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AN ATTEMPT TO ASSESS THE INFLUENCE OF DRY AND WET PERIODS UPON RIVER RUNOFF. AN EXAMPLE OF THE DRWĘCA RIVER (POLAND)

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Abstract
The study assesses variability of moisture conditions over the years 1961-2005 using the Standardized Precipitation Index (SPI), Standardized Precipitation Evaporation Index (SPEI), and runoff conditions using the Standardized Flow Index (SFI). The examination focused upon the drainage basin of the Drwęca River and its two inflows. The values of the indices were determined in the cycles of 1, 3 and 12 months. Seven precipitation stations, one air temperature measurement station and three hydrological stations were used for the study. Over the years 1961-2005 there was no regularity in the occurrence of wet and dry periods. All the data of the Mann-Kendall trend were statistically insignificant. In the case of the SPEI positive statistics (Z) was obtained. Though it was not statistically significant it may inform of upcoming changes to the existing hydroclimatic cycle. The correlation between the indices with respect to the monthly values was not statistically significant. That results from the influence of the conditions prevailing in the drainage basin upon transformation of precipitation into runoff. Only the Rypienica river, with the smallest underground inflow, showed correlation indices at the limit of significance. In a longer time period, i.e. from 3 to 12 months, the correlations of indices were statistically significant.

Keywords: air temperature, precipitation, flow, SPI, SPEI, SFI indices, drainage basin of the Drwęca river

1 INTRODUCTION

Climatic conditions observed in the form of global warming have influence upon hydrological systems. Precipitation is the stimulus leading directly to river runoff. The drainage basin reacts to the excess or deficiency of precipitation through the formation of a high or low flow. The development of a low-flow has been recognised quite well. It is formed slowly or even unnoticeably. In its initial phase atmospheric drought is defined as an extreme weather phenomenon brought about by rain-free period. Drought is a climatic characteristic defined as noticeable lack of water which causes damage to the natural environment and economy, and noticeable difficulty or even threat to humanity (Hisdal&Tallaksen 2000). Due to precipitation deficiency water balance of an area is disturbed, and soil gets dried (soil drought). Further stages include lowering of phreatic waters and decrease of river water levels and flows (hydrological drought). Excess of precipitation may be the reverse phenomenon which reveals itself in high water stages in rivers.

In order to assess changeability of moisture conditions, the Standardized Precipitation Index (SPI) was used among many hydroclimatic characteristics. This index is widely applied to the assessment of atmospheric drought (McKee et al. 1993). It was used for the first time in Poland by Łabędzki (2004). Taking into consideration global warming, which reveals itself in Poland by the increase in air temperature by approximately 1^{O}C for the last 50 years, an index using air temperature must also be applied. The increase in air temperature results in higher potential evaporation which should influence upon the exchange of conditions to recharge rivers. To check the tendency of changes in the climatic water balance the Standardized Precipitation Evaporation Index (SPEI) was used. This index was applied by Vicente-Serrano et al. for the first time (2010), in Poland by Wibig (2012). The connection of climatic conditions with hydrological conditions of rivers was accomplished by the Standardized Flow Index (SFI).

The objective of this study is to examine the influence of moisture conditions on river runoff. The Drwęca river and its two inflows (Wel and Rypienica).were selected for the study. The analysis deliberately comprised the drainage basins of various areas and conditions which form the runoff.

The Drwęca river is a typical lowland river draining a young glacial area of the Polish Lowland. Its recharge structure is dominated by the share of groundwaters (80%). The Wel and Rypienica are the inflows of the Drwęca river (Tab. 1), and they show the underground recharge of 81 and 60% respectively. That is why, the Rypienica runoff is more dependent on temporary atmospheric conditions.

Table 1. Main parameters of the analysed rivers

River	Lenght (km)	Catchment area (km^2)	Flow (m^3s^{-1})
Drwęca	210	4959	29.6
Wel	104	764	5.3
Rypienica	21	99	0.54

2 METHODS

2.1 Standardized precipitation index (SPI)

The SPI was developed by Mc-Kee et al. (1993) to assess precipitation deficit in a different time scale. In Poland this index was applied for the first time by Łabędzki (2004).

$$SPI = \frac{Y - \hat{\mu}}{\hat{\sigma}}$$

Y- a random variable, monthly sums of precipitation converted into normal distribution

$\hat{\mu}$ – a value of the estimator of σ parameter (mean values of the normalised series of precipitation sums)

$\hat{\sigma}$ – a value of the estimator of σ parameter (standard deviation of the normalised series of precipitation sums).

The positive values of the SPI indicate precipitation is greater than a median, whereas the negative values of the SPI indicate precipitation is lower than a median. The introduced classification system of the SPI (Tab. 2) serves to define the intensity of precipitation periods for every time scale. The constant negative value of the SPI, which equals -1.0 or less, corresponds to reoccurring drought. The excess of precipitation causes the distinction of wet periods, which start from the value of 1.0. The SPI was computed using the program SPI_SL_6 (W.M.O 2012).

2.2. Standardized Precipitation Evaporation Index (SPEI)

Beside precipitation the SPEI additionally accounts for air temperature. The values of climatic water balance are obtained from the difference between precipitation (P) and potential evaporation (PET). The potential evaporation (PET) is computed using the Thornthwaite equation. In Poland the possibility to apply the formula to estimate PET was examined by Wojciechowski (1968), who found slightly greater values as compared to evapotranspiration obtained through other methods. However, the correlation coefficients of 0.9 allow applying the Thornthwaite equation.

The distribution of the climatic water balance is not normal, therefore, the log-logistic distribution is applied. The distribution parameters are estimated using the L-moment method. The SPEI was computed in this study using the program SPEI (Vicente-Serrano et al. 2009, 2010).

2.3 Standardized Flow Index (SFI)

The SFI was computed on the grounds of the similar rules as for the SPI. Instead of precipitation data, the mean values of monthly flows of the three rivers were taken into consideration. The calculation of SFI was carried out in Excel. The SFI has been discussed in numerous works (Wen et al. 2010).

For the indices covering the period of 3 and 12 months the accumulated values of the SPI, SPEI and SFI were computed. These values provide information on the likelihood of a drought or a wet period. The period of drought in 1 month corresponds to an atmospheric drought, in 3 months to soil drought, and in 12 months to hydrological drought. The classification of indices is presented in Tab. 2.

Table 2. Classification of SPI, SPEI ,SFI values and the dryness and wetness categories

Range of index SPI, SPEI, SFI	Category of dryness/wetness
> - 2.00	Extremely dry (1)
- 1.99 do – 1.50	Very dry (2)
- 1.49 do –1.00	Dry (3)
-0.99 do 0.99	Normal (4)
1.49 do 1.00	Wet (5)
1.99 do 1.5	Very wet (6)
> 2.00	Extremely wet (7)

2.4 Trend test

In order to detect the trend of the course of the determined indices the Mann-Kendall non-parametric test was applied. The Kendall's sum S divided by the root of variance S provides test statistics.
The S value:

$$S = \sum_{i<j} sng(a_j - a_i)$$

$a_1, ..., a_n$ denote data series

The estimate of the trend slope was carried out using the non-parametric Sen's method (Salmi et al. 2002). In Sen's rank method a strong influence of extreme values is tempered, and the linear model of the trend assumes $f(t)=Qt + B$, where Q is an estimator of the linear regression coefficient, B – an absolute term. Q – is a median in an increasing sequence Q_i computed for all the variable pairs x:

$$Q_i = \frac{x_j - x_k}{j - k}$$

where: j>k, n number x_j, number of the entire time series equals: N = n (n-1) 2.

2.5 Data

The location of the measurement stations is presented in Fig. 1. The data come from the years 1961-2005, and they were obtained from the the Institute of Meteorology and Water Management – National Research Institute. The SPI was computed from seven precipitation stations (Czernikowo, Ostrowie, Tomkowo, Pietrzwałd, Jaśkowo, Lubawa, Toruń). The SPEI was computed from one station (Toruń), and the SFI was calculated from three hydrological stations located at the rivers: Drwęca, Wel and Rypienica.

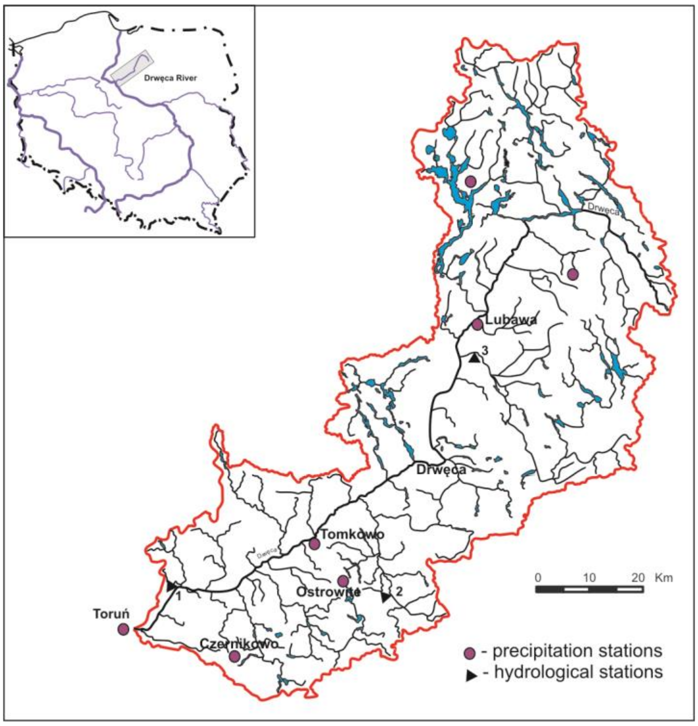

Figure 1. The location of the measurement stations in Drwęca River basin. Symbols: 1. Drwęca River, 2. Rypienica River, 3. Wel River.

3 RESULTS AND DISCUSSION

The occurrence of droughts and wet periods in the particular months does not show any regularity or relation to the location of the precipitation station. Apart from the months with extreme drought there are extremely wet periods (Fig. 2). This refers both to the SPI, SPEI and the SFI to a less degree. In the monthly SPI drought was observed most frequently in Ostrowite (in 95 months of the study period, approx. 18%), Jaśkowo (in 94 months, approx. 17%), Lubawa (in 91 months, approx. 17%), more rarely in Czernikowo and Pietrzwałd (in 84 months, approx. 15%). The biggest number of wet months was recorded in Ostrowite (in 84 months out of the analysed multi-year period, approx. 15%), then in Tomkowo (82 months). On the other hand, the smallest number of wet months was recorded in Czernikowo (75 months, approx. 14%). In total, months with precipitation differing from the mean values constitute approximately 30-35% of all in the study period.

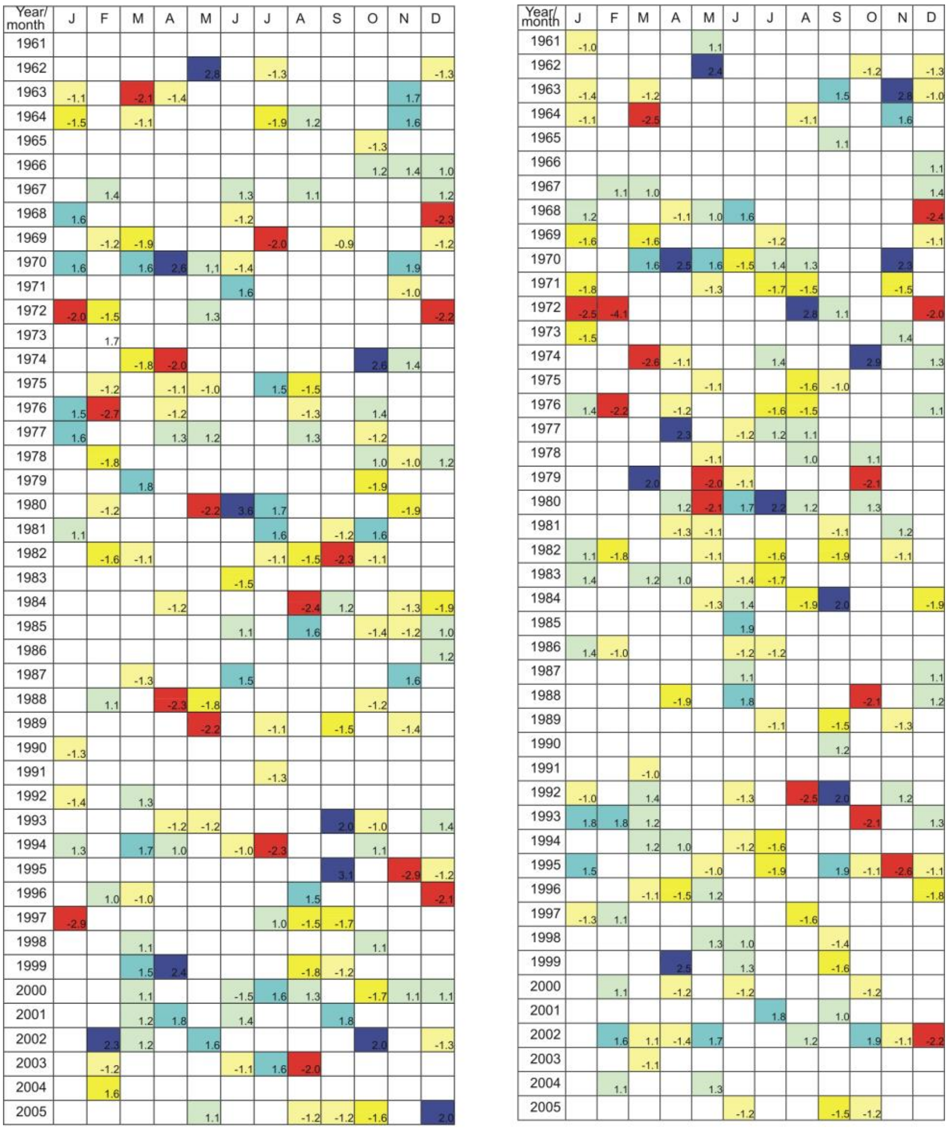

Figure 2. Dryness and wetness categories in the particular months from the selected stations. Symbols as in Table. 1

Similarly to the SPI, the SPEI shows considerable variability and a yearly cycle. The minimum values occur in summer and the maximum ones in winter (Fig. 3). The minimum values are noted in summer as precipitation is lower than potential evaporation. Therefore, in warmer months rivers are recharged with the resources from the active groundwater exchange zone. Resources get restored in the colder seasons of the year.

The course of the SFI values in the periods from 3 to 12 months is slightly different as compared to the SPI and SPEI. Dry and wet periods show a grouping tendency, which is expressed by smaller changeability as compared to climatic indicators (Fig. 4). This is the effect of the influence of the conditions prevailing in the particular drainage basins upon transformation and retention of precipitation. Moreover, the extreme periods in the Rypienica river drainage basin are shorter as compared to those in the drainage basins of the Drwęca and Wel rivers.

The analysis of the course of climatic and hydrological indices in the 12-month time cycle makes it possible to distinguish particularly dry periods in the years: 1962-1964, 1969, 1976, 1983, 1988-1989, 1991-1993, 1997 and 2004/2005. Wet periods occurred in the years: 1966-1967, 1971, 1974/1975, 1979-1982, 1987/1988, 1995, 2002/2003. Both wet and dry periods, differentiated by various indices (SPEI, SPI, SFI) did not take place at the same time. Climatic indices often appeared to be ahead of hydrological ones.

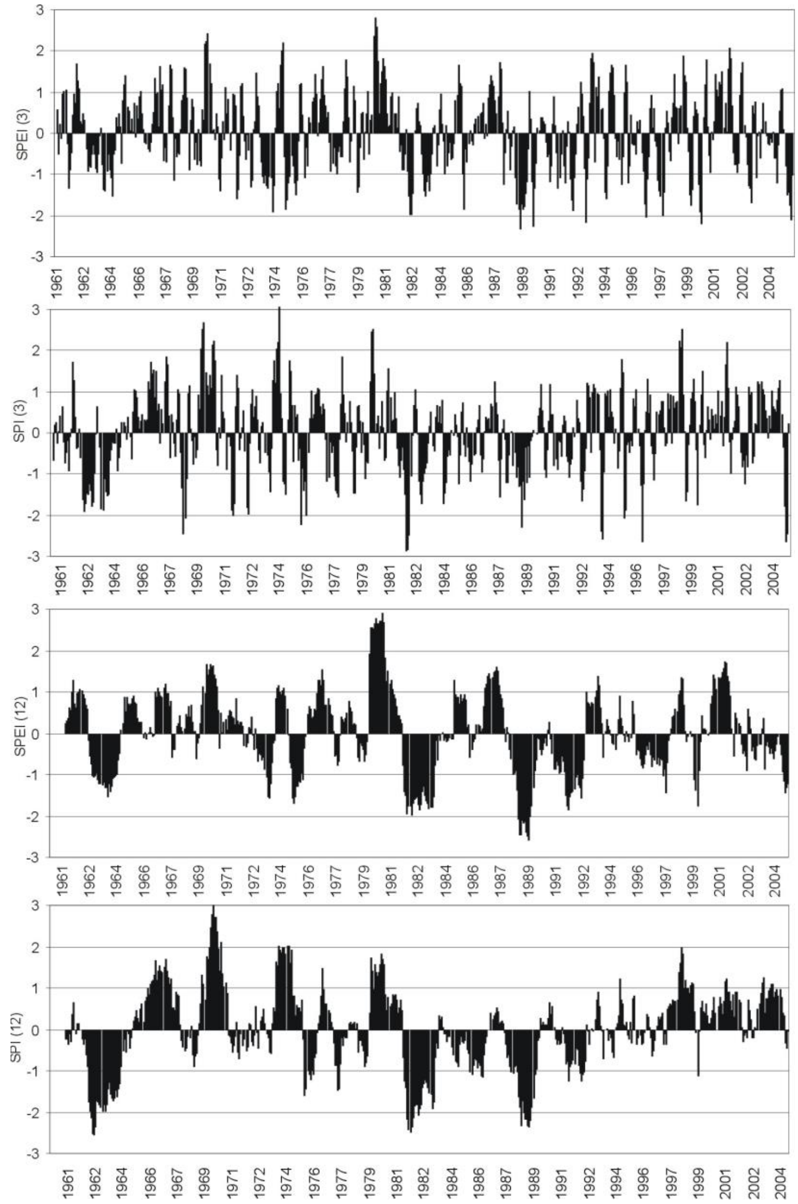

Figure 3. Course of SPI and SPEI indexes (example from the meteorological station in Toruń)

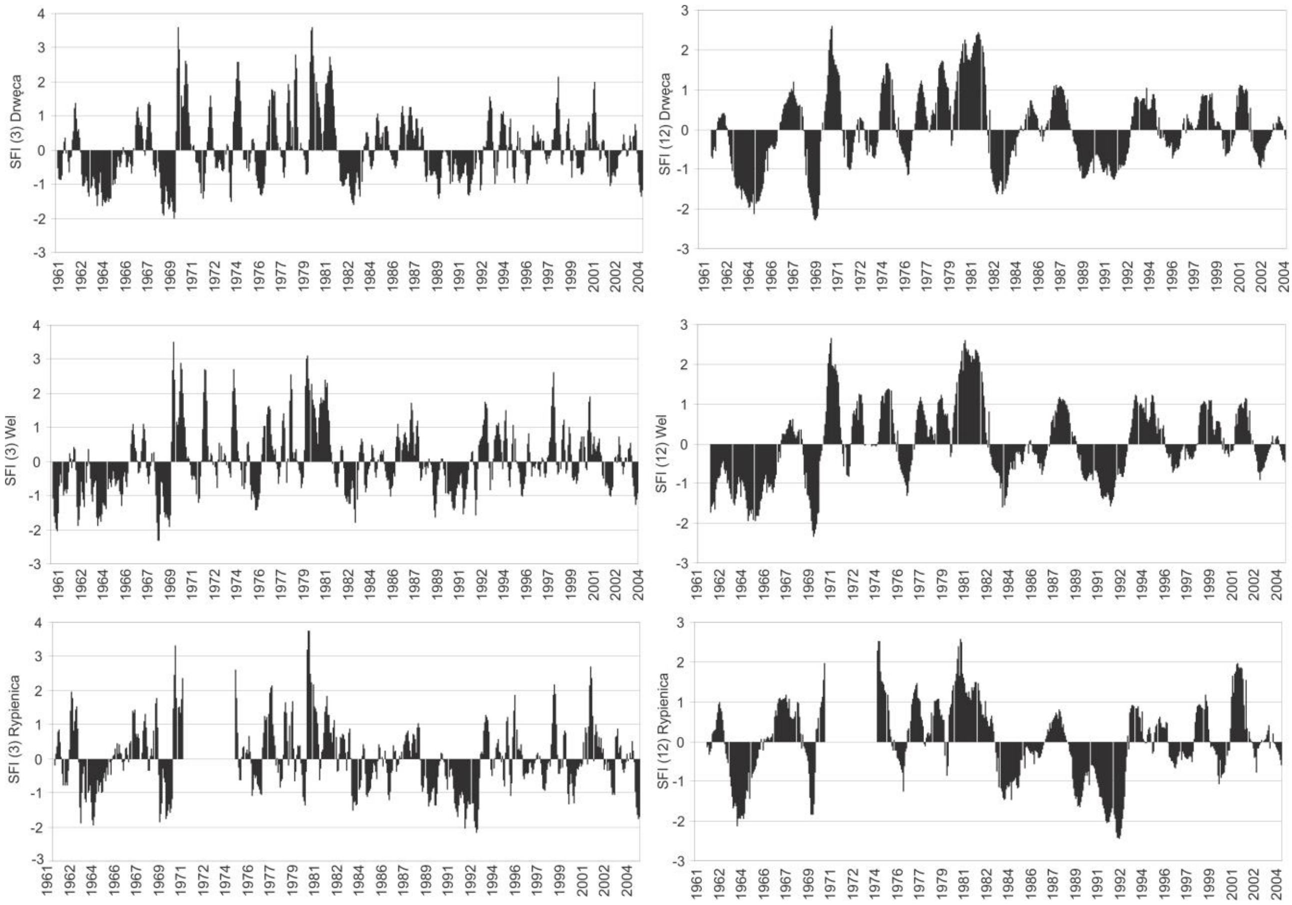

Figure 4. Course of SFI index from the flows of the Drwęca, Wel and Rypienica rivers

The frequency of dry and wet periods in a 12-month cycle did not exceed 30% of the entire data distribution. Wet and dry periods dominate after approximately 10%. Extreme periods occurred the least, from 1% to 3%.

The course of the SPI, SPEI and SFI does not show any trend in a 12-month cycle. The statistics of the Mann-Kedall test proved the lack of tendency in all the analysed indices (Tab.3). Taking into consideration very small water resources of Poland, estimated as one of the lowest ones in Europe (Lwowicz 1979), it is a positive phenomenon. Grouping the periods of water deficiency may, therefore, be considered a hydroclimate characteristic of Poland. Similar regularities can be observed with respect to wet periods.

Table 3. Tendencies of the analysed climatic and hydrological characteristics

Month 12	Statistic Z	Slope (change per year)
SPEI	1.29	0.013
SPI	0.14	0.001
SFI Drwęca	0.46	0.007
SFI Wel	1.16	0.016
SFI Rypienica	-0.66	-0.006

The correlations of the indices for 12-month time cycles are significant (Tab. 4). The highest correlations were found between SPEI and SPI (r = 0.77). The correlation of SPEI and SFI was lower than in the case of the SPI and SFI. Though, it seemed that taking the PET into consideration should lead to their higher correlation. The differences in the courses of the SPEI and SPI have been noticed earlier (Ward 2013). Moreover, this difference may result from the computations of the PET using the Thornthwaite's method, which gives slightly overestimated results (Wojciechowski 1968). Consequently, faintly lower values of the SPEI are obtained. The correlation of the SPI and SFI amounted from 0.52 to 0.60. No significant correlation was found in the case of the monthly values of the climatic and hydrological indices.

Table 4. Correlations between climatic and hydrological indicators.

month 12	SPEI	SPI Rypienica	SPI Wel	SPI Drwęca	SFI Drwęca	SFI Wel	SFI Rypienica
SPEI	1						
SPI Rypienica	0.66	1					
SPI Wel	0.58	0.70	1				
SPI Drwęca	0.77	0.86	0.92	1			
SFI Drwęca	0.41	0.53	0.56	0.60	1		
SFI Wel	0.30	0.46	0.53	0.54	0.92	1	
SFI Rypienica	0.42	0.52	0.47	0.53	0.81	0.78	1

4 CONCLUSIONS

The search for reliable indices to define the moisture relations between atmosphere and river runoff is important both in the context of changes in the hydroclimatic systems and the monitoring of threats related to drought. It is not always easy to present the precipitation-runoff relation in a satisfactory way, or explain it by using indices and statistics. The analysis did not prove any trends of drought or wet periods occurrence, which is certainly positive from the point of view of water management. The positive values of the SPEI trend indicate that changes are to come in the closest future (Tab. 3). They suggest water resources will decline as a result of greater evaporation.

The distinguished periods with drought or moisture excess line up well with other hydrological situations, with low-flows among others (Tomaszewski 2007), or deviations from the mean multi-year value. The applied indices make it possible to compare the obtained results for various drainage basins, regardless of the natural conditions prevailing there.

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