ESTIMATION OF LOCAL DROUGHT FREQUENCY IN CENTRAL POLAND USING THE STANDARDIZED PRECIPITATION INDEX SPI[†]

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ABSTRACT

Poland is situated in a transitory temperate climate zone; nonetheless droughts occur, posing a serious economic, social and environmental problem. The central part has the lowest precipitation in the country, where frequent meteorological and agricultural droughts occur. To estimate meteorological drought frequency in the region, the SPI methodology is used. The analysis is made using the long-term record of precipitation from 1861 to 2005 for the Bydgoszcz area, at 3-, 6-, 12-, 24- and 48-month timescales. The detailed characterization of chosen meteorological and agricultural droughts in 1991–2005 is presented in this paper.

The results show that the frequency of months in which drought was identified at 3-, 6-, 12-, 24- and 48-month time scales, is about 30%. According to the equation as proposed in this study, the number of droughts of different duration in 100 years statistically is from 8 for the 48-month drought to 120 for the 3-month drought. On the basis of the analysis of the meteorological and agriculture drought in 2000, it has been shown that the 1–3 month SPI better reflects agricultural drought development than the 6-month SPI.

To better understand and characterize droughts in agricultural areas additional indices should be used for the evaluation impacts of meteorological drought. Other indices need to be investigated to form a system of indices giving the best evaluation of droughts in a given region. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: meteorological drought; standardized precipitation index SPI; drought impacts in agriculture

Received 1 February 2006; Revised 12 October 2006; Accepted 24 October 2006

RÉSUMÉ

Bien que la Pologne soit située dans une zone de climat tempéré transitoire, des sécheresses apparaissent sur son territoire, créant d'importants problèmes économiques, sociaux et environnementaux. La partie centrale du pays reçoit des précipitations plus faibles qu'au niveau national, avec des sécheresses météorologiques et agricoles. Pour estimer la fréquence des sécheresses météorologiques dans cette région, la méthodologie SPI a été appliquée. Dans la région de Bydgoszcz, l'analyse d'une longue série de précipitations dans les années 1861–2005 a été effectuée sur une échelle de temps de 3, 6, 12, 24, 48 mois. L'article présente les caractéristiques détaillées des sécheresses météorologiques et agricoles des années 1991–2005.

Les résultats montrent que la fréquence des mois où la sécheresse a été identifiée aux échelle de temps choisis (3, 6, 12, 24 et 48 mois) est d'environ 30 %. Selon l'équation proposée dans l'étude, le nombre de sécheresses de diverses durées sur 100 années va de 8 pour une sécheresse de 48 mois jusqu'à 120 pour une sécheresse de 3 mois. L'analyse de la sécheresse météorologique et agricole de 2000 montre qu'un indice SPI de 1-3 mois reflète mieux le développement de la sécheresse agricole qu'un indice SPI de 6 mois.

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[†]Estimation de la fréquence des sécheresses en Pologne centrale à l'aide d'un indice de précipitation standardisé (SPI).

Pour comprendre et mieux caractériser les sécheresses dans les zones agricoles, il faut utiliser des indices complémentaires pour estimer les conséquences de la sécheresse météorologique, le résultat étant un système d'indices qui permettent d'évaluer au mieux les sécheresses d'une région donnée. Copyright © 2007 John Wiley & Sons, Ltd.

MOTS CLÉS: sécheresse météorologique; indice de précipitation standardisée SPI; conséquences des sécheresses dans l'agriculture

INTRODUCTION

Poland is situated in a transitory temperate climate zone; nonetheless droughts occur, posing a serious economic, social and environmental problem. Droughts in Poland have a character of atmospheric anomaly following the rainless period. Natural conditions are favorable for agriculture, but drought can be an important risk factor. Droughts in Poland are hardly predictable. It is difficult to forecast the term of their occurrence, duration, territorial range and intensity. This leads to difficulties in operational planning and in undertaking the proper advance measures to mitigate the negative effects. In spite of this unpredictability and irregularity of drought occurrence in Poland, one may observe some statistical properties of their frequency, duration and the regions affected.

Drought phenomena in Poland have been mentioned in the chronicles since the fourteenth century and were found to occur many times a century: in the fourteenth century 20 times, in the fifteenth 25 times, in the sixteenth 19 times, in the seventeenth 24 times and in the eighteenth 22 times. Since the nineteenth century, when permanent precipitation records were started, the number of droughts were estimated as 23 in the nineteenth century and 20 in the twentieth century. These droughts were identified using different indices and parameters related to precipitation and/or reference evapotranspiration. The most often used were the percentage of normal precipitation, the ratio of reference evapotranspiration and precipitation, the number of days without precipitation or the non-exceedance probability of a given precipitation sum (Bąk and Łabędzki, 2002; Bobiński and Meyer, 1992a,b; Byczkowski and Meyer, 1999, 2001; Czaplak, 1996; Farat *et al*., 1994; Sasim *et al*., 1994, 1995). It is commonly assumed that droughts appear in Poland once every 4–5 years. Central Poland has the lowest annual precipitation sum in the country which on average (in 1945–2004) is about 500 mm, whereas in the growing season (April–September) it is 279 mm. Frequent and severe droughts occur in this area, which sometimes experiences extremely long periods without rain.

The definition and identification of droughts have been the object of many studies. Wilhite and Glantz (1985) reviewed more than 150 published definitions and grouped them into four types – meteorological, agricultural, hydrological and socio-economic. There is an agreement among authors that there is no universally accepted definition of drought (Tate and Gustard, 2000). According to recent studies and investigations, droughts should be defined as a natural but temporary imbalance of water availability, consisting of a persistent lower than average precipitation, resulting in diminished water resources availability (Paolo and Pereira, 2006; Pereira *et al*., 2002). Generally the definitions state that drought is due to the breakdown of the rainfall regime. Meteorological drought is most often expressed in terms of rainfall in relation to some average amount and the duration of the dry period and can be defined as a period with a lack of precipitation or with rainfall lower than average, lasting sufficiently to cause hydrological and agricultural hazards. The object of this paper is meteorological drought defined in that way.

Many indices and methods have been developed and are used to identify and determine the intensity of meteorological and other types of droughts (Boken *et al*., 2005; Vogt and Somma, 2000). Among them the standardized precipitation index SPI has received special attention in recent years since it was introduced by McKee *et al*. (1993, 1995). It was applied to the analysis of regional droughts in Portugal (do Ó, 2005; Paulo and Pereira, 2006, Paulo *et al*., 2002), in Crete (Tsakiris and Vangelis, 2004), in Sicily (Bonaccorso *et al*., 2003), in Hungary (Szalai and Szinell, 2000; Szalai *et al*., 2000) and for the whole of Europe (Lloyd-Hughes and Saunders, 2002). It is widely recommended as a very simple and objective measure of meteorological drought (US National Drought Mitigation Center, 2006; Vermes, 1998; Vermes *et al*., 2000). The SPI has not been used and studied in Poland and has not been tested for the local climatic conditions in the country.

The objective of the study is to perform an analysis of local meteorological droughts in the Bydgoszcz area for the years 1861–2005, located in Central Poland, using the SPI methodology, and to verify the up-to-date evaluation of drought risk in this location. In-depth analysis of the agricultural drought in 2000 with the background of meteorological drought is carried out.

MATERIAL AND METHODS

The subject of this study is the region of Bydgoszcz, in the central part of Poland, with an area of about $2500 \, \text{km}^2$, characterized by extensive agriculture, mainly cereals, sugar beet, vegetables, meadows and pastures. The climatological conditions of the area under consideration are represented by the Bydgoszcz-IMUZ (Institute for Land Reclamation and Grassland Farming) meteorological station with the coordinates: $\varphi = 53°08'$, $\lambda = 18°01'$ and $H_s = 46 \, \text{m a.s.l.}$ The analysis of droughts was performed using the 145-year record of monthly precipitation sums from 1861 to 2005.

The SPI was calculated for each month of this series of years at 3-, 6-, 12-, 24- and 48-month timescales. For this purpose, for each month of the calendar year the new series was created with the elements equal to corresponding precipitation moving sums. For example, the 3-month SPI calculated for June 2000 utilized the precipitation total of April 2000 through June 2000 in order to calculate the index. Likewise the 12-month SPI for June 2000 utilized the precipitation total for July 1999 through June 2000.

In this study a 3- and 6-month SPI is used for a short-term or seasonal drought identification, a 12-month SPI for an intermediate-term drought identification, and a 24- and 48-month SPI for a long-term drought identification. SPI on shorter timescales describes drought events affecting agriculture (soil moisture depletion, crop yield reduction), while SPI on the longer ones is more suitable for water resources hazards (reservoir storage, stream flows, groundwater levels).

The SPI is an index based on the probability distribution of precipitation. It depends on the fitted density probability function, the length of the series used to estimate the parameters of the probability function and the method of estimation. In the study a gamma probability density function was fitted to the monthly series for the selected timescale, checking goodness of fit by using the χ^2-Pearson test. The parameters were estimated by the maximum likelihood method. Then an equiprobability transformation was applied from the fitted distribution to the standard normal one. The values of the standard normal variable are actually the SPI values.

The negative values of SPI are compared with the boundaries of different classes of drought. There are many classifications used by different authors. Originally McKee et al. (1993) distinguished four categories of drought: mild, moderate, severe and extreme, with the threshold value of SPI for the mild drought category equal to $\text{SPI} = 0$ (Table I). Agnew (2000) writes that in this classification all negative values of SPI are taken to indicate the occurrence of drought – this means that for 50% of the time drought is occurring. He concluded that it was not rational and suggested alternative, more rational thresholds. According to Vermes (1998) three categories are proposed with the first class starting at $\text{SPI} = -1$. The class of mild drought ($-1 < \text{SPI} < 0$) was aggregated with the slightly wet class ($0 \leq \text{SPI} \leq 1$) into the near normal class.

In this study the three-category drought classification is used according to Vermes (1998), with the modified threshold for the first class of moderate drought. According to the recommendations of the WMO, drought has been determined if the monthly values of the relative precipitation index (RPI) were found to be below 60% and the yearly values below 75% (Palfai, 2002). Kaczorowska (1962) proposed two criteria: 75% of monthly sums of precipitation and 90% of the sum of precipitation in longer periods. Such criteria for drought detection indicate that the threshold of the first class of drought (moderate) should be greater than -1.0. The threshold of SPI for moderate drought ($\text{SPI} = -1.0$) corresponds to precipitation (with less) with a probability of occurrence of 16%. In our opinion this probability level is far too low. The first and the most important reason for the required modification is that the meteorological conditions in Poland are highly variable (high value of standard deviation). That is why

Table I. Classification of the SPI values and drought category

SPI	Drought category according to	
	McKee (1993)	Vermes (1998)
0 to −0.99	Mild drought	Near normal
−1.00 to −1.49	Moderate drought	Moderate drought
−1.50 to −1.99	Severe drought	Severe drought
≤ −2.00	Extreme drought	Extreme drought

Table II. Classification of the SPI values and drought category used in the study

SPI	Drought category	Symbol	Cumulative probability for the lower threshold
−0.50 to −1.49	Moderate drought	D1	0.3085
−1.50 to −1.99	Severe drought	D2	0.0668
≤ −2.00	Extreme drought	D3	0.0228

precipitation deficit (in regard to the mean precipitation), less than that corresponding to SPI = −1.0, is commonly evaluated as mild drought. Poland is situated in a climatic zone without distinct rainy and dry seasons. Most of annual rainfall occurs in summer and droughts also occur in the same season. For the above reasons it is proposed to spread the range of SPI in the first class from −1.0 to −0.5. SPI ≤ −0.5 corresponds to precipitation (with the lower) of a probability of occurrence equal to 31%. The SPI values in the range (−0.5; −1.0), enabling us to distinguish periods with mild drought, can be a source of additional information on the periods with insufficient precipitation in a given region and significant for monitoring of soil and hydrology drought. The modified classification of dry periods, used in this paper, is shown in Table II.

The number of months N_i in each class of drought intensity according to Table II was computed for the 3-, 6-, 12-, 24- and 48-month timescales. Then the number of droughts per 100 years was calculated as:

$$N_{i,100} = \frac{N_i}{i \cdot n} \cdot 100 \tag{1}$$

where $N_{i,100}$ = the number of droughts for a timescale i in 100 years
N_i = the number of months with droughts for a timescale i in the n-year set
i = timescale (= 3, 6, 12, 24, 48 months)
n = the number of years in the data set (= 145).

EVALUATION OF DROUGHTS IN 1861–2005

The time series of the monthly values of SPI for each timescale in the years 1861–2005 is shown in Figure 1. Drought events changes as timescale changes. When timescale is small the SPI moves frequently above and below zero. For longer timescales the SPI changes slowly due to changes in precipitation. Periods with negative SPI are less frequent but longer in duration. When using the 48-month timescale, the drought events are more concentrated and last longer than the 3-month drought events that are more dispersed – they occur more often and last a shorter time. This is the characteristic observed in many other locations by different authors: by McKee *et al.* (1993) for Fort Collins, Colorado, USA, Lloyd-Hughes and Saunders (2002) for South Dalton, Yorkshire, UK, and Szalai and Szinell (2000) for Szarvas in Hungary.

Longer timescales (24- and 48-month SPI) are better suited for the detection of historically significant drought events. Extreme drought events lasting 24 months are observed at the end of 50 months in 1886, 1901, 1922, 1944 and in 1990–93 (SPI24 < −2.0) and 48 months – at the end of 36 months in 1886/87 and 1989–93. The lowest value of SPI48 (= −3.71) was observed at the end of September 1992. The extreme droughts lasting four years (SPI48 < −2.0) were determined for each month from November 1991 till August 1993. It was the series of very dry years (1990–93), with the culmination of negative effects of droughts in 1992.

Shorter timescales show the frequent seasonal and interannual precipitation variations closely, giving a very high number of events. For 12-month timescale (SPI12), the most severe droughts were identified at the end of September 1921 and 1989. Short-term extreme droughts (SPI3 and SPI6) often occurred in the period 1861–2005. The most extreme drought lasting 3 months (SPI3) was observed at the end of October 1959 (SPI3 = −3.85) and it was the lowest SPI for any of the timescales under analysis.
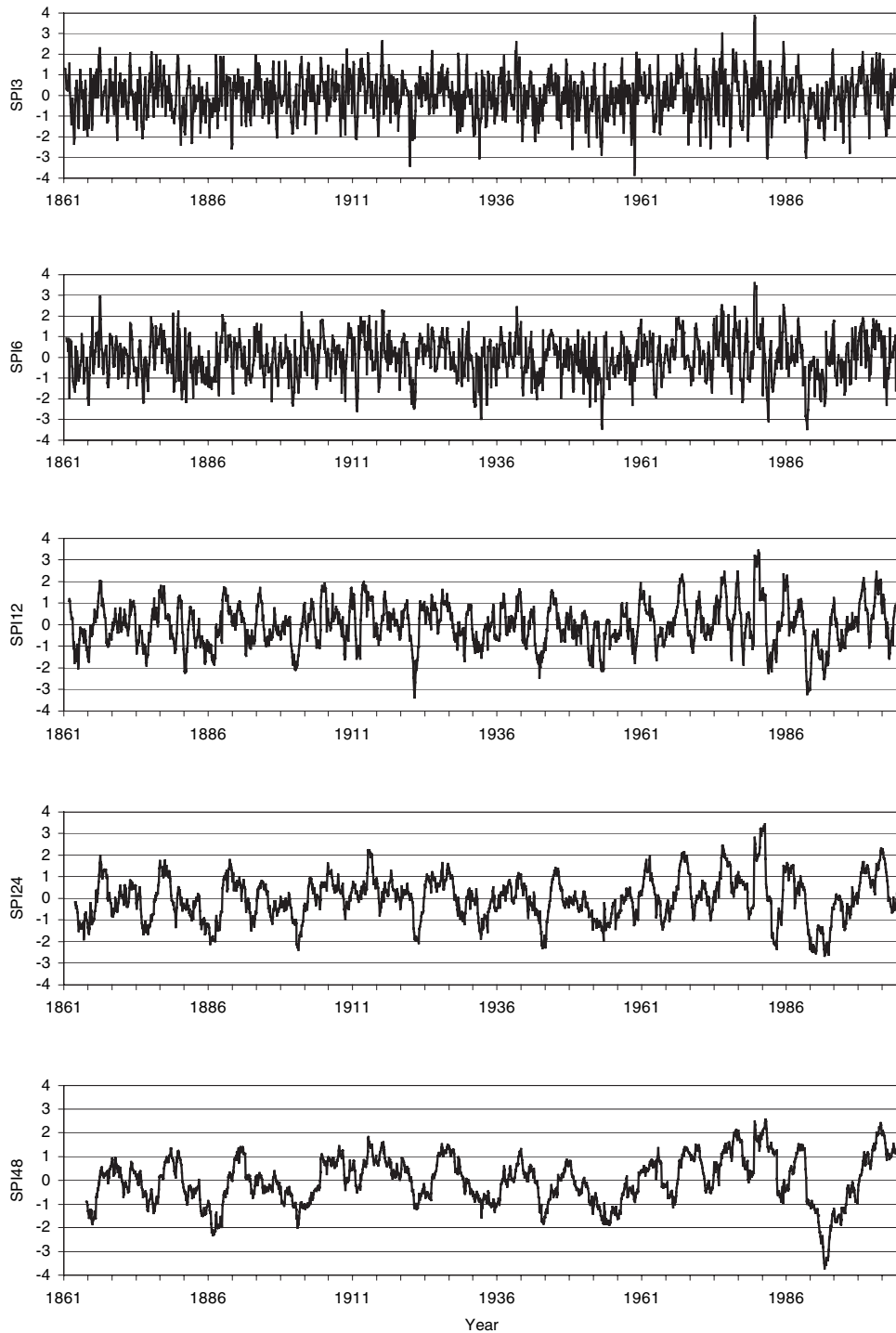
Figure 1. The course of the 3-, 6-, 12-, 24- and 48-month SPI in each month of 1861–2005 at the Bydgoszcz IMUZ meteorological station

Table III. Number of months in the classes of drought computed with the SPI for 3, 6, 12, 24 and 48 month timescales

Timescale (months)	Drought severity class				
	N	D1	D2	D3	Droughts total
3	1222	389	75	54	518
6	1216	405	69	50	524
12	1195	418	85	42	545
24	1237	386	67	50	503
48	1192	433	79	36	548

Notes: N – no drought, D1 – moderate drought, D2 – severe drought, D3 – extreme drought.

Table IV. Number of droughts per 100 years in the classes of drought for 3, 6, 12, 24 and 48 month timescales

Timescale (months)	Drought severity class			
	D1	D2	D3	Droughts total
3	90	17	12	119
6	46	8	6	60
12	24	5	2	31
24	11	2	1	14
48	6	1	1	8

Notes: D1 – moderate drought, D2 – severe drought, D3 – extreme drought.

The characteristics of drought events for different timescales are more easily visible when analyzing the number of months (Table III) in which a drought event is identified according to the classification from Table II, and the number of drought events in 100 years for different timescales (Table IV).

It can be observed that the occurrence of months in which drought is detected in all severity classes is almost equal for different timescales and corresponds to about 30% of the entire time under analysis. The frequency of months with extreme droughts amounts to 2% for the 48-month SPI, 2.5% for the 12-month SPI and 3% for the 3- and 6-month SPI. The highest frequency of months is observed in the class of moderate droughts (22–25%). The shorter timescale SPI is more dispersed and changes quickly, while the longer timescale SPI values are concentrated in the series of consecutive months within one year or the succeeding several years (e.g. 1989–93).

Transforming these values into the number of droughts in 100 years according to Equation (1), one can expect about 120 droughts with a duration of 3 months, 60 droughts of 6 months, 30 droughts of 12 months, 15 droughts of 24 months and 8 droughts per 100 years lasting 48 months (Table IV).

The above results, obtained according to the SPI analysis, give very valuable characteristics of the local climate in central Poland. It has been assumed for many years that this is the region of frequent droughts, but only the SPI for the different timescales gives the opportunity to illustrate the relationship between the number of months with droughts for different timescale, drought frequency and drought duration.

EVALUATION OF DROUGHTS IN 1991–2005

Because of observed more frequent drought events since 1991, the more detailed analysis of this period was carried out in relation to the consequences in agriculture. For the characteristics of meteorological droughts in a whole
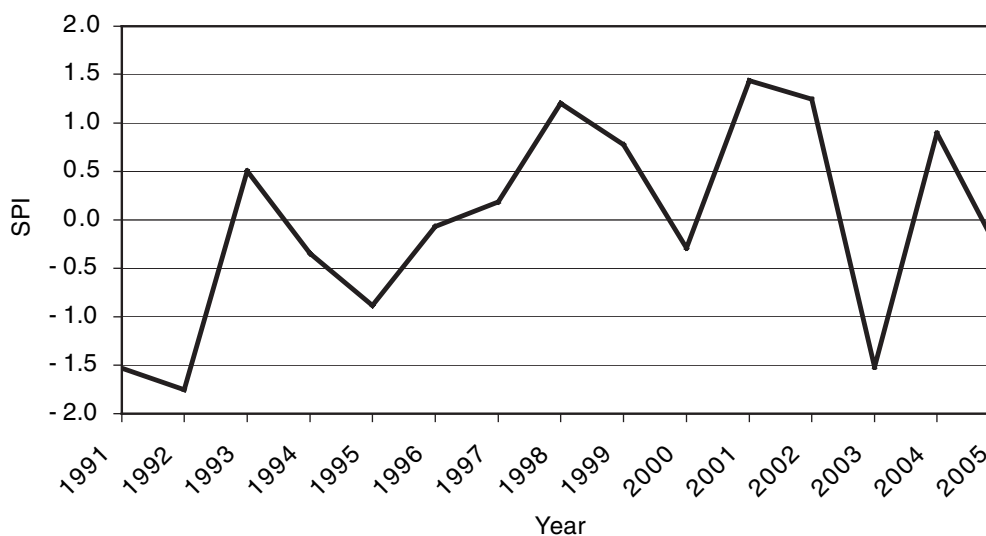
Figure 2. The course of the 12-month SPI in December 1991–2005 at the Bydgoszcz IMUZ meteorological station

calendar year the SPI12 at the end of December is chosen, and in a whole growing season (April–September) SPI6 at the end of September of each year.

The course of the 12-month SPI values in December 1991–2005 is shown in Figure 2. The years with negative values of SPI12 in December prevail (8 years). Three years can be classified as severely dry (1991, 1992, 2003), one as moderately dry (1995) and four years (1994, 1996, 2000, 2005) were normal, but with negative SPI12. Out of seven years with positive SPI12 in December, four years were normal and three (1998, 2001, 2002) moderately wet, according to the classification by Vermes (1998). In the 1991–2005 series analyzed, there was one extreme drought event characterized by SPI6 in September (1992), four moderately dry and two normal with negative SPI6 (Table V).

The results of SPI calculation are in rather good agreement with observations made in these years concerning hydrological conditions and impacts on agricultural production. The drought in 1992 was a disaster. High air and soil temperatures, very high insolation and a negative climatic water budget characterized it. From the middle of

Table V. The 6-month SPI (SPI6) at the end of September in the 1991–2005 from the measurements at the Bydgoszcz IMUZ meteorological station

Year	SPI6	Classification of the period
1991	−0.81	Moderately dry
1992	−2.35	Extremely dry
1993	0.24	Normal
1994	−0.96	Moderately dry
1995	−0.10	Normal
1996	0.68	Normal
1997	0.52	Normal
1998	0.95	Normal
1999	0.30	Normal
2000	−0.74	Moderately dry
2001	1.73	Very wet
2002	0.07	Normal
2003	−1.02	Moderately dry
2004	0.34	Normal
2005	−0.38	Normal

April precipitation did not exceed 50% of the average and in June there was no precipitation at all. Precipitation during the second half of the growing period (July–September) was 40–55% of the multiannual average. Its negative consequences were: long-lasting, burdensome heat, dried soil, grasslands turned yellow in midsummer, a lack of the second and the third grass cuttings, a deficit or a total loss of the grain and potato crops, lack of fodder and consequently an increase in food prices. It is estimated that this drought decreased the value of crops by 25%. Total crops of grain, potatoes and bulk fodder, expressed in cereal unit, were lower by 31% in 1992 than those in 1991. Meadow hay crops decreased by 27% in comparison to the average from 1986 to 1990. In the region analysed, 6–10 Mg ha^{-1} of hay were obtained under irrigation while non-irrigated grasslands on better soils yielded no more than 2 Mg ha^{-1} of hay and on worse soil they were completely dried out.

The precipitation shortage was reflected in very low water tables and outflows from the rivers and in a significant decrease of shallow groundwaters. Such a situation caused a complete drying up of the smaller streams, whose watershed covered several hundred square kilometres, thus affecting any life dependent on them. A critical situation arose in the retention reservoirs, which were filled only to 10% of their average levels. This caused difficulties in supplying water to irrigation systems and villages. The pollutant load delivered to the surface waters caused, because of low water levels and the hot weather, an increase in pollution and in oxygen deficit in the rivers and an increase in the costs of water acquisition and treatment. The drought was also a factor in the increased frequency of fires, resulting in the burning of thousands of hectares of forests, peatlands and numerous settlements.

It should be mentioned that 1992 was the next dry year after the severely dry 1991, the moderately dry 1990 and extremely dry 1989. In this period the SPI48 in September 1992 was −3.71 and in December 1992 was −3.55. In the valley of the Notec river, covering a part of the region under consideration, the region of substantial and frequent water deficits in plant production, in the extremely dry year 1989 the precipitation sum was so low that the probability of not exceeding it was less than 1%. The crop of hay from non-irrigated grasslands was about 5 Mg ha^{-1} while in an average year (1987) the mean crop was 8–10 Mg ha^{-1}. This succession of the dry 1989–92 years caused the accumulation of negative impacts on aerial water retention, water supply conditions and agricultural production.

A similar coincidence of SPI and effects on agriculture was observed in 1982–83. The SPI12 in December 1982 was equal to −2.2 (extremely dry) and SPI6 = −2.1. In the growing season of 1982 (April–September) precipitation was nearly half that of 1951–90. The SPI6 in September 1983 was equal to −1.6 (severely dry). In the two very dry years 1982–83, an average decrease in grain crops was 5–30% and that of potatoes from 10 to 40%, compared to the average crop amounts in 1985–87.

The year 2000 was the next one with high drought risk. In April and May 2000 non-typical meteorological conditions occurred. Therefore drought monitoring using SPI was started in the region as the first in Poland. The course of the 1-, 3- and 6-month SPI values from October 1999 till September 2000 are shown in Figure 3. In agriculture the successive effects of droughts occurring before the analyzed period are important for evaluation of the harmful effects of droughts. For that reason timescales longer than 1 month (3-month and 6-month SPI) are also applied to reflect not only monthly but also the cumulative rainfall anomalies. The timescales of 2–6 months reflect well the negative effects of precipitation deficit in agriculture (soil moisture, groundwater table depth, crop yield) (Boken et al., 2005; Szalai and Szinell, 2000; Szalai et al., 2000).

Precipitation in the autumn–spring period of 1999/2000 was approximately normal, although SPI3 indicated moderate drought in October and November 1999. After-winter soil water reserves were sufficient at the beginning of the growing period of 2000 (approximate to field water capacity). Groundwater table was at a depth of 50–60 cm, which was optimal for grassland vegetation. From the beginning of the April drought, identified by the 1-month SPI, occurred in the region, classified as moderately dry. The SPI3 and SPI6 did not identify a drought event in that month, which means that the 3-month and 6-month precipitation sums were not significantly less than median. The last significant rainfall occurred on 16 April, with the sum of precipitation from 10 to 20 April only 9 mm. It caused systematic decrease of soil water reserves and groundwater tables. In the period between 20 and 30 April there were only 2 mm of rainfall. Soil moisture content decreased below the minimum admissible value and groundwater tables decreased below 1 m from which capillary rise did not meet crop water demands. The conditions changed radically for the worse in the first 10 days of May with a complete lack of rainfall (extremely dry period). These rainfall conditions are well reflected by SPI1 and SPI3, but not by SPI6. This situation with additionally high evaporation was an event threatening most crops. The beginning of June was the driest, which caused the
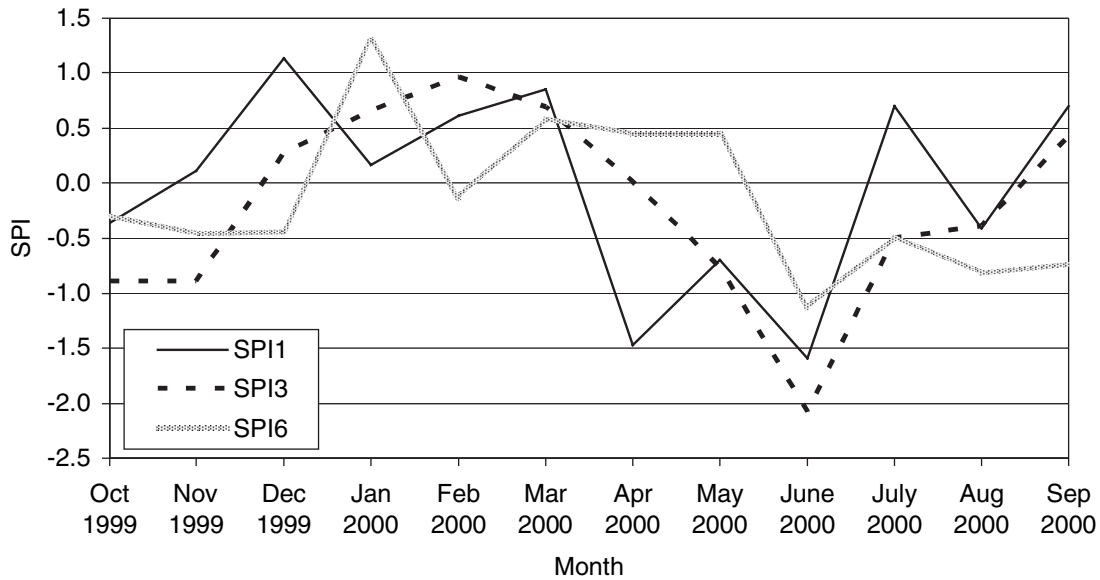
Figure 3. The course of the 1-, 3- and 6-month SPI from October 1999 through September 2000 at the Bydgoszcz IMUZ meteorological station

whole month to be classified as extremely dry on the basis of SPI1. The SPI3 also indicated a drought event, but only severe, and SPI6 indicated moderate. Meteorological conditions in the next months of the growing period were normal according to SPI1 and SPI3, but they did not reduce the negative effects of the spring drought in that year. In the whole period analyzed of October 1999–September 2000, the 6-month SPI identified droughts in June, July and August 2000, whereas SP1 and SPI3 did not detect droughts in those months. For small timescales of 1 and 3 months, each new month had a great impact on the precipitation sums in these periods so that SPI responsed quickly. For a larger timescale of 6 months the effect of very small precipitation since April 2000 reflected in SPI only in June 2000, after 3 months.

Analyzing the 1-, 3- and 6-month SPI values and comparing them with field observations and measurements of soil moisture content and shallow groundwater table depths, it can be said that the SPI6 seems not to reflect well the quick development of agricultural drought and the worsening actual state of water conditions in agricultural areas in that year. It is in good agreement with the results obtained by Bussay *et al*. (1998) and Szalai and Szinell (2000) who assessed that agricultural drought (described by soil moisture content) followed best the SPI on a scale of 2–3 months. Further analysis for multi-year periods should be done for the region to answer the question of which timescale best reflects the response of agricultural drought to precipitation anomalies.

CONCLUSIONS

The results of the analysis presented in this paper confirm that the standardized precipitation index SPI greatly helps to identify and characterize local droughts. The SPI is easy to use because it requires only precipitation data. Different timescales for which it is calculated make it possible to determine frequency and duration of meteorological droughts which are the result of rainfall anomalies in antecedent periods.

The analysis was made using the long 145-year set of monthly precipitation sums and it showed that the frequency of months in which drought was identified at the 3-, 6-, 12-, 24- and 48-month timescale, is about 30%. According to the equation as proposed in this study, the number of droughts of different duration in 100 years is statistically from 8 for a 48-month drought to 120 for a 3-month drought.

Comparing field observations and measurements of indices of agricultural and hydrological drought in 2000 (soil moisture, groundwater table depth) with meteorological drought, it has been shown that the 1–3 month SPI better reflects agricultural drought development than the 6-month SPI.

For a better understanding and characterization of droughts in agricultural areas additional indices should be used to evaluate impacts of meteorological drought on evapotranspiration, soil water content, groundwater depth and crop yield. It is worthwhile noting that in many cases not just one index, but several indices should be used for a better characterization of a given drought event in a given area. Other indices need to be investigated to form a system of indices giving the best evaluation of droughts in a given region. It is also urgent to investigate which timescale of SPI is the best to show agricultural and hydrological drought under the climatologic conditions of central Poland.

Finally, it should be noted that the SPI should be the first basic index for evaluating an agricultural drought hazard in a given region. For the full evaluation of agricultural drought risk, one should realize that drought is a relative rather than an absolute phenomenon and should be related to a given agricultural area, soil and crop. In addition, the SPI needs careful interpretation. It is a relative measure, indicating precipitation lower than normal for the period and location under consideration. For agriculture, meteorological drought and its index SPI are not so relevant, as the negative effects on crop production can be different for different crops and soils. In the location in which the study is concerned, the precipitation amount in an average year does not satisfy crop water demands and irrigation is necessary. According to the SPI methodology such conditions are treated as normal, whereas in agriculture they are often evaluated as dry for a particular crop and soil (e.g. sugar beet, potatoes, vegetables). From this point of view there is a need use a system of indices instead of just one index for a complex evaluation of meteorological and agricultural drought.

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