Climate evolutionary trends resulting from a thermo-pluviometric profile made between the Carpathian peaks and the Dniester Valley

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ABSTRACT: The change in the parameters for the climatic elements and phenomena has become the main topic of many current researches. Given to the complexity and the local distinctions of the climatic factors, these changes are not homogenous and thus some regions get warmer, while others get colder, some become more arid, others more humid. The purpose of the current study is to identify the thermo-pluviometric changes recorded in the geographical area localized between the Eastern Carpathians and the Dniester Valley, based on the meteorological data registered between 1961 – 2010 at the Ceahlău-Toaca, Suceava, Iași (in Romania), Chișinău, and Tiraspol (in the Republic of Moldova meteorological stations. In order to determine the evolutionary trends, the Mann-Kendall test was applied combined with Sen`s slope. Therefore, based on the research performed, it was found that, during the 1961 – 2010 period, in the area localized between the Carpathians and the Dniester, there has been a general trend of climatic warming and a slight decrease of the rainfall quantity (especially for the Ceahlău mountain area). This result is confirmed and reinforced by other studies of climate conducted at European level, hence allowing these climate trends to be integrated easily into the general trend of regional warming.

KEY WORDS: temperature, rainfall, climate trends, Moldova.

1. Introduction

The evolution of the climatic trend in a region like Moldavia that has a predominantly agricultural economy, awakened the interest of many climatology researchers. Mihăilă and Briciu (2012) analysed the thermic and pluviometric evolutionary trends for the climate in the North-Eastern part of Romania highlighting a slight warming of this region. In 2013, Piticar (2013) determined that the average annual temperature increased for the North-Eastern part of Romania during the analyzed period of time (1961-2010) with 0.16 – 0.33°C/decade. Mihăilă et al. (2017) researched the spatial distribution and the chronological evolution of the climatic water balance in the area between the Carpathians and the Dniester demonstrating for a great number of stations in this area – among them are the ones used by the current analysis – the evolution of this climatic index trend. Potopová et. al (2016) analyzed the trend of rainfall following agricultural productivity and showed that for a similar period, the amount of rainfall has decreased considerably, especially for the summer months. Therefore, recent studies shape an evolutionary scenario from where two major conclusions can be drawn: regional warming and the reduction of the entire area water reserve due to the diminution of rainfall quantity, but mostly due to the increasing geo-chronological disproportion of the water balance parameters.

2. Study area

The study area covers the North-Eastern region of Romania and the entire region of Republic of Moldova being bordered on the West side by the Eastern Oriental Carpathians.

The mathematical position of the study area, traversed by the 47°30'th parallel North on its central sector emphasizes the fact that it is located in a typical temperate climate region. In addition to that, the study area being located on the South-Eastern area of Central Europe, traversed by the 27th meridian east, highlights the continental transition characteristic. The layout of the landforms located in the proximate region of the study area (the mountain chain, the Siret, Prut, Dniester valley corridors) confers several climate particularities to this region which have an important impact on the atmospheric dynamics and on the air temperature. The Oriental Carpathians orographic barrier and the wide opening towards the Russian Plain are defining elements that determine the evolution and distribution of the characteristics of the main climatic elements in the studied area.

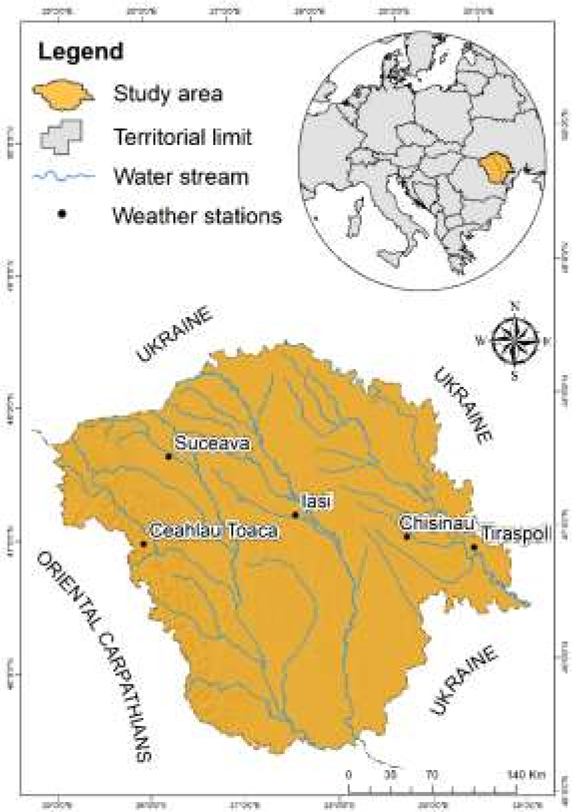

Figure 1 Delimitation of the study area and the location of meteorological stations in the studied area.

For the current study, chronological series of meteorological data recorded at five meteorological stations were used, being representative given the geographical and climatic position of the stations in the area of interest. One of the stations is located in the mountain range (Ceahlău-Toaca), two of them in the plateau range (Suceava and Chișinău), and the other two located in the plain range (Iaşi and Tiraspol). The geographical coordinates and the location of the stations from where the meteorological data were gathered for the current study are illustrated in Table 1 and in Fig. 1.

Table 1 Meteorological stations locations on the climatic profile studied.

Station	Altitude (m)	Latitude (N)	Longitude (E)
Ceahlău-Toaca	1897	46°59′	25°57′
Suceava	350	47°38′	26°16′
Iași	102	47°10′	27°38′
Chișinău	172	47°01′	28°86′
Tiraspol	38	46°84′	29°64′

The study seeks to cover an imaginary profile W-NW ÷ E-SE, taking into account several stations located at different relief units elevation in order to emphasize the climatic differences imposed by the local climatic factors and on the other hand, the differences or similarities between the evolutionary trends, specific to each location.

3. Methods

The chronological series of temperature and rainfall recorded at the five stations between 1961-2010 were used to calculate the average (for temperature) and the sums (for rainfall) on a monthly, seasonal, and annual basis for the elements mentioned previously. Using data collected between 1961-2010 allowed drawing valid conclusions, the 50 years period of time being homogeneous and without lack of data caused by nonclimatic factors. All climatic data used come from the National Meteorological Administration (NMA) archive.

These climatic indexes (averages and sums) were transferred into Excel work sheets and analysed using the Microsoft Office Excel Worksheet, and for depicting their territorial recurrence, the Detrended Kriging method was used because, in our case, this is the most recommended interpolation method for climate data (Patriche, 2009). The method was applied in ArcGIS 10.4 Program. These research techniques and methods were successfully used in many climatic studies (Goovaerts, 2000; Garen and Marks, 2005; Guan and Wilson, 2006; Piticar, 2013).

In order to determine the trends in the monthly, seasonal, and annual chronological series the Mann- Kendall (Mann, 1945; Kendall, 1975) test was used combined with Sen` slope (Gilbert, 1987). The calculations using these two methods were put together in the MAKESENS calculation program (Mann- Kendall test for trend and Sen's slope estimates), created by the researchers at the Finnish Meteorological Institute (Salmi et al., 2002). In the MAKESENSE program, the levels for statistical significance α are 0.001***, 0.01**, 0.05* and 0.1+. These static methods were recommended by O.M.M. to determine the trends in the climatic variables and being utilized on a large scale in the climatic and hydrologic applications (Zhang et al., 2005; Moberg et al., 2006; Choi et al., 2009; Micu, 2009; El Kenawy, 2011; Del Rio et al., 2012; Fan et al., 2012; Piticar, 2013).

4. Results and discussion

4.1. The average temperature of air and the changes observed in its numerical value fluctuations

The average air temperature differs based on the regional particularities. There are three rules when it comes for the geographical distribution of the temperature above the studied region. The first rule is related to altitude, the air temperature rising significantly once the altitude decreases according to the vertical thermal gradient, on the general direction W-NW ÷ E-SE. The second rule demonstrates the fact that the air temperature is rising constantly as long as the stations are located more towards the South. Lastly, there is a noticeable link between the stations' latitudinal position and the air temperature which is slightly rising on a W-E general direction as much as the continentalism degree is increasing (Fig. 2).

Therefore, the average annual temperature was 0.7°C at the Ceahlău-Toaca station, 7.8°C at Suceava, 9.7°C at Iași, 9.9°C at Chișinău, and the calculations for Tiraspol station indicated a value of 10.1°C.

The average annual air temperature of the whole region between the Carpathians and the Dniester was 7.6°C.

The graphic representation of the linear trends (Fig. 3) is in concordance with the results from the Mann-Kendall test, the regression coefficients (y) having positive values for all five stations in the studied area.

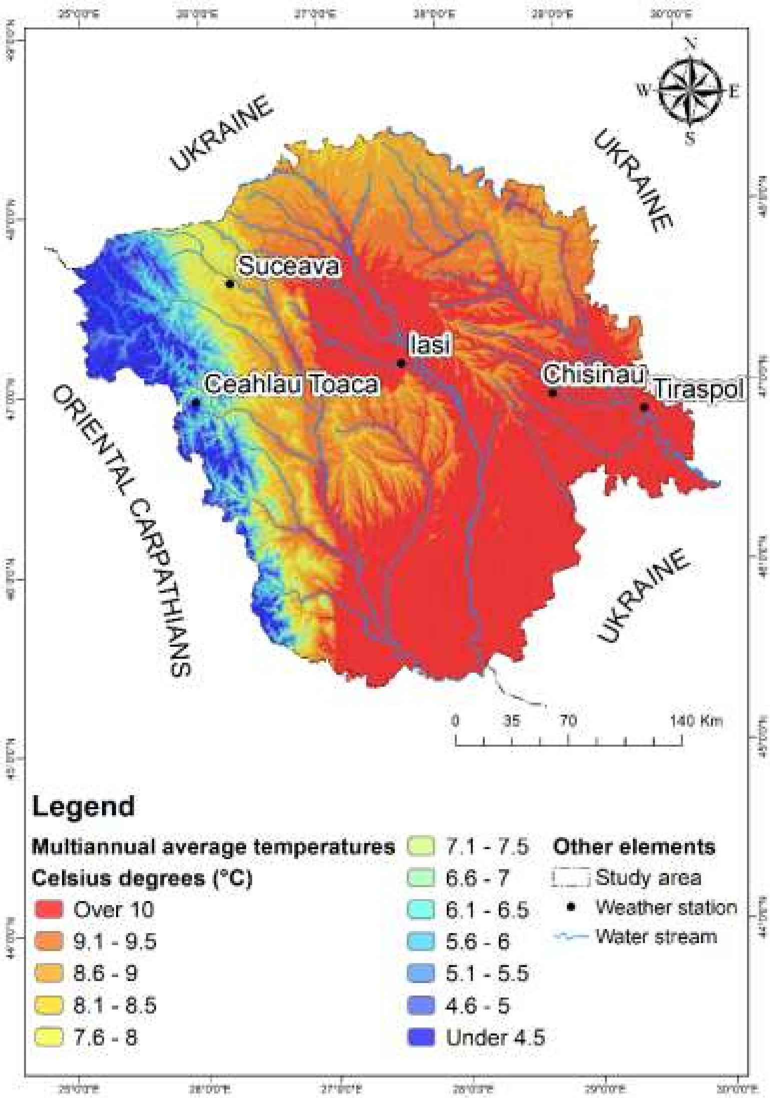

Figure 2 The repartition of the average annual air temperature values in the studied area (1961-2010).

According to the Mann-Kendall test combined with Sen` slope, related to the 1961-2010 period, an increase in the average annual air temperature with values between 0.16 and 0.27°C / decade can be observed, which means that the average annual air temperature has increased along the 50 years period with values between 0.8 and 1.35°C. From a statistical point of view, this positive trend of the average annual temperature is significant for all meteorological stations studied (Table 2).

The increase in the average air temperature was not identical along one year and in order to emphasize this, the Mann-Kendall test was applied for seasonal and monthly intervals.

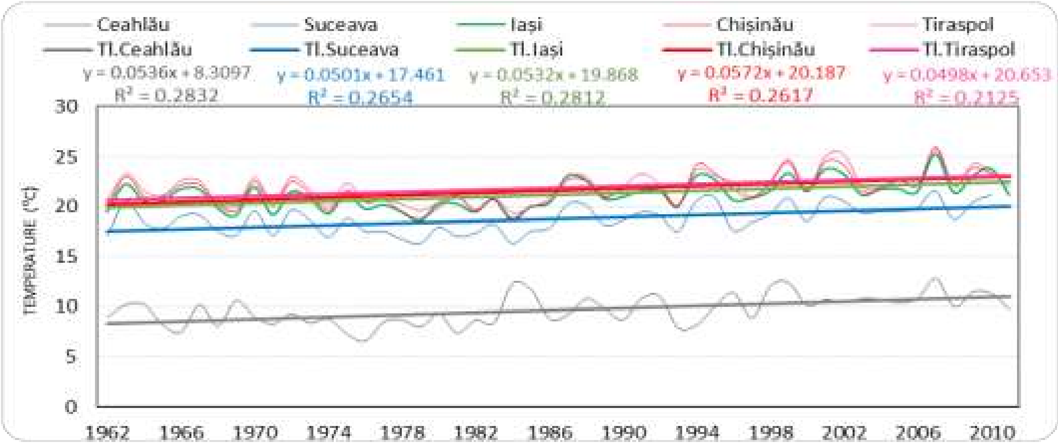

Figure 3 The interannual regime of the average annual air temperature values (°C) and their chronological series trends recorded at the meteorological stations Ceahlău-Toaca, Suceava, Iași, Chișinău, and Tiraspol between 1961-2010.

As illustrated in Fig. 4 and Table 2b, there are major differences between the temperature trends occurring in the cold season and those occurring in the warm season of the year. It can be remarked that in the warm season the positive trends are statistically significant at all five meteorological stations in the studied area.

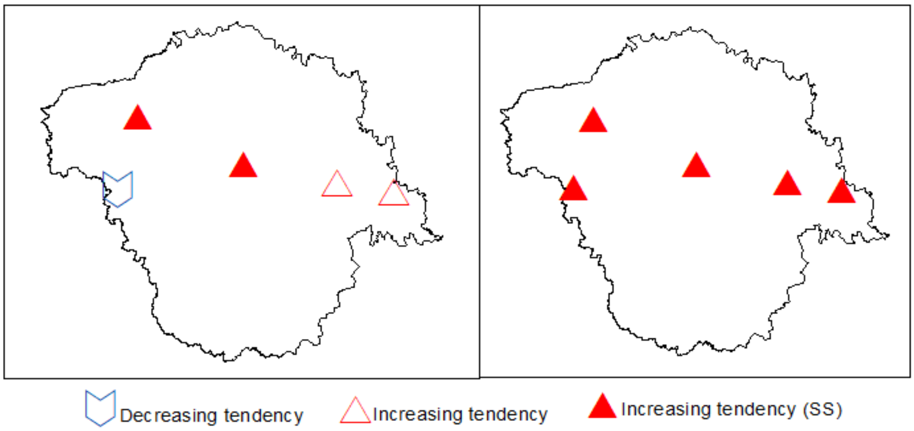

Figure 4 The territorial distribution of the semestrial air temperature trends (°C) in the studied area: left – cold season; right – warm season (1961-2010).

At a seasonal level, in the summer season, it can be observed that the increase in the numerical value for the air temperature has the greatest statistical significance (α=0.001***) for all stations. This increase in the average air temperature with 0.39 - 0.44°C / decade occurred at each particular station analysed. A significant warming was noticed in the spring and winter seasons as well, the average air temperature numerical values for the winter season increasing by 0.01 - 0.52°C / decade. The greatest increase of air temperature in the winter season occurred at the meteorological station Suceava.

Table 2a The average numerical values of the annual and seasonal trends of the air temperature (°C / decade) in the studied area (1961-2010).

Station		Annual	Winter	Spring	Summer	Autumn	Cold season	Warm season
Ceahlău-Toaca	Q.	**0.16**	0.01	0.10	**0.44**	0.09	-0.02	**0.29**
	S.	*			***			***
Suceava	Q.	**0.27**	**0.52**	**0.33**	**0.39**	0.03	**0.29**	**0.28**
	S.	***	*	*	***		*	***
Iași	Q.	**0.27**	**0.44**	**0.33**	**0.39**	0.00	**0.36**	**0.28**
	S.	**	*	**	***		**	**
Chișinău	Q.	**0.24**	0.39	0.24	**0.40**	0.05	0.21	**0.26**
	S.	**	+	+	***		+	**
Tiraspol	Q.	**0.20**	0.31	0.21	**0.41**	0.02	0.17	**0.25**
	S.	*		+	***			**

*Q= Sen` slope; the values in bold are statistically significant; S=statistical significance α=0,001***; 0,01**; 0,05*; 0,1⁺*

At a monthly level, as illustrated in Table 2b, it has been observed that for all stations analysed, the most important air temperature increase occurred during the summer months: June, July, and August. Nonetheless, the major and most significant increasing trend was recorded in July when the average monthly air temperature increased with values between 0.50°C / decade (Suceava and Tiraspol) and 0.57°C / decade (Ceahlău-Toaca). The increase trend in the average monthly air temperature applies to all stations analysed for the following months: January, April, May, June, July, August, October, but the increase registered was not statistically significant for all chronological samples analysed. For the month of January, the increase registered in Suceava and Iași were statistically significant where the temperature increased with 0.79°C, respectively 0.67°C / decade. For the month of November, at Suceava, Iași and Tiraspol, the temperature trends was a negative one (decreasing trend), but this didn't have statistical significance.

Table 2b The average numerical values trend for the monthly air temperature (°C / decade) in the studied area (1961-2010).

		J	F	M	A	M	J	J	A	S	O	N	D
Ceahlău-Toaca	Q.	0.06	-0.04	-0.15	0.17	0.20	**0.33**	**0.57**	**0.50**	0.00	0.16	0.20	0.00
	S.						*	***	***				
Suceava	Q.	**0.79**	0.59	0.50	0.20	0.25	**0.33**	**0.50**	**0.44**	-0.05	0.08	-0.09	0.23
	S.	*	+	+			*	***	***				
Iași	Q.	**0.67**	**0.67**	**0.61**	0.14	0.27	**0.36**	**0.53**	**0.41**	-0.03	0.08	-0.12	0.09
	S.	*	*	*			**	***	**				
Chișinău	Q.	0.57	0.46	0.48	0.02	0.13	0.26	**0.53**	**0.56**	0.00	0.19	0.00	0.00
	S.	+		+			+	**	***				
Tiraspol	Q.	0.42	0.36	0.43	0.00	0.08	0.23	**0.50**	**0.50**	0.00	0.14	-0.06	-0.04
	S.			+				**	**				

*Q= Sen` slope; the values in bold are statistically significant; S=statistical significance α=0,001***; 0,01**; 0,05*; 0,1⁺*

In the analysis performed according to the Mann-Kendall test for the average monthly air temperature registered between 1961-2010, there were no significant decreasing trends. In the studied area, the positive trends took precedence over the negative ones at a proportion of 61 %, and the significant positive trends had a proportion of 29 %. The stationary trends were noticed on 4 % of the cases.

It can be stated that the evolutionary trend between Carpathians and the Dniester leads to a climate with increasing temperature. This trend fits into the category that indicates the regional warming which marked large geographical areas located in the temperate climate region on the northern hemisphere.

These results are in concordance with those aggregated in other studies performed in the same region (Piticar, 2013), but also for other regions in Romania, Republic of Moldova and on the European continent (Del Rio et al., 2005; Micu and Micu, 2006; Hobai, 2009; Busuioc et al., 2010; Corobov et al., 2010; Dragotă and Kucsicsa, 2011; Sfică, 2011, Croitoru et al., 2012; Potopová et al. 2019).

4.2. Atmospheric rainfall and the changes observed in their numerical value fluctuations

By analyzing the pluviometric data from the five stations in the studied area, there were identified differences in the annual rainfall quantities from one point to another. In the mountains, the annual rainfall average quantity was 912.6 mm at Ceahlău-Toaca, in the hills and plateaus, it was between 620.2 mm at Suceava and 553.4 at Chișinău, while in the plains, at Iași it was registered 580.9 mm/year and at Tiraspol 509.1 mm/year. For the period 1961-2010 the annual rainfall average quantity recorded for the entire studied area is 635.2 mm.

The chronological series of the annual sums of rainfall recorded between 1961-2010 were first filtered through the linear trends representation in Excel program and these indicate the differences registered for the quantitative devolution trend (at the Ceahlău-Toaca and Iași stations) or for the slightly perceived evolutionary trend (Suceava, Chișinău, and Tiraspol) which marked during this interval the rainfall at the stations (Fig. 5).

In order to emphasize the evolutionary trends of the atmospheric rainfall chronological series, the results of the Mann-Kendall test combined with Sen` slope are presented in a tabular form for each station in the studied area (Table 3a and Table 3b). As a result of an overall analysis, it was found that the trends for the rainfall chronological series had different signs based on the location and the temporal entity studied. From a statistical significance point of view, the most series showed non-significant evolutionary trends.

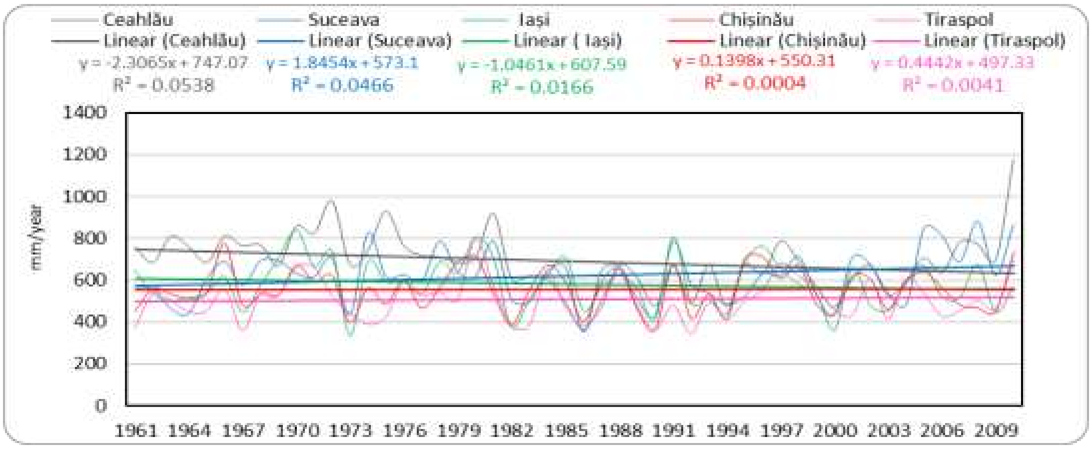

Figure 5 The interannual regime of the annual sums of atmospheric rainfall (mm) and their chronological series recorded at the meteorological stations Ceahlău-Toaca, Suceava, Iași, Chișinău, and Tiraspol during 1961-2010.

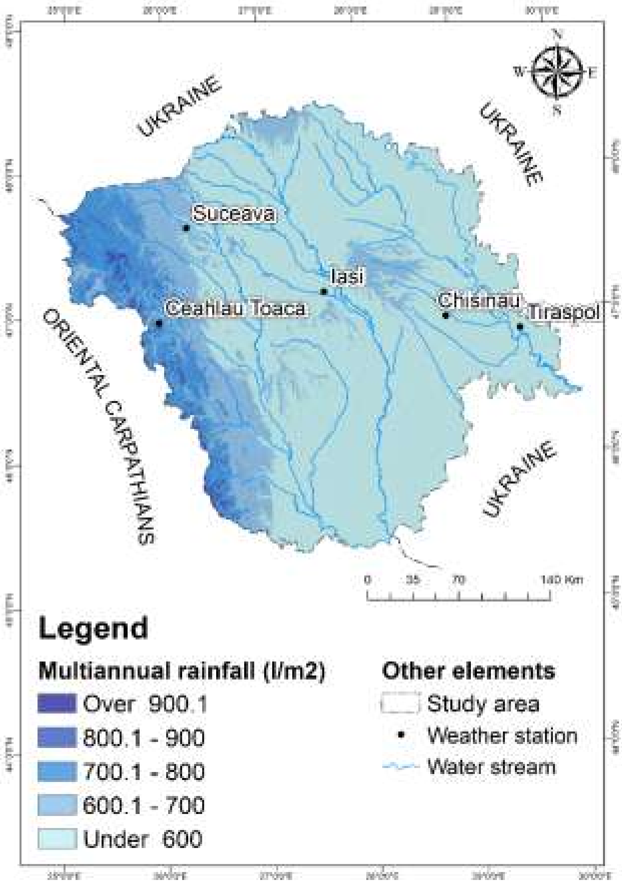

Figure 6 The territorial distribution for the annual rainfall quantity (l / sqm; mm) in the studied area (1961-2010).

For the annual chronological series, according to the tests applied, it can be noticed an increasing trend recorded at three of the five studied stations. The numerical value recorded is between 3.08 and 18.21 mm / decade, but this trend does not have statistical significance. Only at the Ceahlău-Toaca and Iași meteorological stations it was noticed a trend of decreasing the annual rainfall quantity. At the mountain range level, the decrease was emphasized (-30.14 mm / decade at Ceahlău) and also statistically significant. It is possible that for the Ceahlău-Toaca station (as in the case of other mountain stations like Rețitiș station in Călimani mountains) there might be certain shortcomings when it comes to rainfall monitoring and thus, due to this, the results about the rainfall quantity recorded do not accurately reflect the pluvionivometric reality on this area. Therefore, the results of the pluviometric trend tests should be cautiously. Nonetheless, the pluviometric trends indicated by the statistical tests are alarming for the Ceahlău station.

During the cold semester, it has been distinctively observed the decreasing trend of the rainfall quantity at the Ceahlău-Toaca station. According to the Mann- Kendall test, the Ceahlău mountain level was the most affected area by this numerical value decrease recorded for the rainfall quantity (-33.24 mm / decade).

At a seasonal level, it has been observed as well that the rainfall quantity is decreasing for all meteorological stations in the Moldavia region during the winter season, but this decreasing trend was statistically significant only for the Ceahlău Toaca station (i.e. $\alpha = 0.05$). During the spring season, the trends continued to be negative. At the Chișinău station, the trend was stationary. During the summer season, the West side of the region (Ceahlău-Toaca, Suceava) has recorded a pluviometric positive trend, the rainfall quantity increasing with 11.5 – 12.30 mm / decade, while on the East side of the region (Iași, Chișinău, Tiraspol), the general trend was negative. The absolute values for the increase and decrease in the rainfall quantity recorded were reduced for all the five stations. During the autumn season, the general trend of the values was generally positive, statistically significant being only the increased numerical values recorded at the Tiraspol station.

At a monthly level, only several particular characteristics can be observed for the evolutionary trends (Table 3b). As highlighted in the seasonal level analysis, the most important of the numerical values for the average rainfall quantity were recorded at the mountain level for Ceahlău-Toaca, especially during the cold months of the year (November – February interval).

Table 3a Annual, semestrial, and seasonal trends for the rainfall quantity (mm / decade) in the studied area (1961-2010).

		Annual	Winter	Spring	Summer	Autumn	Cold season	Warm season
Ceahlău-Toaca	Q.	**-30.14**	**-21.77**	**-10.29**	11.5	-3.85	**-33.24**	0.73
	S.	*	***	*			***	
Suceava	Q.	18.21	-0.82	-2.00	12.30	6.42	1.95	13.0
	S.							
Iași	Q.	-11.02	-5.29	-6.83	-6.47	7.95	-0.67	-12.14
	S.							
Chișinău	Q.	3.08	-6.15	0.00	-1.19	7.33	2.86	0.95
	S.							
Tiraspol	Q.	4.64	-5.76	-1.20	-1.25	**10.5**	2.50	4.33
	S.					*		

*Q= Sen` slope; the values in bold are statistically significant; S=statistical significance α=0,001***; 0,01**; 0,05*; 0,1⁺*

Table 3b Monthly trends for the rainfall quantity (mm / decade) in the studied area (1961-2010).

		J	F	M	A	M	J	J	A	S	O	N	D
Ceahlău-Toaca	Q.	**-5.78**	**-9.11**	-3.04	-1.57	-3.56	-2.19	2.42	7.18	1.43	-0.06	**-4.78**	**-4.75**
	S.	**	***									**	*
Suceava	Q.	-0.43	-0.03	-0.25	0.02	-3.40	-0.85	6.09	4.08	3.76	**5.00**	-1.08	0.56
	S.										*		
Iași	Q.	-0.50	-2.59	-0.35	-2.77	-3.13	-4.88	-1.03	1.07	1.67	**5.43**	-0.20	0.43
	S.										**		
Chișinău	Q.	0.31	-2.94	0.80	-0.37	-1.11	-5.56	-2.24	2.27	3.23	**6.67**	0.00	0.00
	S.										**		
Tiraspol	Q.	0.00	-2.73	1.15	0.00	-2.78	-3.16	-0.67	**2.00**	**6.07**	**5.52**	0.73	-1.82
	S.							*	*	*			

*Q= Sen` slope; the values in bold are statistically significant; S=statistical significance α=0,001***; 0,01**; 0,05*; 0,1⁺*

Significant decrease in the rainfall quantity at the high mountain level during similar yearly timeframe was observed as well in Micu's (2009), Drogotă and Kucsicsa's (2011), and Piticar's (2013) researches. Rainfall quantity decreases during winter season was reported in other European regions as well (Del Rio, 2005; Lopez-Moreno et al., 2010). During the month of October the pluviometric trend was increasing for all stations studied, except for the Ceahlău-Toaca. Tiraspol station recorded such a positive trend and also statistically significant with regards to the rainfall quantity during the months of August and September, on the reference interval increasing with 2.00 - 6.07 mm / decade.

Among the other monthly data series it can be observed the time and space variability of the trends for this climatic element, without clear trends with notable statistic value.

Therefore, it has been observed that in the mountain area, the negative pluvionivometric trends were the most important, this devolutionary process being noticed in other European level researches (Del Rio, 2005; Lopez-Moreno et al., 2010). For Republic of Moldova, Potopová V. et.al (2016) and Constantinov T. et al. (2010) analyzed the trend of rainfall following agricultural productivity and showed that for a similar period, the amount of rainfall has decreased considerably especially for the summer months.

5. Conclusion

The average annual temperature increased with 1.14°C during 1961-2010, related to the entire studied area. Suceava and Iași stations recorded the most notable temperature increase (0.27°C /

decade). During the 50 years period the average annual temperature increased at these two stations with 1.35°C.

The average annual rainfall trend is decreasing, the rainfall quantity diminishing for the entire studied area with 3.04 mm / decade. At the mountain level the decrease is noteworthy (-30.14 mm / decade for Ceahlău-Toaca, which means -150.7 mm during the 1961-2010 period), this being statistically significant.

As emphasized by the results obtained, the climate of the region between the Carpathians and the Dniester recorded during 1961-2010 a general warming trend and a slight diminishing of the pluvionivometric input (especially for the Ceahlău-Toaca station located in the high mountain area). These results are confirmed and reinforced by other climatic studies conducted at the European and regional level, therefore allowing these climate trends to be integrated easily into the general trend of regional warming. The abundance of the climate consequences generated by this warming process have not been very clearly outlined yet at the level of the pluviometric system and water balance decline level.

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