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IMPACT OF METEOROLOGICAL DROUGHT ON STREAMFLOW DROUGHT USING STANDARDIZED INDICES IN THE TRANS-BOUNDARY PRUT RIVER BASIN

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Abstract

- The trans-boundary Prut River Basin (PRB) is one of the most drought vulnerable areas in the Republic of Moldova, Romania and Ukraine due to high water exploitation. In the years with a lack of snow were caused water deficiencies in the high flow season. This paper focuses on the Moldavian portion of Prut River's catchment within in the framework of the project IMDROFLOOD. The main objective of this study was to exploring the link between the standardized precipitation evapotranspiration index (SPEI) and the standardized streamflow index (SSI) in the PRB. The main procedures were the following: 1) correlating the SSI and SPEI at various lags to select the most proper timescale of SPEI; 2) identifying meteorological and streamflow drought events using the SPEI and SSI, and 3) analysing the corresponding relationship and the possible lag of occurrence time between meteorological and streamflow drought events. Hydrological excess (flood) or deficit availability of water in the SSI can be profoundly explained by dryness and wetness conditions in the SPEI. The magnitude of correlation between SPEI and SSI displays an evident seasonality within the Prut Basin. The results show the highest correlation for early spring (on preceding season snowmelt). The highest flow is registered in June and is equal to 117-127 $m^{-3}s^{-1}$, and the minimal flow, under 60 $m^{-3}s^{-1}$, is registered during winter months. In the lower course of the river Prut in extreme dry months (SSI≤-2.0) volume of the river flow was below the ecological flow, which affecting the hydrological regime.

Keywords: drought, floods, standardized precipitation evapotranspiration index, standardized streamflow index

Study area

The Prut River's catchment is shared by Moldova, Romania and Ukraine (Fig. 1), and it is a trans-border river with 952.9 km in length, the first 211 km of the river is on Ukrainian territory, 31 km represents border between Romania and Ukraine, and the remaining 711 km represent a natural border between Romania and Moldova (71.9% of its total length). In terms of length it is the second longest tributary of the Danube. It is the last important tributary of the Danube before the latter discharges into the Black Sea. The hydrographical network measures 11000 km, of which 3000 km are permanent (33%) and 8,000 km have intermittent runoff (67%). The network has a density of 0.41 km/km². The catchment basin is part of the temperate continental climate, where rains are heavy.

Introduction

- Drought often manifests itself as a creeping phenomenon, as the effects of drought often accumulate slowly over a prolonged period and may linger for years after the main event ceases. In our study, therefore, this issue is addressed with two multiscalar drought indices, i.e., the standardized precipitation evapotranspiration index (SPEI; Vicente-Serrano et al., 2010) and the standardized streamflow index (SSI; Modarres, 2007, Telesca et al., 2012), as it successfully allows for the evaluation of the time lag that exists between the onset of the water shortage and the identification of its consequences in the trans-boundary Prut River Basin (PRB).
- All droughts originate from a deficiency of precipitation but other types of drought and impacts cascade from this deficiency (Fig. 2a). Drought is modified by hydrological catchment processes that are changed by human activities (Fig. 2b). The drought types can be grouped together as "climate-induced" drought and drought types based on human processes can be termed "human-induced" drought.
- Romanescu (2017) demonstrated the influence of Stânca-Costești reservoir on the manifestation of flood waves within the upper and the lower sector of PRB. The timing of floods and the shape of the hydrograph are signs of the influences exerted by genetic factors, precipitations, dam and runoff on the Prut River.

Data and methods

- Our study integrated hydrological and climatological observational networks such as five hydrological gauges (Sirauti, Braneste, Ungheni, Leova and Brinza) and four climatological stations (Briceni, Falesti, Leova and Cahul) which cover the PRB key area of the Republic of Moldova (Table 1-2).
- Monthly data of 7 meteorological variables (the maximum [Tmax] and minimum [Tmin] temperatures, mean temperature [Tmean], wind speed [V], sunshine duration [S], relative air humidity [R], and precipitation amount [P]), and two hydrological variables (streamflow [Q] and water level [H]) over a 30-year period were used (Table 3).

Tab. 1 The top years with the highest and lowest observed daily and monthly flows (1986-2015).

	Daily				Monthly				
	Min. flow ($m^{-3}s^{-1}$)	Date min.flow	Max. flow ($m^{-3}s^{-1}$)	Date max.flow	Normal	Min. flow ($m^{-3}s^{-1}$)	year	Max.flow ($m^{-3}s^{-1}$)	year
Jan	7.3	26.01.2004	716.0	30.01.2002	36.6	11.4	1993	80.1	2011
Feb	6.7	28-29.02.2012	210.0	09.02.2004	40.2	13.2	2003	91.1	2002
Mar	9.0	12.03.2005	868.0	31.03.2006	78.8	32.9	1991	210.0	1999
Apr	31.7	19.04.1990	1270.0	19.04.1996	115.0	43.8	1996	241.0	2006
May	26.4	30.05.2000	1980.0	22.05.1998	112.0	42.5	2000	242.0	1998
Jun	21.3	27.06.2003	1910.0	30.06.2010	127.0	27.7	2000	450.0	2010
Jul	17.0	24-25.07.2012	4090.0	30-31.07.2008	124.0	21.9	2000,2012	539.0	2010
Aug	16.0	29.08.2012	1820.0	21.08.2005	88.0	23.5	2012	268.0	2005
Sep	15.2	15,18.09.2012	1260.0	10.09.1996	72.5	17.7	2012	170.0	1996
Oct	15.8	27-29.10.2012	784.0	07.10.2008	55.0	16.9	2012	132.0	2008
Nov	11.2	30.11.1993	468.0	19.11.1995	50.9	17.6	2011	96.8	1998
Dec	9.6	18.12.2012	290.0	11.12.2010	40.7	14.7	2012	73.3	1996

Tab. 2 The top years with the highest and lowest observed daily water levels (H, cm).

Gauging station	Normal cm	H_{max}		H_{min}	
		cm	date	cm	date
Şirăuţi	111	1164	28.07.2008	22	15-18.09.2012(2)
Brăneşti	268	832	31.07.2008	170	12-22.1994(2)
Ungheni	97	699	09.07.2010	-86	19.02.1983, 27.12.1984
Leova	107	620	05-06.05.1996	-114	16-17.12.2015
Brînza	203	527	20.07.2010	0	13-14.02.1984

Tab. 3 The long-term of hydrological and climatological characteristics at the catchment level for the period 1986-2015.

	Winter	Spring	Summer	Autumn	Annual
upstream sector					
Q, $m^{-3}s^{-1}$	38.2	100.5	103.0	53.5	73.7
H, cm	235	282	297	246	265
P, mm	104	149	244	123	621
ETo, mm	34.2	241.9	416.9	140.9	833.9
Tmean, °C	-3.0	8.7	18.8	8.6	8.3
Tmax, °C	0.0	13.9	24.7	13.4	13.0
Tmin, °C	-5.8	4.1	13.6	4.7	4.2
R, %	84	70	70	78	76
S, hours	198	567	818	407	1982
V, ms^{-1}	2.7	2.7	2.1	2.3	2.5
downstream sector					
Q, $m^{-3}s^{-1}$	47.0	137.2	113.8	63.2	90.3
H, cm	156	218	219	164	189
P, mm	103	126	189	122	540
ETo, mm	45.4	264.1	447.6	162.9	920.0
Tmean, °C	-1.2	10.2	21.1	10.9	10.3
Tmax, °C	2.0	15.6	26.9	15.8	15.1
Tmin, °C	-3.8	5.8	16.0	7.0	6.3
R, %	84	70	70	78	76
S, hours	247	607	891	496	2236
V, ms^{-1}	4.1	4.1	3.3	3.5	3.8

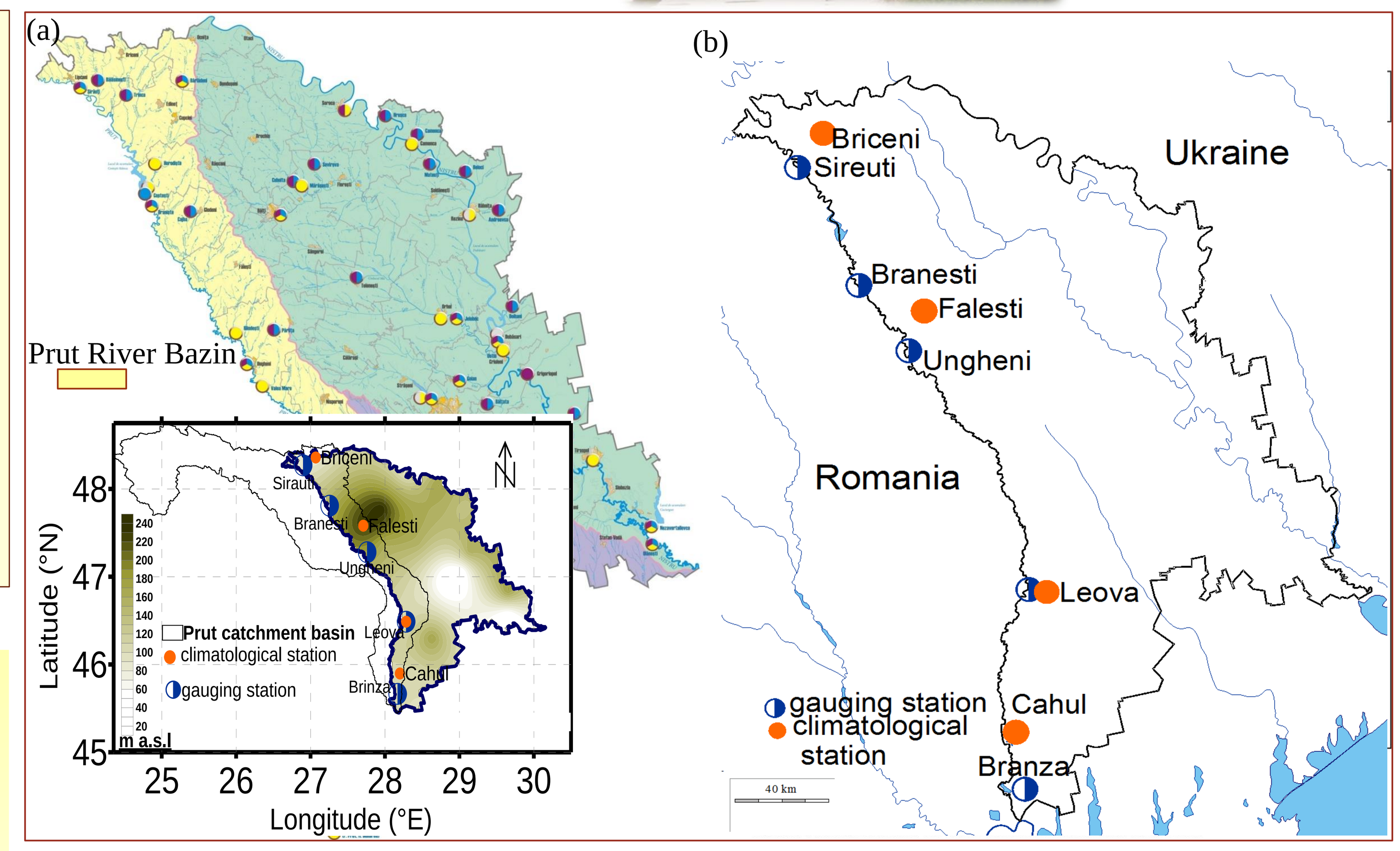


Fig. 1 Distribution of the main climatological and hydrological stations in the Prut River's catchment.

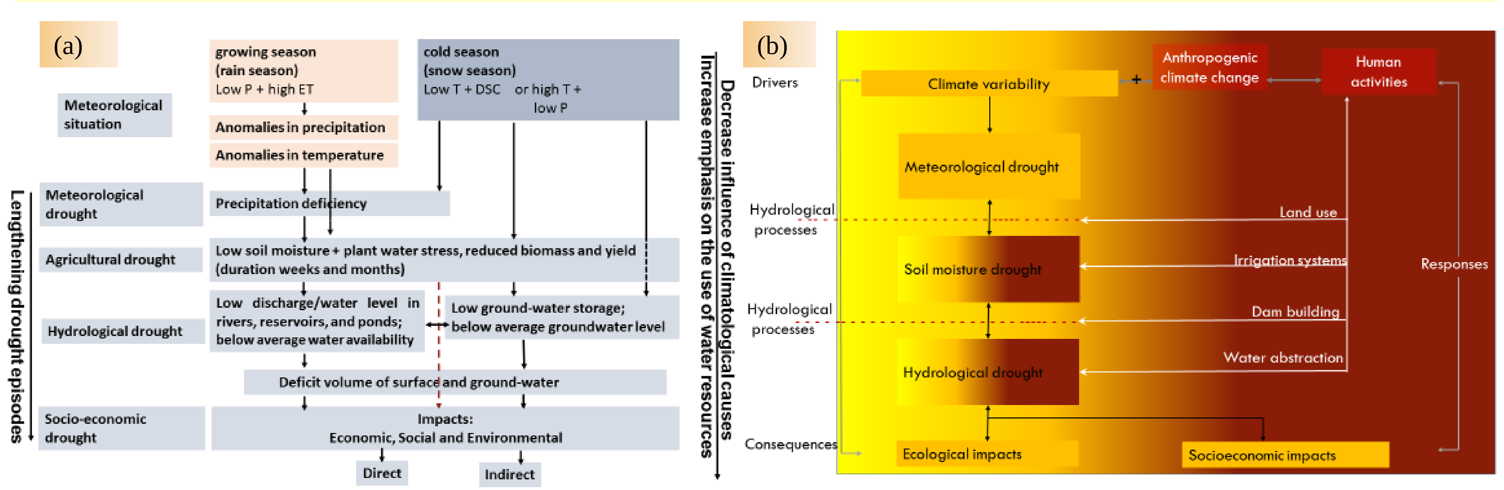


Fig. 2 a) Drought types and their dependence on meteorological factors in the snow season and the growing season. **b)** Drought propagation processes including natural and human drivers and feedbacks.

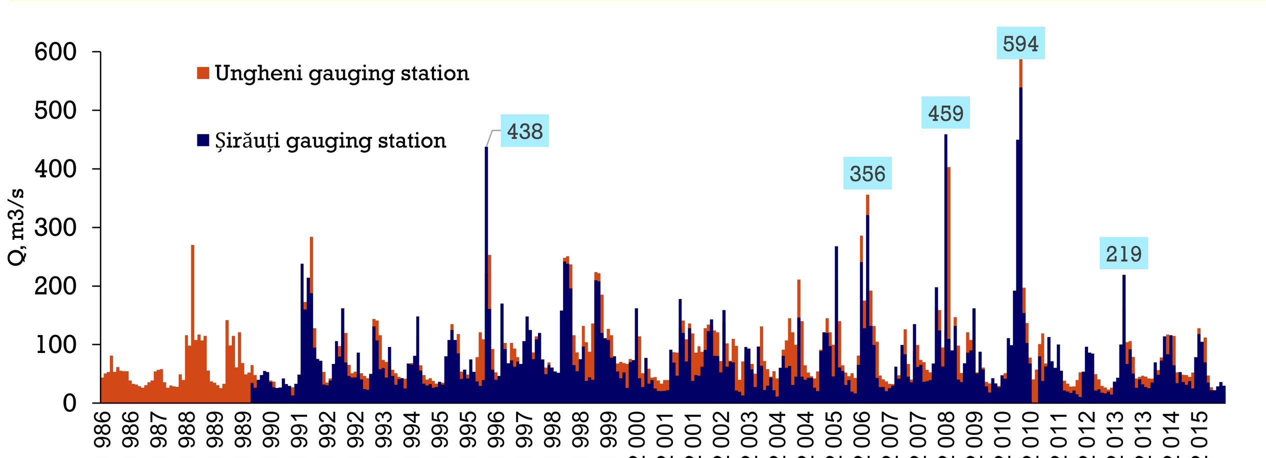


Fig. 3 Temporal evolution of the mean monthly discharge at Ungheni and Sirauti gauges (Prut River Basin) during the period 1986-2015 (1990-2015).

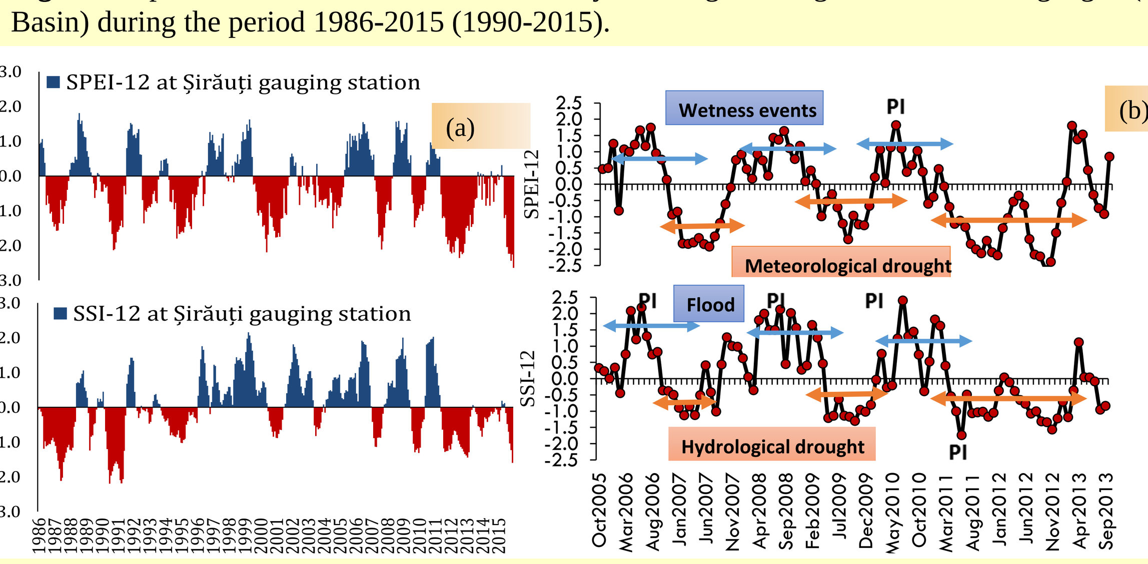
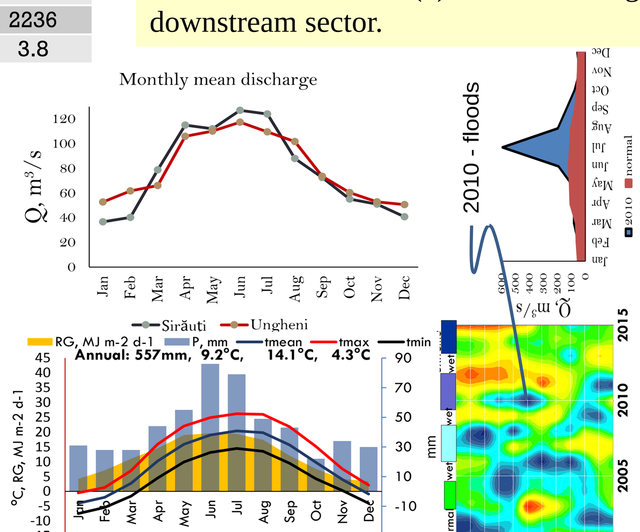


Fig. 4 (a) Temporal evolution of the SPEI and SSI at 12-month lag during January 1986 to December 2015 in the downstream sector. (b) The time lag between meteorological drought and streamflow drought events in the downstream sector.

Results

- The top years with the highest and lowest measured daily and monthly flow at Sirauti st. are shown in Table 2. The summer flood wave of 2008 was the highest in the history of the PRB.
- The top years with the highest and lowest observed daily water levels are for five hydrological gauges are shown in Table 3.
- These results indicate that in the PRB, discharge is more determinates by precipitation and/or climate water balance of previous 2 months than over longer periods.
- Hydrological excess (flood) or deficit availability of water in the SSI can be profoundly explained by dryness and wetness conditions in the SPEI (Fig. 3-6).
- In the PRB, SSI is quickly responding to precipitation, but storage in reservoir (regulate water flows) causes some delay in downstream sector.



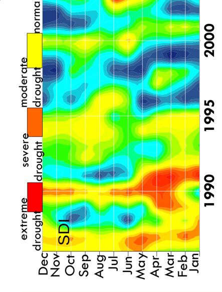


Fig. 5 The multiannual cycle of the monthly discharge and air temperatures, precipitation totals and average daily solar radiation.

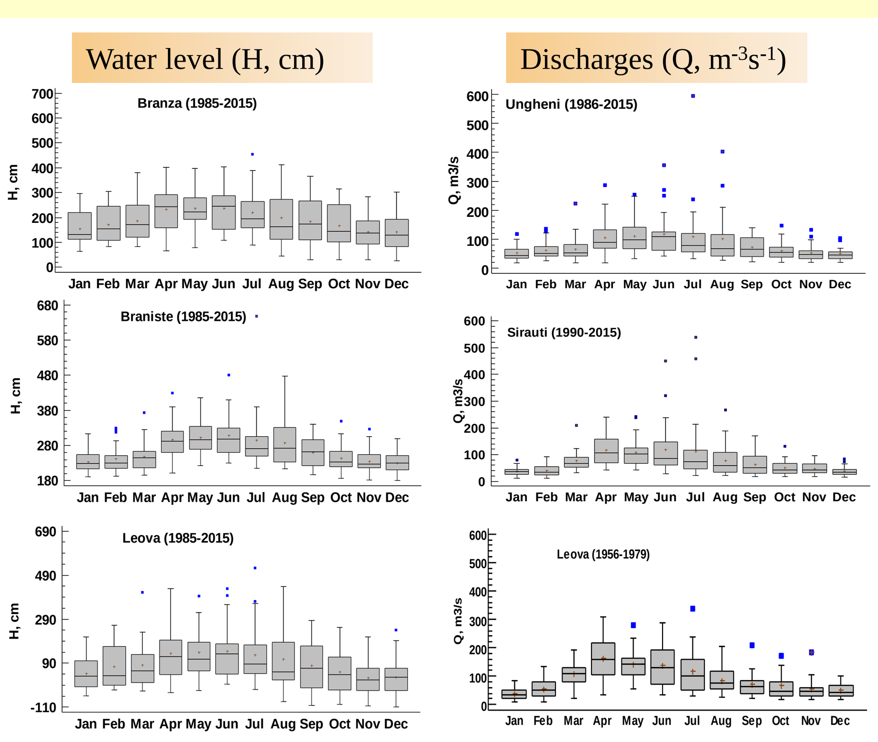


Fig. 6 Boxplots of the monthly mean discharges (Q, $m^{-3}s^{-1}$) and water level (H, cm) of the main gauging stations.

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