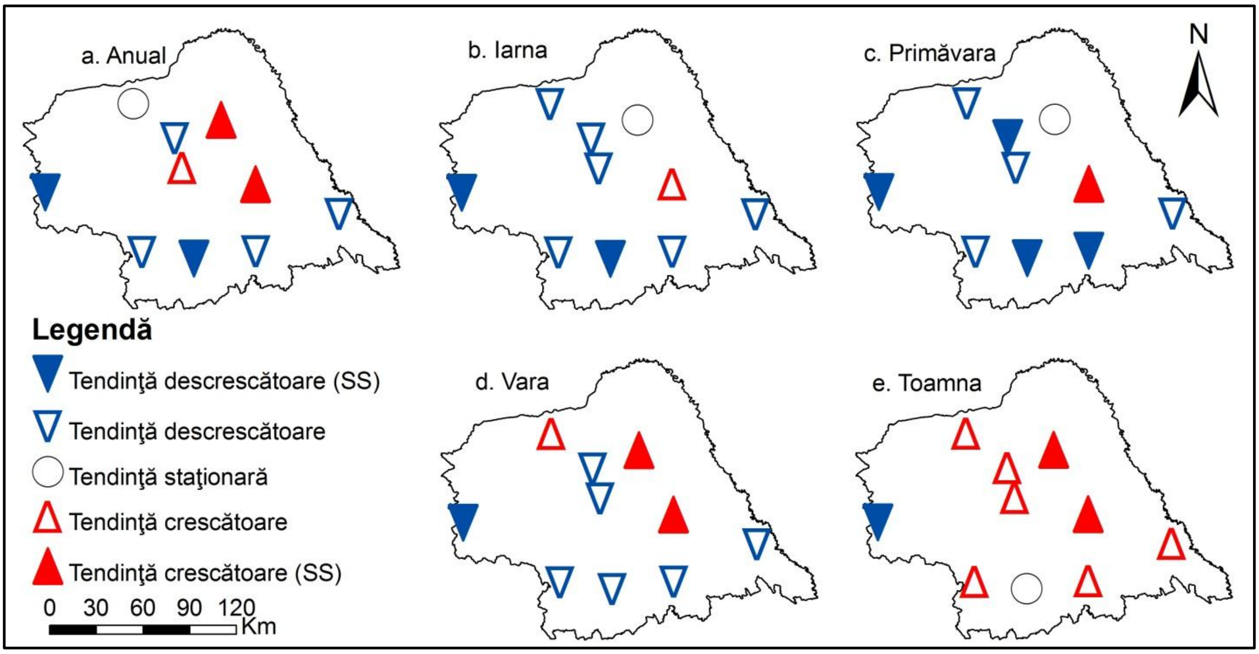


Figure 19. Spatial distribution of total cloud cover trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.4. Changes in sunshine duration

Changes in sunshine duration are presented in Table 17 and Figure 20.

Table 17. Slopes for sunshine duration (hours/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	1,15	-5,84	-2,52	0,31	-2,07	3,66	0,48	4,10	2,89	1,42
F	**8,09**	-2,31	5,75	6,07	**7,34**	**6,25**	4,33	**7,48**	**7,34**	**7,00**
M	**6,38**	**-10,43**	3,54	4,05	3,69	4,46	3,10	6,81	**8,60**	3,76
A	4,80	0,62	2,60	2,53	4,22	-0,24	1,73	**11,50**	**7,80**	5,00
M	**12,96**	9,86	**13,42**	**12,47**	**10,13**	**12,10**	**8,45**	**19,65**	**18,35**	**8,89**
J	5,58	8,48	4,23	3,67	4,73	2,59	6,28	**12,19**	**8,11**	0,38
J	**7,92**	4,27	7,59	5,08	7,33	**10,03**	-3,19	**16,10**	**15,05**	4,12
A	1,16	3,80	0,49	-0,49	0,44	0,03	-5,23	**11,18**	6,16	3,71
S	-2,59	-5,75	-6,58	-6,39	-5,33	-5,86	**-18,22**	-1,05	-3,56	-4,22
O	0,87	-7,47	-2,54	-4,10	-2,92	-2,41	**-11,24**	0,70	-0,69	-3,25
N	**6,73**	2,20	3,22	1,66	3,50	4,15	0,33	5,31	**5,26**	4,23
D	1,67	3,05	0,61	0,50	2,41	2,18	1,97	2,26	2,56	1,50
Winter	**13,22**	-5,67	5,53	8,81	**14,42**	**14,24**	4,89	**16,38**	**14,32**	**9,42**
Spring	**25,33**	-1,28	**20,02**	**19,81**	**19,55**	**18,06**	13,77	**41,51**	**37,74**	**19,53**
Summer	16,55	16,06	**14,87**	9,18	11,20	11,65	-4,32	**38,44**	**30,89**	6,64
Autumn	5,22	-14,31	-7,55	-8,93	-4,96	-3,01	**-26,70**	1,74	0,40	-5,12
Annual	**61,63**	-8,53	**31,27**	**27,96**	**43,50**	**37,28**	5,00	**94,81**	**81,07**	**27,94**

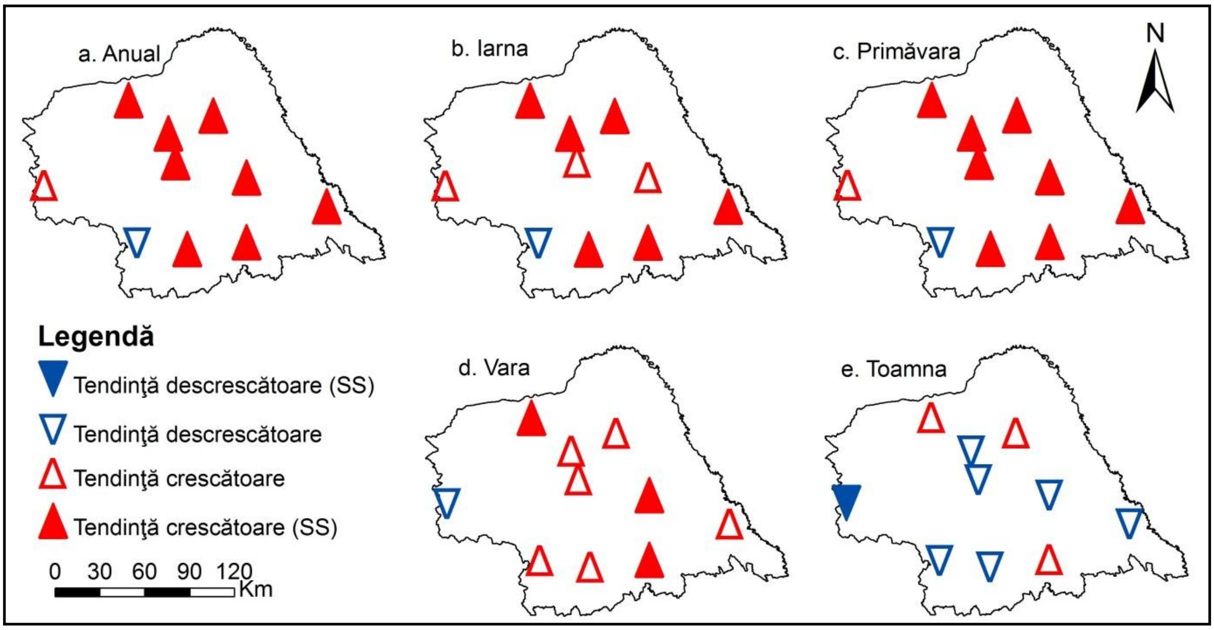


Figure 20. Spatial distribution of sunshine duration trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.5. Changes in relative humidity

Changes in relative humidity are presented in Table 18 and Figure 21.

Table 18. Slopes for relative humidity (% /decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	**-1,76**	**3,89**	0,00	-0,29	**-1,29**	-0,29	**1,07**	**-1,11**	-0,42	-0,42
F	**-2,22**	**2,14**	-0,91	**-1,05**	**-2,43**	-1,11	0,41	**-1,76**	**-1,25**	-0,94
M	**-2,31**	**3,21**	-0,73	**-1,33**	**-2,34**	-0,87	0,46	**-1,84**	**-2,31**	**-1,52**
A	-0,67	**2,35**	0,36	0,00	-1,11	0,68	0,28	**-1,33**	**-1,33**	-0,43
M	-1,60	**2,00**	0,00	-0,63	**-1,61**	0,00	-0,27	**-1,76**	**-1,71**	-0,88
J	-0,63	**1,82**	0,35	0,00	-0,86	0,47	-0,83	-0,71	-0,61	-0,37
J	-1,08	**1,71**	0,31	0,00	**-1,33**	0,75	-0,21	-0,65	-0,71	0,00
A	0,00	**2,14**	0,27	0,00	-0,56	1,07	0,00	0,00	0,00	0,00
S	0,67	**2,16**	**1,59**	0,16	-0,36	**1,11**	0,76	0,00	0,00	0,34
O	-0,26	**3,33**	**1,25**	0,42	0,00	**1,82**	0,59	0,23	0,24	0,63
N	-0,67	**1,67**	0,44	-0,16	**-1,43**	0,00	0,42	-0,25	0,00	0,00
D	**-1,54**	1,33	0,00	0,00	**-1,54**	0,26	**0,72**	-0,38	-0,26	0,00
Winter	**-1,88**	**2,59**	-0,65	-0,62	**-1,79**	-0,42	**0,84**	**-1,13**	-0,76	-0,52
Spring	-1,25	**2,64**	-0,20	**-0,80**	**-1,80**	0,16	-0,02	**-1,59**	**-1,72**	**-0,92**
Summer	-0,60	**1,86**	0,45	0,00	-0,91	0,80	-0,28	-0,65	-0,63	-0,15
Autumn	0,00	**2,30**	1,03	0,20	-0,76	**1,17**	0,52	0,00	0,00	0,43
Annual	-0,87	**2,56**	0,25	-0,26	**-1,31**	0,83	0,26	**-0,78**	-0,72	-0,30

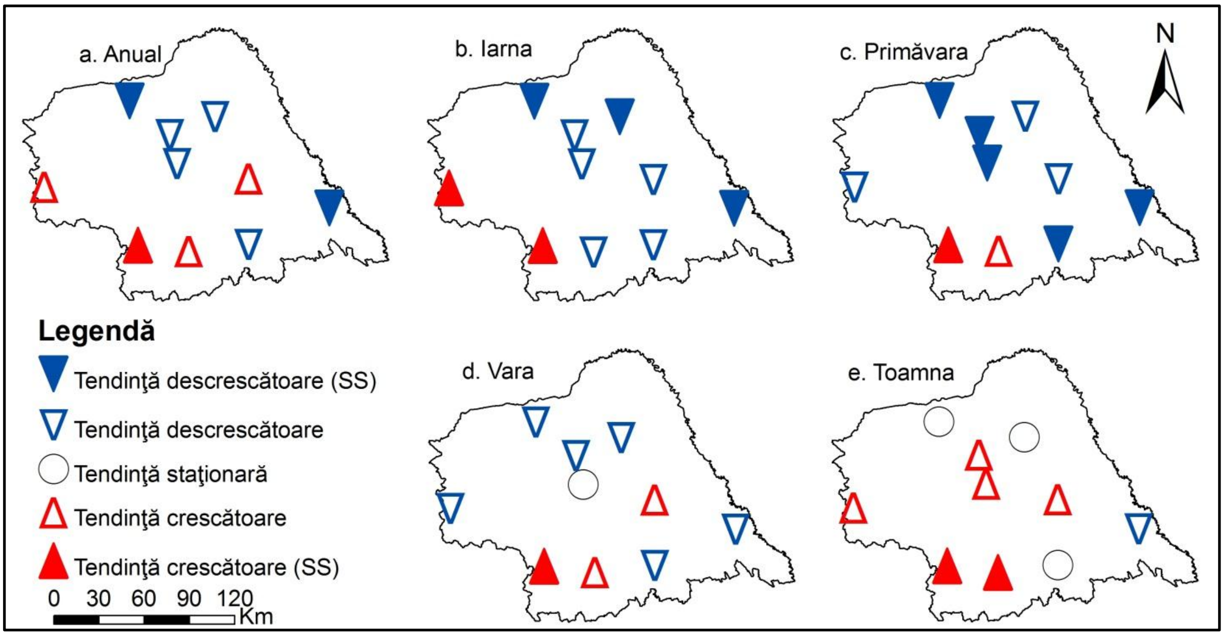


Figure 21. Spatial distribution of relative humidity trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.6. Changes in soil surface temperature

Changes in soil surface temperature are presented in Table 19 and Figure 22.

Table 19. Slopes for soil surface temperature (°C/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	**1,00**	**0,66**	**0,79**	**0,84**	0,23	**0,92**	**0,85**	**0,71**	0,57
F	0,59	0,59	0,61	0,33	0,40	0,49	0,64	0,57	0,53
M	0,63	0,57	0,57	**0,62**	0,20	0,18	0,47	**0,59**	0,55
A	0,18	0,23	0,20	0,18	0,00	0,33	0,26	0,22	0,20
M	**0,60**	**0,55**	0,33	**0,86**	0,24	0,16	0,11	0,47	0,18
J	**0,59**	0,36	0,37	**0,75**	0,06	**0,69**	0,14	0,33	0,10
J	**0,83**	**0,63**	**0,50**	**0,84**	0,21	**0,67**	**0,44**	**0,46**	**0,37**
A	0,35	0,28	**0,29**	**0,55**	0,08	**0,55**	0,33	0,35	0,17
S	-0,14	-0,13	-0,23	-0,13	-0,26	0,00	-0,26	-0,13	-0,26
O	0,05	0,15	0,06	0,21	0,16	**0,32**	-0,04	0,12	0,00
N	-0,32	-0,20	-0,21	-0,33	0,26	0,51	-0,12	-0,07	-0,10
D	0,23	0,16	0,21	0,00	-0,18	0,62	0,33	0,30	0,26
Winter	**0,54**	**0,49**	**0,57**	0,33	0,13	**0,65**	**0,61**	**0,50**	**0,44**
Spring	**0,48**	**0,45**	**0,35**	**0,48**	0,12	0,24	0,30	**0,42**	**0,33**
Summer	**0,59**	**0,41**	**0,41**	**0,67**	0,18	**0,62**	**0,34**	**0,38**	0,19
Autumn	-0,09	-0,06	-0,10	-0,06	-0,01	**0,34**	-0,09	-0,04	-0,14
Annual	**0,34**	**0,30**	**0,26**	**0,31**	0,08	**0,37**	**0,26**	**0,26**	**0,18**

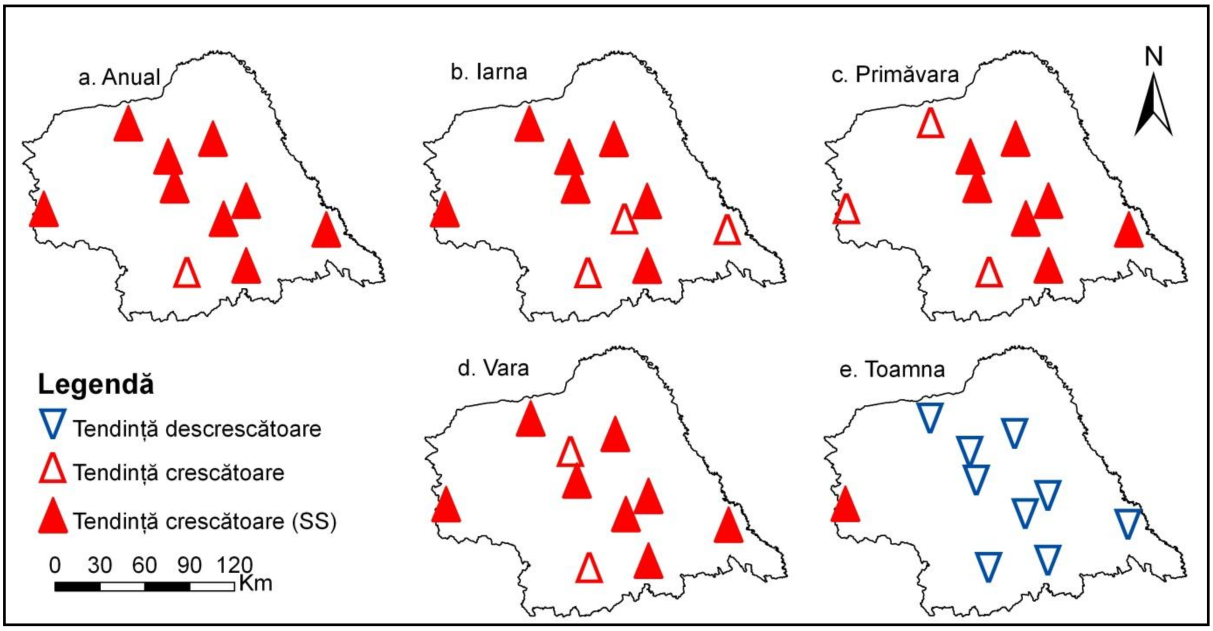


Figure 22. Spatial distribution of soil surface temperature trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.7. Changes in atmospheric pressure

Changes in atmospheric pressure are presented in Table 20 and Figure 23.

Table 20. Slopes for atmospheric pressure (hPa/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	0,28	0,54	-0,11	0,14	0,18	-0,71	0,36	0,08	-0,33	-0,27
F	0,50	0,40	0,07	0,39	0,27	0,08	0,40	0,24	-0,11	-0,24
M	0,47	-0,05	-0,37	-0,03	0,23	-0,07	-0,08	0,04	-0,29	-0,44
A	**0,55**	**0,56**	-0,35	0,09	0,43	-0,07	0,33	0,41	0,17	0,00
M	**0,50**	0,22	-0,12	0,26	0,35	-0,06	0,19	0,25	0,00	-0,03
J	0,33	0,36	-0,31	0,12	0,14	-0,24	0,00	0,04	-0,24	-0,32
J	0,27	**0,43**	**-0,42**	0,00	0,06	-0,17	0,00	0,09	-0,32	-0,30
A	0,19	**0,37**	**-0,47**	-0,14	0,00	0,06	0,00	0,00	-0,28	-0,25
S	-0,05	0,07	**-0,81**	-0,37	-0,26	-0,12	-0,37	-0,31	**-0,57**	-0,43
O	0,10	0,00	-0,58	-0,16	-0,13	-0,07	-0,33	-0,18	-0,50	-0,47
N	**0,53**	0,28	-0,09	0,32	0,35	-0,02	0,00	0,13	-0,15	-0,26
D	**1,50**	0,65	0,77	**1,00**	**1,29**	0,25	**0,78**	0,75	0,64	0,75
Winter	**0,78**	0,58	0,29	0,57	**0,68**	-0,09	**0,65**	0,55	0,20	0,22
Spring	**0,44**	0,26	-0,27	0,10	0,29	0,00	0,15	0,18	-0,06	-0,12
Summer	**0,25**	**0,39**	**-0,41**	0,00	0,05	-0,09	0,05	0,04	**-0,27**	**-0,22**
Autumn	0,21	0,13	**-0,48**	-0,10	0,00	-0,07	-0,22	-0,15	**-0,43**	**-0,35**
Annual	**0,40**	**0,42**	**-0,28**	0,16	0,22	-0,10	0,13	0,13	-0,10	-0,15

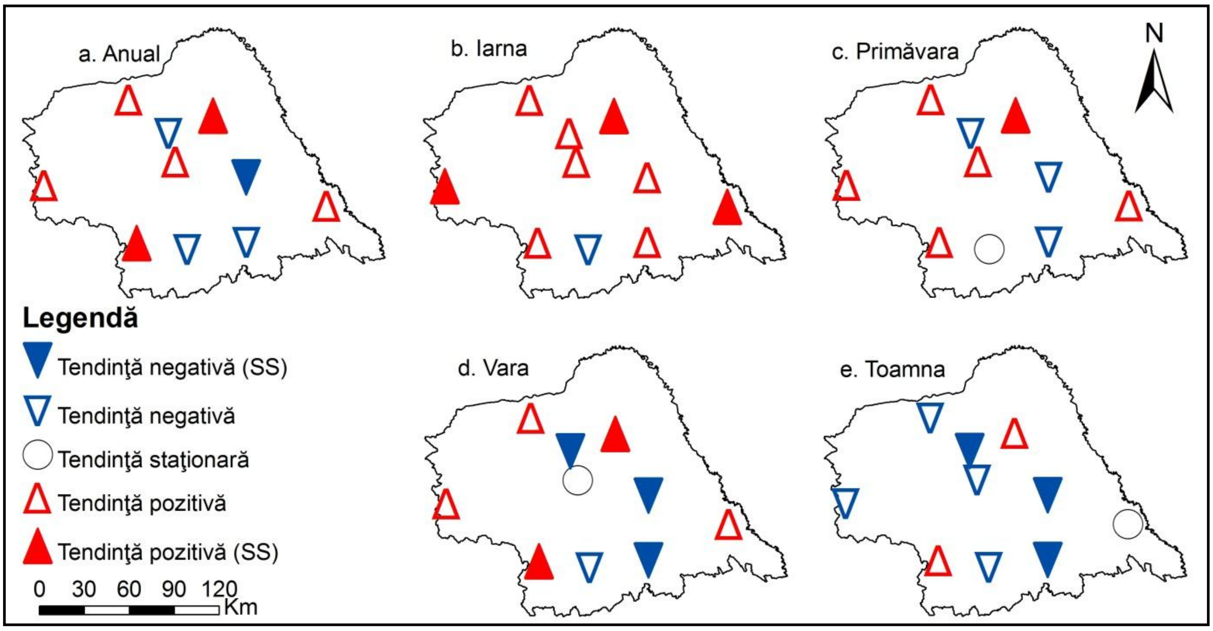


Figure 23. Spatial distribution of atmospheric pressure trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

3.8. Changes in wind speed

Changes in wind direction and speed are presented in Table 21 and Figure 24.

Table 21. Slopes for wind speed (m/s/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	0,05	-0,46	0,00	0,00	**-0,32**	0,04	-0,10	**-0,34**	0,13	-0,12
F	0,06	-0,71	0,13	0,06	**-0,45**	-0,05	**-0,27**	**-0,47**	0,04	-0,18
M	0,19	-0,20	0,21	**0,18**	**-0,31**	0,00	**-0,20**	**-0,21**	**0,23**	-0,05
A	0,07	**-0,73**	0,03	**0,13**	**-0,36**	**-0,21**	**-0,24**	**-0,35**	0,13	-0,07
M	**0,18**	**-0,39**	0,09	0,10	**-0,19**	**-0,25**	**-0,17**	**-0,25**	**0,14**	0,00
J	**0,15**	-0,21	0,01	0,06	**-0,16**	**-0,42**	**-0,17**	**-0,18**	**0,17**	0,00
J	0,13	-0,31	0,00	0,04	**-0,17**	**-0,39**	-0,12	**-0,14**	**0,16**	0,06
A	0,07	0,00	-0,03	0,02	**-0,20**	**-0,44**	**-0,21**	**-0,17**	0,08	0,04
S	**0,19**	-0,19	**0,21**	0,08	-0,07	**-0,25**	-0,11	-0,03	**0,24**	0,10
O	0,13	-0,57	0,07	0,00	**-0,20**	**-0,18**	-0,08	**-0,20**	**0,20**	-0,04
N	0,11	-0,61	0,05	0,04	**-0,20**	0,00	**-0,23**	**-0,28**	**0,24**	-0,13
D	0,00	**-0,82**	0,01	0,06	**-0,33**	0,03	**-0,16**	**-0,27**	**0,18**	-0,08
Winter	0,05	**-0,65**	0,02	0,00	**-0,40**	0,00	**-0,24**	**-0,37**	0,10	**-0,17**
Spring	0,12	**-0,51**	0,10	**0,12**	**-0,29**	**-0,14**	**-0,23**	**-0,29**	**0,18**	-0,04
Summer	0,13	-0,14	0,00	0,03	**-0,18**	**-0,42**	**-0,17**	**-0,19**	**0,13**	0,01
Autumn	**0,15**	**-0,44**	0,11	0,05	**-0,14**	**-0,14**	**-0,17**	**-0,17**	**0,22**	-0,04
Annual	0,12	**-0,46**	0,05	0,06	**-0,23**	**-0,17**	**-0,22**	**-0,26**	**0,15**	-0,08

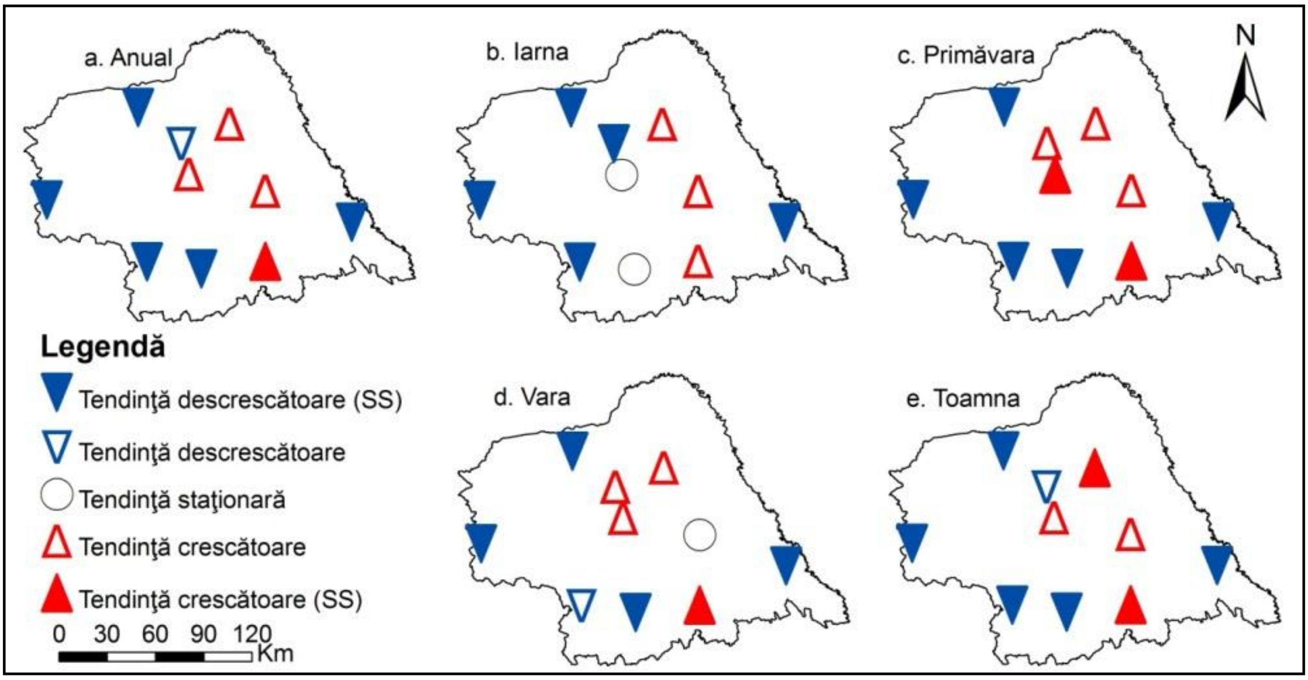


Figure 24. Spatial distribution of wind speed trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

4. Changes in the evolution of hazardous atmospheric phenomena

Changes in the evolution of hazardous atmospheric phenomena are presented in tables 22-27 and figures 25-29.

Table 22. Slopes for number of days with hoarfrost (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
S	0,00	0,00	0,00	0,00	0,00	0,00	**-0,97**	0,00	0,00	0,00
O	0,00	0,00	0,00	-0,77	0,00	0,00	**-1,35**	-0,67	**-0,65**	0,00
N	**0,80**	**0,10**	**0,88**	0,00	**1,62**	-0,24	0,00	0,00	0,00	0,71
D	**1,25**	0,00	**1,76**	0,00	**2,67**	**-0,94**	0,00	-0,29	-0,41	0,00
J	**1,38**	0,00	**1,43**	**1,00**	**2,41**	0,00	0,00	0,00	0,00	0,00
F	**1,48**	0,00	**1,20**	**0,10**	**3,33**	0,00	0,00	0,00	0,00	**0,10**
M	0,36	**0,10**	0,47	0,42	**1,33**	-0,23	0,00	0,00	0,33	**0,82**
A	0,00	**0,10**	0,00	0,00	0,00	**-0,31**	-0,86	**-0,51**	0,00	0,30
M	0,00	**0,10**	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Autumn	0,00	**-0,42**	0,62	-0,71	0,83	0,00	**-2,46**	-1,36	-0,94	0,48
Winter	**3,95**	**0,10**	**4,38**	**2,97**	**8,24**	-1,41	0,00	0,29	0,65	**2,22**
Spring	0,71	**0,10**	0,29	0,79	**1,85**	-0,64	-1,00	-0,46	0,00	**1,54**
Annual	**4,17**	**-1,43**	3,81	3,33	**9,33**	-2,39	**-3,33**	-1,79	0,51	**3,75**

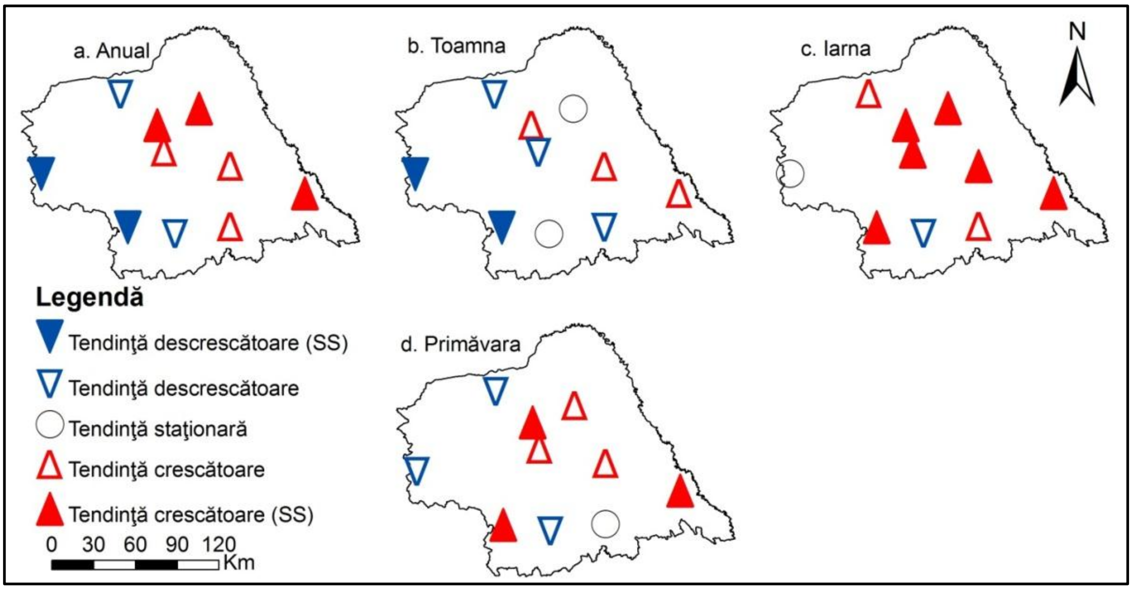


Figure 25. Spatial distribution of number of days with hoarfrost trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 23. Slopes for number of days with glaze frost (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

Station	Annual
Botoşani	0,00
Ceahlău	**-0,38**
Cotnari	0,26
Fălticeni	0,00
Iaşi	0,45
Piatra-Neamţ	0,00
Poiana Stampei	**-0,10**
Rădăuţi	-0,38
Roman	**0,66**
Suceava	0,29

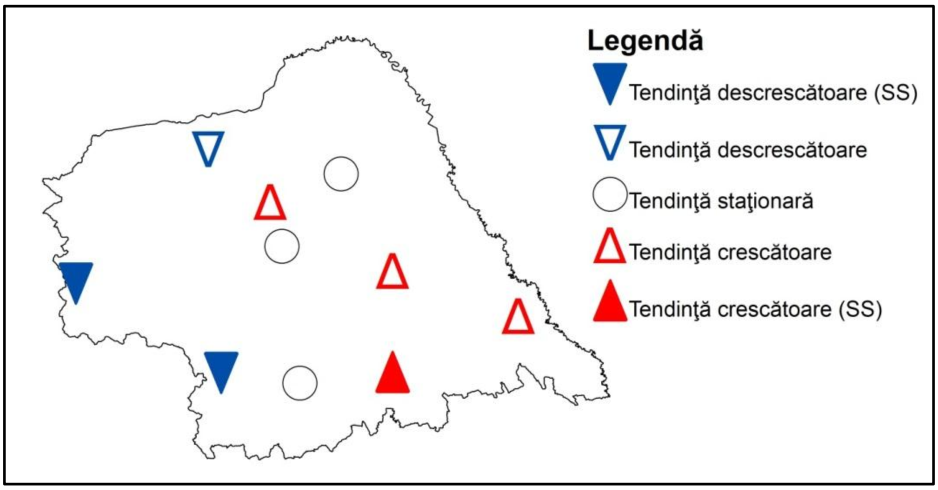


Figure 26. Spatial distribution of number of days with glaze frost trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 24. Slopes for number of days with fog (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	**-1,84**	0,40	-0,27	-0,83	0,00	0,34	**-0,74**	0,00	-0,31	0,00
F	**-2,00**	0,00	**-1,52**	**-1,60**	0,00	0,00	**-0,53**	-0,56	-0,39	**-1,00**
M	**-1,54**	0,30	**-1,25**	-0,87	**-0,65**	0,00	**-0,71**	**-1,06**	**-1,25**	**-1,43**
A	**-0,10**	-0,49	**-0,53**	0,00	0,00	0,00	**-0,77**	0,00	0,00	**-0,29**
M	**-0,10**	0,00	0,00	0,00	**-0,10**	0,00	**-1,61**	0,00	0,00	0,00
J	0,00	-0,57	**-0,10**	0,00	0,00	0,00	**-2,00**	0,00	0,00	0,00
J	0,00	**-1,25**	0,00	0,00	0,00	0,00	**-1,25**	0,00	0,00	0,00
A	0,00	-0,53	0,00	0,00	0,00	0,00	**-1,25**	0,00	0,00	0,00
S	0,00	0,00	0,00	0,00	0,00	0,00	-1,08	0,00	0,00	0,00
O	0,00	0,53	0,00	**-1,23**	0,00	0,00	**-1,25**	**-0,27**	0,00	0,00
N	**-1,18**	-0,43	-1,14	-0,68	0,00	0,49	**-1,25**	-0,67	0,00	-0,57
D	**-1,62**	-0,69	-0,50	0,00	0,00	0,50	-0,50	0,00	0,00	-0,45
Winter	**-5,17**	0,00	**-2,50**	-2,00	-0,91	1,11	**-2,50**	-0,61	**-1,82**	**-1,36**
Spring	**-2,19**	-0,56	**-1,87**	-1,43	**-0,91**	0,00	**-3,33**	**-1,36**	**-1,48**	**-2,00**
Summer	0,00	**-2,17**	**-0,10**	0,00	0,00	0,00	**-4,82**	0,00	0,00	0,00
Autumn	**-1,30**	0,37	-1,33	-2,22	0,00	0,54	**-3,85**	**-1,11**	-0,24	**-1,11**
Annual	**-10,00**	-2,22	**-7,00**	-6,00	-1,20	1,94	**-15,71**	**-3,75**	**-3,73**	**-5,31**

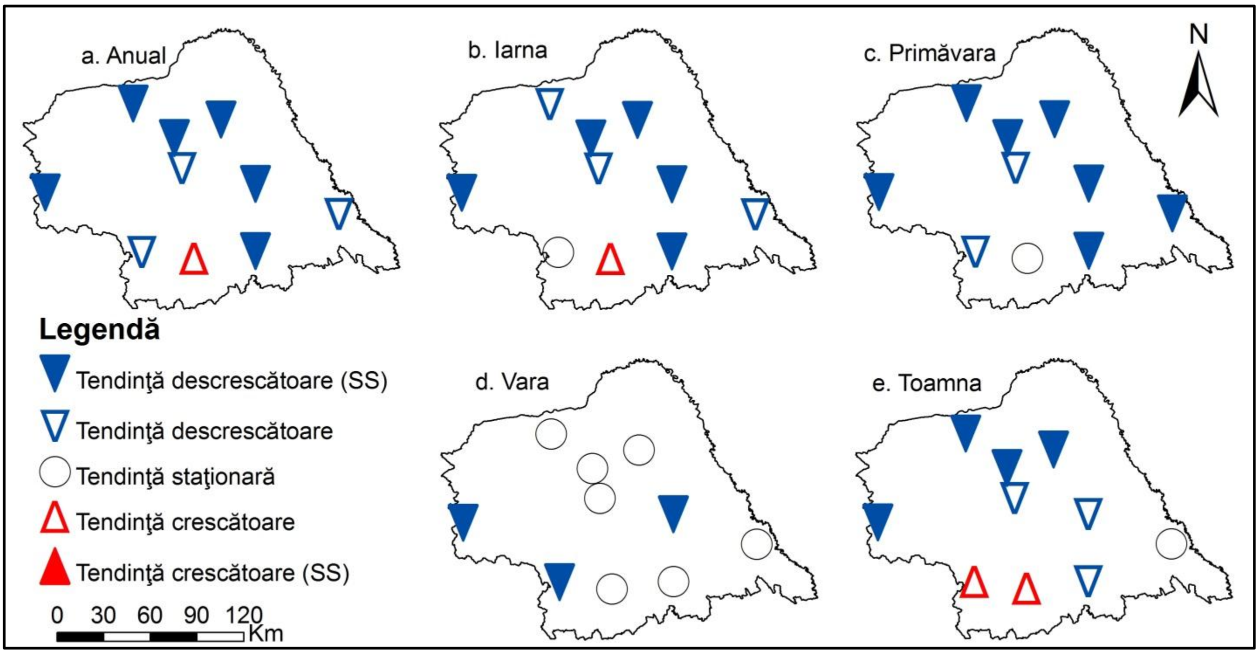


Figure 27. Spatial distribution of number of days with fog trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 25. Slopes for number of days with blizzard (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

Station	Annual
Botoşani	**-0,53**
Ceahlău	**-10,00**
Cotnari	**-0,34**
Fălticeni	**-1,80**
Iaşi	**-0,87**
Piatra Neamţ	0,00
Poiana Stampei	0,00
Rădăuţi	**-0,80**
Roman	**-0,32**
Suceava	**-0,10**

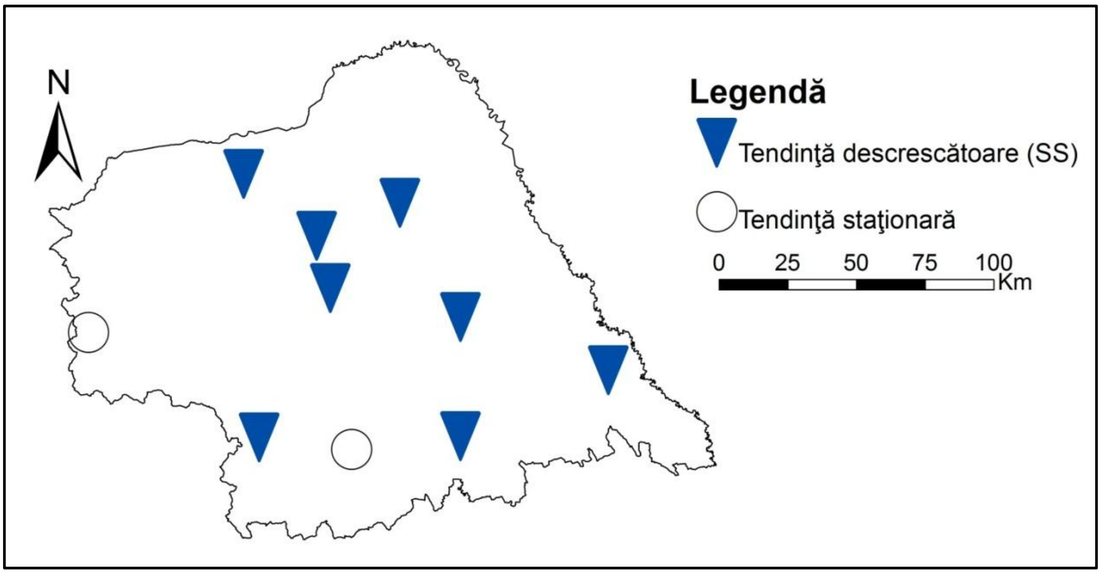


Figure 28. Spatial distribution of number of days with blizzard trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

Table 26. Slopes for number of days with hail (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

Station	Annual
Botoşani	**0,10**
Ceahlău	**-1,11**
Cotnari	0,00
Fălticeni	0,00
Iaşi	0,00
Piatra Neamţ	0,00
Poiana Stampei	0,00
Rădăuţi	0,00
Roman	0,00
Suceava	0,00

Table 27. Slopes for number of days with thunderstorm (days/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at α = 0.05 level

Station	Annual
Botoşani	0,67
Ceahlău	0,37
Cotnari	-2,00
Fălticeni	0,00
Iaşi	0,83
Piatra Neamţ	**2,92**
Poiana Stampei	1,30
Rădăuţi	**-2,00**
Roman	**1,56**
Suceava	0,53

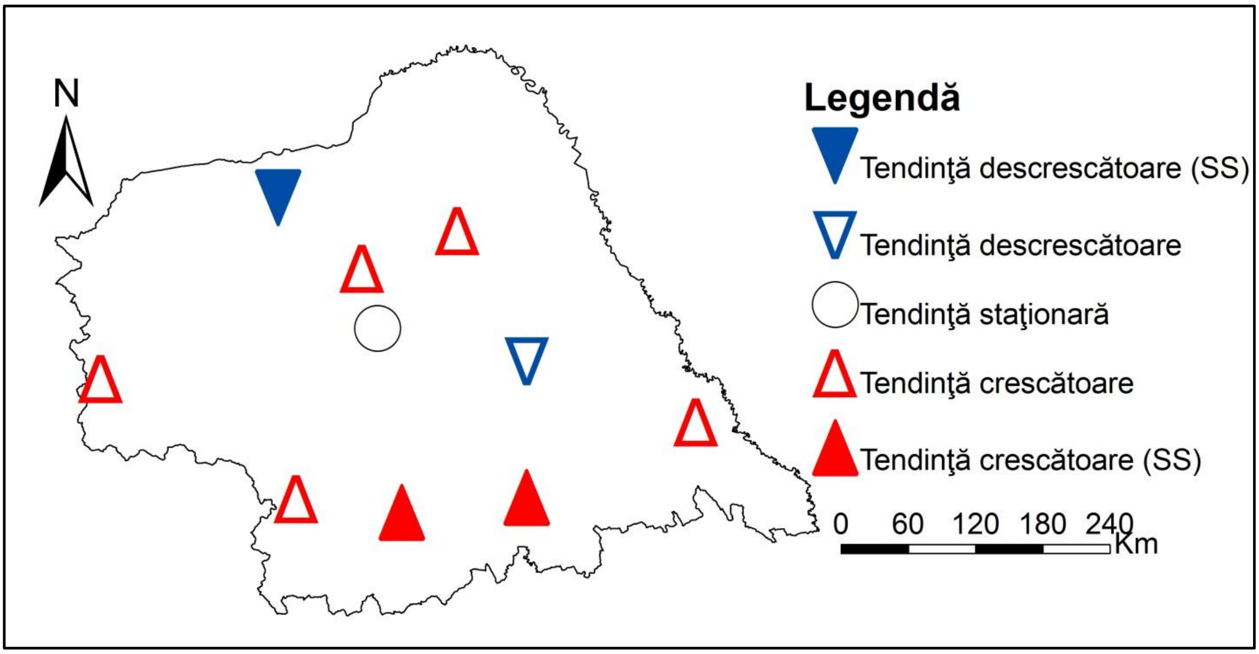


Figure 29. Spatial distribution of number of days with thunderstorm trends in northeastern Romania (1961-2010). SS – statistically significant at α = 0.05 level

5. Aridity

As a result of the droughts have become a recurrent phenomenon in many regions of the world, especially in the subtropics and mid-latitudes, affecting more and more ecosystems and society (Croitoru et al., 2013b) we proceeded to investigate this phenomenon in northeastern Romania.

5.1. Methods

Aridity phenomenon was analyzed on the basis of de Martonne aridity index (de Martonne, 1920, cited by Croitoru et al., 2013b). It can be calculated for both annual and for shorter period. For annual values, it may be calculated as presented in equation (1):

$$IDM = \frac{P}{T_a + 10}, \qquad (1)$$

where P is the annual amount of precipitation (in millimeters) and T_a is the mean annual air temperature (in degree Celsius).

To identify the arid characteristic of a specific month, we used equation (2) (Coscarelli et al., 2004).

$$IDM = \frac{12P_l}{T_{al} + 10}, \qquad (2)$$

where P_i is the monthly amount of precipitation (in millimeters) and T_a is the mean monthly air temperature (in degree Celsius) recorded in the considered month.

For seasonal aridity, the index was calculated as in equation (3) (Croitoru et al., 2013b):

$$IDM = \frac{4P_s}{T_{as} + 10}, \qquad (3)$$

where P_s is the seasonal amount of precipitation (in millimeters) and T_{as} is the mean seasonal air temperature (in degree Celsius) for the analyzed season.

In the present paper, we have calculated the index also for the growing seasons for the main cereal crops cultivated in the area under study, wheat and maize. For winter wheat, we have considered a 9-month period from October until June and, for maize, a 7-month period from April until October, respectively. We have developed the formulas adapted for the growing seasons of each crop according to their duration: for winter wheat (equation 4) and for maize (equation 5).

$$IDM = \frac{1{,}333 P_{vs}}{T_{avs} + 10} \qquad (4)$$

$$DMAI = \frac{1{,}714 P_{vs}}{T_{avs} + 10} \qquad (5)$$

where P_{vs} is the total amount of precipitation in the growing season (in millimeters) of the specific crop and T_{avs} is the mean air temperature of the growing season (in degree Celsius).

Until now, for the Romanian territory, the IDM was calculated only on an annual basis (Paltineanu et al., 2007b; Lungu et al., 2011). We considered it necessary to use it also for shorter periods because the climate parameters vary considerably from one season to another (Croitoru et al., 2013b).

In order to identify the trends, the formulas were applied to each year or shorter periods to get the datasets for trend calculation.

5.2. IDM Trends

Trends of the IDM series for annual values are both positive and negative for the area under study, but most of them are statistically insignificant (Figure 30a). Positive slopes may be associated with a decrease in aridity, while negative slopes indicate an increase in the aridity process. The only station that shows a unique behavior for the annual IDM series is Ceahlău, which, over the period analyzed, has indicated a significant downward trend that may be associated with a decrease in precipitation.

For winter, spring, January, and October–June IDM datasets, decreasing trends prevail (95% of the cases), but most of them are insignificant (Figure 30b, c, g, i). Statistically significant downward slopes are more frequent in winter.

For summer, August, and the maize growing season, the IDM data series revealed mostly positive slopes (75% of the series), but none of them ware statistically significant (Figure 30d, e, f, h).

For a better understanding of the issue, we have to take in consideration also the trends of the input data (temperature and precipitations) datasets at those stations. Both temperature and precipitations are increasing in the area for the same 50- year interval 1961-2010. However, we still have to be cautious since the great majority of the trends in precipitations and the IDM datasets are not statistically significant, while the increases in temperature are significant. If the trends continue in the same direction, it is possible to find significant negative trends in the IDM in a short time, meaning an increase in aridity, especially in those areas and periods of the year where statistically insignificant slopes are now present.

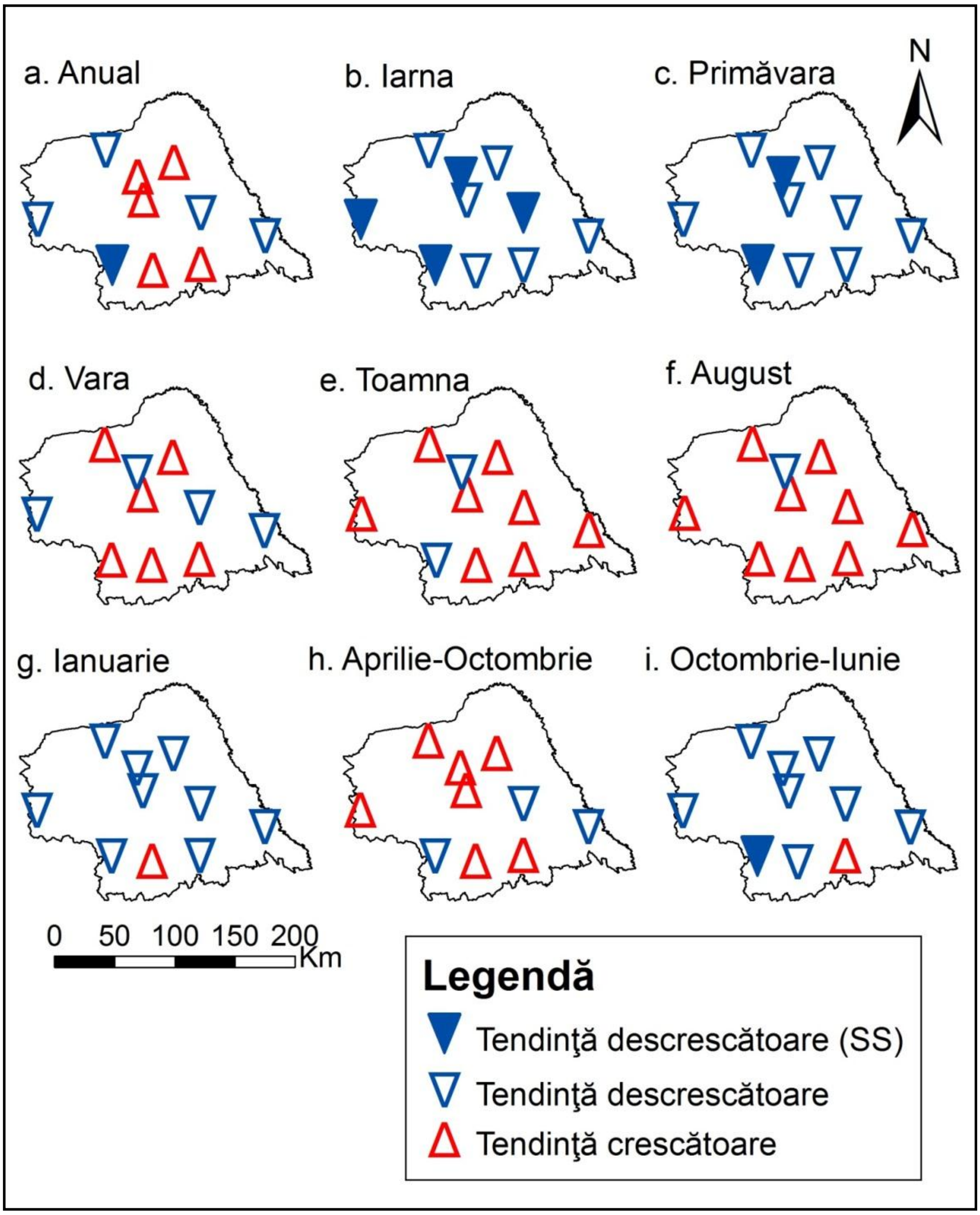


Figure 30. Spatial distribution of IDM trends in northeastern Romania (1961-2010). SS – Statistically significant at α = 0.05 level

6. Reference evapotranspiration ET_0

Recent climate changes were detected not only in isolated temperature or precipitation, but also on complex parameters, like evapotranspiration (Croitoru et al., 2013c). Whereas temperature and precipitation, as individual parameters, are very useful in studying climatic change, the overall expression and significance of climatic change in bioclimatic terms is better expressed by complex parameters computed from a different combination of simple parameters (Kafle and Bruins, 2009). Evapotranspiration is the most important parameter for revealing the climate change and the temporal-spatial patterns of parameters influencing the eco-hydrological processes, which control the evolution of the surface ecosystem. It controls energy and mass exchange between terrestrial ecosystems and atmosphere. It plays a crucial role in the heat and mass fluxes of the global atmospheric system and should provide a sensitive tool to monitor the changes of energy and moisture transfer from the ground to the atmosphere, because it is governed by a variety of climatic variables such as sunshine, temperature, wind speed and atmospheric humidity and due to its related effects on soil moisture and surface albedo (Chen et al., 2006).

As one of the important parameters of the hydrologic cycle, reference evapotranspiration (ET_0) plays a key role in estimating and predicting crop evapotranspiration, water management, establishing irrigation scheme and other practices of agricultural production. It also reflects the impact of atmosphere evaporation capacity on the crop water requirement in different regions and periods, and it is related only to local weather conditions. Thus, it is clearly that any changes in evapotranspiration would affect agricultural production and also water resource programming (Allen et al., 1998; Francone et al., 2010). Increasing evapotranspiration can affect especially irrigated agriculture mainly in two ways: increasing the crop water needs (water demand), and modifying crop patterns and growing seasons (Döll, 2002; Espadafor et al., 2011).

In Romania, few studies on evapotranspiration have been undertaken so far (Păltineanu et al., 2007a, 2007b, 2012; Lungu et al., 2011). Some of them have been focused on the spatial distribution of different aridity indices computed based on reference evapotranspiration (Păltineanu et al., 2009; Lungu et al., 2011).

One single study on changes in ET_0 has been performed before, but it considered only three locations in the southern part of the country (Păltineanu et al., 2012).

6.1. Methods

ET_0, spatial distribution and changes were calculated on the basis of monthly data sets of air temperature, relative humidity, wind speed and sunshine duration.

For this study, ET_0 was computed using the FAO Penman–Monteith method (Allen et al., 1998).

From the original Penman-Monteith equation and the equations of the aerodynamic and surface resistance, the FAO Penman-Monteith method to estimate ET_0 can be derived (Allen et al., 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (6)$$

where:

- ET_0 – reference evapotranspiration (mm day^{-1});
- Rn – net radiation at the crop surface (MJ m^{-2} day^{-1}), calculated on the basis of sunshine duration; it represents the difference between incoming and outgoing radiation of both short and long wavelenghts;
- G – soil heat flux density (MJ m^{-2} day^{-1});
- T – mean air temperature at 2 m height (°C);
- u_2 – wind speed at 2 m height (m s^{-1});
- e_s – saturation vapour pressure (kPa);
- e_a – actual vapour pressure (kPa);
- e_s-e_a – saturation vapour pressure (kPa)
- Δ - slope vapour pressure curve (kPa °C^{-1});
- γ - psychrometric constant (kPa °C^{-1}).

In order to adjust the wind speed from 10 m to 2 m heights, according to the same methodology (Allen et al., 1998), a logarithmic wind speed profile was used:

$$u_2 = u_z \frac{4{,}87}{\ln(67.8z - 5.42)} \qquad (7)$$

where: *u2* is the wind speed at 2 meters above the ground (m s-1); *uz* is the wind speed at *z* meters above the ground surface (m s-1) and *z* is the measurement height above ground surface (m) and is equal to 10.

CROPWAT 8.0 software was specially developed by the Land and Water Development Division of FAO for ET_0 calculation based on FAO Penman-Monteith formula (Allen et al., 1998) and it was used to get the ET_0 data sets for this study.

6.2. Changes in ET_0

In northeastern Romania have been identified important changes in ET_0 over the considered period (1961-2010). Due to the intense increase in air temperature and sunshine duration over the same period and decrease in relative humidity and wind speed (Croituru et al., 2013c), annual; values indicate increasing trends in almost entire analyzed area, half of these been statistically significant (Table 28 and Figure 31a).

Table 28. Slopes for ET_o (mm/decade) in northeastern Romania over the period 1961-2010. The values in bold are statistically significant at $\alpha = 0.05$ level

	Botoşani	Ceahlău	Cotnari	Fălticeni	Iaşi	Piatra Neamţ	Poiana Stampei	Rădăuţi	Roman	Suceava
J	**1.39**	**-2.80**	0.43	0.59	**0.60**	0.30	-0.12	0.43	0.49	0.40
F	**1.73**	**-1.37**	1.38	**1.21**	**1.39**	0.81	-0.01	**1.03**	**1.05**	**0.89**
M	**3.29**	**-2.62**	1.69	**2.31**	**2.52**	1.67	-0.30	**2.29**	**2.98**	**2.34**
A	1.68	**-1.77**	0.09	1.12	0.24	-1.02	-0.29	**2.09**	**2.70**	1.31
M	**4.60**	-0.81	3.25	**4.00**	2.18	1.23	0.93	**4.37**	**4.82**	2.48
J	2.68	0.24	2.54	2.55	1.46	0.05	1.73	**3.41**	**3.17**	1.97
J	**4.04**	-0.42	3.59	**2.92**	2.82	0.16	1.42	**4.17**	**4.64**	**2.93**
A	1.50	-0.66	1.54	1.40	-0.28	-0.22	1.33	**2.83**	**2.98**	**2.32**
S	0.03	-2.54	-1.67	-0.38	-0.55	-2.21	**-1.19**	0.17	0.26	-0.08
O	0.66	**-4.14**	-1.35	0.13	-0.28	**-1.79**	-0.33	-0.50	0.48	-0.49
N	-0.08	-1.30	-0.48	0.13	0.50	-0.16	**-0.51**	-0.17	0.22	-0.10
D	0.45	**-1.33**	-0.53	-0.23	0.09	-0.32	**-0.63**	-0.33	0.01	-0.28
Winter	**3.67**	**-5.70**	2.15	**1.76**	**2.13**	1.55	-0.83	1.11	**1.28**	1.38
Spring	**8.90**	**-4.73**	5.24	**7.65**	5.13	2.16	-0.07	**8.30**	**10.61**	**6.10**
Summer	**9.22**	-1.83	**8.32**	**7.39**	5.05	0.89	**4.70**	**11.31**	**10.96**	**7.36**
Autumn	0.39	**-8.86**	-4.17	-0.21	-0.40	**-4.15**	**-2.09**	-0.67	0.89	-0.53
Oct-Jun	**16.82**	**-15.80**	9.89	**10.86**	9.18	2.06	0.15	**12.71**	**14.88**	8.66
Apr-Oct	**15.51**	**-11.44**	8.64	**12.05**	8.50	-3.22	3.38	**19.96**	**18.85**	**15.66**
Annual	**22.02**	**-21.63**	13.29	**15.71**	12.00	-0.97	0.73	**17.54**	**24.36**	**13.30**

In winter spring and summer, ET_0 has increase at all stations from low altitude (plateau and plain areas). The most important increase is specific to spring and especially summer when most of the trends were statistically significant (Table 28 and Figure 31b-d).

The autumn is dominated by downward trends of ET_0 and the great majority of the significant ones are located in the Carpathian and Subcarpathian regions (Table 28 and Figure 31e).

During maize and winter wheat seasons, ET_0 increased in almost entire analyzed region (Table 28 and Figure 31f, g). Slope magnitude recorded during the vegetation seasons of the two crops are similar (Table 28).

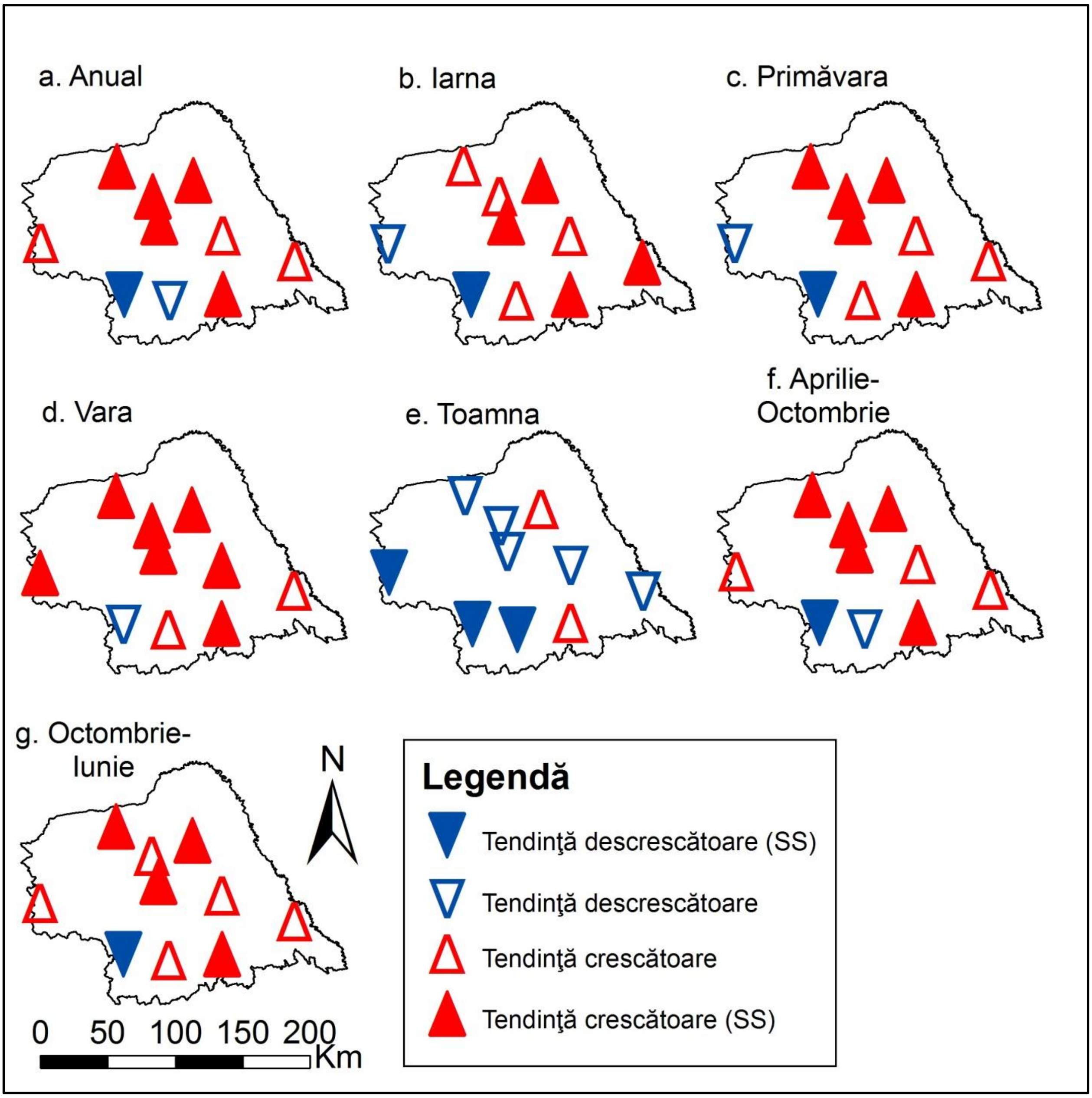


Figure 31. Spatial distribution of ET_0 trends in northeastern Romania (1961-2010). SS – Statistically significant at $\alpha = 0.05$ level

Conclusions

This paper is divided in 7 chapter that cover approx. 220 pages, containing a total of 67 figures and 78 tables which represent the results of processing and analysis of climatic data from 11 weather stations for a period of 50 years (1961-2010).

The results indicate that the climate of the studied area has been significantly changed in the last decades.

The climate of northeastern Romania has become warmer: both mean and extreme temperatures increased statistically significant.

Mean annual temperature has significantly increased by 0.25°C/decade over the entire period of analysis (1961-2010). The most important increase in mean air temperature occurred in the summer season. Thus, the average value of the summer temperature trend is 0.36°C/decade. Negative trends were found only in few data series, especially in autumn months

Daily extreme temperatures, according to analyzed indices indicate that the most intense warming has taken place in extreme seasons (summer and winter), while the transition seasons (spring and autumn) had a moderate increase and even negative trends in autumn.

The most significant increase was detected in the hot extreme indices (SU25, TRD30, TXx). In almost all data series of these indices there were identified statistically significant upward trends. The only exception is in the TXn index which has negative trends in the most cases, but the trends were statistically insignificant

For indices related to cold there are different sign slopes; negative slopes prevail for FD0, ID0, FN-10, TN10p, and TX10p, while mainly positive slopes were detected for TNx and TNmean. But this does not mean that they indicate both warming and cooling. The decrease in number of days under a fixed threshold or a station-related threshold is also evidence for warming and not for cooling, since fewer days have lower temperatures. The significant increase in both maximum and mean annual values of minimum temperatures (TNx and TN mean) completes the warming frame in the analyzed area.

Regarding precipitation has been observed that generally, they increased and became more extreme in terms of both intensity and frequency.

Although these trends are positive in the most of the time, there are important seasonal differences. Thus, the annual, summer and autumn data series showed an increasing trend of precipitation at the most of the locations, while in winter and spring a general decreasing has been observed, but they were significant only at Ceahlău station. Other authors have also identified a significant decrease in precipitation mountainous regions of Romania. The frequency of total positive trends is only slightly higher than the negative ones and those statistically significant are equal.

Analysis of precipitation extremes indices indicate a general increase their values, which means that the climate of northeastern Romania became wetter over the last decades. These results are similar to those of other studies that have shown an increase in extreme precipitation indices at global and regional scale. The strongest trends were recorded for R0.1, R10, R95p, R99p, Rx5d and PRECPTOT indices. Analysis of extreme precipitation indices indicated that for most of them, the statistically significant positive trends has a frequency of 10-50%, the most significant change detected from this point of view is in PRCPTOT index. The number of consecutive dry days (CDD index) decreased, which also indicates an increase in extreme precipitation in northeastern Romania.

Although precipitation in northeastern Romania had positive trends in the most of the time, we should be cautious in interpreting the results since the statistically significant trends have a low frequency.

Due to increasing air temperature, the number of days with snow decreased statistically significant in almost entire analyzed area. The number of days with snow cover is also declining, but not statistically significant. Along with the decrease in number of days with snow and days with snow cover, snow cover depth has decreased in almost entire area. Only in southwestern part of the analyzed territory the trend of snow cover depth was positive.

Changes in cloudiness are closely related to global warming, decreasing in this climatic element contributing to rising temperatures. They significantly influence the sunshine duration, air humidity and air and air temperature. Total cloudiness decreased for the most of the time in annual, winter, spring and summer series and increased in autumn.

The trend of annual sunshine duration increased statistically significant in most of the locations. Also, it increased almost generalized in winter, spring and summer seasons and decreased in autumn.

It was observed that increasing of sunshine duration in annual, winter, spring and summer time series coincided with decreasing of total cloudiness from the same time series, while the decreasing trend of autumn sunshine duration coincided with the increase of total cloudiness of the same season.

Annual trend of relative humidity increased in Carpathian area and decreased in the rest of the analyzed territory. At seasonal time-scales, the relative humidity decreased, generally, in winter, spring and summer and increased in autumn.

The trends in relative humidity are similar with the trends in total cloudiness, at the base of both parameters being the same cause: the general circulation of the atmosphere and geographic local factors.

Data analysis showed that the temperature at the soil surface has increased in northeastern Romania. This increase is similar to increase of air temperature. Thus, annual, winter, spring and summer trends of soil surface temperature are positive and most of them are statistically significant. In autumn, the trends are generally negative, but statistically insignificant. The frequency of positive trends prevailed over the negative ones having a value equal to the air temperature (81%).

Air pressure evolution in northeastern Romania has not experienced major changes over the analyzed period. It indicated an almost generalized increasing in winter and decreasing trends in autumn. Positive trends have the highest frequency (51%), but only 11% are statistically significant.

An important conclusion of wind speed analysis is that this climatic element is dominated by negative trends and it can be observed that statistically significant negative trends have a high frequency. Spatial distribution of wind speed trends doesn’t show a clear pattern. In terms of the frequency of the wind direction trends, the results showed an increasing trend at the most of the stations from the north and west. The trends of wind from western direction have a greater magnitude and half of them are statistically significant. Incresed wind frequency from western direction coincides with the changes identified in the general circulation of the atmosphere expressed by positive trends of EA and NAO indices which characterizes the intensity of westerly winds.

The analysis of hazardous phenomena showed notable changes in the number of days with fog and days with blizzard. Thus, the number of days with fog decreased in northeastern Romania, the most important change in this direction occurred in spring when most of the trends were statistically significant. Trends in the annual number of days with blizzard are declining significantly in almost all analyzed stations. The number of days with frost recorded a significant increase in winter season.

In the warm period of year (April-September) there is a moderate increase in the number of days with thunderstorms. This increase was statistically significant in the southern region at Piatra Neamţ and Roman stations.

Although droughts may occur at any time of the year, in the study area, the impact of droughts is more severe during spring and summer. The most exposed to dry conditions are Moldavian Plane and eastern side of Suceava Plateau, during the warm semester an irrigation system is absolutely necessary.

Analysis of De Martonne aridity index (IDM) indicated that in winter, spring, January and during the growing season of winter wheat decreasing trends prevail, i.e. an increase in aridity, while in summer, autumn, August and during the growing season of maize series, data showed, for the most of the time positive trends, i.e. a decrease in aridity. Overall trends are most negative, but most of them are statistically insignificant. Thus, since most of them are not statistically significant we have to be cautious with interpreting the results because the trends may change in a short time in one direction to another, or they may become statistically significant.

Analysis of spatial distribution of reference evapotranspiration (ET_0) reveals that the areas with highest values are in East and Southeast. The ET_0 mean multiannual amounts have values that exceeds 700 mm per year which represents more than 30% above the annual amount of precipitation. In central and western part, annual values of ET_0 are lower and they are more balanced in relation to precipitation values.

The results of the Mann-Kendall test showed a frequency of 68% of positive trends and 32% of the total series were statistically significant.

Due to the intense increase in air temperature and sunshine duration over the same period and decrease in relative humidity and wind speed, ET_0 values indicated upward trends in most of the analyzed area and half of them are statistically significant for annual, winter, spring, summer and maize and winter wheat growing seasons. The most intense increasing of ET_0 took place in spring and summer due to increase of air temperature and sunshine duration and downward trends of relative humidity. Only the autumn season is dominated by decreasing trends when the air temperature and sunshine duration were also recorded a decrease at most of the analyzed stations.

During the growing seasons of maize and winter wheat ET_0 increased throughout the regions where these crops are cultivated and almost half of the identified trends are statistically significant. Only a few negative trends were recorded which are specific to the western region.

The results of ET_0 could contribute to a better agricultural management, especially in the lower regions of the studied area. Under evapotranspiration increase conditions, water requirement will increase and more water will be needed, mainly during spring and summer. If the detected trends would continue at the present rate or would intensify during critical seasons (spring, summer, crop growing seasons), water limitation will lead to crop productivity diminishing, which could have a severe impact on the entire economy of northeastern Romania. Irrigation system will become a necessity for the crops.

From the obtained results it can be concluded that in northeastern Romania, agriculture is the most vulnerable economic component to climate change, plants being more and more affected from stress caused by higher temperatures and more intense evapotranspiration.

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List of scientific publications included in thesis theme (2010-2013)

ISI Articles

1. **Piticar, A.,** Ristoiu, D., 2012. *Analysis of air temperature evolution in Northeastern Romania and evidence of warming trend*. Carpathian Journal of Earth and Environmental Sciences, Vol. 7, No. 4, p. 97-106. Factor de impact: 1,450.
2. Croitoru, A.-E., **Piticar, A.,** 2013. *Changes in daily extreme temperatures in the extra-Carpathians regions of Romania.* International Journal of Climatology, 33, p. 1987-2001, doi: 10.1002/joc.3567. Factor de impact: 2,906.
3. Croitoru, A.-E., **Piticar, A.,** Imbroane, A.M., Burada, D.C., 2013. *Spatiotemporal distribution of aridity indices based on temperature and precipitation in the extra-Carpathian regions of Romania.* Theoretical and Applied Climatology, 112, p. 597-607. Factor de impact: 1,940.
4. **Piticar, A.,** Ristoiu, D., 2013. *The influence of changes in teleconnection patterns on changes in temperature and precipitation in northeastern Romania.* Meteorology and Atmospheric Physics, în curs de publicare. Factor de impact: 1,327.
5. Croitoru, A.-E., **Piticar, A.,** Dragotă, C.-S., Burada, C.D., 2013. *Recent changes in reference evapotranspiration in Romania, Global and Planetary Change,* în curs de publicare. Factor de impact: 3,155.

Articles indexed in international database

1. **Piticar, A.,** Ristoiu, D., Mihăilă, D., 2012. *Characteristics of the soil surface temperature in Northeastern Romania.* Ecoterra, 31, p. 63-67.
2. **Piticar, A.,** Ristoiu, D., 2013. *Spatial distribution and temporal variability of precipitation in northeastern Romania.* Riscuri şi Catastrofe, în curs de publicare.

Articles published in conference book

1. **Piticar, A.,** 2013. *Caracteristici ale temperaturii aerului în nord-estul României.* Volumul de lucrări al Workshop-ului: Tendinţe şi cerinţe de interdisciplinaritate în cercetare. Prezentarea rezultatelor obţinute de doctoranzi, Edit. Politehnium, Iaşi, p. 71-80.