THE ASSESSMENT OF SOME HYDROMETEOROLOGICAL DROUGHT INDICES IN THE BEND SUBCARPATHIANS AND PERIPHERAL ZONES

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Abstract: *This study tackles an interdisciplinary water resources issue, comprising one of the joint researches in Meteorology, Hydrology, Soil Science and Agronomy. Thereby, the main hydrometeorological parameters for identifying areas affected by water deficit will be discussed. Drought is one of the major natural hazards that may cause great losses to the rural community each year, due to the dependence of agriculture on water resources, especially water scarcity. In the investigated area (Bend Subcarpathians and peripheral zones), a greater frequency of dry autumn seasons characterizes especially northern part, starting from Buzău. A higher frequency has been identified along the Prahova Valley, too. In some areas, the mean maximum ranges of the consecutive dry days exceed annually 30. A larger interval for average number of days with no rainfall is registered in autumn (more than 22 days in nearly the whole Subcarpathians area). An analysis of frequency of annual minimum monthly mean discharges highlights the same temporary pattern with that of rainfall analysis: more than 50% occurrence in autumn season, especially for subcarpathian basins, with higher frequency in Prahova Subcarpathians (over 60%). In Vrancea Subcarpathians, these values recorded a large frequency in summer, too. The lowest mean monthly discharges, as well as the number of consecutive days with no flow have been analysed also. The most severe hydrological droughts have been identified on Cricovul Dulce, Nişcov, Râmna, Câlnău and Putna rivers (the last one at Mirceşti RGS).*

Key words: *drought indices, SPI, CDD, minimum runoff, monthly discharge, Bend Subcarpathians*

INTRODUCTION

The changes that occurred in Romania after 1990 leaded to a new structure of agricultural area, more fragmented, small farms occupying about 66.5% from the total agricultural area of the country. These farming systems are oriented more to subsistence, with limited investments in developing irrigation systems, soil fertilization or modern technologies. The productivity of agricultural soils is related also to the direct influence of climatic factors. For example, it is assumed that the lack of irrigation in the condition of a long and pronounced drought as that of 2000, leaded to a decrease of cereals yields to 40% from the previous year (POPOVICI and BĂLTEANU, 2010).

First of all, it has to notice a difference between drought and aridity. Thus, drought is considered a climatic phenomenon, marked by a temporary and periodical anomaly, which arise from the lack of precipitation over an extended period of time (SUBRAHMANYAM, 1983). Some authors associated it with a deficit availability of water resources (ROSSI, 2000; TSAKIRIS and VANGELIS, 2005) Aridity instead is a permanent characteristic of climate, associated with low rainfall regions, subjected to the frequent or continuous incidence of droughts (SUBRAHMANYAM, 1983).

Drought is one of the major natural hazards that may cause great losses to the rural community each year, due to the dependence of agriculture on water resources, especially water scarcity, during different phenological phases of crop growth. Adapting agriculture to extreme phenomena has to be done through changes in agricultural practices and crops. The agricultural management is based, among other main inputs, on the knowledge of water resources and of the identification of areas currently affected by water deficit, as well as of the risk of different drought occurrence (meteorological, hydrological or pedological) or of aridity degree of a territory. For this purpose, several indicators have been developed, providing information about the state of the water deficit.

Therefore, the aim of this paper is the assessment of some hydrometeorological drought indices in a study area, comprising the Bend Subcarpathians (about 6,417 km^2), a mid-elevation morphostructural unit located outside the Carpathians, between the mountains and the lower units (Romanian Plain and Siret Valley), but also its peripheral zones (Fig. 1). The vicinity of Carpathians orographic barrier creates a topographic shelter during movement of maritime or continental air masses, leading to a 'mild' topoclimate in the Subcarpathians area, characterized by lower thermal contrasts, diminished intensity, duration or frequency of the temperature inversions, etc. (BOGDAN and MIHAI, 1979; BOGDAN and NICULESCU, 1996). Additionally, the foehn wind has an important role for the climatic features of the area, occurring on the leeward slopes of mountains (southern and eastern slopes), as a result of Carpathians bending. Western air masses characterized by high humidity produce rainfall on northern and western slopes, while on the eastern or southern part resulting foehn effects. It causes a decrease in rainfall, but also an increase of sunlight duration and solar radiation which contribute to the temperature increasing, relative humidity decreasing and to the occurrence of dryness and drought phenomena (BOGDAN, 2005).

Most of the drainage network belongs to the Siret Basin (tributaries: Şuşiţa, Putna, Râmnicu Sărat and Buzău) and the Ialomiţa Basin, with a smaller extent, main tributary being Prahova. There are two more drainage basins in the area, rather insignificant in terms of coverage, Argeş and Călmăţui. Many of the Vrancea Subcarpathians rivers are characterized by low discharges and confluence directly with Siret, the more important being Şuşiţa.

MATERIAL AND METHODS

In order to develop an accurate analysis of water resources, and to investigate their relationships with elevation, data from 68 river gauging stations (RGSs) have been used, located in Bend Subcarpathians (23 RGSs), in runoff formation areas from Carpathians (18 RGSs), as well as in plain area (22 RGSs). For climatic parameters, data from 22 weather stations, located mainly in peripheral zones, have been used (Fig. 1).

For identifying the areas with high frequency of meteorological droughts, two indices, ***the Standardized Precipitation Index*** (SPI) and ***Consecutive Dry Days*** (CDD), have been studied.

The SPI is used to quantify the precipitation deficit and excess (being normally distributed, can be used to monitor wet, as well as dry regime) for different time periods. At the beginning, periods of 3, 6, 12, 24 or 48 months have been used (MCKEE et al., 1993), further the researches have been extended for shorter periods (a month or a week). One of its main limitations is due to the use of precipitation data exclusively, even if its goal is to describe a complex phenomenon like drought.

The goal is to compare the precipitation amounts for a certain weather station and for a specific time period with the multiannual average amounts of precipitations for the same time period, computed for long-term data sets. Therefore, SPI is the number of standard deviations by which the precipitation values recorded for a particular location would differ from the mean over certain periods (PALTINEANU et al., 2009). In order to determine SPI, the precipitation are accumulated for the selected number of months and fitted to a Gamma probability distribution function. The SPI is the value of z from the standard normal distribution calculated based on the same cumulative probability of the gamma distribution (GUERREIRO et al., 2007)

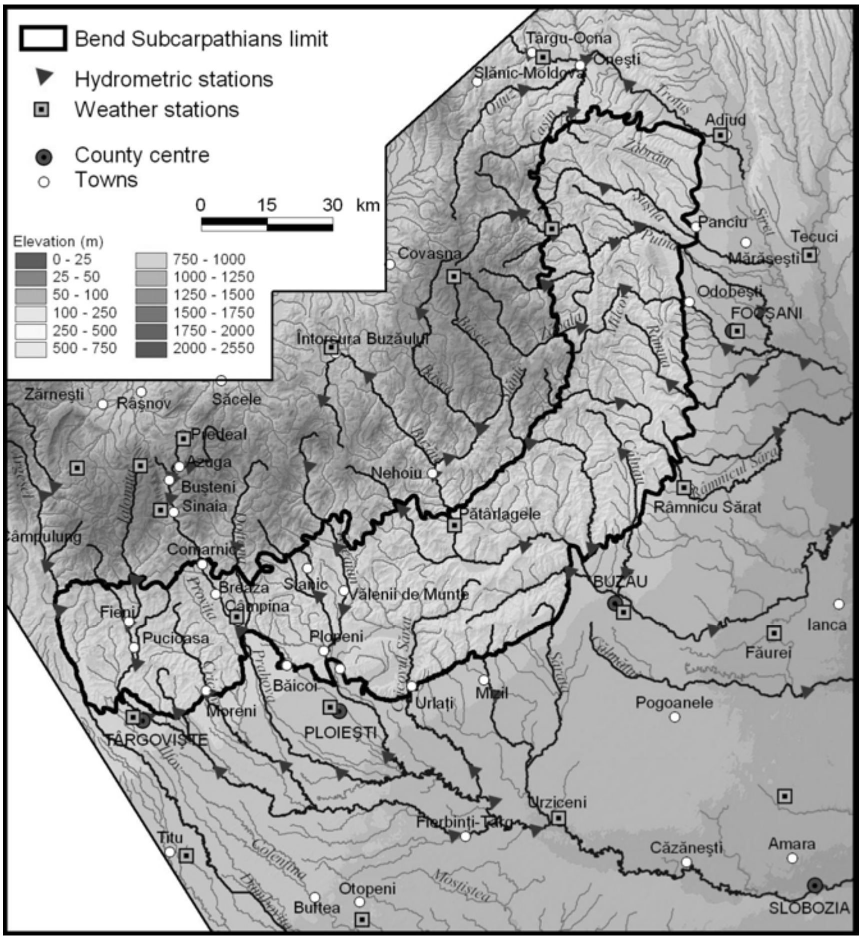


Figure 1. Hydrometric and weather stations used for the assessment of aridity and drought indices in the Bend Subcarpathians and peripheral zones

The SPI has been computed seasonally and annually and the values have been classified according Hayes methodology (HAYES, 2000) (Table 1).

Table 1

Rainfall anomalies classes for months or other period of analysis according to SPI values

SPI Values	**≤-2.00**	**-1.99 – -1.50**	**-1.49 – -1.00**	**-0.99 – +0.99**	**1.00 – 1.49**	**1.50 – 1.99**	**≥2.00**
Rainfall anomalies classes	Extremely dry	Severely dry	Moderately dry	Near normal	Moderately wet	Very wet	Extremely wet

Regarding the CDD, the index expresses the number of consecutive days with daily precipitation amount less than 1 mm. Maximum range has been identified for each year or each season, thus defining the longest period during a certain time period when no measurable precipitation was recorded. Usually the mean maximum annually and seasonally intervals is used, obtained by averaging over a long-term data series. Another analysis presented in this paper refers to the number of ranges selected for 3 CDD thresholds: 20, 30, and over 39. The identification of these ranges has been done on the basis of the entire time series daily values, the transition from one period to another not being taking into account. This index is used as a simple indicator for identifying areas with potential drought conditions.

Hydrological drought occurs during the minimum runoff periods caused by meteorological droughts, when stream channels are recharged exclusively from groundwater, their flow rate being dependent on the state of aquifers depletion, as well as on the manner to which river channels intercept the water table. The selected indices to study this phenomenon are the ***frequency of annual minimum monthly mean discharges***, as well as ***the number of consecutive days with no flow***. As regarding the first parameter, the month in which the mean discharge is the lowest for a given year has been selected. For each month, the number of cases is counted. If for a year there are at least two or more months with the lowest value, each of them is considered a separate case and counted in consequence. The monthly frequency has been computed by expressing the sum of cases as percentage, relative to the total cases of the entire period (Fig. 2). This is an indicator expressing the primary susceptibility to hydrological droughts occurrence for each month.

Month / Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	No. cas.	Mth. min
1990											x		1	XI
1991												x	1	XII
1992												x	1	XII
1993		x											1	II
1994	x												1	I
1995		x											1	II
1996			x										1	III
1997		x											1	II
1998	x												1	I
no. cas.	**14**	**15**	**3**	**0**	**0**	**0**	**0**	**0**	**1**	**2**	**3**	**12**	**50**	
%	**28,0**	**30,0**	**6,0**	**0,0**	**0,0**	**0,0**	**0,0**	**0,0**	**2,0**	**4,0**	**6,0**	**24,0**	**100,0**	

Figure 2. Computing the monthly frequency of minimum monthly mean discharges (for each year, the “x” is placed in the month with the lowest mean discharge)

RESULTS AND DISCUSSIONS

The drought analysis has been done on the basis of seasonally and annually frequencies of the SPI values. This phenomenon shows a large spatial variability, occurring with different magnitudes in every region. As expected in a temperate climate, it could be noticed the high frequency of normal years and seasons. Regarding the extreme precipitation deficit, in some areas about 11 - 15% of the total number of considered years are at least “dry”, and reach in some extreme cases over 20% (Table 2). These maximum values are recorded at two weather stations, one in Carpathians and the second in plain area. The high frequency of dry periods in the mountain areas could be the result of the biased precipitation measurement. CHEVAL et al. (2010) argue that the annual precipitations measured in the mountain areas are often underestimated with 20% of the fallen amounts, due mainly to the wind and snow influence. For example, the rain gauge placed at Sinaia (1500 m a.s.l.) records 1031 mm as an annual average, while the adjusted amount reaches 1170 mm.

On the other hands, it has to notice that the cumulated weight of extreme values of precipitation deficit (extremely dry and very dry) is less than 10% for most weather stations. A particular case is that of Făurei, where no years fall in these classes. As SPI is defined, it does not refer to the classification of precipitation amounts, but only to the comparison between values recorded during different periods and the average. Thus, in the plain units there could be areas with moderate droughts, but with high aridity.

The frequency of droughty autumns is higher starting from Buzău to north, both for outside and inside Subcarpathians, as well as from Subcarpathian unit towards Romanian Plain. Therefore, the area most affected by drought in this season is the peripheral area of Subcarpathians, respectively Romanian Plain and the south part of Moldavian Plateau. If only that classes indicating extremely deficit (extremely dry and very dry) are considered, the autumns are dryer at Râmnicul Sărat (11%) and the least dry in Prahova Subcarpathians. Taking into account the all 3 classes for drought, the frequency of dry seasons reaches about 25% in the sector located north to Buzău, with a similar trend for summer seasons, too.

Table 2

The frequency (%) of years and seasons with precipitation deficit

Weather station	Year		Spring		Summer		Autumn		Winter	
	S	S_E	S	S_E	S	S_E	S	S_E	S	S_E
Câmpulung Muscel	11.1	8.9	13.4	6.7	15.5	6.6	17.8	6.7	13.6	11.3
Târgovişte	15.5	6.6	13.3	8.9	17.7	6.6	17.7	4.4	20.5	9.1
Predeal	11.1	11.1	13.3	6.6	17.8	6.7	20.0	6.7	20.5	4.6
Sinaia 1500	15.5	6.6	20.0	8.9	17.8	8.9	22.2	4.4	15.9	11.4
Câmpina	17.7	6.6	13.4	13.4	15.5	4.4	17.7	4.4	9.1	6.8
Ploieşti	15.5	4.4	15.5	8.8	20.0	4.4	17.7	4.4	18.1	4.5
Urziceni	15.6	4.4	11.1	1.4	13.3	8.9	17.8	6.7	22.7	6.8
Pătârlagele	18.2	6.8	22.2	6.6	15.8	9.0	15.6	8.9	13.7	4.6
Buzău	15.5	4.4	15.5	4.4	17.7	4.4	24.5	8.9	18.2	6.8
Făurei	20.0	0.0	12.5	5.0	12.5	7.5	20.0	10.0	12.8	5.1
Lăcăuţi	20.0	8.9	13.3	8.9	17.8	4.4	15.6	8.9	13.6	9.1
Râmnicu Sărat	17.8	6.7	15.5	8.8	24.4	2.2	22.2	11.1	13.6	6.8
Tulnici	14.3	9.6	9.6	7.2	19.1	4.8	21.4	9.5	19.0	9.5
Târgu Ocna	17.7	6.6	13.3	8.9	20.0	2.2	17.8	6.6	18.1	11.3
Adjud	15.9	4.5	13.6	6.8	15.5	4.4	24.4	6.6	15.9	6.8
Tecuci	17.7	6.6	15.5	8.8	22.2	8.9	24.5	8.9	9.1	6.8

S = sum of frequencies (%) for "Extremely dry", "Very dry" and "Dry" classes

S_E = sum of frequencies (%) for "Extremely dry" and "Very dry" classes

Another areas affected by drought are those of interhill depressions and large crossing valleys from Subcarpathians, especially Prahova Valley. At Pătârlagele, the phenomenon is characteristic to springs, being influenced by foehn wind.

Table 3

Statistic of maximum CDD between 1961 and 2005

Weather station	The average of maximum annually and seasonally intervals					Number of time intervals					
						20-29 days		30- 39 days		> 39 days	
	Sp	S	A	W	Year	No_i	i_m	No_i	i_m	No_i	i_m
Câmpulung Muscel	15.8	10.8	20.5	20.5	28.3	50	22.8	13	33.8	8	43.9
Târgovişte	18.1	13.5	23.1	22.2	31.1	60	23.2	15	34.3	13	47.8
Predeal	12.9	9.9	17.2	14.8	20.3	27	23.1	2	31.5	1	44.0
Sinaia 1500	20.8	20.3	24.7	20.5	22.3	78	23.4	33	33.4	9	49.1
Câmpina	16.5	12.1	21.2	21.3	28.6	57	23.2	15	32.7	5	55.2
Ploieşti	18.0	13.1	22.6	21.6	29.8	59	23.5	18	34.3	7	46.9
Urziceni	20.8	17.6	24.4	21.4	32.6	87	23.8	24	33.5	9	47.0
Pătârlagele	18.4	13.3	22.9	24.3	31.4	81	23.1	25	34.0	8	48.3
Buzău	18.8	16.4	24.8	24.6	32.2	90	23.8	23	33.8	9	50.9
Lăcăuţi	13.4	10.1	19.5	14.4	23.0	32	23.5	8	33.3	0	0.0
Râmnicu Sărat	18.8	16.6	23.6	25.1	32.1	89	23.9	24	32.8	9	52.2
Târgu Ocna	17.7	12.3	23.0	24.3	30.6	68	23.9	20	33.9	7	50.3
Tecuci	21.0	16.3	24.3	25.3	33.0	92	23.8	29	32.4	12	49.3

No_i: number of intervals with a specific threshold value of CDD;

i_m: average number of days per time interval;

Sp: Spring; S: Summer; A: Autumn; W: Winter.

The average of the maximum CDD (consecutive dry days), calculated for annually or seasonally values, gives additional information on potential of drought occurrence or rivers drying up. The multiannual average exceeds 30 days for the main large crossing valleys (Prahova, Buzau, etc.), well sheltered from the oceanic influences, as well as for the plain located at the contact with Bend Subcarpathians, and also for the southern part of Moldavian Plateau (Table 3). In autumn, the average CDD exceeds 22 days in nearly the whole Subcarpathian area, and more than 23 - 24 days outside it. In winter, it could be noticed the larger time interval characteristic to Buzau Subcarpathians as an effect of higher temperature for the same elevation.

The analysis of the maximum CDD based on three different thresholds (Table 3) highlights the higher values for 20-29 days interval in eastern and northern part of the study area, excepting the mountains. For this extended areal, around two intervals of 20-29 dry days per year are registered. The largest number of intervals with 30-39 dry days is recorded in the same area, but less than one per each year, generally one at each two years. The larger intervals of CDD are specific for plain areas and southern of Moldavian Plateau. In Subcarpathians, at Pătârlagele, the number of large intervals is comparable with that of plain areas. The periods most affected by the lack of precipitation are September – November 1969 and October – November 1977. Other long dry intervals have been recorded in 1990, 2000, and 2002 (in Romanian Plain and Bârlad Tableland).

In the period of water accumulation in soil (November – March, and especially January - February), the drought occurrence on agricultural lands is more frequent for the entire study area. There are several years with intervals without precipitations exceeding 30 days for this season.

Table 4

The frequency (%) of annual minimum monthly mean discharges for 1950-2000 at main RGSs

RG Station	River name	H (m)	A (km^2)	W	Sp	S	A	A/W
Moroeni	Ialomiţa	1386.1	264.7	70.0	8.0	2.0	20.0	0.3
Fieni	Ialomicioara	917.1	92.2	28.6	2.0	2.0	67.3	2.4
Pucioasa	Bizdidel	638.1	93.7	17.0	3.8	17.0	62.3	3.7
Gura Ocniţei	Slănic	360.8	60.0	14.8	5.6	18.5	61.1	4.1
Bălenii Români	Ialomiţa	772.3	914.7	49.0	2.0	6.1	42.9	0.9
Buşteni	Valea Cerbului	1532.9	24.8	81.6	6.1	2.0	10.2	0.1
Câmpina	Prahova	1123.6	486.6	75.5	0.0	2.0	22.4	0.3
Cheia	Teleajăn	1275.6	42.2	44.0	2.0	10.0	44.0	1.0
Vărbilău	Slănic	516.6	41.4	25.0	0.0	11.7	63.3	2.5
Moara Domnească	Teleajăn	556.7	1408.3	38.8	2.0	12.2	46.9	1.2
Cioranii de Jos	Cricovul Sărat	293.0	597.1	19.7	3.0	21.2	56.1	2.8
Adâncata	Prahova	553.8	3694.9	42.9	2.0	10.2	44.9	1.0
Baba Ana	Istău (Ghighiu)	269.9	119.4	18.2	9.1	22.7	50.0	2.8
Slobozia	Ialomiţa	363.6	9234.7	42.9	2.0	6.1	49.0	1.1
Sita Buzăului	Buzău	941.9	366.0	49.0	0.0	6.1	44.9	0.9
Comandău	Bâsca Mare	1275.8	107.8	75.5	6.1	0.0	18.4	0.2
Varlaam	Bâsca Mica	1201.7	238.1	56.0	6.0	0.0	38.0	0.7
Nehoiu	Buzău	1043.1	1576.9	56.0	2.0	2.0	40.0	0.7
Chiojdu	Bâsca Chiojdului	908.1	107.1	28.6	0.0	14.3	57.1	2.0
Cernăteşti	Slănic	594.3	411.1	30.6	4.1	10.2	55.1	1.8
Potârnicheşti	Câlnău	351.2	192.5	21.6	10.3	19.0	49.1	2.3
Baniţa	Buzău	674.7	4012.6	42.0	0.0	8.0	50.0	1.2
Tulburea	Râmnicul Sărat	806.4	190.1	36.7	0.0	8.2	55.1	1.5
Mărtineşti	Coţatcu	135.2	320.3	17.0	9.4	35.8	37.7	2.2
Tulnici	Putna	1013.0	364.3	68.0	0.0	0.0	32.0	0.5
Nereju	Zăbala	1174.8	264.4	76.0	2.0	0.0	22.0	0.3
Vidra	Vizăuţi	468.6	76.4	42.0	0.0	12.0	46.0	1.1
Goleşti	Milcov	414.3	409.8	23.1	3.8	23.1	50.0	2.2
Jilişte	Râmna	322.7	321.8	21.2	3.8	30.8	44.2	2.1
Boţârlău	Putna	577.2	2480.9	44.9	4.1	10.2	40.8	0.9
Ciuruc	Şuşiţa	597.6	175.9	34.0	0.0	12.0	54.0	1.6
Cireşu	Călmăţui	62.5	1133.6	24.5	6.1	36.7	32.7	1.3
Haloş	Caşin	731.4	213.0	60.8	0.0	2.0	37.3	0.6

The frequency of annual minimum monthly mean discharges computed for the entire studied period highlights high values in winter (70%) for the mountainous area of Ialomița and Prahova basins (Table 4) due to lower temperatures, the snow form of precipitation and the formation of freeze-up jams on rivers. This frequency is similar also for Bâsca Mare and the upper basin of Putna, as well as for mountainous tributaries of Trotuş. There are yet mountainous areas where the minimum monthly mean discharge has a smaller percentage in this season, due to different factors: oceanic influences leading to a milder topoclimate in winter in the upper sector of Buzău or to foehn effects in Bâsca Mică basin.

In the Subcarpathians basins, the minimum values are recorded in autumn in over 50% of years, with a higher frequency in Prahova Subcarpathians (over 60%) and lower in Vrancea Subcarpathians, where the minimum monthly mean discharge could be recorded even in summer for over 30% of years (at Jilişte RGS on Râmna). The causal factors for the minimum values in summer are the higher temperatures from July-August and the small amount of rainfalls, leading to the depletion of groundwater resources (in the case of a permeable lithologic substrate) or to the lack of their drainage (for a clayly lithologic substrate) on lower river basins (Fig. 3). Towards the plain area, the frequency of minimum monthly mean discharges increases in summer to 35 - 36%, being almost the same with that of autumn, or even greater towards the inner Romanian Plain.

Figure 3. The riverbed of Bâsca Chiojdului (a) and Putna (b) in the dry period of summer 2007

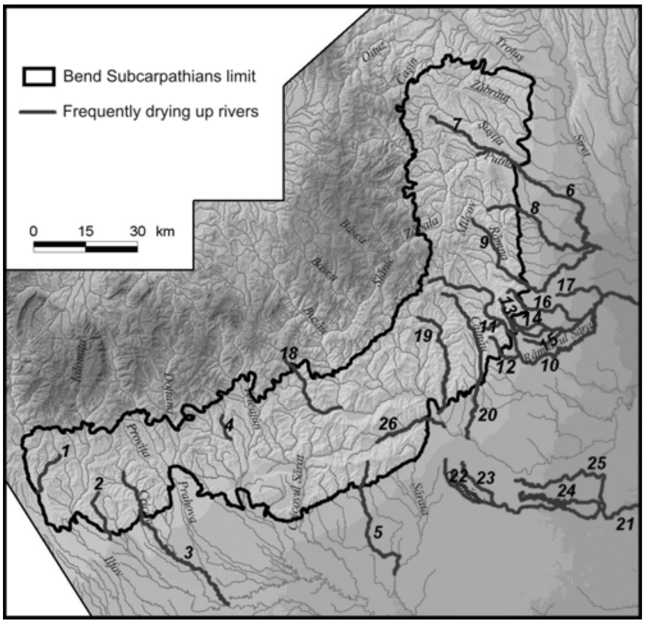
The ratio between the frequency of minimum values occurring in autumn and winter depends on several factors, as elevation, air temperature, lithology, precipitations for the two seasons, etc., being difficult to correlate the ratio A/W with a certain parameter. It reaches maximum values in Prahova Subcarpathians, where exceeds 3, even 4.1 in Slănic basin, at Gura Ocniței. Towards the plain area, it decreases as a consequence of frost days during winter and small amounts of rainfall during autumn, as well as the droughts occurring during summer, all these leading to a balanced distribution of the frequency of minimum monthly mean discharges over the year.

The lowest monthly mean discharges have zero value to some river gauging stations, highlighting intense phenomena of hydrological droughts. The most obvious case is that of Câlnău River, located at the boundary between Buzău and Vrancea Subcarpathians. At RGS Potârnicheşti, 98 months with no flow cases have been recorded: 14 in August, 18 in September, 19 in October and 12 in November. There are many cases recorded also in winter. About 60% cases have been recorded in 1982-1995 period, confirming the dry tendency of this time period. Other rivers with no flow are Cricovul Dulce, Nişcov, Râmna, as well as Putna, in the sector of the RGS Mirceşti (in this last case, the causes are related both to the lithology of the area, and to the water consumption for irrigation).

The rivers drying up, having unfavourable socio-economic consequences like floods (especially for agriculture), it is considered a risk phenomenon, too. Some of the causes leading or favouring the rivers drying up processes are as follows:

- The degree of aridity (expressed as a ratio between precipitations and temperature);
- The heavy soils not allowing the natural drainage of aquifers by streams in dry periods;
- The sandy lithologic substratum, loessoid deposits (aeolian or colluvial formations) and/or in combination with gravel (alluvial unconsolidated formations), increasing the infiltration coefficient, especially during periods of low rainfall;
- The presence of alluvial fans, as deposits in which the water are easily infiltrating, thus groundwater being well replenished;
- The surface of river basins and the stream network density, a high value leading to an increasing of discharge through the groundwater interception, etc.

The drying up process is generally specific for rivers that gather the tributaries from Outer Subcarpathians, from Putna and Râmna piedmont glacis and from the high plain, located in the vicinity of hilly region. It could occur even on rivers with very small basins, such as Slănic of Ialomița, Slănic of Teleajăn, Râul Alb, etc. (Fig. 4).



ID	River
1	Râul Alb
2	Slănic
3	Cricovul Dulce
4	Slănic
5	Ghighiu
6	Putna
7	Vizăuți
8	Milcov
9	Râmna
10	Râmnicul Sărat
11	Izvorul Pietrelor
12	Greabăn
13	Coțatcu
14	Cireş
15	Viroaga
16	Slimnic
17	Bălan
18	Bâsca Chiojdului
19	Slănic
20	Câlnău
21	Călmățui
22	Ruşavăț
23	Negreasca
24	Strâmbul
25	Buzoel
26	Nişcov

Figure 4. Main rivers affected by drying up processes

The 1987 – 1994 period has been characterized by drought, leading to the water resources deficit and causing the lack of daily flow (daily discharge with value equal to 0) on some rivers that did not record such phenomena before 1987. The analysis of the larger periods with no flow highlights the lack of water for long periods in some years, especially on rivers with small drainage basins from Buzău and Vrancea Subcarpathians, as follows:

- On Cricovul Dulce, the drying up process starts in 1987. The largest time intervals with no flow were August - September 1987, August - October 1989, July – December

1990 (149 days), August – October 1992, August - September 1993. In 1987 – 2002, 493 days with no flow were recorded;

- On Nişcov, the droughty periods are generally similar to Cricovul Dulce; the larger intervals with no flow were July – October 1990 (with small interruptions), and May – October 1994 (152 days interrupted by two small breaks);
- The most severe drying up phenomenon is characteristic for Câlnău between Costomiru and Potârnicheşti RGSs. At the first one, a single large interval without flow was recorded (73 days in 1990), while at Potârnicheşti RGS, no less than 7934 days with no flow were recorded between 1965 and 2003. There were 49 intervals with over 40 consecutive days without water (with an average of 88 days per interval), 35 intervals with more than 30 - 39 days, and 41 intervals with more than 20 - 29 consecutive days. The longest intervals were over 200 days;
- Râmna (Jilişte RGS) had no flow in 861 days between 1952 and 2004. No flow was recorded in maximum 67 consecutive days. Upstream, at Groapa Tufei RGS, no flow was been recorded in 168 days between 1961 and 2004;
- On Putna, at Mirceşti RGS, between 1998 and 2004, 497 days were recorded with no flow. The longest drought period had 53 days (August – November 1994).

On Râmna, drying up phenomenon often occurs. At RGS Jilişte, the mean duration or this process is 12 days, with a mean annually frequency of occurrence of 1.5 (ZAHARIA, 1999). The droughts with an extent of less than 10 days are more frequent (65%), followed by those of 11 - 20 days (19%). The prolonged droughts (over 41 days) account for 8% of the total cases. The droughts in the winter season are more significant, followed by those that occur at the end of summer – beginning of autumn.

For Putna, the data from Mirceşti RGS highlights that the drying up phenomenon is an important characteristic of runoff for this river section. Therefore, between 1988 and 1995, 23 hydrological droughts have been recorded, meaning an average annually frequency of occurrence equal to 3 (ZAHARIA, 1999). From the point of view of dry up frequency with different extent or dry up distribution along a year, there are similarities with Râmna.

CONCLUSIONS

For identifying the areas with high frequency of meteorological drought in the Bend Subcarpathians and the peripheral zones, two indices, the Standardized Precipitation Index (SPI) and the number of consecutive dry days (CDD), have been studied. Other two indices have been selected for the study of extent and intensity of hydrological drought, namely the frequency of annual minimum monthly mean discharges and the number of consecutive days with no flow.

In some areas, about 15 - 20% of the considered years are characterised by precipitation deficit, 6-10% being very or extremely dry. The average of the maximum CDD exceeds 32 days in some areas, those being the most affected by drought. Instead, In Carpathians, the range is less than 25 days, even if SPI value indicates a higher frequency of dry periods. Since SPI only compares the precipitation amounts for a given period and the average for the same time interval, in the plain units there could be areas with moderate droughts, but most probably characterised by high intrinsic aridity. It can be concluded that, used independently, the SPI is less useful for irrigation management practices, but it could be taken into account for crop selection considering the adaptation capacity of water requirements to the precipitation deficit.

In terms of the two indicators, areas most affected by meteorological drought are the main large crossing valleys (Prahova, Buzău, etc.), the plain located at the contact with Bend

Subcarpathians, as well as the southern part of Moldavian Plateau. The driest season is autumn, especially for peripheral area of Subcarpathians. In the period of water accumulation in soil (November – March, and especially January - February), the drought events are frequent for the entire studied area.

The hydrological drought is a very complex phenomenon, the soil characteristics in the river basins, as well as the parental rocks of the riverbed being more important factors in rivers drying up than the meteorological conditions. Thus, the two types of drought show a different spatial pattern. The drying up process is specific especially for rivers that gather the tributaries from Outer Subcarpathians, from Putna and Râmna piedmont glacis and from the high plain. The most severe drying up phenomenon is characteristic for Câlnău between Costomiru and Potârnicheşti RGSs, but also for Cricovul Dulce, Nişcov and Râmna. It could occur even on rivers with very small basins, such as Slănic of Ialomiţa, Slănic of Teleajăn, Râul Alb, etc. In the Subcarpathians basins, the lowest monthly mean discharge are recorded in autumn for over 50% of years, with a higher frequency in Prahova Subcarpathians. Towards the plain area, as well as in the Vrancea Subcarpathians, the frequency of annual minimum monthly discharges increases in summer.

The analysis of consecutive days with no flow highlighted the need to define an indicator for hydrological drought similar to CDD, determining a threshold below which the flow values are to be ignored.

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