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DROUGHT MONITORING USING SELF-CALIBRATING PALMER'S INDICES IN THE SOUTHWEST OF ROMANIA*

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Abstract. The Palmer Drought Severity Index (PDSI) has been used for more than 30 years to quantify the long-term drought conditions for a given location and time. The recently introduced self-calibrating Palmer Drought Severity Index, scPDSI and self-calibrating Palmer Hydrological Drought Index, scPHDI are a convenient means of describing the spatial and temporal variability of hydro-meteorological drought. The analysis of this index was done for the southwestern part of Romania, for the period 1961–2005, evaluating the drought and testing the applicability of the self-calibrating Palmer's indices for Romanian area.

Key words: PDSI, PHDI, self-calibrating Palmer Drought Severity Index (scPDSI), scPHDI.

1. INTRODUCTION*

The scientists have developed many methods used in drought assessment. The aim of this study is to give a hydro-meteorological analysis on basis of self-calibrating Palmer Drought Severity Index (scPDSI) and self-calibrating Palmer Hydrological Drought Index (scPHDI), the new version of PDSI&PHDI, known worldwide in agro-climatic analysis.

The PDSI is widely used in the USA in drought management, planning and monitoring (http://drought.unl.edu); it is related to fire activity (Hall & Brown, 2003), or contribute to reconstruction of past drought conditions from tree-ring data (Levinson, 2005). It is also a useful tool in climate change impact study (Dubrovsky et al., 2005). In analysis of moisture extremes over Europe using the Palmer Drought Severity Index has showed the scale variability in drought frequency (Hulme, 1999); it was also an indicator of soil moisture in Hungary (Mika et al., 2005). This index of drought stress has been used to test two-coupled ocean-atmosphere GCMs over the Mediterranean region for the last 500 years

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(Brewer, 2007). Near equivalence is demonstrated between the PDSI and other indices, like Standardized Precipitation Index, SPI (Lloyd-Hughes & Saunders, 2002). Dai et al. (1998, 2004) showed that area-averaged PDSI is significantly correlated ($r = 0.63–0.75$) with streamflow of the twentieth century over the United States, midlatitude Canada, Europe, and southeast Australia. The significant hydrological extremities of Hungary and the eastern part of the Great Hungarian Plain were analyzed using PDSI (Horvath et al., 2005).

The PDSI has been less applied in Romania (Mares et al., 2002; Mares et al., 2006). The Romanian authors showed the relationship with NAO; a positive NAO determines a negative value of PDSI, and a lower level of discharge.

The 4th Report of Intergovernmental Panel on Climate Change accentuated that, globally, very dry areas (Palmer Drought Severity Index, PDSI<–3) have more than doubled since the 70th due to a combination of ENSO events and surface warming (IPCC, 2007). Under these circumstances, a drought evaluation for a well known dry area using Palmer's indices seems to be welcome.

The index is based on water supply and demand, which is calculated using a rather complex water budget system using the historic records of precipitation and temperature and the soil characteristics of the site being considered. The quantities involved in the calculation are:

(i) potential evapotranspiration, computed using the Thornthwaite method;

(ii) the amount of moisture required to bring the soil to field capacity;

(iii) the amount of moisture that is lost from the soil to evapotranspiration;

(iv) runoff.

Based on potential values for these four quantities, Palmer defined the "climatically appropriate for existing conditions" precipitation, and it is the difference between this value and the actual precipitation that is at the heart of the PDSI. The departure from normal precipitation is then multiplied by a weighting factor, termed the "climatic characteristic," to produce a "moisture anomaly index." The purpose of the weighting is to adjust the departures from normal precipitation such that they are comparable among different areas and different months. Subsequently, Palmer (1965) related the drought severity for a given month to the weighted sum of the moisture anomaly index of that month and the drought severity of the previous month. These latter weighting factors, termed the "duration factors," determine the balance in the PDSI between sensitivity to short-period moisture fluctuations and a more persistent character. All weighting factors in Palmer's algorithm were empirically derived from a limited amount of data, largely from the U.S. Great Plains, but are frequently treated as fixed parameters regardless of the climate regime in which the index is computed (van der Schrier et al., 2006).

The main advantage of the PDSI&PHDI is its 'standardized' nature, which facilitates the quantitative comparison of drought incidence at different locations and different times. But the index needs to be used with caution because of its limitations (IPCC, 2007):

– Sensitivity to the available water content (AWC) of a soil type.

– The two soil layers within the water balance computations are simplified and may not be accurately representative of a location.

– Exclusion of snowfall, snow cover, and frozen ground. All precipitation is treated as rain, so that the timing of PDSI&PHDI values may be inaccurate in the winter and spring months in regions where snow occurs.

– The natural lag between precipitation falls and the resulting runoff is not considered. In addition, no runoff is allowed to take place in the model until the water capacity of the surface and subsurface soil layers is full, leading to an underestimation of runoff.

– Approximation of potential evapotranspiration, using Thornthwaite's method.

– Inability to recognize differences in areas with large topographic variations.

– Failure to consider human impacts such as irrigation usage and reservoir storage amounts.

– Less effectiveness in areas with extreme variability in rainfall and runoff.

– Arbitrary thresholds.

– Complex computation, which requires substantial input of meteorological data.

– It does not include variables such as wind speed, solar radiation, cloudiness and water vapor.

In order to solve many of these problems, the self-calibrating PDSI (scPDSI) and scPHDI were developed, as modified versions of the PDSI&PHDI. The empirical constants are replaced with dynamic values, in order to ensure consistency with the climate at any location (Wells et al., 2004; IPCC, 2007).

The self-calibrating Palmer Drought Severity Index represents a more appropriate means of comparing spatial relationships between areas of differing moisture climates because the scPDSI provides a more realistic metric of relative periods of drought or excessive moisture supply (van der Schrier et al., 2006).

The first chapter of the paper presents the methodology of Palmer's indices computation and the data used for their estimation.

The second chapter includes the Palmer's indices analysis for Jiu River basin, its conclusions being presented in the last part of the paper.

2. DATA AND METHODOLOGY

2.1. DATA

The analysis was performed on the monthly mean precipitation and temperature datasets of six meteorological stations (Table 1) situated in southwestern part of Romania (Fig. 1), which corresponds to the catchment of Jiu River, for the period between 1961 and 2005. The monthly mean discharges of the 5 hydrometric stations were also used (Table 2). They are located next to meteorological stations. The datasets were taken from the database of National Institute of Hydrology and Water Management, Bucharest, Romania.

Table 1

Selected meteorological stations and their climatological characteristics

Meteorological station	Coordinates (lat, long)	Altitude (m)	Multi-annual precipitation (mm)	Peak climatological value (mm) [month]	Multi-annual temperature (°C)
Băileşti	44°01', 23°20'	57	557	60.7 [May]	11.2
Calafat	43°59', 22°57'	61	527	58.2 [May]	11.6
Craiova	44°19', 23°52'	192	584	71.3 [May]	10.8
Drobeta Turnu Severin	44°38', 22°38'	77	664	72.1 [May]	11.8
Parâng	45°23', 23°28'	1548	952	138 [June]	3.6
Targu Jiu	45°02', 23°16'	203	784	94.3 [June]	10.2

Table 2

Selected hydrometric stations

Hydrometri c station	River	Coordinates (lat, long)	Area (km^2)	Altitude (m)	Lenght (km)	Multi-annual discharge (m^3/s)
Podari	Jiu	44°15', 23°48'	9334	446	255	84.4
Iscroni	Jiu	44°22', 23°21'	496	1134	54	10.9
Breasta	Raznic	44°21', 23°40'	465	201	39.4	1.08
Albesti	Amaradia	44°24', 23°46'	877	273	105	2.49
Runcu	Jales	45°07', 23°08'	118	976	19.8	2.52

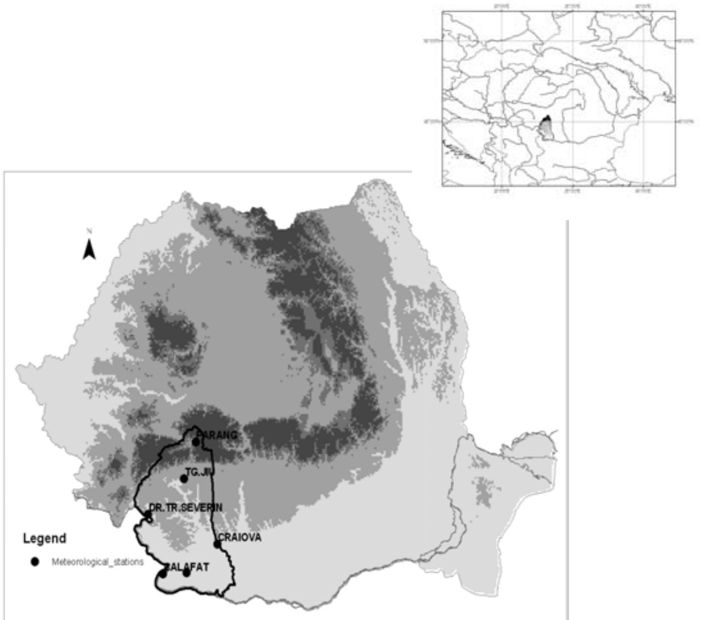

Fig. 1 – Map of Romania, the studied area and selected meteorological stations.

The climatological characteristics (Table 1) corresponds with the temperate-continental climate of Romania, due to its geographic location in the southeastern part of Europe, being influenced by the varied relief. The Carpathians act as a barrier for the Atlantic air masses, restricting their oceanic influences to the western and central part of the country. In the southwest of the country, Mediterranean influences ensure a milder climate.

The Available Water Capacity of the soil (AWC) was provided by Research Institute of Soil Science Agrochemistry in the report "Pedo-climatical regionalization of agricultural lands in Romania", in 1971-1972 (Table 3).

Table 3

AWC used for scPDSI/ scPHDI computation

Meteorological station	AWC (%)
Băileşti	13
Calafat	10
Craiova	11
Drobeta Turnu Severin	11
Parâng	14
Targu Jiu	9

2.2. PALMER DROUGHT SEVERITY INDEX AND PALMER HYDROLOGIC DROUGHT INDEX

The PDSI was developed during the early 1960's by W. C. Palmer as a standard way to quantify the severity of drought conditions. Palmer published his method in the 1965 paper, "Meteorological Drought" for the Office of Climatology of the U.S. Weather Bureau. Since then, the PDSI has become one of the most widely used drought assessment tools. Wells (2003, 2004) presented an exhaustive description of this index, and a brief one is adopted in this paper.

The PDSI is based around a supply and demand model of the soil moisture at a location. The supply is the amount of moisture in the soil plus the amount that is absorbed into the soil from rainfall. The demand, however, is not so as easy to see, because the amount of water lost from the soil depends on several factors, such as temperature and the amount of moisture in the soil. The Palmer Hydrologic Drought Index (PHDI) uses a modification of the PDSI to assess moisture anomalies that affect stream flow, ground water, and water storage (Steinemann, 2003), being more sensitive to hydrological components.

The index is a sum of the current moisture anomaly and a fraction of the previous index value. The moisture anomaly is defined as:

$$d = P - \hat{P}, \tag{1}$$

where P is the total monthly precipitation, and $\hat{P}$ is the precipitation value climatologically appropriate for existing conditions' (Palmer, 1965). $\hat{P}$ represents the water balance equation defined as:

$$\hat{P} = \overline{ET} + \overline{R} + \overline{RO} - \overline{L} , \tag{2}$$

where $\overline{ET}$ is the evapotranspiration, $\overline{R}$ is the soil water recharge, $\overline{RO}$ is the run off, and $\overline{L}$ is the water loss from the soil. The overbars signify that these are average values for the given month taken over some calibration period. $\hat{P}$ is a hydrological factor and needs be parameterized locally.

The Palmer moisture anomaly index (*Z* index) is then defined as:

$$Z=Kd, \tag{3}$$

where d represents the deficit or surplus of moisture, adjusted for the seasonal changes in climate, and PDSI for month i is defined as

$$PDSI_i = 0.897 PDSI_{i-1} + \frac{1}{3} Z_i . \tag{4}$$

K acts as a climate weighting factor and is applied to yield indices with comparable local significance in space and time. PDSI is usually calculated over a monthly period. However, there is nothing to prevent calculations across other time periods, e.g. weekly or bi-monthly.

The values of 0.897 and (1/3) are empirical constants that Palmer derived using data from two climate divisions. They are known as the **Duration Factors**, because they determine how long a spell will last. The Duration Factors actually affect the sensitivity of the PDSI to precipitation and the lack thereof. Palmer used one set of Duration.

Each value of each of the indices is a combination of a fraction of the previous index value and a fraction of the current moisture anomaly. Expanding upon this fact, it could be said that a value of the index is simply a combination of all previous moisture anomalies. This is not quite true. Because of the rules involved in the way the PDSI is chosen from the three indices, the historical perspective of the PDSI reaches only to the start of the current spell. There is a theory floating around that says something to the effect that the PDSI has an inherent 9-month window over which it evaluates the climate trend. This is not true either, because a PDSI value 12 months into a drought is based on the moisture anomalies from the last 12 months.

The **Palmer Hydrological Drought Severity Index** (PHDI) is very similar to the PDSI, using the identical water balance assessment on a two-layer soil model. The distinction is that the PHDI has a more stringent criterion for the elimination of the drought or wet spell, which results in the index rebounding gradually – more slowly that the PDSI – toward the normal state. Specifically, the

PDSI considers a drought finished when moisture conditions begin an uninterrupted rise that ultimately erases the water deficit, whereas the PHDI considers a drought ended when the moisture deficit actually vanishes (Keyantash et al., 2002). This retardation is appropriate for the assessment of hydrological drought, which is a slower developing phenomenon than meteorological drought.

2.3. THE SELF-CALIBRATING PDSI&PHDI

Values for the duration factors and the climate characteristic can be calculated for each location by examining the historical climate of the location. This will calibrate the behavior of the index based on the climate of the location, giving more consistent results.

The duration factors affect the sensitivity of the index to moisture deficits or surpluses by determining how much weight is given to the current moisture anomaly and the previous index value. The duration factors are most important, however, in determining when an established spell ends. If the duration factors do not represent the characteristics of the given climate, an extreme drought may never end, and the PDSI value would get steadily more negative.

Clearly, one location will be more sensitive to a given moisture deficit than another location. Also, one location may be more sensitive to a moisture deficit than to a moisture surplus of the same magnitude. Thus, two sets of duration factors are needed for each location; one will be used during wet spells and the other during dry spells.

Climate Characteristic. Palmer also used an empirical value in the definition of the climate characteristic, *K*.

Taking into account the classification of PDSI values that Palmer developed, extremely dry PDSI values are defined as those at or below –4.00. Similarly, extremely wet PDSI values are at or above 4.00. By intuition, these extreme events should not occur much more often than once in a generation, or twelve months out of very 50 years. This corresponds to a frequency of 2% of extremely dry and extremely wet PDSI values. This means that the expected 2nd percentile of the PDSI values is -4.00 and the expected 98th percentile is 4.00. Using these two expected values of the PDSI in a definition of the ratio leads to the following formula for *K*.

$$K = \begin{cases} \left({-4.00}\big/{2^{\text{nd}}\ \text{percentile}} \right) K^i & \text{if} \quad d < 0 \\ \left({4.00}\big/{98^{\text{th}}\ \text{percentile}} \right) K^i & \text{if} \quad d \geq 0 \end{cases} . \tag{5}$$

This definition of *K* may seem a little confusing because it depends on the PDSI values, which in turn rely on the climate characteristic. The solution to the problem is to calculate the PDSI using as the climate characteristic. Then the *K* can be used as the climate characteristic to recalculate all the PDSI values. This procedure calibrates the PDSI so that 2% of its values fall at or below –4.00 and 2% at or above 4.00. This, in all practicality gives the index upper and lower bounds. These bounds also lend more meaning to the intermediate values of the index. The analysis of the self-calibrating PDSI has shown that it performs much more consistently than the original PDSI (Wells, 2002).

2.4. CLASSIFICATION OF PDSI/ PHDI AND SCPDSI&SCPHDI

Table 3

scPDSI&scPHDI classification

scPDSI&scPHDI ranking	Climatic condition
+4.00 or more	Extremely wet
+3.00 to +3.99	Very wet
+2.00 to +2.99	Moderately wet
+1.00 to +1.99	Slightly wet
+0.50 to +0.99	Incipient wet spell
-0.49 to +0.49	Near normal
-0.99 to -0.50	Incipient dry spell
-1.99 to -1.00	Mild drought
-2.99 to -2.00	Moderate drought
-3.99 to -3.00	Severe drought
-4.00 or less	Extreme drought

The PDSI&PHDI and scPDSI&scPHDI roughly vary between – 6.0 and + 6.0, where values of + 4.0 or more and – 4.0 or less represent extreme conditions and values close to zero represent normal conditions. Table 3 outlines the scPDSI&scPHDI scale and the climatic condition that is assigned to each value. As implied in the above description, the PDSI&PHDI are usually calculated over a monthly period.

3. RESULTS

Taking into account that the self-calibrating PDSI&PHDI (scPDSI&scPHDI) were created to be more appropriate for geographical comparison of climates in different regions, and they have statistical properties that seem superior to the old

PDSI, these indices were selected for analysis. The computation of scPDSI&scPHDI was done using the program offered by National Agricultural Decision Support System (NADSS), through the site http://nadss.unl.edu.

The scPDSI and scPHDI match quite well for all the stations, except the periods after severe and moderate drought, respectively 1995-1998 and 2002-2005, as they can be seen on Fig. 2. The primary difference between the scPDSI and scPHDI is their beginning and ending times of a dry spell, based on Pe – the ratio of moisture received to moisture required to terminate a drought, where Pe is greater than or equal to zero and less than or equal to one. With the scPDSI, the drought is considered to have ended when Pe is greater than zero. With the scPHDI, however, the drought does not end until Pe is equal to one. In order to accomplish this condition, the values of scPHDI are less than scPDSI after very drought periods.

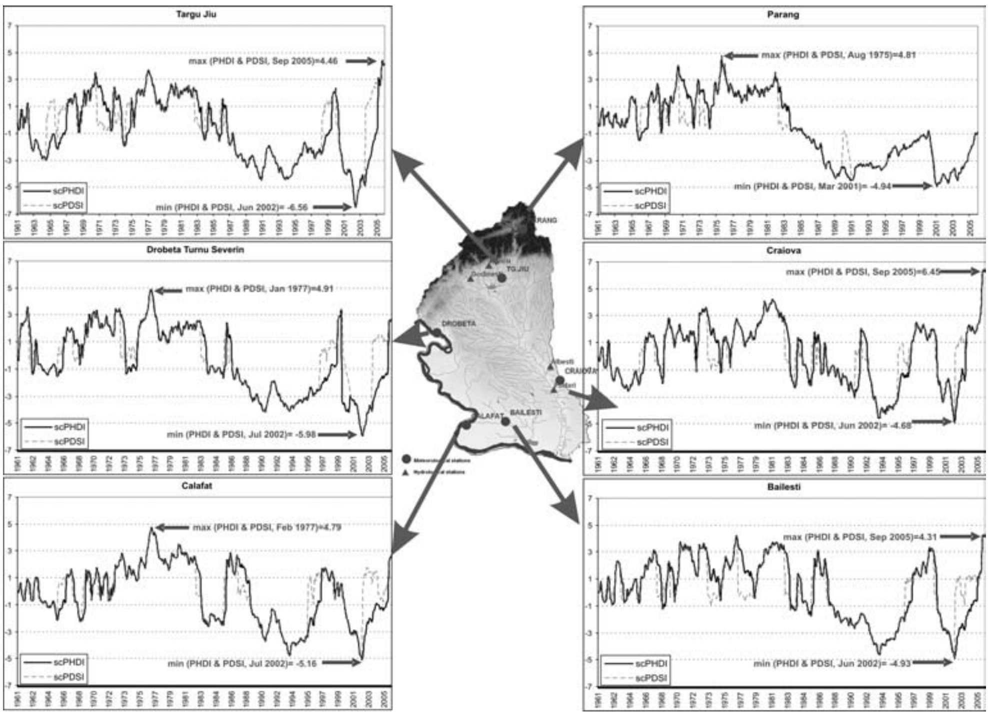

Fig. 2 – Temporal variability of scPDSI&scPHDI.

Data presented in Table 4 show the increase in the number of months with negative values of scPHDI from the onset towards the end of the period studied. Hence, out of total number of the months (540), 35.9% were drought, with the following distribution of drought categories: 3.9% - extreme drought (scPHDI ≤–4), 9.3% - severe (scPHDI ranging from –3.99 to –3), 10% - moderate (scPHDI from –2.99 to –2), and 12.8 – mild (scPHDI from –1.99 to –1), with the traits of severe and extreme drought was registered over the last 20 years, particularly over 1992–1995 and 2000–2003 (Fig. 3). The occurrence of drought is also presented for two periods, 1961–1983 and 1984–2005; for the last 20 years the percentage of drought exceeding even 60%. Two severest droughts occurred in 1993 and 2002 (Fig. 3), the scPHDI values reaching –6.56 in June 2002 at Targu Jiu station. Fig. 3 presents the temporal variability of scPHDI computed for Jiu basin and for two representative stations, a wet one (Parang) and a drought one (Calafat).

Table 4

The number of occurrence and percentage of mild, moderate, severe and extreme drought in Jiu River basin over 1961–2005

Drought	scPHDI	1961-1983		1984-2005		**1961-2005**	
Extreme	≤ -4	0	0.0%	21	8.0%	**21**	**3.9%**
Severe	-3 to -3.99	0	0.0%	50	18.9%	**50**	**9.3%**
Moderate	-2 to -2.99	8	2.9%	46	17.4%	**54**	**10.0%**
Mild	-1 to -1.99	21	7.6%	48	18.2%	**69**	**12.8%**
Total		25	10.5%	119	62.5%	**194**	**35.9%**

As Figs. 2 and 3 show the tendency of scPHDI&scPDSI is negative over the Jiu basin (Fig. 3) from 1961 to 2005, being positive from 1961 to 1983, and negative from 1984 to 2005. The trends were calculated using all monthly data.

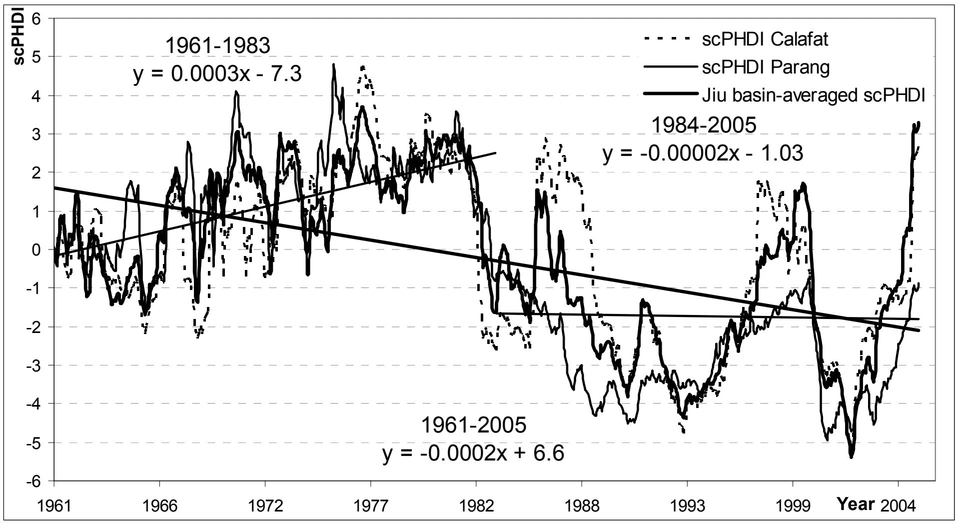

Fig. 3 – The scPHDI for studied area, and for a wet and a drought station. The linear trend of scPHDI is showed.

Cartographic presentation (Fig. 4), considering two of the most severe annual droughts during analyzed period, 1993 and 2002, is an illustration of the drought extent and intensity in the south-western part of Romania. In the both examples, drought assumed extreme characteristics in the southern part of studied area, and became incipient to north, where a mountain zone is, and the amount of precipitation is higher.

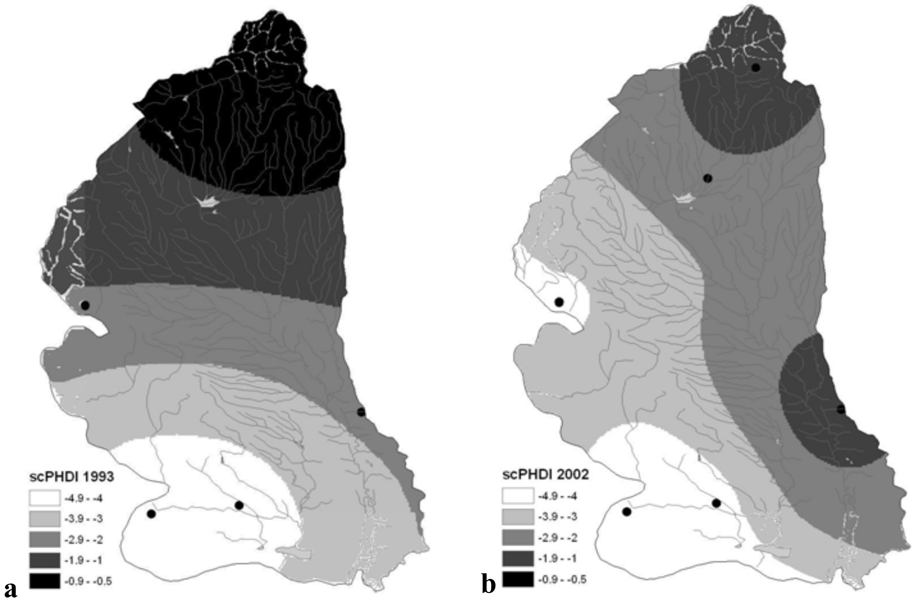

Fig. 4 – Spatial distribution of drought indices and its severity expressed in annual scPHDI values for: a) 1993 and b) 2002.

The applicability of the Palmer indices to the assessment of drought conditions over Jiu basin was evaluated by comparing the temporal variability of PHDI and scPHDI to annual total streamflow recorded at 5 hydrometric stations (Table 2), for the period from 1961 to 2005 (Fig. 5). A qualitative visual assessment of the correlation between the scPHDI and annual total streamflow indicates a reasonably strong similarity in the patterns of variation.

The correlation between Palmer indices and the annual streamflow (Table 5) are stronger for PDSI&PHDI (correlation coefficient $r = 0.48\text{-}0.8$) comparing with that computed for self-calibrating indices ($r = 0.43\text{-}0.66$).

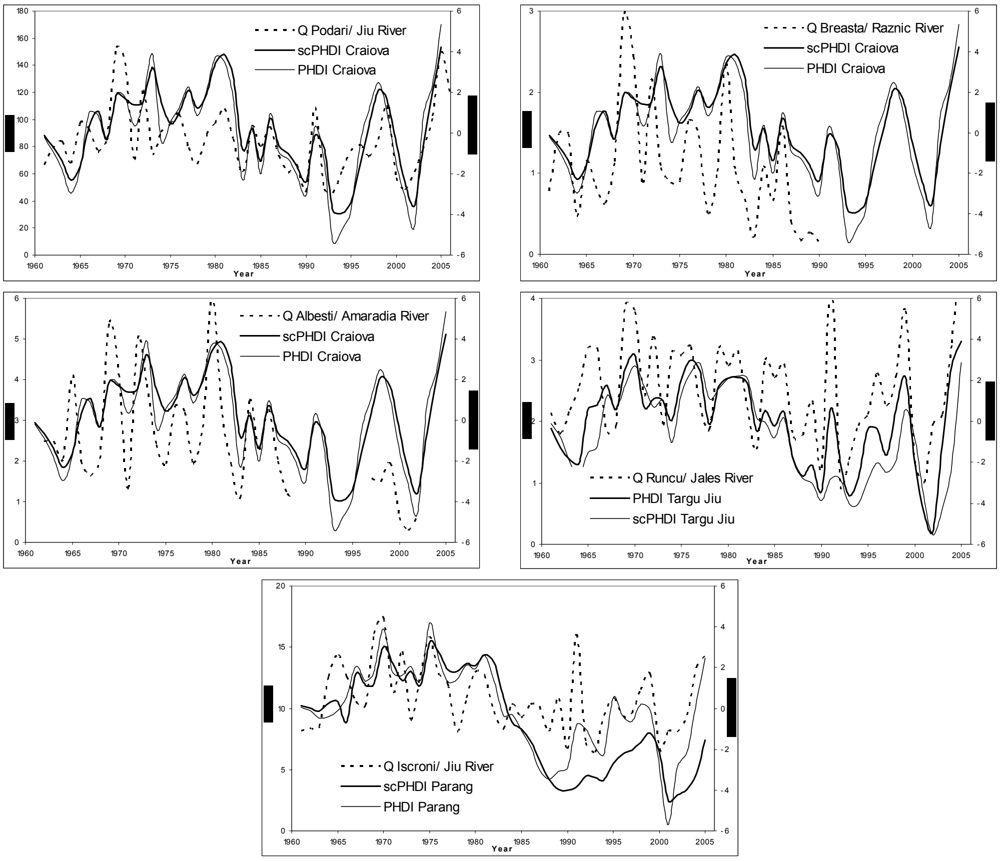

Fig. 5 – Temporal variability of monthly streamflow and PHDI&scPHDI.

Table 5

Correlations coefficients between Palmer indices and streamflow (*Q*)

	PDSI Craiova	PHDI Craiova	scPDSI Craiova	scPHDI Craiova
Q Podari/ Jiu River	0.65	0.67	0.66	0.63

	PDSI Craiova	PHDI Craiova	scPDSI Craiova	scPHDI Craiova
Q Breasta/ Raznic River	0.48	0.56	0.52	0.48

	PDSI Craiova	PHDI Craiova	scPDSI Craiova	scPHDI Craiova
Q Albesti/ Amaradia River	0.56	0.61	0.54	0.54

Table 5 (continued)

	PDSI Targu Jiu	PHDI Targu Jiu	scPDSI Targu Jiu	scPHDI Targu Jiu
Q Runcu/ Jales River	0.80	0.73	0.59	0.47

	PDSI Parang	PHDI Parang	scPDSI Parang	scPHDI Parang
Q Iscroni/ Jiu River	0.61	0.62	0.43	0.44

4. CONCLUSIONS

A monthly PDSI&PHDI and scPDSI&scPHDI dataset were derived for 1961-2005 using monthly precipitation and surface air data for Jiu River Basin.

The analysis of Palmer Drought Indices over the last 45 years revealed a higher concentration of drought years in the region studied during the last two decades, with significantly pronounced drought intensity. These results justify the need of further study on local climate changes within the stated estimations of future global and regional climate changes (IPCC, 2007).

The temporal variability of the scPDSI&scPHDI values distinguishes two drought periods 1992–1995 and 2000–2003 over Jiu River basin. Trend in the scPHDI values indicates a negative tendency, resulting from a combination of precipitation and surface temperature trends, suggesting values of Palmer indices below normal after 2005.

The spatial distribution of scPDSI values over the southwestern part of Romania shows that its south faces more severe drought than the northern part.

The scPDSI&scPHDI variations are correlated ($r = 0.43–0.66$) with those in the river flow, suggesting that the Palmer index can be a good predictor for streamflow, even if the correlation between PDSI&PHDI and streamflow is better ($r = 0.48–0.80$).

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