Climatic features of the Muscel Valley (Buzău Subcarpathians, Romania) as from the registered data during 1961–2003

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Keywords: Buzău Subcarpathians, extreme rainfall events, Thornthwaite, types of climate.

Riassunto. L'area di studio è un bacino di circa 20 km^2, localizzato nella Curvatura dei Subcarpazi rumeni, fortemente interessata da erosione e movimenti di massa sia per le sue caratteristiche geologiche che climatiche: queste ultime in particolare sono l'oggetto del presente studio che ha come scopo principale quello di caratterizzare il clima della valle del Muscel ma anche quello di fornire dati utili a future ricerche volte a stabilire le relazioni tra la franosità e le condizioni climatiche. Gli elementi utilizzati per questo studio sono le temperature giornaliere dell'aria, le precipitazioni mensili e gli eventi pluviometrici estremi. La serie copre il periodo 1961-2003 ed è stata registrata alla stazione termopluviometrica di Pătârlagele (45°20'N), situata nel tratto finale del torrente Muscel e gestita dall'Istituto di Geografia dell'Accademia Rumena.

Per il periodo analizzato il valore medio annuo delle temperature è stato di 10.4 °C, con un campo di variazione tra 8.9 °C (1976) e 11.7 °C (1989–1994); la tendenza interannuale è generalmente positiva, specialmente a partire dagli anni '70. Le temperature invernali sono state analizzate attraverso il conteggio dei giorni con gelo (numero di giorni con T_{min} ? 0°C), giorni di gelo (numero di giorni con T_{max} ? 0°C) e le temperature minime assolute di ciascun anno. Le temperature estive invece sono state analizzate attraverso il conteggio del numero di giorni tropicali (numero di giorni con T_{max} ? 30°C), il numero di giorni con T_{max} ? 35°C e le temperature massime assolute di ciascun anno della serie.

Anche per quanto riguarda le precipitazioni sono stati calcolati i valori medi, in particolare la media del periodo è risultata pari a 630.1 mm, con un campo di variazione oscillante tra 389.0 mm (2000) e 857.2 mm (1969). Il regime generale delle piogge presenta un massimo principale in estate (40%), stagione caratterizzata da frequenti e intensi temporali che talvolta rappresentano veri e propri eventi estremi: un esempio è rappresentato dall'evento del 2 Luglio 1975, giorno in cui cadde il 25.5% del totale delle piogge di quell'anno. L'andamento pluviometrico interannuale mostra una tendenza negativa che diventa più evidente a partire dagli anni '90.

Infine, sulla base dei parametri ricavati dallo sviluppo del bilancio idrico-climatico, calcolato con il metodo di Thornthwaite, è stato possibile studiare il ciclo dell'acqua nel suolo e definire il tipo climatico medio (C_1 B'_1 d b'_3), quello dell'anno più arido (D B'_1 d b'_3) e quello dell'anno più umido (B_1 B'_1 r b'_3).

Introduction

The overall climate of Romania is temperate continental of transition bearing different regional features such as: mountain conditions over the highh relief brought by the cold air masses from the sarmatic region or steppe features in the plains. The general climate is determined by many factors, the most important being its geographical settings. In fact, because it extends over 5 degrees of latitude, Romania registers a 3°C thermic difference between its northern and southern regions. The Carpathians also play an important role in the climatic zonation separating the north-western area, characterized by an oceanic influence, from the eastern one, where continental features are more evident. Another important factor is the Black Sea, which exerts a thermic regulation effect over the south-est of the Country where the Buzău Subcarpathians are located. Here, fairly mild Winters and cool Summers are tipical, moreover, the climate of this region is dominated

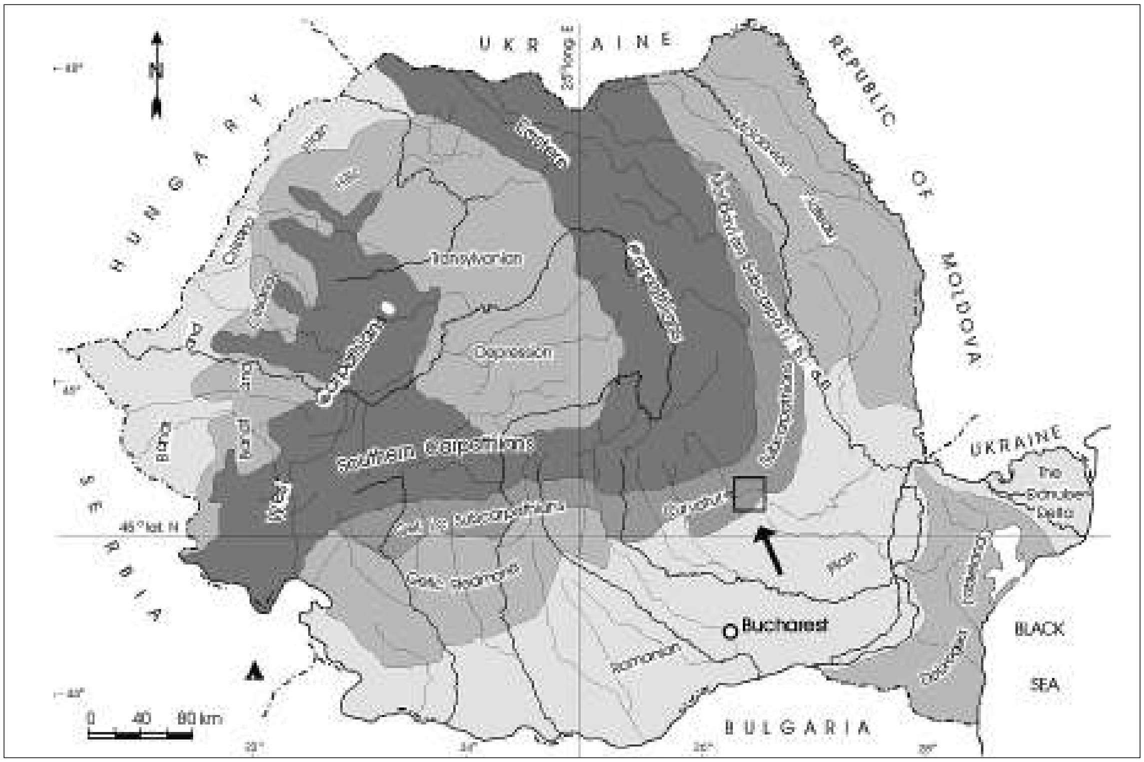

Fig. 1. Geographic sketch of Romania with physiographic units (grey areas). Location of the study area is indicated.

by air masses coming from north/north-east during Winter, when the Siberian anticyclone arrives in Transylvania, while in Summer western masses prevail (Bogdan *et al.*, 1980; Bogdan, Mihai, 1977; Neamu, 1980).

The Buzău Subcarpathians have been studied by various authors, all underlining the intensity and variety of the present-day slope processes classifying almost 85% of the slopes as unstable (Bălteanu, 1971, 1983, 1994; Bălteanu, Dinu, Cioacă, 1996; Dinu, Cioacă, 1998). Among the major factors that generate or facilitate the development of mass movements and erosion processes, authors indicate the less erosion-resistant lithology, the neotectonic movements (0,5-1 mm/y), the strong earthquakes that affect the entire Vrancea region, and the intensity of rainfall. Starting from these researches, the present paper, a climatic study of a small catchment located in this area (Muscel valley) (Fig. 1), could represent a contribution for future studies focused on the relationship between climate and mass movements in this region.

The hydrographic basin of the Muscel river, tributary on the right of the Buzău, covers an area of about 19.70 sq km. Its borders are given by a range of hills, among which Vârful Pătârlagele (908.7 m), Piatra Scrisa (754.3 m) and Vârful Catnei (790.9 m) are the highest. As far as their geology is concerned Oligocene flysch formations (Kliwa sandstone) mount to almost 33% of the basin's surface, while the rest mostly consists of highly folded and faulted Miocene and Pliocene marls, clays, sandstone and sand (Bălteanu, 1983).

The data analysed in this research were recorded by the thermopluviometric station located in the final sector of the Muscel river (Pătârlagele) over the period 1961–2003. It consists the daily recorded maximum and minimum temperatures, monthly precipitation and extreme rainfall events. The August temperatures for 1961 are missing so we considered them to be equivalent to the average of the following August months. According to WMO current climate is defined by the mean the meteorological features monitored

	J	F	M	A	M	J	J	A	S	O	N	D	Year	Range
Max	4.0	5.7	10.4	16.5	22.0	25.1	27.0	26.7	22.6	17.1	10.6	5.2	16.1	23.0
Min	-5.1	-4.0	-0.7	4.5	9.2	12.6	14.2	13.6	9.8	4.7	0.5	-3.5	4.6	19.3
Mean	-0.5	0.9	4.9	10.5	15.6	18.9	20.6	20.2	16.2	10.9	5.6	0.9	10.4	21.1

Tab. 1. Mean monthly temperatures and yearly range (°C)

			Winter				
	T_{min}	T_{max}	T_{mean}	Days T_{min}= 0°C	Max.n°cons frost days	Days T_{max}= 0°C	Absolute T_{min}
Min	–8.8	0.7	–3.3	81	14	3	–25.5
Date	1985	1963	1963	1966	1990/99	1989	1963
Max	–1.0	8.3	3.3	136	76	46	–11.4
Date	1966	1989	1966	2003	1985	1985	1970
Mean	–4.2	5.0	0.4	113.1	29.2	18.0	-

Tab. 2. Range of mean Winter temperatures, days with Tmin = 0°C, days with Tmax = 0°C, maximum number of consecutive frost days and absolute minimum temperatures

in a given location for the past 30 years (normal values). The choise of this conventional time lenght results as a compromise of the necessity of considering a sufficiently long period in which the climatic conditions are defined and stable, keepeing in mind at the same time the variations of the climatic features given by an excessively long interval (Rosini, 1988).

The study series record 43 years. This is not much longer than the conventional period therefore we consider it representative for studying the climate of the area.

In the present work, the results of air temperature, precipitations and extreme rainfall events analysis are presented. Moreover, the Thorthwaite's method was used to obtain the water balance and the climatic classification of the studied area.

Air temperatures

The air temperature study is based on the analysis of the data recorded at Pătârlagele station between 1961 and 2003. Besides daily temperatures, the mean monthly, seasonal and annual temperatures were calculated and analysed. The region has a mean annual temperature of 10.4 °C. The coldest month is January, with a mean temperature of –0.5 °C; this value is below 0.0 for most of the studied years. The warmest month is July, with a mean temperature of 20.6 °C. The annual thermic range is 21.1 °C varying from 23.0 °C, where we consider the mean of maximum temperatures, to about 19 °C if we consider the mean of minimum temperatures. (Tab. 1).

The mean temperature amplitude is 2.8 °C, representing the difference between the mean temperature of the coldest year (1976 with 8.8 °C) and that of the warmest years (1989–1994 with 11.7 °C).

Winter temperatures. After the analysing the maximum, minimum and mean temperatures of the Winter months, the features of this season were examined concerning some parameters normally used in climatology, such as frost days (number of days with T_{min} = 0 °C), maximum number of consecutive frosty days, number of days with T_{max} = 0 °C and the absolute minimum temperatures. (Pinna, 1977) (Tab. 2).

The mean Winter temperature is 0.4 °C and ranges from –3.3 °C (1963) to 3.3 °C (1966), the mean value of minimum and maximum temperatures are –4.2 °C and 5.0 °C respectively. The number of days with T_{min} = 0 °C, which are on average 133.1 per year, varies from 81 (1966) to 136 (2003), while the number of days with T_{max} = 0 °C ranges between 3 (1989) and 46 (1985).

1963 and 1985 registered the coldest Winters: these years recorded the absolute minimum temperatures of the study period, –25.5 °C (January, 23, 1963) and –24.6 °C (January, 17,

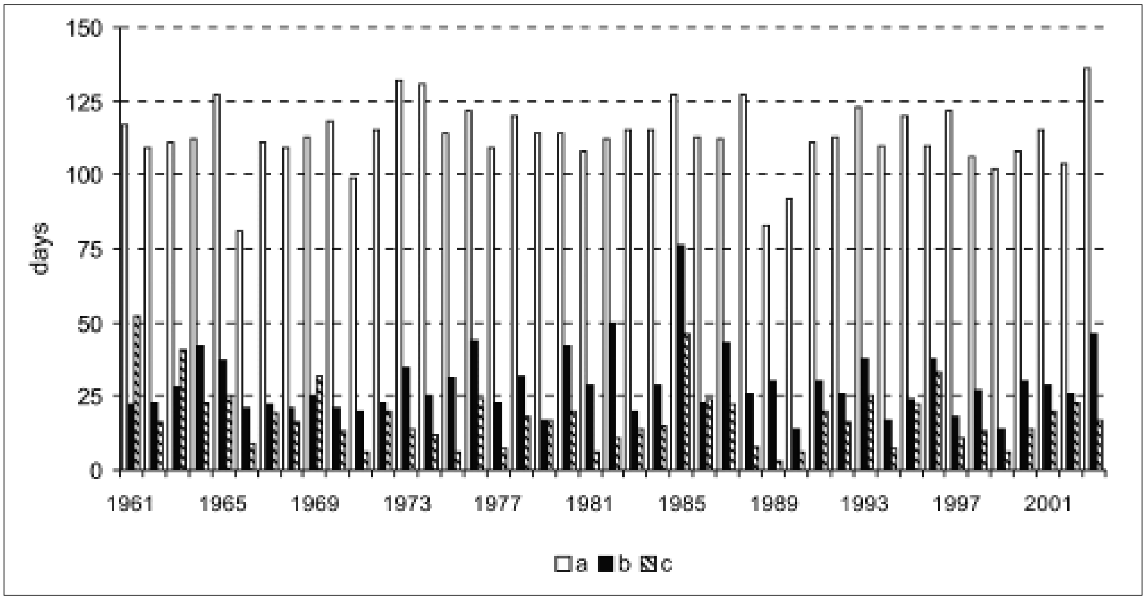

Fig. 2. Interannual trend of number of days with T_{min}= 0°C (a), consecutive days with T_{min}= 0°C (b) and days with T_{max}= 0°C (c) recorded at Patârlagele (1961–2003).

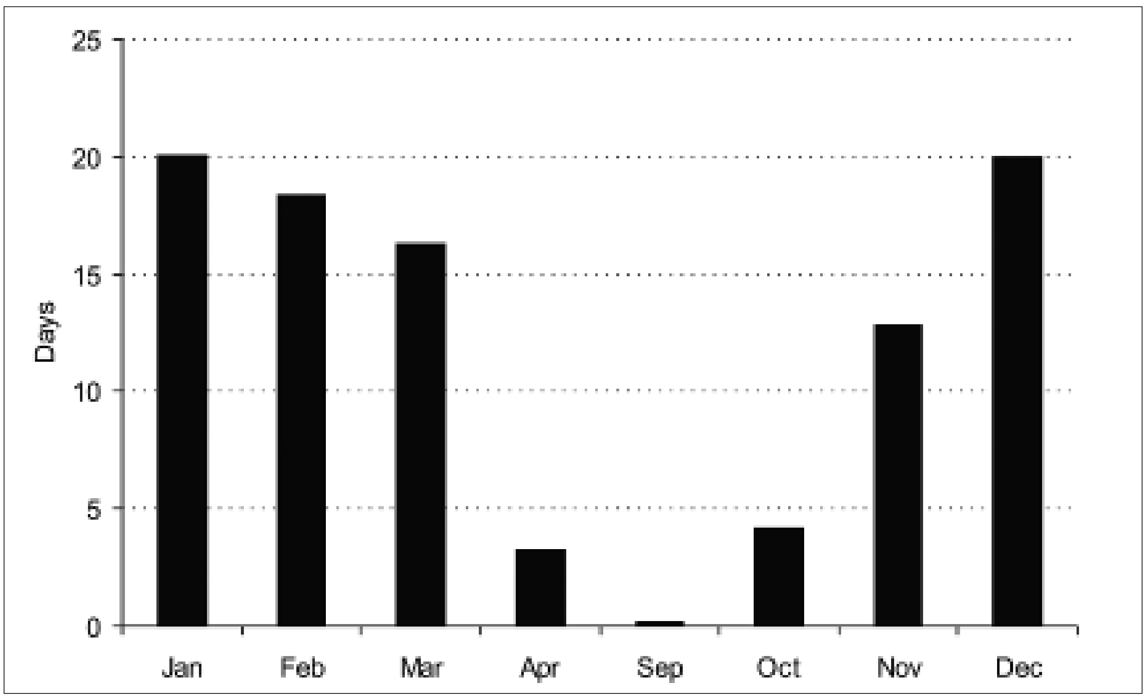

Fig. 3. Monthly trend of the number of days with freeze-thaw cycle at Patârlagele (1961–2003).

1985). Moreover, 1985 had the maximum number of consecutive frost days (76) and the maximum number of days with T_{max} = 0 °C (46). The frost days and the days with T_{max} = 0 °C do not show a significant variation along the study period, except for the particularly cold years already mentioned (Fig. 2).

Winter months are also characterised by a lot of freeze-thaw cycles, about 65% of their days per year. Moreover each day is likely characterised by different freeze-thaw cycles, not evaluated because the data set consists only of daily values. For this reason it is not possible to better analyse this parameter in spite of its importance in triggering slope instability (Fig. 3).

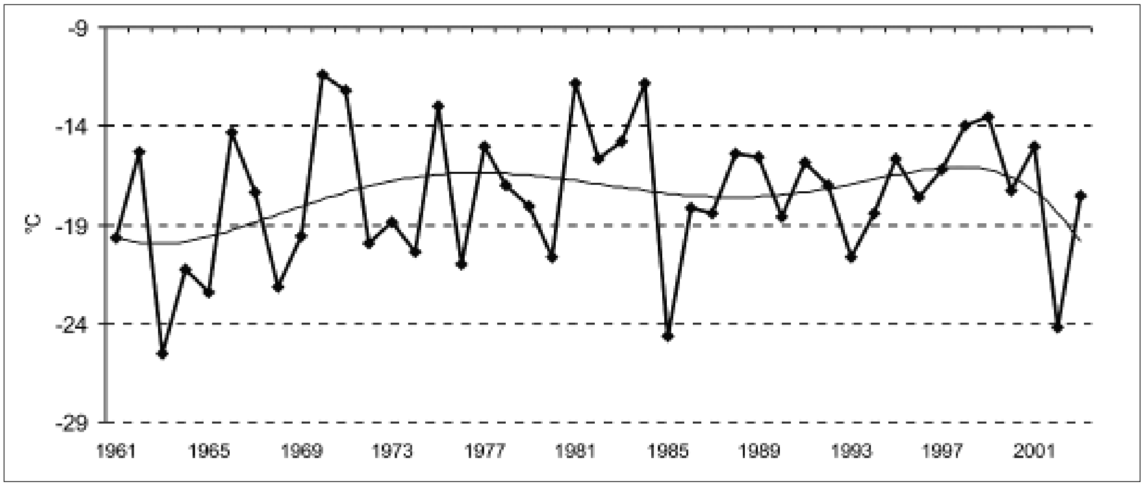

Fig. 4. Interannual trend of the absolute minimum temperatures at Patârlagele (1961–2003).

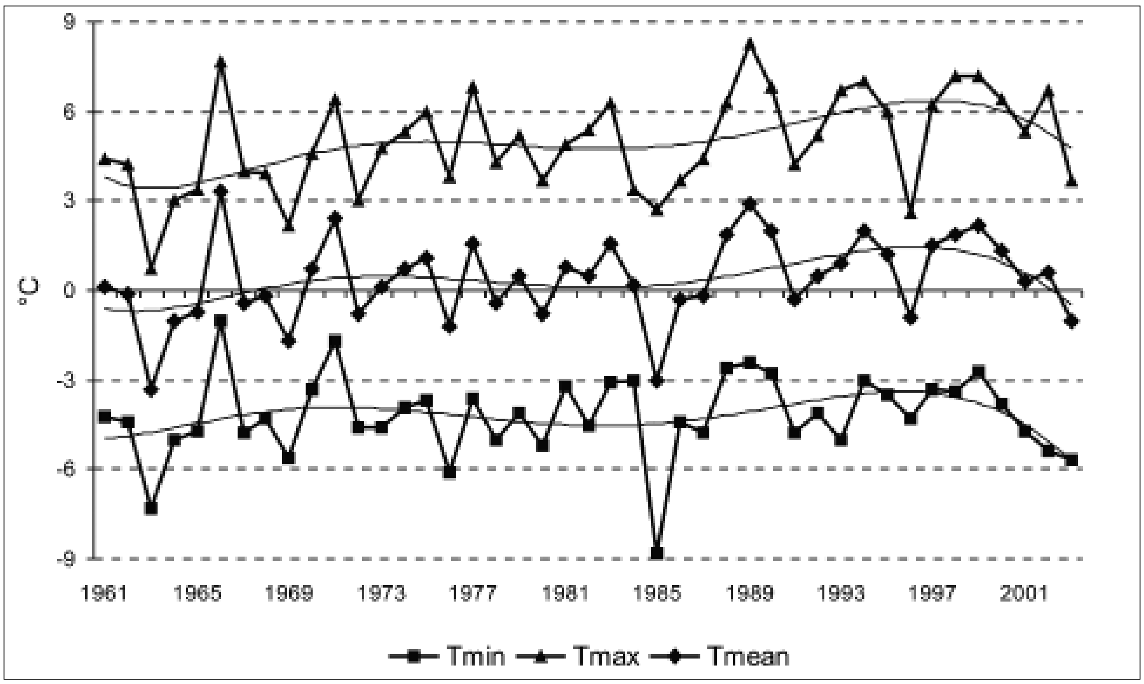

Fig. 5. Interannual trend of minimum, maximum and mean winter temperatures at Patârlagele (1961-2003).

In contrast with the parameters analysed above, the absolute minimum temperature shows a positive trend. This behaviour is more evident if we consider that the absolute minimum temperature exceeded –19 °C ten times in the period 1961–2003 and 23 times in the last two decades (Fig. 4).

Also the mean minimums and maximums present a similar trend, but to a slightly lesser extent, with two negative oscillations: the first in the period 1975–1985 while the second started at the beginning of the new century (Fig. 5).

Summer temperatures. Besides the analysis of mean, maximum and minimum temperatures, the climatic features of the Summer months were examined concerning the number of tropical days (T_{max} < 30 °C), maximum number of consecutive tropical days, number of days with T_{max} = 35 °C, and the absolute maximum temperatures (Tab. 3).

The mean Summer temperature is 19.9 °C and ranges from 17.6 °C (1976) to 21.3 (1999), the mean values of the minimum and maximum temperatures are 13.5 °C and 26.3 °C

			Summer				
	Tmin	Tmax	Tmean	Tropical days	Max.n°cons. tropical. days	Days Tmax = 35°	Tmax asso-luta
Min	11.2	23.9	17.6	1	1	0	30.4
Date	1976	1984	1976	1978	1978	vari	1978
Max	15.1	28.3	21.3	40	12	8	39.0
Date	1999	1987/2000	1999	2000	1987	1987	1987
Mean	13.5	26.3	19.9	16.5	4.9	0.7	-

Tab. 3. Range of mean Summer temperatures, number of tropical days, maximum number of consecutive tropical days, number of days with Tmax = 35°C and absolute maximum temperatures

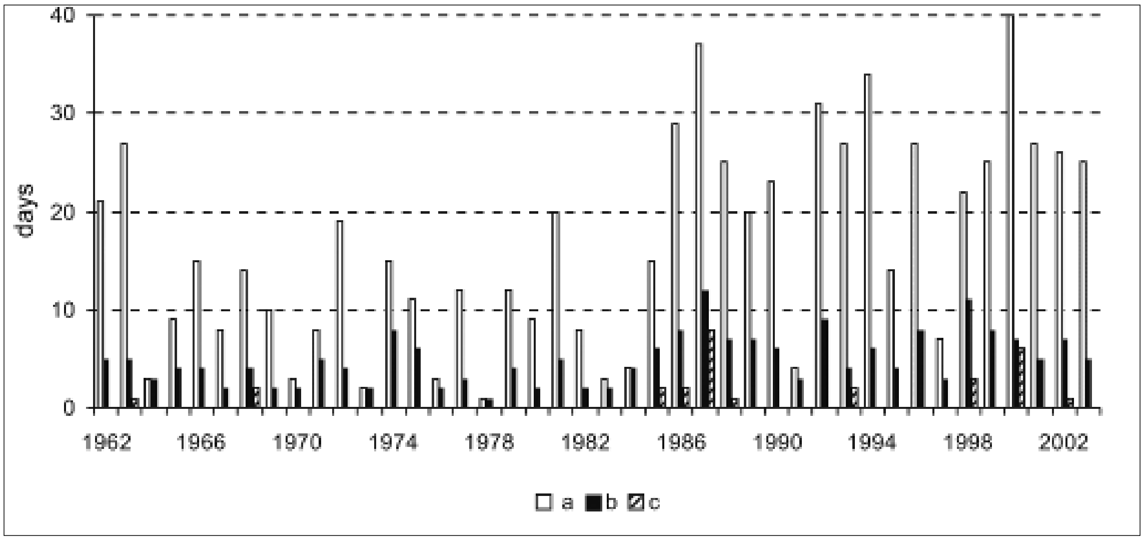

Fig. 6. Interannual trend of number of tropical days (a), maximum number of consecutive tropical days (b), number of days with T_{max}= 35°C (c) at Patârlagele (1961–2003).

respectively. The number of tropical days, with a mean value of 16.5 days per year, varies between 1 (1978) and 40 (2000). Less frequent are the days with T_{max} = 35 °C in fact this value is reached only in about a quarter of the analysed years. The Summer of 1976 is the coolest of the series, this only once the mean summer temperature lowered below 18 °C. Also the summer of 1978 was very cool, the temperature of only one day exceeded 30 °C.

The trend of the summer parameters that we analysed underlines a general increase in temperatures over the last few decades (Fig. 6).

The trend of the number of tropical days shows a remarkable increase since the second half of the 1980s. In fact in the period 1961-1980 the temperature exceeded 30 °C for 210 times, while between 1981 and 2003 this threshold was exceeded 493 times, 247 of which in the last 7 years. Also the trend of days with T_{max} = 35 °C shows a similar pattern but it is less marked. The values exceeding 35 °C were recorded for 3 times during the period 1961-1980 and 25 times in the period 1981-2003. Also the absolute maximum temperatures show the same trend (Fig. 7).

Comparing the general trend of the interannual Summer mean temperatures shows an increase that is more evident for the maximum temperatures than for the minimum ones (Fig. 8).

In conclusion, the air temperature analysis highlights a general positive trend, interrupted by a first oscillation during the 70s and another one that started at the beginning of the 21st century, following a period charac-

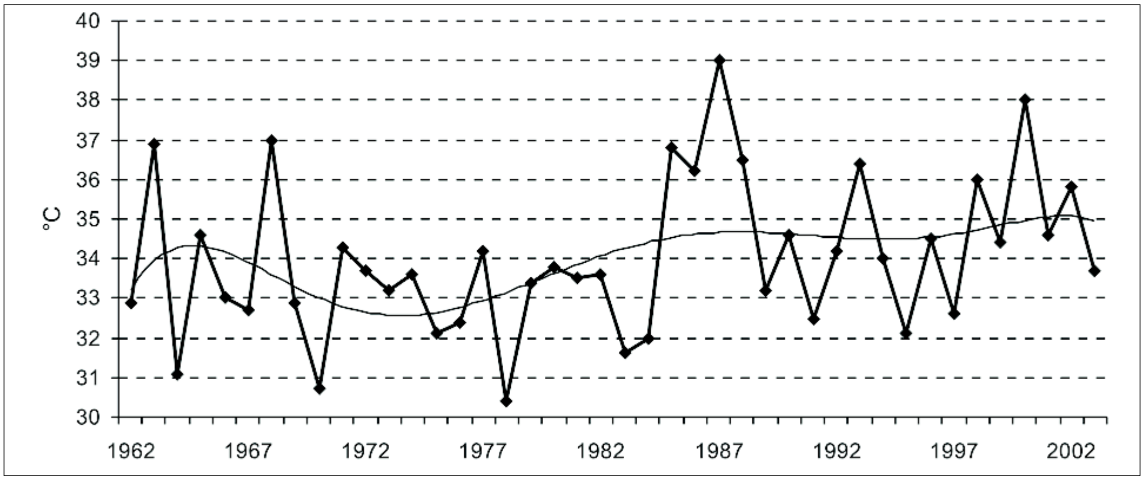

Fig. 7. Interannual trend of the absolute maximum temperatures at Patârlagele (1961–2003).

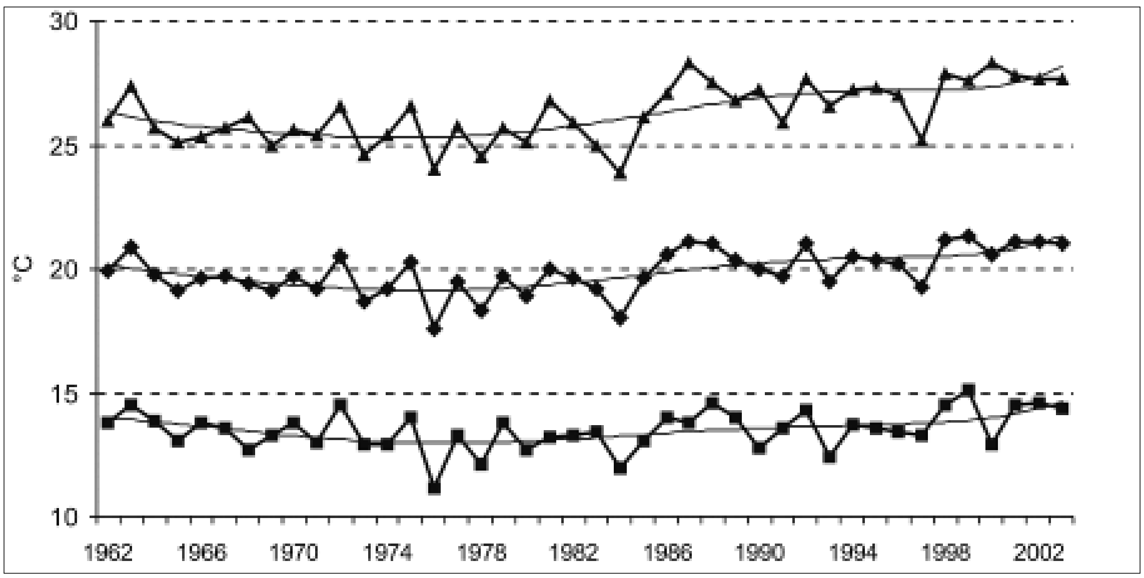

Fig. 8. Interannual trend of maximum, minimum and mean Summer temperatures at Patârlagele (1961–2003).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Min	1.7	1.3	2.6	6.3	10.8	35.4	9.2	0.1	4.8	0.8	0.5	0.5	389.0
Date	1989	1967	2002	1968	1982	1981	1977	1962	1983	2000	1990	1975	2000
Max	108.3	94.4	97.5	101.4	208.2	188.1	282.5	180.4	129.5	131.0	167.8	182.3	857.2
Date	1965	1969	1962	1997	1988	1969	1975	1972	2001	1972	1966	1969	1969
Mean	30.0	29.2	29.0	43.3	80.6	93.2	91.4	70.0	45.9	38.8	40.9	37.8	630.1

Tab. 4. Mean monthly and yearly rainfall at Patârlagele (1961-2003).

terised by a fast and constant increase in temperatures.(Fig. 9)

Rainfall

The data set available consisted of monthly values of precipitation and extreme pluviometric events for each year (Tab. 4).

The mean annual rainfall is 630.1 mm, ranging from 389.0 (2000) to 857.2 (1969). The rainiest month is June, followed by July and May, while March is the poorest in the least precipitations (Fig. 10).

The general rainfall regime has a main maximum during Summer (40%) followed by Spring (24%). During the study period, six

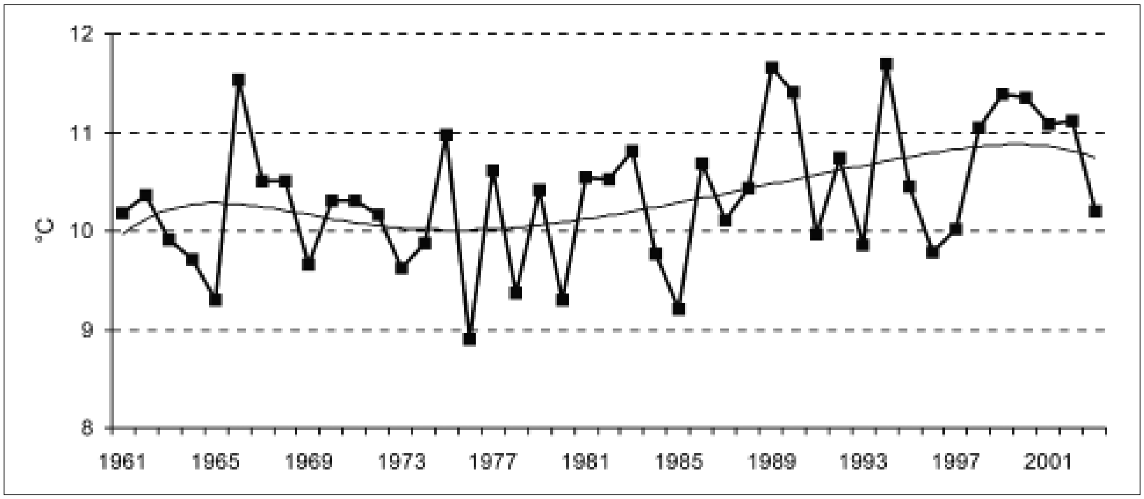

Fig. 9. Interannual trend of annual mean temperatures at Patârlagele (1961–2003).

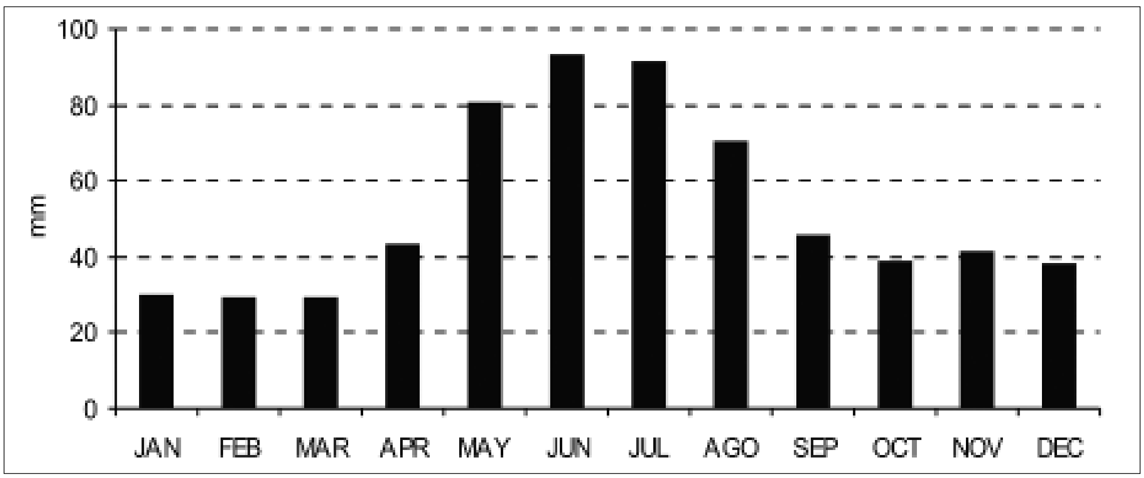

Fig. 10. Monthly rainfall regime at Patârlagele (1961–2003).

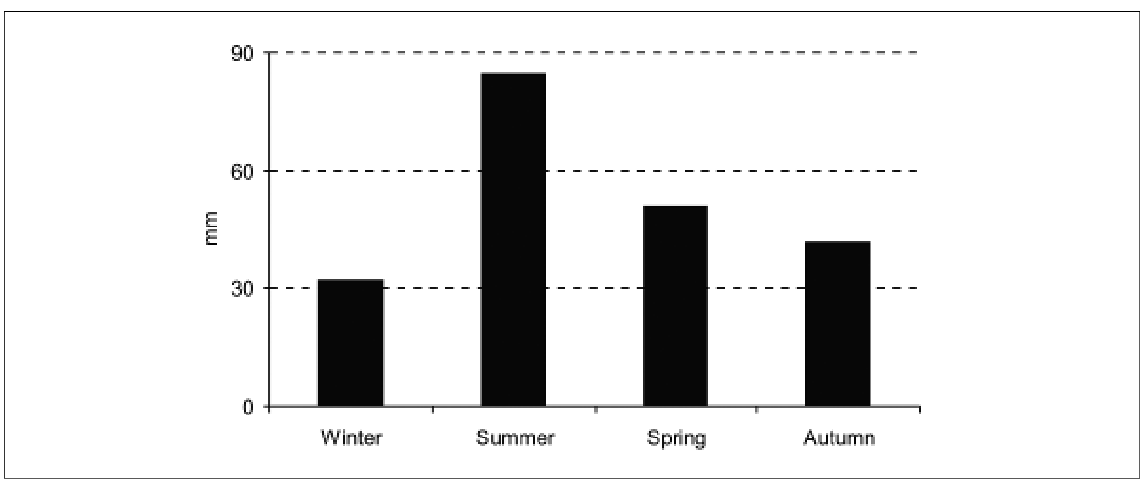

Fig. 11. Seasonal rainfall regime at Patârlagele (1961–2003).

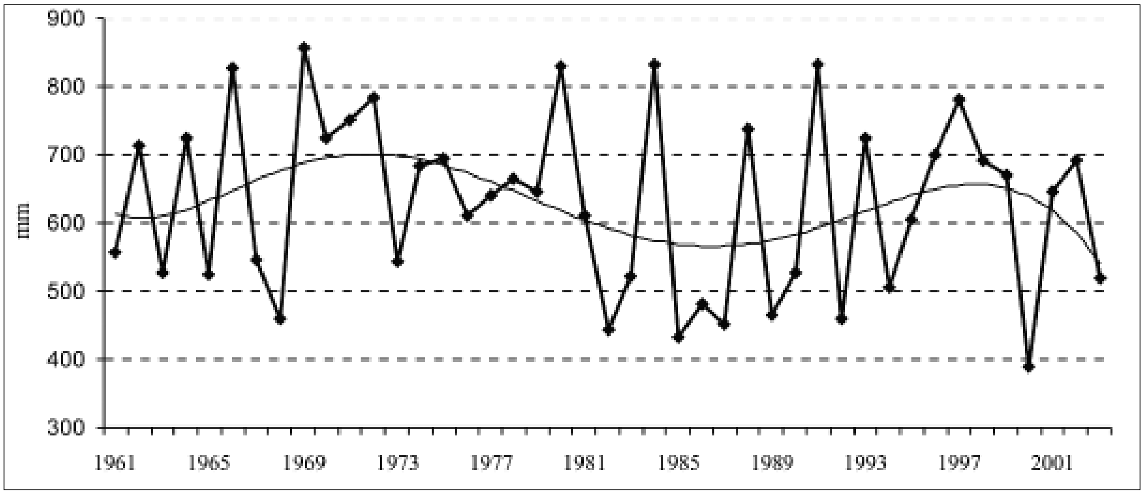

Fig. 12. Interannual trend of rainfall (mm) at Patârlagele (1961–2003).

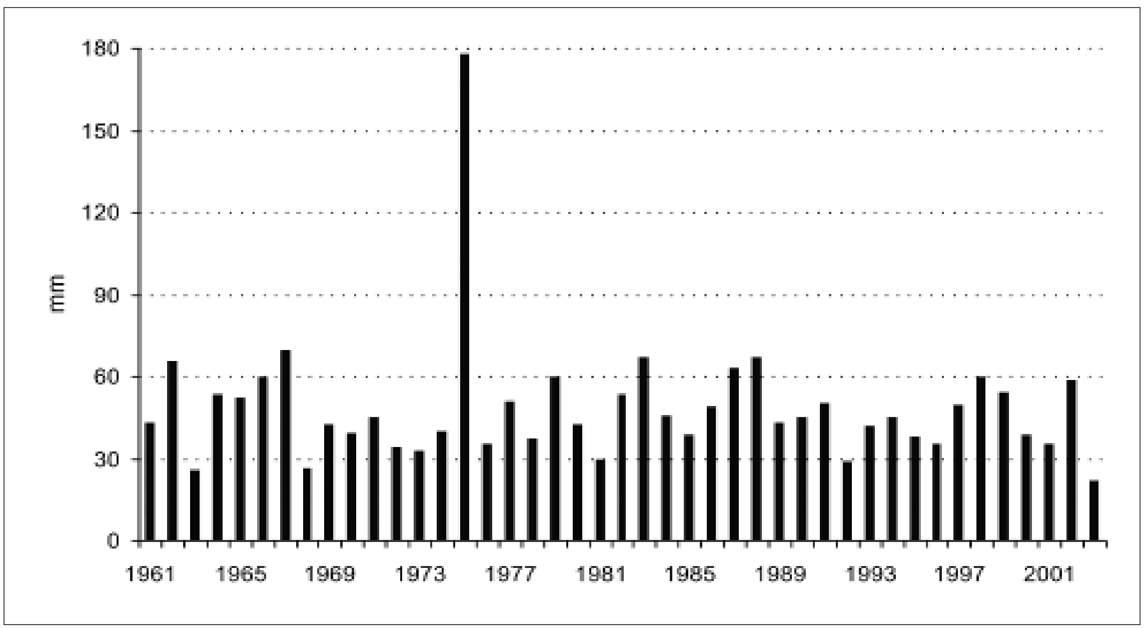

Fig. 13. Maximum daily rainfall at Patârlagele (1961–2003).

years had summer rainfalls of more than 50% of the total rainfall of the year while in 1983 this value surpassed 75% (Fig. 11).

The interannual precipitation variability is 2.2, this parameter expresses the ratio between the amount of rainfall in the most humid and most arid year.

The interannual trend of rainfall shows a general negative trend characterised by wide fluctuations. The amount of precipitation shows increases between 1965 and 1975 and again in the first half of the 1990s. It is important to underline that also during the period characterised by a negative trend we can have very rainy years such as 1984, 1988 and 1991 (Fig. 12).

Extreme rainfall events. During Summer the study area experiences torrential rainfalls, which have a great impact on the slopes triggering mass movements and causing floods. The maximum daily rainfall for each year of the study period ranges generally between 30 and 70 mm. These low values underline the exceptional nature of the event that occurred on July, 2nd, 1975 when 177.8 mm of rain fell in 24 hours. This value corresponds to 25.5% of the total amount of rain that fell in 1975 (Fig. 13).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Min. min	0.0	0.0	0.2	33.7	76.6	98.5	114.3	100.0	62.0	31.5	0.0	0.0	621.9
Date	Sever.	Sever.	1987	1997	1991	1966	1979	1976	1996	1979	1993	Sever.	1976
Max	8.3	18.8	39.8	68.4	114.3	129.9	154.8	140.5	101.0	60.2	30.9	9.5	710.9
Date	1983	1966	1990	1961	2003	1964	1987	1992	1994	1966	1969	1985	1994
Mean	1.7	4.2	18.3	50.3	91.7	116.2	131.2	118.1	77.8	43.7	16.7	2.9	672.8

Tab. 5. Monthly and annual EP and its range.

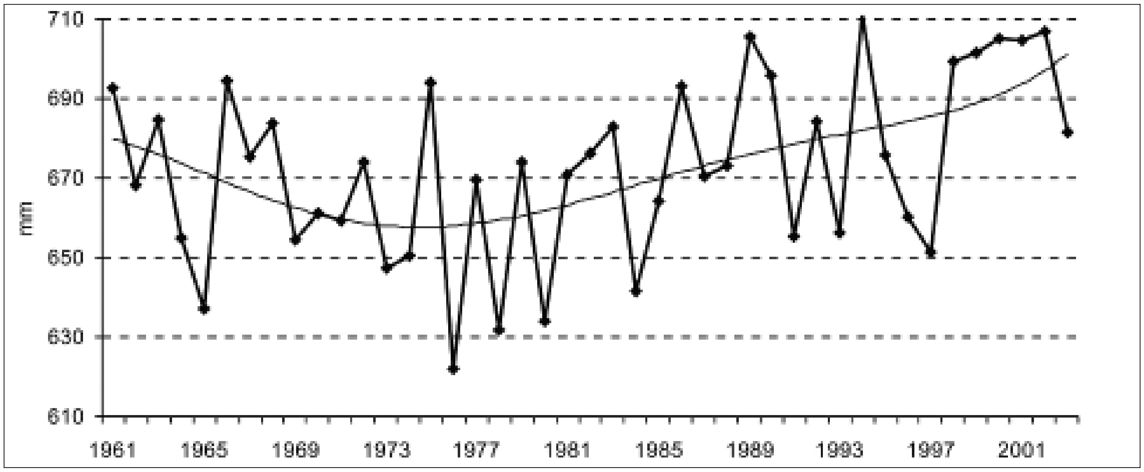

Fig. 14. Interannual trend of EP at Patârlagele (1961–2003).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Min. min	0.0	0.0	0.0 00.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Date	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.
Max	90.7	91.8	83.1	39.1	119.4	46.7	84.8	0.0	14.6	98.1	59.7	89.1	225.4
Date	1966	1984	1962	1962	1988	1991	1975	Sever.	1972	1972	1966	1969	1984
Mean	7.7	8.9	14.1	5.1	14.1	3.6	3.0	0.0	0.3	2.3	1.6	7.2	67.8

Tab. 6. Mean monthly and annual Surplus and its range.

Water balance and climatic classification according to Thornthwaite

In order to calculate the climatic classification and the water balance for the study area, we chose Thornthwaite's method due to its capacity of representing the water needs of the vegetation, and in order to assess soil susceptibility to erosional processes (Thorthwaite, 1948; Thorthwaite, Mather 1957). Thornthwaite's method is based on the concept of Potential Evapotranspiration (EP), defined as the amount of water that would be evaporated under an optimal set of conditions, such as an unlimited supply of water (Tab. 5).

The mean annual value of EP is 672.8 mm and varies from 621.9 mm (1976) to 710.9 mm (1994). The mean value of CEET (the ratio summer/ annual EP), is 54.3% but some years it exceeds 58% (1987–1988). The interannual trend of EP shows a decrease starting at the beginning of the 1970s with the lowest values recorded in 1976,1978 and 1980. In contrast, in the last two decades there has been a weak but uniform increase (Fig. 14).

Adopting Thornthwaite's method, knowing the values of EP and rainfall, it is possible to calculate other parameters such as Deficit (D) and Surplus (S) (Tab. 6).

The annual average of Surplus is 67.8 mm ranging from 0.0, a value recorded in many years, to 225.4 mm (1984). During August and September the Surplus remains close to 0.0, while it reaches the highest values in March and May.

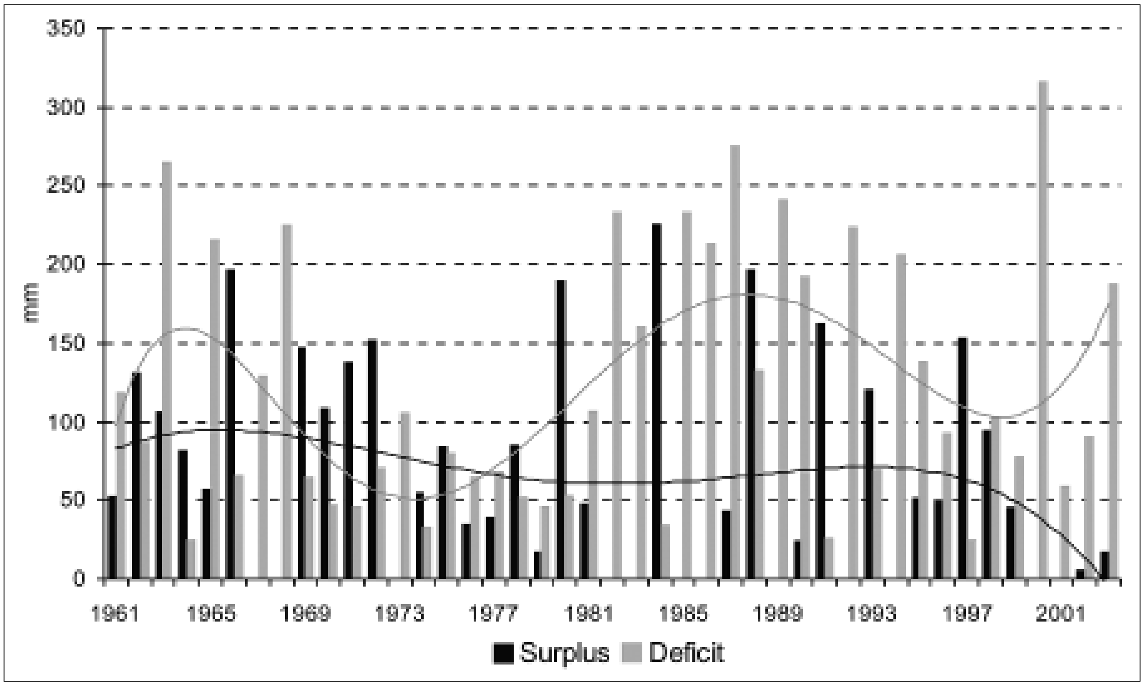

Fig. 15. Interannual trend of Surplus and Deficit at Patârlagele (1961–2003).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
Min. min	0.0	0.0	0.00 0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.3
Date	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	Sever.	1964
Max	4.1	0.5	10.3	36.8	56.7	61.6	90.6	92.2	67.5	37.8	8.5	2.2	315.9
Date	1983	1995	1989	1983	1982	1968	1987	2000	1987	2000	1990	1971	2000
Mean	0.2	0.0	1.2	4.6	11.3	12.8	25.0	31.4	24.4	10.4	1.6	0.1	122.9

Tab. 7. Mean monthly and annual Deficit and its range.

	J	F	M	A	M	J	J	A	S	O	N	D
Min	27.4	51.9	46.9	37.5	11.7	20.3	13.1	6.8	6.5	5.0	4.7	7.6
Date	1989	1989	1989	1976	2000	2000	2000	2000	2000	2000	2000	2000
Max	209.3	269.4	150.0	150.0	150.0	150.0	150.0	143.7	150.0	150.0	150.0	218.5
Date	1996	1969	Sever.	Sever.	Sever.	Sever.	Sever.	1997	1972	1972	1964	2002
Mean	125.7	142.2	129.3	121.9	105.7	94.3	76.5	59.7	51.8	57.8	76.7	106.8

Tab. 8. Mean monthly and annual soil moisture budget and its range.

The Deficit, which supplies an estimation of the duration and intensity of the arid period, presents a mean annual value of 122.9 mm and varies from 24.3 mm (1964) to 315.9 mm (2000) (Tab. 7).

The interannual trend of Surplus is negative and this tendency became particularly obvious in the last year of the series, while the general trend of Deficit shows wide oscillations (Fig. 15).

Soil moisture budget. The amount of water held in the soil depends on the rainfall and EP, while the amount of water that the soil can hold depends on the characteristics of the ground, such as texture and quantity of organic substances contained. This parameter is known as field capacity and its value is 150 mm in the Muscel valley. During an average year the field capacity is never reached while during the study period this value is reached and even exceeded in almost all the months (Tab. 8). When the soil is saturated the Surplus becomes an underground, hypodermic and superficial flow.

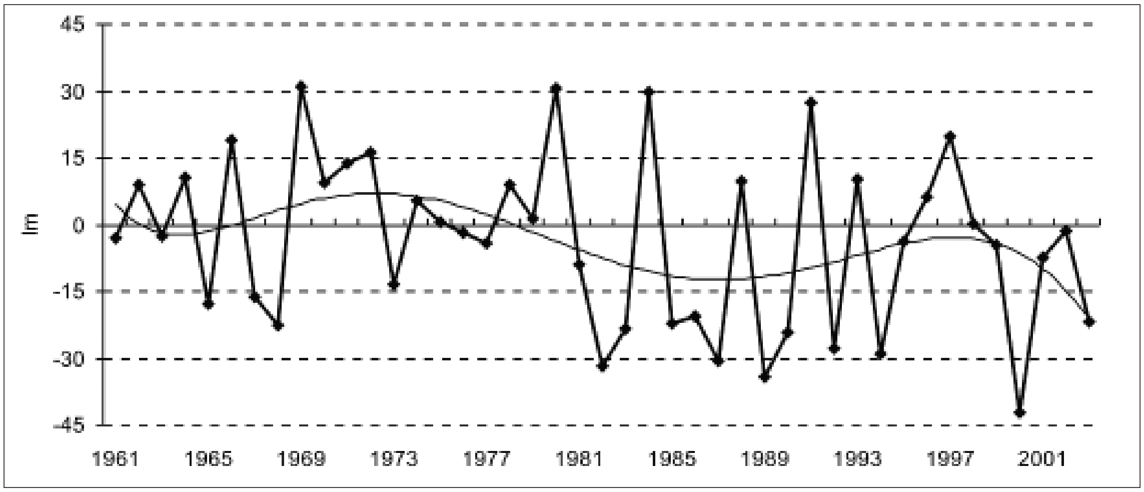

Fig. 16. Interannual trend of Im at Patârlagele (1961–2003)

	EP	S	D	CEET	Im
Min. values	621.9	0.0	24.3	50.7%	-42.0
Date	1976	Several	1964	1966	2000
Max. values	710.9	225.4	315.9	58.4%	31.0
Date	1994	1984	2000	1987	1969
Mean values	672.8	67.8	122.9	54.3%	-3.6

Tab. 9. Summary of water balance parameters.

	Years	Climatic formula	Description
Most arid year	2000	D B'1 d b'3	Semiarid, first mesothermic, no water excess, CEET 53.2% quasi
Most humid year	1969	B1 B'1 r b'3	Humid, first mesothermic, small deficit, CEET 53.5%
Average year	1961-2003	C1 B'1 d b'3	Subarid, first mesothermic, small excess of water, CEET 54.3%

Tab. 10. Summary of climatic formulas.

Climatic formula. Some important indices can be calculated combining EP, S and D. In particular the relation I_m=(S–D)/EP results into the index of global moisture (I_m), which is the most important index in the climatic classification suggested by Thornthwaite (Fig. 16).

The mean value of I_m for the study period is -3.6 and this corresponds to the subarid type C_1. The minimum value recorded in this period was –4.2 (2000) and corresponds to type D (semiarid), while the maximum is 31 and represents the humid type (B_1) (Tab. 9).

Using the analysed values it is possible to obtain a climatic formula composed of four letters. The first indicates the Im, the second represents the EP, the third is the Index of aridity or humidity and the last is the value of CEET. This formula indicates the climatic features of the study area, taking into consideration latitude, temperatures, precipitation and soil field capacity (Tab. 10)

Conclusions

The analysis of the thermopluviometric data recorded at Pătârlagele station in the period 1961–2003 enables us to define the general climatic characteristics of the study area and, at the same time, to identify the rainiest period and the extreme rainfall events.

The mean yearly temperature is 10.4 °C ranging from 8.9 °C (1976) to 11.7 °C (1989-1994). The general trend shows an increase since the end of the 1970s, consisting in greater increase of Summer temperature as comparered to those of Winters; the pattern is quite regular even if sometimes it is interrupted by some cold years. In particular since 2000, a rapid decrease of temperatures has occurred which is much more evident in 2003, when it was very hot in many European countries. This anomalous heat wave did not affect Romania probably because the Azores Anticyclone, responsible for this event together with the North-African anticyclone, only slightly influences this area.

Regarding rainfall, the mean yearly precipitation is 630.1 mm, ranging from 389 mm (2000) to 857.2 mm (1969), with the main maximum in Summer. This season is affected by extreme rainfall events, the most well-known is that of July 2nd 1975, which caused widespread floods and many mass movements in the valley. The general trend is negative, especially in the few last years.

The climate of the Muscel valley is classified as subarid, first mesothermic, characterised by a small excess of water and with a CEET of 54.3%. In the last years a tendency to dryness has been recorded due to the increase in temperatures and decrease in rainfall, giving semiarid features to the climate.

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