DRY SPELLS ON THE ROMANIAN BLACK SEA COAST

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ABSTRACT. **- Dry spells on the Romanian Black Sea coast.** The main goal of this paper was to identify and analyse the dry spells in the driest region in Romania: the Black Sea coast. Daily precipitation data sets from 3 weather stations (Constanta, Sulina and Tulcea) for a period of 49 years were used. A dedicated software was employed to identify dry spells and to calculate their main parameters. Then, Mann-Kendall test and Sen's slope estimation were used to detect trends in those parameters. Two of the three weather stations (Constanta and Tulcea) show a similar behaviour with higher numbers of dry spells and lower duration values. Sulina shows different results: the lowest number of dry spells, the highest values of cumulated and average duration and the multi-annual maximum duration of dry spells. The Tulcea inland station has the highest number of dry spells. Duration parameters at Constanta follow those identified at Sulina. All dry spells parameters show statistically significant trends for Sulina data sets: decreasing in the annual number of dry spells and increasing in all duration-related parameters. The short and very short dry spells are most frequent in the area, while considering multi-annual cumulated duration; very short, short and medium dry spells have similar frequency values (24-30 %). Long and very long dry spells have the highest frequency both as case number and for cumulated duration at Sulina.

Keywords: precipitation, dry spell, trend, Mann-Kendall test and Sen's slope, Romanian Black Sea Coast.

1. INTRODUCTION

The Romanian Black Sea Coast belongs to the driest region of Romania, Dobrodja, located in the southeast of the country (Bojariu, 2009). Studies on precipitations in Romania took into account the entire territory of the country and usually only a few weather stations from the south-eastern region were considered. Based on monthly precipitations records, the dryness and drought phenomena have a mean duration of about 6 months in the analyzed region (from April to October) (Bogdan and Niculescu, 1995).

Studies on the precipitation trends in Romania established a correlation with the NAO phases (Busuioc and Von Storch, 1996, Paul and David, 2006, Tomozeiu et al., 2005) or only in the extra-Carpathian region, including the Black Sea Coast

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(Ghioca, 2006). Busuioc et al. (2008) identified a pronounced interdecadal variability and an intensification of precipitation deficit over the southern regions after 1961, for the 1891-1996 period. The authors also found a decreasing trend for Sulina, especially after 1961 and an increasing one for Constanta. Similar results were revealed by Croitoru et al. (2011) while analysing a 30 years interval (1978-2007).

The main purpose of this study is to identify characteristics and trends of the dry spells on the Romanian Black Sea Coast, using 49 years data series.

2. DATA AND METHODS

2.1. Data

Daily precipitation data sets were used in order to analyze the dry spells parameters and trends for a 49 years period (1961-2009), in three weather stations belonging to the national weather stations network (figure 1): Constanta, Sulina and Tulcea. The data were provided by the European Climate Assessment Database (*Klein Tank et al.*, 2002). Precipitations amount has been measured with the IMC pluviometer for 45 years. Since 2004 or 2005, recordings during the warm season have been made using automatic weather stations.

Each of the three stations has its own specificity in terms of location. Thus, Constanta is located on the shore, at 12.8 meters above the sea level, Sulina is on the seawall protecting the navigation channel, 2.7 m height; Tulcea is an inland station, 4.4 m height, located on the Danube River banks, just before the river entering its delta (figure 1).

Fig. 1. ***Location of the analyzed weather stations***

2.2. Methods

Douguedroit (1987) and Dragotă (2006) studied dry or wet spells based on daily data, while Maheras et al. (1999) used monthly data for the wet and dry spells study in the Mediteranean basin.

A dry spell is defined as a sequence of consecutive dry days where the precipitation is < x mm (Douguedroit, 1987). Thus, the dry spell begins in the day when daily rainfall is below the defined threshold (x) and ends when the precipitation amount increases over it. The threshold chosen for this study was 0.1 mm rainfall because this amount can be recorded by automatic weather stations when abundant dew or trace of rainfall occurrs, especially during the warm season.

A dedicated software was employed to identify dry spells and to calculate their main parameters: number of cases, duration (average, cumulated, maximum of an event). The soft finds the intervals with running days with daily precipitation less than or equal to the specified threshold. Up to 12 thresholds may be chosen depending on the period of the year. The software identifies the beginning date, calculates the duration (in consecutive days) and the total amount of precipitation in the drought period. It also associates a dry spell to the month/year containing its first day, even though it overlaps between two adjoining months/years.

The software have been successfully employed to identify and to study hydrological drought events in Central Romanian Plain (Croitoru and Toma, 2011).

Five classes were established considering the duration: very short dry spells (1…5 days), short dry spells (6…10 days), medium dry spells (11…20 days), long dry spells (21…30 days) and very long dry spells (31 days or more).

The Mann-Kendall test and the Sen's slope estimation were used in order to detect if there are changes in the dry spells structure (considering all calculated parameters)

Calculation of the trend and slope were made using the Excel template MAKESENS (Mann-Kendall test for trend and Sen's slope estimates), developed by researchers of the Finnish Meteorological Institute (Salmi et al., 2002). In Romania, the same method was used with good results in order to identify trends in different data series (temperature, precipitations, snow cover), (Holobaca et al., 2008, Croitoru and Toma, 2010, Micu, 2008, 2009). Karagiannidis et al. (2009) used the method to show the decreasing trend of the number of extreme precipitation cases/year in Europe after 1963.

The procedure is based on the nonparametric Mann-Kendall test for the trend and Sen's nonparametric method for the magnitude of the trend (Mann, 1945, Kendall, 1975). 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 MAKESENS software performs two types of statistical analyses: the presence of a monotonic increasing or decreasing trend is tested with the nonparametric Mann-Kendall test and then, the slope of a linear trend estimated with Sen's nonparametric method is computed (Gilbert, 1987). In MAKESENS, the tested significance levels (α) are 0.001, 0.01, 0.05, and 0.1. Both methods are used here in their basic forms.

3. RESULTS AND DISCUSSIONS

3.1. General features of precipitation on Romanian Black Sea Coast

In the studied area, annual amounts of precipitation range from 257.6 mm, recorded at Sulina, to 460.9 mm, recorded at Tulcea (table 1, figure 2), with higher values from May till November and lower amounts during wintertime (figure 3). The vicinity of the Black Sea and of the Danube River greatly influences the annual distribution of the precipitation (Croitoru et al., 2011) Thus, the difference between winter and summer months is not so high compared to the other regions of the country (Croitoru, 2006, Dragota, 2006, Bogdan and Marinica, 2007).

Table 1. ***Precipitation amounts on the Romanian Black Sea Coast***

Period	Constanta (1)	Sulina (2)	Tulcea (3)
1961-2009	**420.5**	**257.6**	**460.9**
1961-1990	396.3	281.4	445.9
1971-2000	402.1	260.3	448.7
1980-2009	425.2	229.3	463.3

Considering multi-annual precipitation amounts for the analysed period and for sequences of 30 years[4], different behaviours were revealed for the three stations. The annual precipitation is dramatically decreasing at the Sulina station from one 30 years-long sequence to another, with a difference of more than 50 mm from the 1961-1990 interval to the last one (1980-2009). The multi-annual mean value for the last sequence is under the limit of arid areas on the Globe (229.3 mm), while the average value for the 49 years period is only 7.6 mm above that limit.

The other two stations recorded almost double rainfall rates compared to Sulina, with more than 420 mm/year each. They still remain among the lowest values in Romania, despite the continuous increasing values from the first 30 years-long sequence to the last one (17.3 mm at Tulcea and 28.8 mm at Constanta).

Constanta and Sulina stations show very different precipitation amounts. Results for Constanta look much more like the inland station, Tulcea (table 1, figure 2).

Different findings of Sulina may be due to its location on the seawall, above the seawater. The water surface might generate more low-level thermal inversions that diminish the precipitation amount. It behaves similarly to Gloria weather station, located on the Black Sea (figure 1).

3.2. Dry spells analysis

In the general context of that dry region, drought analysis was made not in terms of monthly values, but considering the dry spells. We tried to identify if there is any change in the dry spells structure, from duration and occurrence period during the year points of view. Four parameters of dry spells were considered: annual number of dry spells, mean annual duration of a dry spell, annual cumulated duration of dry spells and annual maximum duration of a dry spell.

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[4] Since 2010 data were not available, for the last sequence, the period 1980-2009 was considered.

For the number of dry spells, the highest value was found for the inland station, Tulcea, while the lowest was identified at „between waters" station, Sulina (table 2). All the results show higher values compared to those calculated for 1961-2000 interval (*Dragotă*, 2006). For all the other three duration parameters, the stations may be ranged in reverse order: the highest values are specific to Sulina and the lowest to Tulcea. Always, Constanta stays in the middle of the range, but its recorded values are more similar to those of Tulcea than those of Sulina.

Mean multi-annual cumulated values range, generally, from 270 to 292 days/year. This means that 71...80% days of a year are dry days. Recorded maximum annual values goes up to more than 300 days.

Mean multi-annual maximum duration of a dry spell varies between almost 26 days and 32 days, while the maximum values are higher than 40 days (at Tulcea and Constanta) and reaches 75 days at Sulina.

At Sulina, dry spells are less in number, but longer compared to the other stations.

Table 2. ***Mean multi-annual values of dry spells parameters***

Parameter/ Weather Station		Constanta	Sulina	Tulcea
Number of spells	Minimum	39	33	31
	Mean	49.6	45.9	52.3
	Maximum	62	60	61
Mean duration of a dry spell (days)	Minimum	4.1	4.3	4.4
	Mean	5.7	6.5	5.2
	Maximum	7.3	9.0	10.0
Mean annual cumulated duration (days)	Minimum	241	249	260
	Mean	277.4	291.1	269.7
	Maximum	304	310	319
Maximum annual duration (days)	Minimum	15	16	12
	Mean	28.7	32.0	25.9
	Maximum	41	46	75

Trends of dry spells were calculated both for the entire year and for May-September interval (table 3). The May-September interval was choose because of the temperature features favouring outdoor tourism activities in the area.

The parameters of dry spells seem to have no statistically significance for Constanta and Tulcea. For Sulina important changes are specific, considering the 49 years-period, to all parameters and to only three of them for the last 30 years sequence. Thus, decreasing trends were identified for the number of dry spells and increasing trends for all the duration parameters. This way, mean multi-annual calculated slopes confirm the mean three-decadal values. All parameters, except the maximum duration of a dry spell, show also statistically significant trends for the sequence 1980-2009, with more abrupt slopes compared to those of the 1961-2009 period. This means that abrupt change of the last 30 years sequence played an important role for the trend of the entire 49 years interval.

For May-September interval, during the 1980-2009 sequence, changes with statistical significance were identified at Sulina for all the parameters, except the maximum duration of a dry spell.

Analysis of dry spells duration shows that 60 - 70% of the dry spells are covered by very short spells class; together with the short spells class they get more than 80% of the total number of spells (figure 2).

Medium duration dry spells are considered those that may trigger a drought event (11-20 days). They have a total frequency of 10-13 %. Long dry spells cover 2-4%, while very long dry spells, responsible for severe drought events, have a very low frequency of 0.4-1.4%.

The cumulated duration was also analyzed and an intense decreasing of the frequency of the very short and short dry spells was found (figure 3).

Table 3. ***Trends in dry spells parameters (slopes are calculated in mm/decade)***

Weather Station / Parameter	Sequence	Constanta		Sulina		Tulcea	
		a[1]	b[2]	a	b	a	b
Number of spells	**1961-2009**	**0.000**	**0.351**	**-1.250*[3]**	**-0.245**	**0.000**	**0.328**
	1961-1990	-0.370	0.952	0.000	0.625	-1.111	0.000
	1971-2000	0.556	0.000	0.000	-0.714	0.357	0.000
	1980-2009	0.769	0.000	-2.727*	-1.034*	0.167	0.909
Mean duration of a dry spell (days/decade)	**1961-2009**	**0.017**	**-0.138**	**0.300****	**0.254**	**-0.009**	**-0.114**
	1961-1990	0.117	-0.435	0.136	-0.414	0.165	-0.208
	1971-2000	-0.067	0.043	0.130	0.477	-0.118	0.086
	1980-2009	-0.074	0.009	0.551*	0.677*	-0.018	-0.175
Mean annual cumulated duration (days/decade)	**1961-2009**	**0.667**	**-1.200**	**5.395 ****	**1.000**	**1.667**	**-0.294**
	1961-1990	2.632	-2.500	4.615	1.429	4.000	-3.000
	1971-2000	0.000	-0.833	2.500	0.909	-2.857	0.000
	1980-2009	-0.769	0.000	5.789+	3.750*	0.045	1.538
Maximum annual duration (days/decade)	**1961-2009**	**0.000**	**0.000**	**2.075***	**0.000**	**-0.548**	**0.000**
	1961-1990	0.625	-1.250	2.222	1.176	0.952	-1.154
	1971-2000	1.053	2.000	2.000	1.000	0.435	2.30.8
	1980-2009	0.000	0.909	3.333	0.000	-0.227	-1.111

Note: [1] – series for annual values; [2] – series for May-September interval; [3] - Statistically significance: + – $\alpha = 0.1$; * - $\alpha = 0.05$; ** - α=0.01.

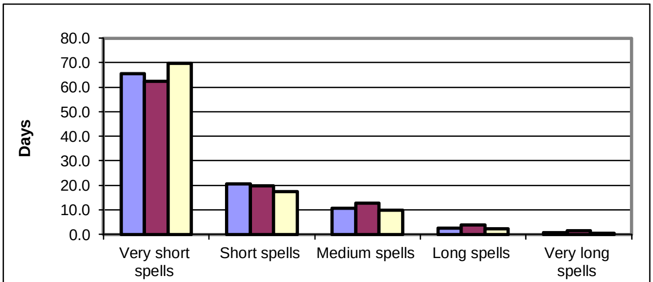


Fig. 2. ***Frequency of dry spells classes for number of cases. 1.- Very short spells; 2.- Short spells; 3.- Medium spells; 4.- Long spells; 5.- Very long spells***

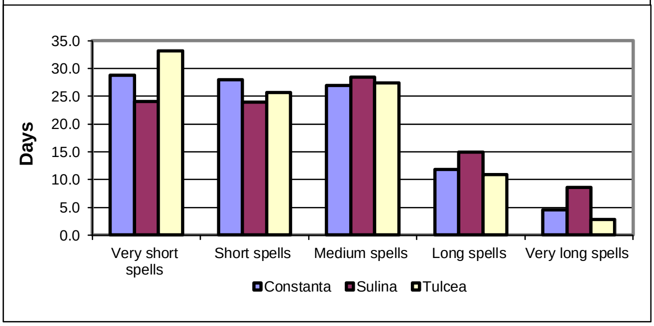
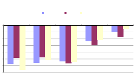


Fig. 3. ***Frequency of dry spells classes for the cumulated duration. 1.- Very short spells; 2.- Short spells; 3.- Medium spells; 4.- Long spells; 5.- Very long spells***



The very short spells get 24...34 % and respectively, less than 60 %, if very short and short dry spells are considered together. The cumulated duration of the medium dry spells has a frequency similar to the previous two classes or even higher (especially, at Sulina). Long and very long dry spells cover together between 13 % (Tulcea) and 24 % (Sulina).

4. CONCLUSIONS

The dry spells analysis shows interesting features on the structure of the dryness phenomena and their variations on the Black sea Coast. Constanta and Tulcea weather stations show similar behaviours, while for Sulina different results were found. Tulcea, the inland station, was found to have the highest number in the region of dry spells, both for average and maximum multi-annual values. The lowest number of dry spells, the highest values of cumulated and average duration of dry spells, as well as the annual maximum duration of a dry spells have been recorded at Sulina. For duration parameters, values recorded at Constanta follow those of Sulina's. All parameters of the dry spells show statistically significant trends for Sulina data sets: decreasing in the annual number of dry spells and increasing in all duration-related parameters. For the other two stations no statistically significant changes were found. The short and very short dry spells are most frequent (> 80 % together), while considering cumulated duration, very short, short and medium dry spells have similar frequency values (24-30 %). Long and very long dry spells, with lower frequency, have the highest values in the area, both as case number and as cumulated duration, at Sulina.

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