ASPECTS OF THE HYDROLOGICAL DROUGHT EVALUATION IN THE GALBENA VALLEY WITH STREAMFLOW DROUGHT INDEX (SDI)

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Abstract

The objective of this paper is to monitor the hydrological droughts in the basin of Galbena Valley using flow control records for a period of 20 years (1991 - 2010) using the Streamflow Drought Index (SDI) and comparing the values of this index with those of Standardized Precipitation Index (SPI) calculated using precipitation recorded at the weather stations Ştei and Stâna de Vale.

The Galbena Valley hydrographical basin is located in the western part of Romania, southeast of Bihor County, in the Bihor Mountains, occupying an area of 31.07 km2 of the Apuseni Mountains Natural Park at the base of the Padiş Carpathian Plateau - Fortresses of Ponor.

The characterization of climate droughts using SPI determined by the rainfall recorded at the two meteorological stations in the vicinity of the Galbena Valley for years, seasons and months of the hydrological year indicates different intensities, durations and magnitudes.

SDI determined on the Galbena Valley for the 1991-2010 hydrological years indicates 1997-1998 as extremely dry (-2.26) even if the SPI values from Ştei and Stâna de Vale are positive, indicating an average year.

The values of the Pearson correlation coefficients between SDI as a dependent variable and climatic data recorded at Ştei and Stâna de Vale are less than 0.5, indicating that there is no connection between rainfall, temperatures or SPI in the flowing process on the Galbena Valley.

Key words: hydrological drought, Streamflow Drought Index (SDI), Standardized Precipitation Index (SPI), correlation coefficient Pearson

INTRODUCTION

Droughts are extreme climatic phenomena, which by their effects represent natural calamities characterized by intensity, frequency and duration, manifested by the drastic reduction of precipitation and water reserves for all uses (Wehry et al., 2000).

As a result of global climate change, the current trend is to increase the intensity, duration and frequency of droughts, leading to climate change towards aridation and ultimately desertification.

Desertification is the consequence of the creation of arid climate and anthropic non-ionic intervention that affects soils / lands, manifested by the loss of biological productivity, the partial or total destruction of the vegetal carpet with negative economic and environmental effects (UNCD, 1977).

Depending on their effects, droughts are classified as: meteorological or climatic, agricultural or pedological, hydrological and socio-economic drought (Man et al., 2010). For the monitoring of these drought categories, a wide range of indices are used: climatic indices, agricultural or pedological, hydrological and socio-economic drought indices.

From the climatic index category, the most commonly used meteorological records in the world are the Standardized Precipitation Index (SPI), which has the advantage that it is calculated by precipitation (McKee et al., 1993) and although the calculation methodology is Complicated there are free computing programs (Mohseni Saravi et al., 2009; Krajinović, Radovanović, 2010; Costa, 2011).

As the main cause of droughts is the lack of precipitation, the installation of climatic droughts is followed by pedological droughts, which, depending on their intensity, frequency and duration, lead to a drastic reduction of agricultural production, with serious consequences in ensuring the food needs of the population. As the main possibility of reducing production losses is the application of crop irrigation, the issue of monitoring water resources is a problem, given that climatic and pedological droughts are followed by hydrological droughts.

Indicators for monitoring hydrological droughts are intended to determine the duration, frequency and intensity of water shortages for different uses, including agriculture, using water level records and flows recorded in hydrometeorical stations on surface water courses or the evolution of groundwater level recorded at hydrogeological drilling of observation.

Among the most common clues to surface water monitoring are the Surface Water Supply Index (SWSI), the Reclamation Drought Index (RDI) and the Streamflow Drought Index (SDI) (Shafer, Dezman, 1982; Weghorst, 1996; Vincente-Serrano et al., 2012).

SDI having a calculation methodology similar to SPI, using instead of flow rates in m^3/s, allows monitoring of the hydrological droughts' duration, duration and frequency and their forecast in due time.

The objective of this paper is to monitor the hydrological droughts in the Galbena Valley river basin using the flow recordings from the control section for a period of 20 years (1991 - 2010) using SDI and comparing the values of this index with those of the SPI calculated by precipitation recorded at the meteorological stations of Ştei and Stâna de Vale.

The water catchment area of the Galbena Valley is located in the western part of Romania, southeastern Bihor County, in the Bihor Mountains, occupying an area of 31.07 km2 in the Apuseni Mountains Natural Park, at the base of the Padis Carpathian Plateau - Fortresses of Ponor, having an altitude average of 1,077 m (Iovan, 2012). It is part of the river basin of Crişul Negru, being a left tributary of Crișul Pietros, which in turn is a right tributary of the Crişul Negru (Fig. 1).

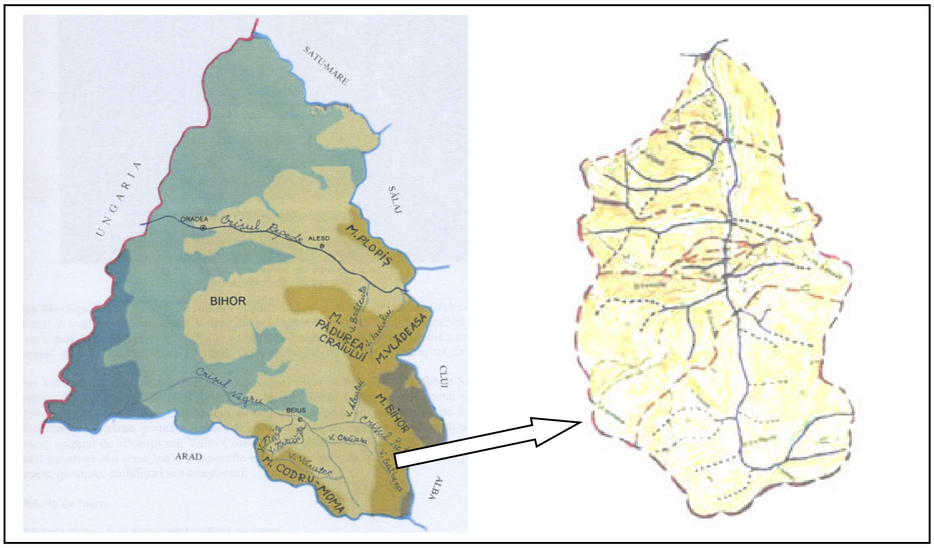

Fig. 1. The site and hydrographic network of the Galbena Valley basin

Considering that there are no records of the main climatic factors on the surface of the Galbena Valley basin, the meteorological data recorded at the closest meteorological stations were used to characterize the area, Ştei located south-east of the basin and Stâna de Vale, located in the north west (Table 1).

Table 1

Characteristics of meteorological stations in the vicinity of the Galbena Valley basin

Meteorological Station	Latitude	Longitude	Altitude (m)	Mean rainfall 1985-2010 (mm)	Mean temperature 1985-2010 (˚C)
Ștei	46,53	22,45	241	689,0	9,99
Stâna de Vale	46,93	22,67	1102	1833,3	4,39

Due to the fact that the two meteorological stations are located at very different altitudes, the Ştei la 689,0 m, the Beiuş Depression and the Stâna de Vale at 1102 m, in the Bihor Mountains, the climatic data recorded vary widely. Thus, the average annual precipitation (1985-2010) is three times higher at Stâna de Vale and the average annual temperature for the same period is more than twice as high in Ştei than at Stâna de Vale (ANMH).

Given that the Galbena Valley hydrographic basin is a small but relatively constant flow, with predominantly forestry use, being located in the Apuseni Mountains Natural Park, the analysis of hydrological droughts with SDI is of importance only for the hydroenergetic use in order to produce the green electricity, which could ensure the consumption of any tourist hostels in the area (Sabău, Iovan, 2013).

MATERIAL AND METHOD

In order to highlight the influence of the climatic data recorded at the two meteorological stations on the drought characterization indices, SPI values (McKee et al., 1993) were calculated in Ştei and Stâna de Vale and SDI (Vincente-Serrano et al., 2012) for the Galbena Valley, for the same periods of time, hydrological year, cold season, hot and lunar resonance, using the DrinC program (Tigkas et al., 2013).

SDI values were calculated for a 19 year hydrological period (1991-2010) using the monthly average flows measured in the Galbena Valley control section (Cadastral Atlas, Romanian Waters, Department of Crişuri; Iovan, Sabău, 2012).

Considering that the calculation methodology for SPI and SDI is similar, the first being calculated from the monthly precipitation and the second one from the average monthly flows (Sabău et al., 2015), after the cumulative distribution function, the normalization of the function and then standardization, Standard Log function was used for standardization (Sabău, Brejea, 2016).

The statistical processing of the climate data strings and the analysis of bilateral correlations were made using the PSPP program, which is the free version of the professional SPSS statistical analysis program (PSPP Users'Guide, 2016).

RESULTS AND DISCUSSION

Differences between precipitation and potential evapotranspiration (R-PET) indicate the existence of a moisture deficit in the summer months (May to September) at Ştei, which in July and August exceeds 40 mm, while under the conditions of Stâna de Vale for all average, these differences are positive, R-precipitations being higher than potential PET evapotranspiration (Fig. 2).

If we compare the evolution of the annual precipitation recorded at the meteorological stations Ştei and Stâna de Vale during the 1991-2010 hydrological years with the multiannual average flows recorded in the control section of the Galbena Valley during the same period, we can not observe the existence of a connection between precipitation and flow. The maximum flows in the Galben Valley were measured in 1994-1995 and 1995-1996 when the maximum precipitation at Ştei was in 2004-2005 and at Stâna de Vale in 2005-2006 (Fig. 3).

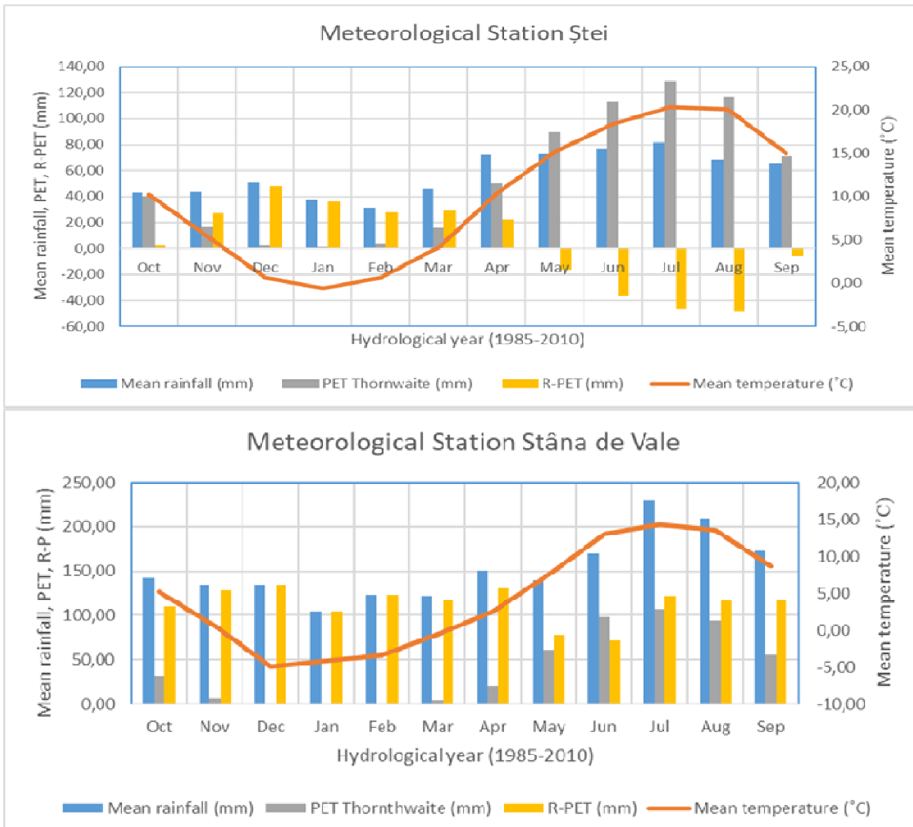

Fig. 2. Climatic Data from average year (1985-2010) at Ștei and Stâna de Vale Stations

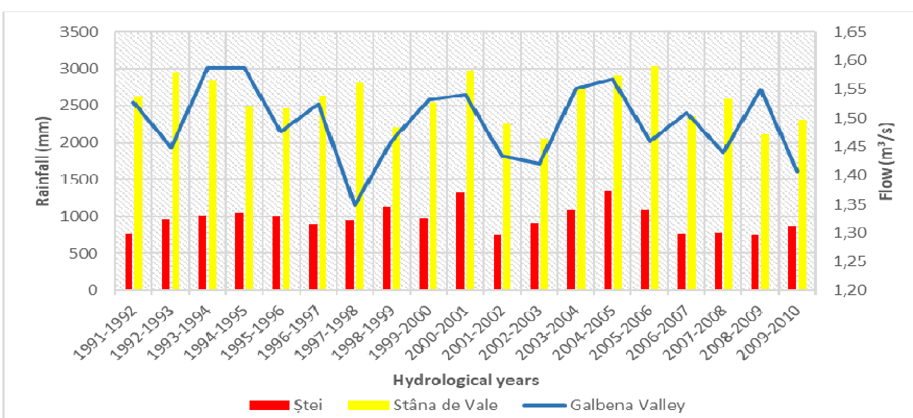

Fig. 3. The annual means of rainfall from Ștei and Stâna de Vale stations and anuall mean of flow on Galbena Valley

The characterization of climate droughts using SPI determined by the precipitation recorded at the two meteorological stations in the vicinity of the Galbena Valley for years, seasons and months of the hydrological year indicates different durations, periods and magnitudes (Table 2).

Table 2

Characterization of drought after SPI from Ștei and Stâna de Vale stations

Meteo Station	Step calculation of SPI	Characterization			Duration (months)	Year	Drought magnitude
		Moderate drought	Very drought	Extremely drought			
Ștei	Annual	4	-	-	6	91-92	7,10
Stâna		3	1	-	5	99-00	6,31
Ștei	Cold season	3	1	-	4	91-92	5,24
Stâna		2	2	-	2	00-01	4,55
Ștei	The month Oct	-	1	1	5	05-10	2,92
Stâna		-	-	2	3	99-02	5,61
Ștei	Nov	3	3	-	5	05-10	3,24
Stana		2	1	-	2	99-01	2,75
Ștei	Dec	3	1	-	4	06-10	3,20
Stâna		-	1	1	4	06-10	3,17
Ștei	Ian	1	2	-	3	96-99	2,72
Stâna		2	1	1	4	95-99	5,98
Ștei	Feb	4	-	-	3	91-94	3,49
Stâna		2	-	1	4	06-10	4,02
Ștei	Mar	2	1	1	5	94-99	4,45
Stâna		3	-	-	4	93-98	3,48
Ștei	Warm season	1	-	1	6	99-00	5,35
Stâna		2	2	-	5	99-00	6,31
Ștei	Apr	-	-	2	2	01-03	2,66
Stâna		2	1	1	3	07-10	4,93
Ștei	May	1	3	-	3	91-94	4,02
Stâna		1	2	-	5	93-98	3,43
Ștei	Jun	2	2	-	9	01-10	6,96
Stâna		-	1	1	4	01-05	4,15
Ștei	Jul	3	-	1	5	05-10	4,19
Stâna		1	2	-	5	05-10	4,45
Ștei	Aug	-	1	1	2	91-93	4,81
Stâna		1	2	-	5	96-01	4,60
Ștei	Sep	5	-	-	5	05-10	4,61
Stâna		-	2	-	4	02-06	3,55

From the 19 years analyzed, at Ştei 4 there are moderate droughts and at Stâna de Vale 3 moderate droughts and one very dry, the maximum duration of drought being 6 months (1991-1992) with a magnitude of 7,1 in the first case and 5 months (1999-2000) with a magnitude of 6,31 in the second case.

Also, the coldest cold season is recorded in Ştei, in the drought year (1991-1992), the magnitude of the 4 months of consecutive drought being 5,24, higher than that of Stâna de Vale registered in 2 consecutive months (4 ,55) of the year 2000-2001 at Stana de Vale, although in the first case we have 3 seasons with moderate drought and only one with very dry compared to Stâna de Vale, where 2 years are moderately dry and two very dry years.

Among the months of the cold season is March, which is characterized by moderate drought in 2 years, 1 year very dry and 1 extremely dry, with a magnitude of 4,45, gathered in 5 consecutive months and at the Stâna de Vale in January, has the same distribution of drought characterization, but with a magnitude of 5,98 in four consecutive months. The characterization of droughts in the warm seasons indicates 1 moderately dry season and 1 extremely dry season, and for Stâna de Vale 2 moderate droughts and 2 very dry seasons. The longest period of 6 consecutive months with a magnitude of 6,31 is recorded at Stâna de Vale, compared with the one from Ştei, which lasts for 4 months and a magnitude of 5,35.

Among the warmer seasons, the driest of Ştei is June, with a magnitude of 6,96 and the Stâna de Vale in April, with the drought magnitude of only 4,93. SDI determined on the Galbena Valley for the 1991-2010 hydrological years indicates 1997-1998 as extremely dry (-2,26) even if the SPI values from Ştei and Stâna de Vale are positive, indicating an average year (Fig. 4).

Anii hidrologici 2002-2003 și 2009-2010 caracterizați de SDI ca moderat secetoși corespund cu ani caracterizați de SPI Stâna de Vale foarte secetoși și respectiv moderat secetoși. Durata cea mai lungă a secetei hidrologice a fost de 10 luni consecutive, în anul 1997-1998, magnitudinea secetei fiind de 13,48 (Table 3).

Table 3

Characterization of hydrological drought after SDI Galbena Valley

Step calculation of SDI	Characterization			Duration (months)	Year	Drought magnitude
	Moderate drought	Very drought	Extremely drought			
Annual	2	-	1	10	97-98	13,48
Cold season	1	1	1	6	97-98	9.47
Warm season	3	2	-	6	05-06	6.68
Sept	1	-	2	3	95-98	2.71

The cold season of the studied period is characterized by SDI determined on the extremely dry Galbena Valley (-2,15) in 1997-1998 when SPI Ştei indicates a moderately dry season (-1,08) and SPI Stâna de Vale an average season (0,42). The cold season in 2002-2003 is very dry according to the SDI values (-1,63) and in the 2009-2010 moderate drought (-2,24) seasons following the dry periods recorded at the two considered meteorological stations. The maximum drought duration of the cold season was 6 consecutive months with a magnitude of 9,47 in 1997-1998.

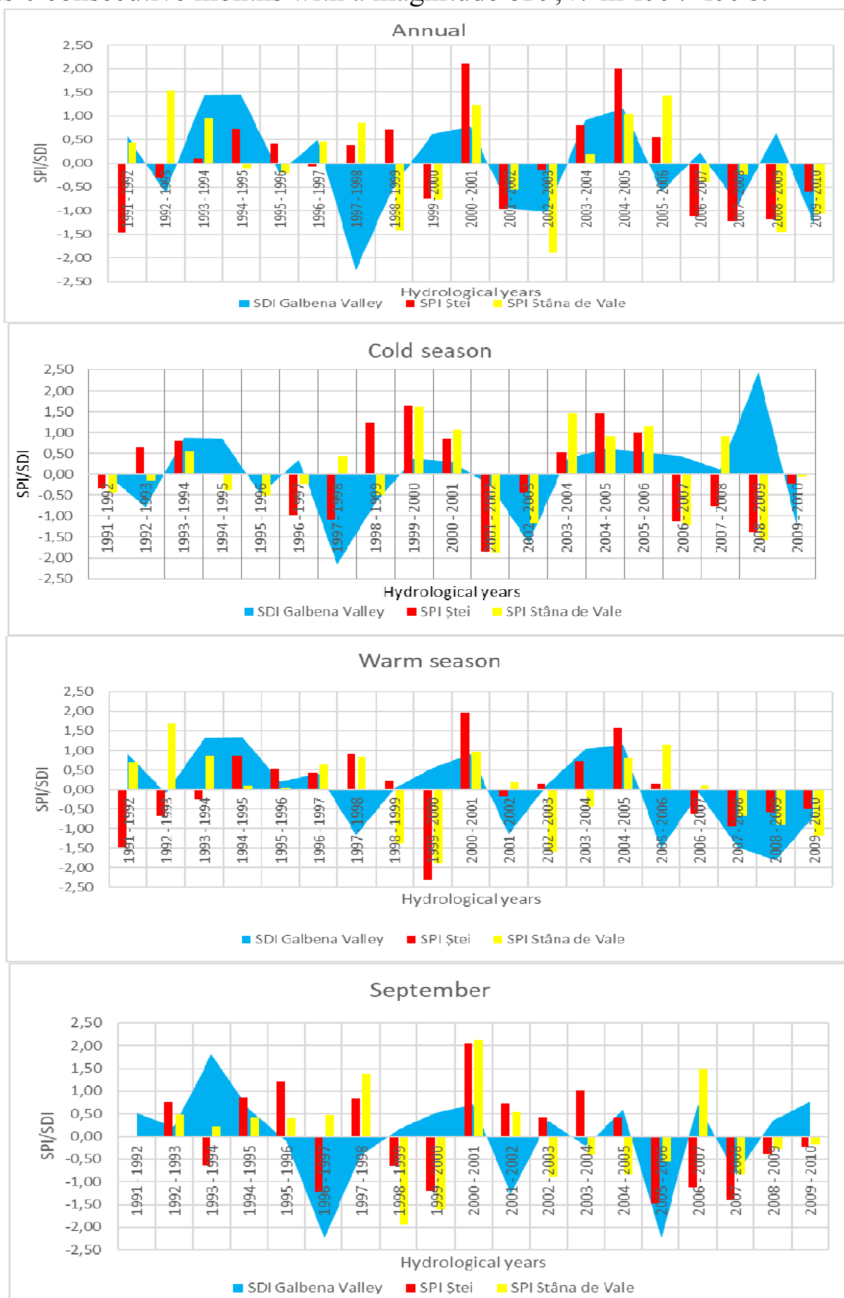

Fig. 4. SDI values of Galbena Valley in compareson with SPI values from Ştei and Stâna de Vale stations

The hot seasons of the analyzed period are characterized by the very low dry SDI Galbena Valley in 2005-2006 and 2008-2009 and moderately drought in 1997-1998 and 2001-2002, during the last 5 years the magnitude of the hydrological drought is 5,57. All these years there were no moderate, very or extremely dry periods at the two analyzed meteorological stations. The longest drought period of the 6-month hot season occurred in 2005-2006, with a magnitude of 6,68.The driest month by SDI values is the last in the warm season, respectively September, 1996-1997 and 2005-2006 being extremely dry (-2,23) months characterized by these years according to SPI Ştei values as moderate droughts. This month, there were 3 consecutive periods of drought (1995-1998 with a magnitude of 2,71.

Analysis of the correlations between SDI values in the Galbena Valley, calculated over years, seasons and the driest month, as independent variable and the measured flow rate of the Galbena Valley control section, respectively, the climatic characteristics (R precipitation, T-temperature, PET evapotranspiration and SPI values) and mediated for the same periods in Weather Stations and Stana de Vale does not indicate any interdependence relationship, except for dependence on the Q flow, which is evident by the fact that SDI is calculated by normalizing and standardizing the average flow rates of different periods (Table 4).

Table 4

Correlation analyses of SDI on Galbena Valley, like independent variable and other variables

Step calculation of SDI	Pearson correlation coefficient								
	Q Galbena	R Ştei	R Stâna	T Ştei	T Stâna	PET Ştei	PET Stâna	SPI Ştei	SPI Stâna
Annual	0,91	0,22	0,16	0,32	0,21	0,13	0,08	0,19	0,17
Cold season	1,00	0,10	0,06	0,12	0,08	0,06	0,11	0,07	0,04
Warm season	1,00	0,31	0,14	-0,12	-0,07	-0,23	-0,10	0,24	0,14
Sept	1,00	0,21	0,09	0,31	-0,12	0,25	-0,17	0,27	0,04

The values of the Pearson correlation coefficients are less than 0,5 for both the values recorded at Ştei and for the values recorded at Stâna de Vale, indicating that there is no connection of rainfall, temperatures or SPI in the flowing process on the Galbena Valley. If we compare the values of the Pearson correlation coefficients recorded by the climatic elements determined at Ştei and those determined at Stâna de Vale we can see that these are slightly higher for all climatic characteristics determined at Ştei.

The absence of correlational correlations between SDI on the Galbena Valley according to SPI determined at Ştei and Stâna de Vale shows that its flow is mainly formed from the flow of the spring, the influence of the surface leakage being reduced. This hypothesis is confirmed by the fact that the flow of the Galbena Valley is large in relation to the surface of its basin, its source being the Galbena Spring, a spring source (artesian spring). This artesian spring brings to the surface the waters collected on Padiș Plateau, in Poiana Ponor and Glăvoi, through a karst system formed by the Cetatii Ponorului Cave crossed by the underground river that comes to the surface through the Galbena Outbreak.

CONCLUSIONS

The Streamflow Drought Index (SDI) is a relatively recent hydrological drought index that allows monitoring of the drought, duration and frequency of droughts and their prognosis in a timely manner, with a calculation methodology similar to that of SPI, using instead of rainfall flows (m^3/s) measured in the watercourse control section.

The characterization of climate droughts using SPI determined by precipitation at Ștei and Stâna de Vale stations in the vicinity of Galbena Valley for years, seasons and months of the hydrological year indicates different intensities, durations, frequencies and magnitudes.

SDI determined on the Galbena Valley for the 1991-2010 hydrological years indicates 1997-1998 as extremely dry (-2,26) even if the SPI values from Ştei and Stâna de Vale are positive, indicating an average year.

The longest duration of the hydrological drought, according to the monthly SDI values, was 10 consecutive months in 1997-1998, the magnitude of the drought being 13,48.

The cold season of the studied period is characterized by SDI determined on the extremely dry Galbena Valley (-2,15) in 1997-1998 when SPI Ştei indicates a moderately dry season (-1,08) and SPI Stâna de Vale an average season (0,42).

The warm seasons of the analyzed period are characterized by the very low dry SDI Galbena Valley in 2005-2006 and 2008-2009, respectively, moderately drought in 1997-1998 and 2001-2002.

The driest month by SDI values is the last in the warm season, respectively September, 1996-1997 and 2005-2006 being extremely dry (-2,23) months characterized by these years according to SPI Ştei values as moderate droughts.

The driest month by SDI values is the last of the warm season, September, in 1996-1997 and 2005-2006 being extremely dry (-2,23) months characterized by these years according to SPI Ştei values as moderate droughts.

The analysis of the correlations between SDI values in the Galbena Valley, calculated over years, seasons and the driest month, as an independent variable, and the climatic characteristics measured and mediated for the same periods in the Ştei and Stâna de Vale meteorological stations do not indicate any relationship of interdependence.

The absence of correlational correlations between SDI on the Galbena Valley according to SPI determined at Ştei and Stâna de Vale shows that its flow is mainly formed from the flow of the spring, the influence of the surface leakage being reduced.

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