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Assessing drought severity with the relative precipitation index and the standardised precipitation index

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Abstract: Assessing drought severity is an element of the drought monitoring. The assessment of severity and frequency of dry periods in a given severity class depends on the assumed criteria of drought. Using the series of precipitation records in the growing periods of 1954-1998 from 6 meteorological stations located in Wielkopolska and Kujawy, the relative precipitation index *RPI* and the standardized precipitation index *SPI* have been calculated. In view of the lack of statistically significant differences in mean precipitation between selected stations, it has been assumed that the region is homogenous in that aspect. According to *RPI* and the Kaczorowska's criteria, dry months constituted 40 % of the growing periods. According to *SPI*, dry months amounted only 15 %. In the paper the values of both indices and their correlations are analysed. The reasons of significant differences in the frequency of occurrence of dry months are indicated. The indices are evaluated with regard to their applicability for drought monitoring.

Key words: *drought, precipitation, relative precipitation index (RPI), standardized precipitation index (SPI)*

INTRODUCTION

Droughts are the atmospheric and hydrological phenomena, which appear periodically in various seasons. Arising from the moisture deficit in soil and air, the droughts interfere in the water balance of a given area. A lack of precipitation or its inadequate amount during a longer period is the reasons for drought appearance. The risk of droughts is higher on areas with insufficient natural water resources. Negative precipitation anomaly is the most important factor to produce the so called meteorological drought.

Long term precipitation deficit is a consequence of the anticyclone (high pressure) circulation over the area. In Poland droughts are produced by the Azores and East European anticyclones. Series of such circulations may last for several months – e.g. in 1992 high pressure dominated over Poland from May till the end of August (BOBIŃSKI, MEYER, 1992; Miesięczny ..., 1992).

East European anticyclone, which brings over Poland dry and hot air masses from Balkans and Asia Minor or persistent anticyclone from Azores mostly favour the appearance and development of droughts. The phenomenon is intensified by high temperatures often exceeding 30-33ºC in the day and 20-18ºC in the night. Subsiding movements dominate during high pressure circulation, which makes air saturation with water practically impossible. Convective processes generating local storms are impeded in that way. Formation of Cb clouds takes place only occasionally but resulting small rain evaporates when precipitating due to a high temperature under the clouds. This is called a "dry storm".

Studies of droughts in Poland between 1951 and 1990 carried out by FARAT, KĘPIŃSKA-KASPRZAK and MAGER (1995) were based upon three criteria: the index of precipitation standards after Kaczorowska, precipitation deficit related to the long term average sum established for a given site and climatic water balance. They enabled to distinguish 21 periods of atmospheric droughts, which covered at least 50 % of the country area. Total sum of duration was 107 months i.e. 22 % of the analysed period. The longest 11 months drought was recorded between February 1982 and December 1982. Several other long droughts lasting 7-10 months were also distinguished within the studied period. The droughts were found to begin in the spring-summer season (65 %) and their further development depended upon atmospheric conditions.

To effectively counteract the drought effects and to undertake appropriate preventive measures one needs to have a checked and reliable indices of precipitation deficits and drought severity. Several such indices have been described in the literature (BYCZKOWSKI, MEYER, 1999; 2001), most of which were already applied in various world regions for practical drought monitoring. Widely used and recommended recently is the index of standardised precipitation *SPI* (How to work ..., 1998; ŁABĘDZKI, 2000, 2002; What is drought?).

This study was aimed to compare the *SPI* index with the index of relative precipitation *RPI* widely used up to now in meteorological and agrometeorological analyses and in water reclamation works.

MATERIAL AND METHODS

Long term records of precipitations (from the years 1954-1998) from stations Bydgoszcz, Toruń, Koło, Poznań, Polanowice near Kruszwica and Płock situated in the regions of Wielkopolska and Kujawy (Fig. 1) were used for analyses. There are other stations in the regions but only those listed possessed a common set of records.

Since droughts and semi-dry periods prevail in the spring-summer time (FARAT, KĘPIŃSKA-KASPRZAK, MAGER, 1995), comparative analyses of monthly precipitation records were made for months of the growing season (April-September) and for periodical sums of precipitation. *RPI* and *SPI* were calculated upon precipitation records for every month separately and for the sums of the whole vegetative period (April--September).

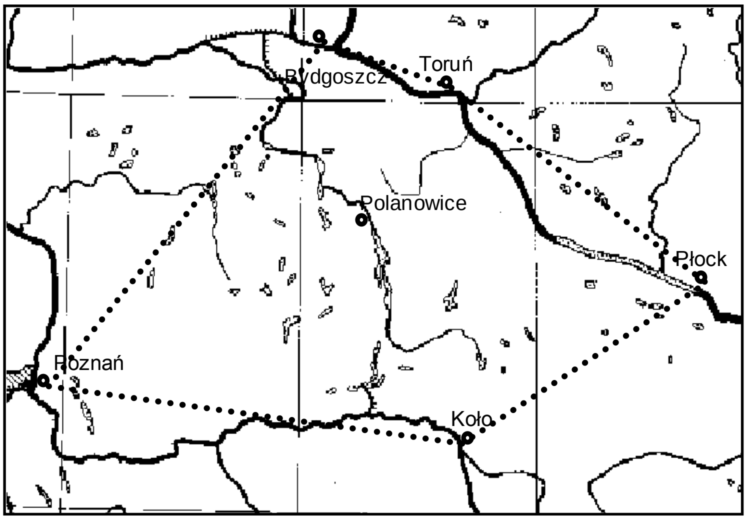

Fig. 1. Location of measurement stations

RPI is the ratio of precipitation sum for the given period *P* and the long term average for the same period $\overline{P}$ expressed in percent

$$RPI = \frac{P}{\overline{P}} \cdot 100\%$$

KACZOROWSKA (1962) proposed two comparative criteria: one related to monthly sums of precipitation and the other related to the annual sum of precipitation. She established 7 classes of precipitation sums (Tab. 1).

SPI was proposed by McKnee in 1993 and is now used for the operational drought monitoring by the U.S. National Drought Mitigation Centre (What is drought?). In Europe the index is used in Hungary, Italy and Spain. Attempts of using *SPI* for the drought monitoring in other countries (Republic of South Africa, Israel, Argentine) are also reported in the literature As in the case of *RPI*, the *SPI* is calculated from the long term precipitation records for a definite period of time. Appropriate probability distribution is fitted to obtained random sample checking its fitness with statistical tests (χ^2). Atmospheric precipitation is a random variable with the lower limit and often positive asymmetry and does not conform to the normal distribution. Most often periodical (10-days, monthly or annual) sums of precipitation conform to the gamma distribution (KACZMAREK, 1970) and therefore precipitation sequence is normalised with the transformation function *f*(*P*). Mean value μ and standard deviation δ are then estimated for the so transformed sequence.

Table 1. Classes of precipitation sums for different periods of time according to Kaczorowska

Period	Symbol	Percent of the average in:	
		month	quarter, year
Extremely dry	ss	0÷24.9	0÷49.9
Very dry	bs	25.0÷49.9	50.0÷74.9
Dry	s	50.0÷74.9	75.0÷89.9
Average	p	75.0÷125.9	90.0÷110.9
Wet	w	126.0÷150.9	111.0÷125.9
Very wet	bw	151.0÷200.0	126.0÷150.0
Extremely wet	sw	>200.0	>150.0

The same precipitation records were used for calculating *SPI* as for *RPI* and elements of the sequence were normalised with the transformation function

$$f(P) = u = \sqrt[3]{x}$$

where: x – the element of precipitation sequence.

Fitness of the distribution of transformed variable *f(P)* to the normal distribution was tested with the χ^2-Pearson's test and visually by checking whether the values of transformed variable plotted on the normal distribution scale form a straight line.

Values of the *SPI* for a given *P* were calculated from equation:

$$SPI = \frac{f(P) - \mu}{\delta}$$

where:

SPI – standardised precipitation index,
f(P) – transformed sum of precipitation
μ – mean value of the normalised precipitation sequence,
δ – standard deviation of the normalised precipitation sequence.

Classification of periods due to the deficit or excess of precipitation is performed upon the *SPI* values according to Table 2.

Because *SPI* are normalised, standardised precipitation values, threshold *SPI* for particular classes correspond to the definite probabilities of non-exceeding a given value of standardised precipitation (Tab. 3). For example a threshold *SPI* for extremely dry period ($SPI \leq -2.0$) corresponds to precipitation (with the lower) with a probability of occurrence of 2 %. $SPI = -3.0$ corresponds to the sum of precipitation (with the lower) with a probability of occurrence 0.1 %.

Table 2. Classification of weather periods according *to SPI* (What is drought?)

Period	*SPI*	Symbol
Extremely dry	≤ –2.0	es
Very dry	–1.99÷(–1.5)	bs
Moderately dry	–1.49÷(–1.0)	us
Normal	–0.99÷0.99	n
Moderately wet	1.0÷1.49	um
Very wet	1.5 ÷1.99	bm
Extremely wet	≥2.0	em

Table 3. *SPI* and corresponding cumulated probability

SPI	Cumulated probability	*SPI*	Cumulated probability
–3.0	0.0014	0.0	0.5000
–2.5	0.0062	+0.5	0.6915
–2.0	0.0228	+1.0	0.8413
–1.5	0.0668	+1.5	0.9332
–1.0	0.1587	+2.0	0.9772
–0.5	0.3085	+2.5	0.9938
		+3.0	0.9986

SPI can be used for various time periods; *SPI* for 1-3 months serves for monitoring short or seasonal droughts, *SPI* calculated for 12 months serves for monitoring many-months (medium term) droughts, that for 48 months – for long term droughts. Cumulated *SPI* values may be used to analyse drought severity. If we have sequences of monthly sums of precipitation and we want to calculate the *SPI* values for three-month periods than first element of a new sequence is the sum of the first three months, the second element is formed by summing precipitation in the 2^{nd}, 3^{rd} and 4^{th} month, the next is a sum from 3^{rd}, 4^{th} and 5^{th} month and so on (GUTTMAN, 1999).

The following statistics have been used for comparative analysis: frequency, correlations, mean values, mean standard deviations, variability coefficients, analysis of variance, tests of significance and Newman-Keuls test (ELANDT, 1964; KACZMAREK, 1970; STANLEY, 1976; WALEWSKI, 1989).

PRECIPITATION CHARACTERISTICS OF THE REGION

According to KONDRACKI (1998) the region is situated on Wielkopolsko-Kujawski Lakeland and comprises part of the Toruń-Eberswald Marginal Valley, Kujawy, Gniezno and Kłodawa Uplands and part of the Warsaw-Berlin Marginal Valley. It is a typically lowland area with most grounds situated 50–100 m a.s.l.

The region belongs to areas where droughts appear most frequently. It is also the region of the lowest sums of precipitation both annual and during the vegetation period. Such conditions are the reason for frequent and pronounced water deficits in agriculture. Characteristic is a temporal variability of atmospheric precipitation (Tab. 4, Figs. 2, 3). Azores anticyclone significantly affects weather and precipitation during summer. Centres of high pressure move usually over Wielkopolska Lowland in summer and early autumn on over 10 % days in July, August and October. Low pressure appears most often in the spring months – in April and May. Over 15 % of days in April are the days with moving barometric systems of low pressure (WOŚ, 1994).

Table 4. Mean sums of precipitations in the vegetation period, standard deviations and coefficients of variability

Locality	Mean mm	Standard deviation mm	Variability coefficient %
Bydgoszcz	327.4	92.3	28.2
Toruń	341.7	91.5	26.8
Płock	337.3	81.5	24.2
Koło	328.6	78.1	23.8
Poznań	323.5	84.8	26.2
Polanowice	312.4	84.8	27.2

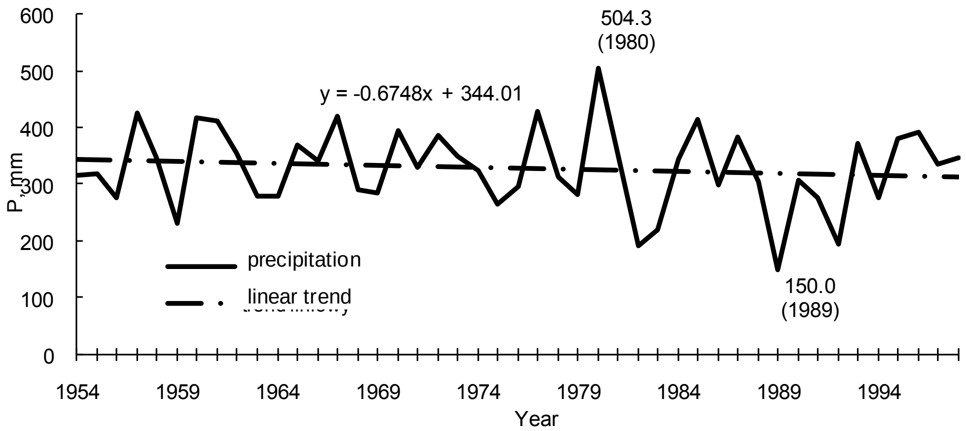

Fig. 2. Mean sums of precipitation in the vegetation periods of the years 1954-1998

The belt of middle lowland part of Poland with the annual difference between evaporation and precipitation amounting 200–300 mm (PRZEDPEŁSKA, 1971; SCHMUCK, 1969) is most exposed to droughts. Mean annual sums of precipitation in the years 1951-1980 in the eastern part of Wielkopolska Lowland did not usually exceed 550 mm and during the vegetative period – 320 mm (WOŚ, 1994). Gniezno Lakeland, part of Kujawy and of Poznań Lakeland are poorest in precipitation. These calculations are in concordance with results obtained by WÓJCIK and TOMASZEWSKI (1987) for the period 1951–1970. According to ROJEK and ŻYROMSKI (1994) mean

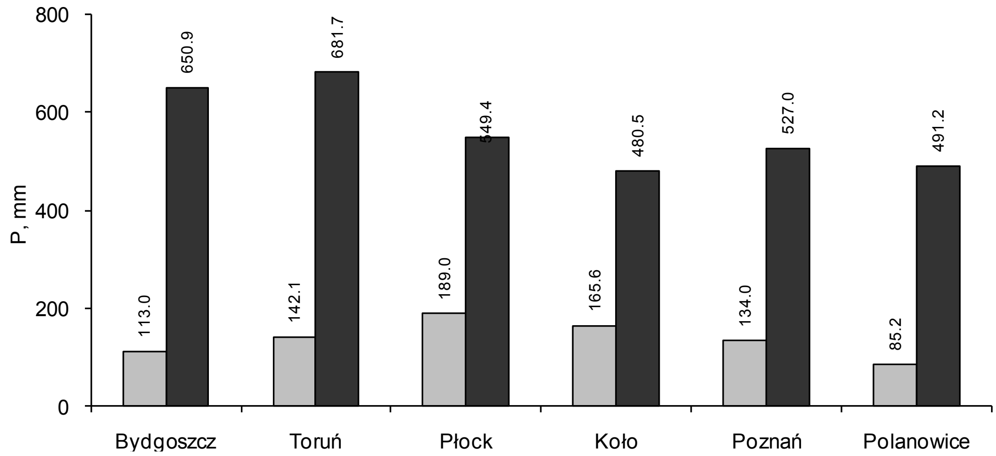

Fig. 3. Minimum and maximum sums of precipitation in the vegetation periods of the years 1954 -1998

sum of precipitation for the vegetative period in the years 1951–1990 was 337 mm in Toruń, 342 mm in Płock, 331 mm in Koło and 319 in Poznań.

Mean precipitation for the vegetative period (April-September) of the years 1954–1998 was 327.4 mm in Bydgoszcz, 341.7 mm in Toruń, 337.3 mm in Płock, 328.6 mm in Koło, 323.5 mm in Poznań and 312.4 mm in Polanowice (Tab. 4). Mean precipitation in the region calculated as an arithmetic mean from these 6 stations was 328.5 mm and ranged from 150.0 mm in 1989 to 504.3 mm in 1980 (Fig. 2). There was a tendency (though not statistically significant) of decreasing mean precipitations in the region during the vegetative period of the years 1954-1998. This trend resulted from records of the years 1988-1992.

Minimum monthly precipitation (2 mm) was noted in Płock in April 1988, maximum (316.5 mm) – in June 1980 in Bydgoszcz. The most dry vegetation period (April--September) was that in 1989 in Polanowice – only 85.2 mm rainfall was recorded there. Most wet was the season of 1980 in Toruń – 681.7 mm (Fig. 3).

One of the criteria to determine drought spells is the method of sequences of precipitation-free days. According to KONOPKO (1988) between 1950 and 1983 in Bydgoszcz drought spells lasting 10 to 20 days occurred on average 3.6 times a year ranging from 1 to six times. Drought spells lasting 20-30 days occurred once (0-3 times) a year. Drought spells of duration over 30 days also happened every 0.4 year on the average. It appears from KOŹMIŃSKI (1986) and KOŹMIŃSKI, GÓRSKI and MICHALSKA (1990) that between 1951 and 1970 on Wielkopolskie Lakeland the precipitation free periods longer than 15 days occurred with a frequency of 80 % and in Kujawy in the years 1951–1980 with a frequency of 70 %. There were 10–12 sequences of precipitation-free periods lasting longer than 15 days during the vegetative seasons of the years 1964–1978 on Kujawy (CZAPLAK, 1996).

Smaller summer precipitation in Polanowice and Koło (Tab. 4) can be explained e.g. by a small contribution of rain from storm phenomena. Storm track near Bydgoszcz-Włocławek runs closer to the Vistula and then moves eastward. A tendency of decreasing precipitation towards the centre of Kujawy was also noted by KONOPKO (1988). In spite of a large year-to-year differentiation of precipitation during the vegetative seasons, mean sums of precipitation at selected stations were similar. To analyse the significance of differences in mean precipitation at six stations we used Newman-Keuls test assuming a null hypothesis of a lack of such differences. Obtained significance levels (Tab. 5) higher than 0.05 demonstrate a lack of differences between stations. Therefore one may take it for granted that the stations represent the Bydgoszcz-Kujawy area as a region of uniform precipitation.

Table 5. Significance levels of differences between stations in mean precipitation during the vegetation periods calculated by the Newman-Keuls test

Locality	Bydgoszcz	Toruń	Płock	Koło	Polanowice	Poznań
Bydgoszcz	–	0.57	0.64	0.91	0.36	0.72
Toruń		–	0.69	0.46	0.89	0.47
Płock			–	0.43	0.16	0.59
Koło				–	0.46	0.88
Polanowice					–	0.32
Poznań						–

RELATIVE PRECIPITATION INDEX

Table 6 presents the occurrence of months and vegetation periods between 1954 and 1998, which belong to a definite class of droughts according to Kaczorowska.

In the years 1954-1998 there were 107 months in the region drier than the average (ss + bs + s**)** and these months constituted 40 % of the whole summer season. Extremely dry periods ss (12 on average) contributed the least. There were three times more (36) very dry periods bs. The greatest contribution was found for dry months s – c. 59. Most months with drought (113) were noted in Polanowice, the least (102) in Poznań. Most extremely dry months (14–15) were recorded at these stations. On average there were 17 dry vegetative periods, which made 38 % of the total.

Table 6. Frequency of occurrence of drought classes according to *RPI* and criteria formulated by Kaczorowska for the years 1954-1998

Symbol	IV	V	VI	VII	VIII	IX	IV-IX	Σ (IV-IX)
				Toruń				
ss	1	1	0	3	3	2	1	10
bs	3	6	6	6	4	7	6	32
s	12	10	14	9	8	11	9	64
Σ	16	17	20	18	15	20	16	106
				Koło				
ss	3	2	0	0	3	3	0	11
bs	5	6	7	6	5	7	5	36
s	6	8	13	13	9	9	13	58
Σ	14	16	20	19	17	19	18	105
				Bydgoszcz				
ss	1	3	0	3	3	2	2	12
bs	3	6	6	9	3	7	4	34
s	15	11	16	7	8	8	9	65
Σ	19	20	22	19	14	17	15	111
				Płock				
ss	3	0	1	0	2	4	0	10
bs	4	9	1	11	6	5	8	36
s	12	10	11	4	6	15	10	58
Σ	19	19	13	15	14	24	18	104
				Poznań				
ss	2	1	4	3	2	3	2	15
bs	5	6	6	9	6	7	4	39
s	9	12	7	7	5	8	10	48
Σ	16	19	17	19	13	18	16	102
				Polanowice				
ss	2	3	1	3	1	4	2	14
bs	7	5	9	7	4	9	6	41
s	7	14	8	10	10	9	8	59
Σ	16	22	18	20	15	22	16	113

Symbols: ss , bs and s as in Table 1.

Based upon the Kaczorowska's drought classes, the centre of Kujawy characterised by records from Polanowice can be recognised the driest region. The highest frequency of the ss periods was observed in September, that of bs – in July and that of s – in June (Fig. 4).

In driest months monthly sums of precipitation did not exceed 10 mm. Extremely low monthly precipitation (2–3 mm) was recorded in April 1988 in Polanowice and

Płock. The next season (half year of 1989) appeared to be equally dry e.g. May, July and September in Polanowice and the period April-September were classified as extremely dry and April and June – as very dry. Since April till the end of September there was only 85.2 mm of precipitation there, which made 27 % of the average precipitation for the growing season.

Summer season of 1989 was extremely dry or very dry also at other stations. In Bydgoszcz *RPI* for the whole vegetative period was 35 %, in Toruń – 42 %, in Koło – 51 %, in Płock – 56 % and in Poznań – 63 % (Fig. 5). The most severe drought in the whole region was noted in May, which was sunny, hot and free from precipitation. 8–14 days were recorded with mean daily temperature ≥15°C and 12–18 days with the maximum temperature ≥20°C. There was soil drought in many regions already in the beginning of May (Miesięczny ..., 1989). July was also very dry with 10-16 days with a temperature ≥25°C. On 7–10 July in Toruń mean daily temperature exceeded 26°C (max. 26.8°C). September was also warm and dry. There were 22 days with the maximum temperature over 20.0°C in Toruń and Koło (Miesięczny ..., 1989).

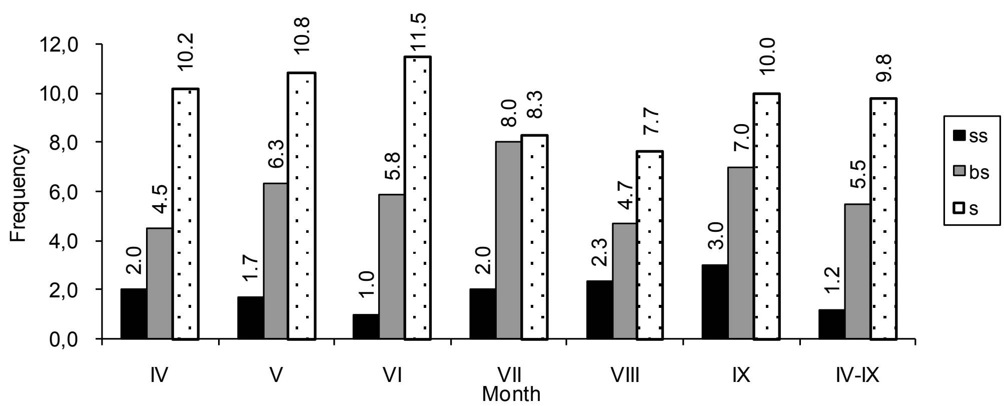

Fig. 4. Mean frequency of drought classes according to Kaczorowska

Analysing all precipitation sequences one can see that the distribution of the Kaczorowska's index is not uniform over the whole region. Decreasing or increasing the index and hence prescribing it to a definite class may depend on local rainfalls. In dry periods local precipitation is usually associated with the movement of barometric fronts. Agrometeorological bulletins often contain the information on short-term weather changes, during which intensive rainfall is possible in amounts close even to the monthly mean for the site. Later on, there may be no rain for several dozen days (drought spell) but this does not change the index. The phenomenon was confirmed by studies on drought spells in the Bydgoszcz region (KONOPKO, 1988). For example mean summer precipitation in Bydgoszcz in 1975 was 315 mm but at the same time 5 drought spells were recorded lasting from 15 to 41 days, during which the total rainfall was only 17 mm.

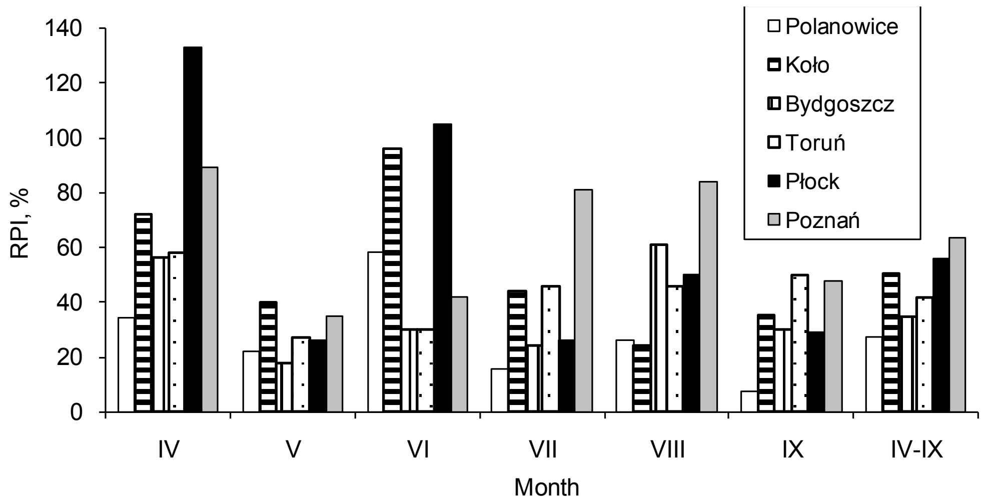

Fig. 5. The course of the *RPI* index in the 1989

STANDARDISED PRECIPITATION INDEX

SPI was calculated for particular months and for the whole vegetative period. Based on these results the frequency of drought periods was established (Tab. 7).

Between 1954 and 1998 there were 41 months drier (es + bs + us) than average, which made up 15 % of the whole summer season. The least contribution was found of extremely dry periods es – only 6 were noted on average in the region. There were twice that (11) very dry periods bs. Most numerous were moderately dry months us – 25. Most drought periods according to the *SPI* were recorded in Koło (48 months) and the least in Toruń (33).

Two areas could be distinguished in the whole region, on which the frequency of dry periods was higher. One involved Koło – Polanowice – Płock and the second was situated near Poznań.

Summary frequency of the drought classes in the region (Fig. 6) achieved the highest values in July (8.0) and the lowest in April (6.3). April is an intermediate month between winter and spring, hence a high variability of weather conditions. Sum of precipitation in the beginning of the month may be close to monthly average and later lack of precipitation does not diminish the *SPI* of the whole month.

Table 7. Frequency of occurrence of the drought periods according to *SPI* in the years 1954–1998

Symbol	IV	V	VI	VII	VIII	IX	IV-IX	Σ(IV-IX)
				Toruń				
es	1	1	0	0	3	1	2	6
bs	2	2	1	3	0	1	0	9
us	2	4	4	3	2	3	4	18
Σ	5	7	5	3	5	5	6	33
				Koło				
es	3	1	0	0	0	3	2	7
bs	0	2	0	4	4	0	1	10
us	5	4	10	2	4	6	3	31
Σ	8	7	10	6	8	9	6	48
				Bydgoszcz				
es	1	1	0	1	2	2	2	7
bs	2	2	0	1	1	0	1	6
us	1	4	5	8	3	5	1	26
Σ	4	7	5	10	6	7	4	39
				Płock				
es	2	0	1	0	1	1	1	5
bs	1	3	1	3	2	3	1	13
us	3	4	3	7	5	3	6	25
Σ	6	7	5	10	8	7	8	43
				Poznań				
es	1	1	2	1	2	2	2	9
bs	4	0	2	2	2	2	1	12
us	2	6	3	5	4	2	3	22
Σ	7	7	7	8	8	6	6	43
				Polanowice				
es	1	0	0	0	1	2	2	4
bs	2	3	3	3	2	0	1	13
us	5	5	5	5	2	3	1	25
Σ	8	8	7	8	5	5	4	42

Symbols: ss , bs and s as in Table 1.

Under favourable weather conditions along with increasing daytime, increasing solar radiation, increasing maximum and mean daily temperatures the summary value of the index increases. In May it achieved 7.2 and it was its second maximum. In other months the value remained at nearly constant level 6.5–6.7.

In August 1984 the lowest monthly *SPI* was noted for the whole analysed period. Monthly sum of precipitation in Toruń was only 2.7 mm, which corresponded to the

SPI = –3.14. Severe drought occurred also in the same month in Płock (*SPI* = –2.94, precipitation 4.4 mm). At the same time *SPI* in Koło achieved 0.86 and in Polanowice 0.04. Intensive storm precipitation in the beginning of the months (Miesięczny ..., 1984) were responsible for such an increase.

The driest summer period measured with the *SPI* was that in 1989 in Polanowice. *SPI* for the season (April-September) was –3.47.

Table 8 presents a list of extremely low monthly and seasonal values of the *SPI*. Noteworthy, *SPI* for the summer season of 1989 in Polanowice was smaller than the lowest monthly value, which proves the extreme drought of the whole half-year.

Drought in 1989 was reflected in values of the *SPI*. Except for Poznań (bs: *SPI* = –1.45) the whole summer can be classified as extremely dry (es). The lowest *SPI* was noted in Polanowice. In the remaining stations the *SPI* was equal: –3.01 in Bydgoszcz, –2.78 in Toruń, –2.12 in Płock and –2.78 in Koło. Fig. 7 presents the course of *SPI* in the summer season of 1989.

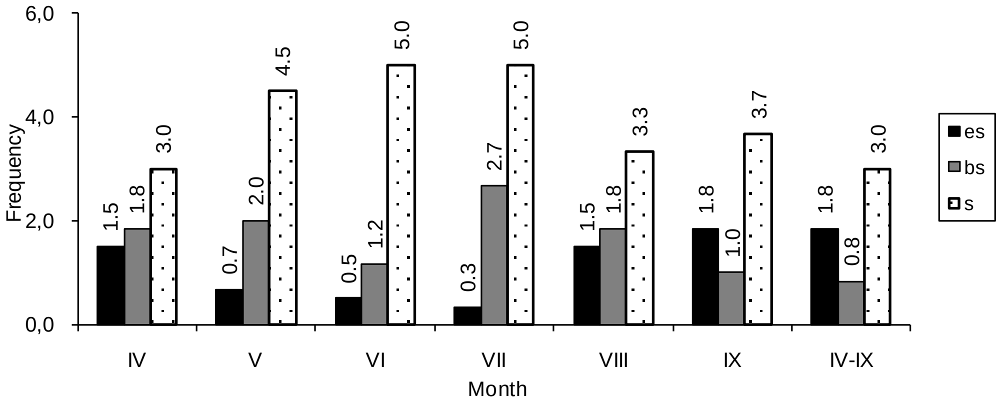

Fig. 6. Mean frequencies of the drought periods according to *SPI*; es, bs and s as in Table 2

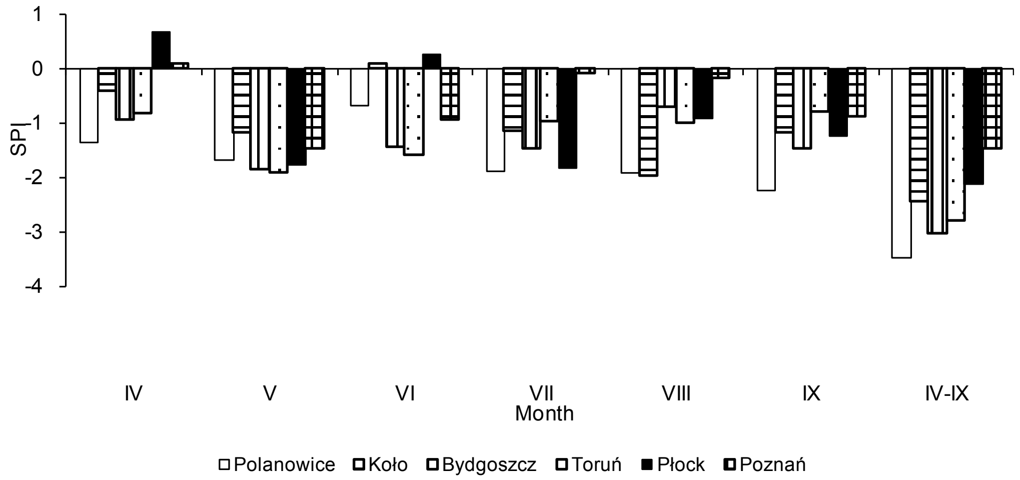

Fig. 7. The course of *SPI* in the 1989

Table 8. Extremely low monthly values of *SPI* (1954–1998)

Month	*SPI*	Year	Station
April	–2.68	1988	Płock
May	–2.66	1990	Koło
June	–2.69	1994	Płock
July	–2.23	1963	Poznań
August	**–3.14**	1984	Toruń
September	–2.60	1982	Bydgoszcz
April-September	**–3.47**	1989	Polanowice

COMPARISON OF THE *RPI* AND *SPI*

The course of mean *RPI* and *SPI* (Fig. 8) against threshold values of the classes of dry periods (*RPI*: s – dry, bs – very dry, ss – extremely dry and *SPI*: us – moderately dry, bs – very dry, es extremely dry) shows a good agreement in changes of the indices and trends show simultaneous decline of both. In spite of the visible decreasing tendency the trends were insignificant at $p = 0.05$.

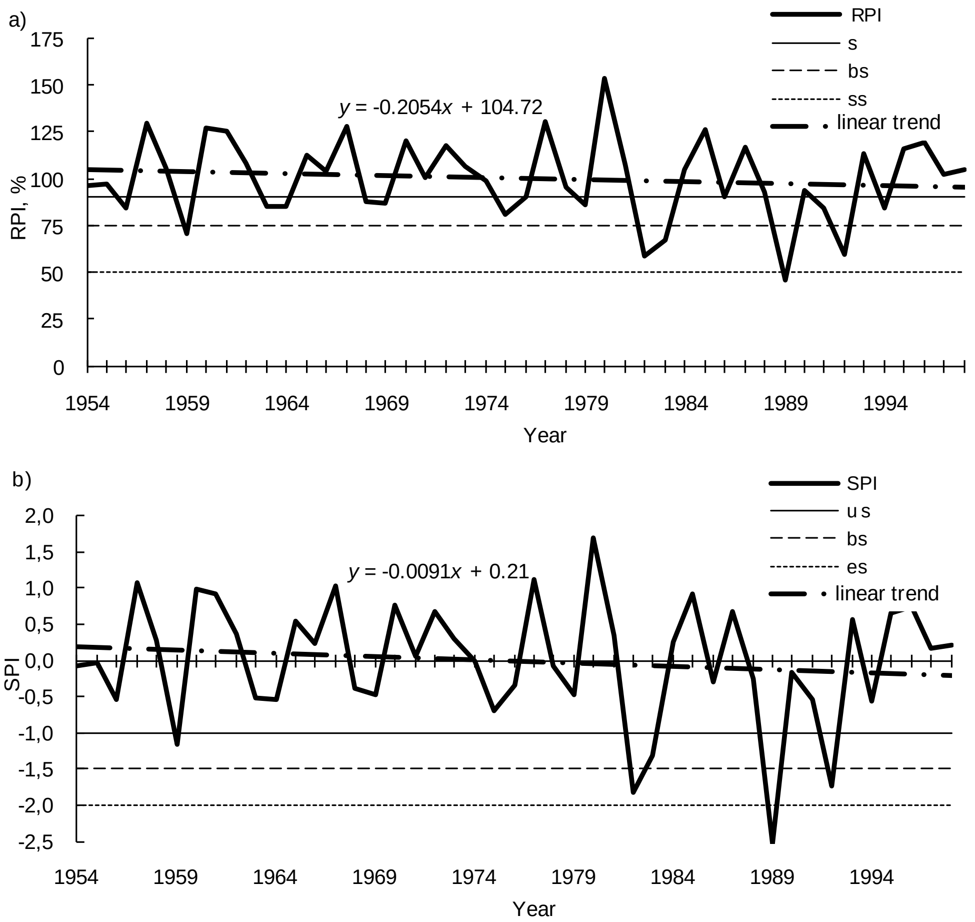

Fig 8. The course of mean values of *RPI* (a) and *SPI* (b) in the region for the vegetative periods against the threshold values of drought periods; s, bs, ss as in Table 1, us, bs, es as in Table 2

Visualisation of the simultaneous course of *RPI* and *SPI* is presented in Tab. 9 for August 1980–1989 in Toruń and Polanowice and for all stations in the years 1989 and 1992 in Fig. 9. There were some regularities observed in all years and at all stations:

– for *SPI* < –1 *RPI* was certainly <75 %,

– if *RPI* < 75 % then *SPI* was not necessarily <–1, most often –1 < *SPI* < 0.

Table 9. *SPI* and *RPI* values in Toruń and Polanowice (August 1980–1989)

Year	Toruń		Polanowice	
	SPI	*RPI* %	*SPI*	*RPI* %
1980	–0.63	59.7	–0.54	67.7
1981	0.30	107.5	–0.58	66.0
1982	–1.35	34.5	–1.88	27.2
1983	–0.32	73.4	0.49	117.4
1984	–3.14	4.4	–0.27	79.1
1985	2.09	258.9	2.16	242.1
1986	0.67	131.6	–0.17	83.4
1987	0.32	108.5	–0.44	71.6
1988	–0.19	79.7	–0.69	61.9
1989	–0.99	46.2	–1.92	26.2

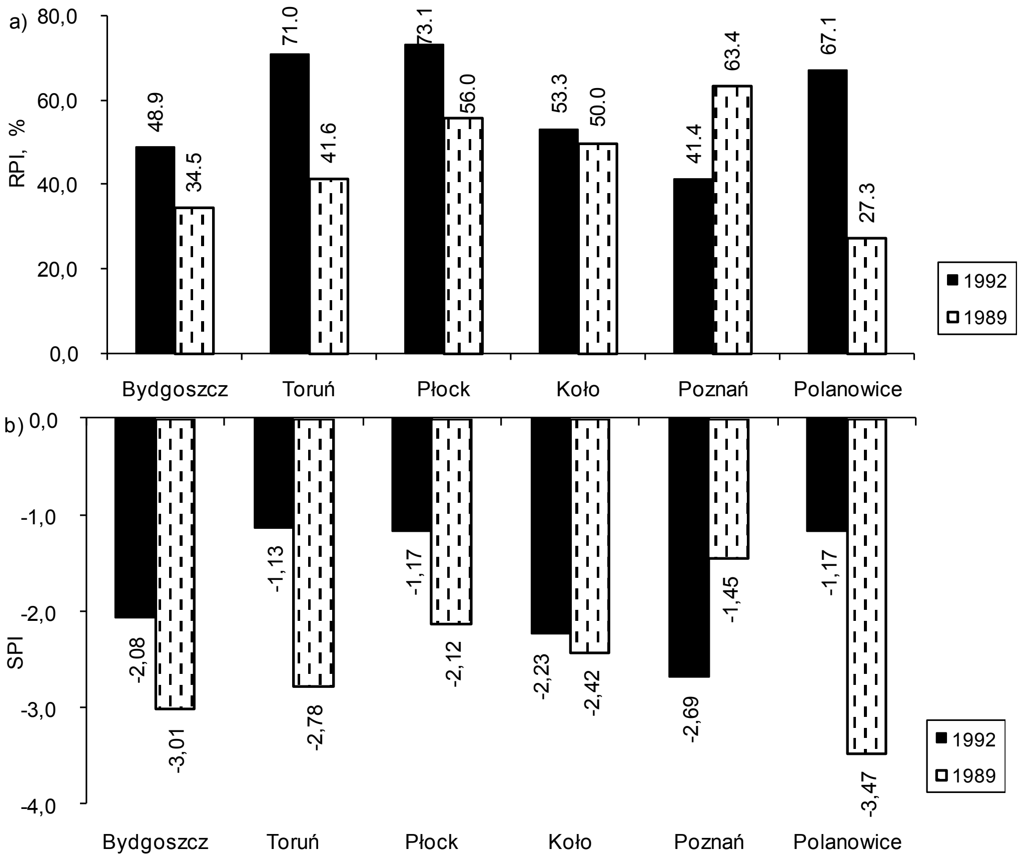

Fig. 9. *RPI* (a) and *SPI* (b) in 1989 and 1992

It can thus be concluded that *RPI* classifies a given period to the first class of drought (s) at a higher precipitation than does *SPI*.

Correlations between *RPI* and *SPI* to evaluate their concordance were calculated according to the following criteria:

– correlations for the whole observation sequences i.e. containing all possible precipitations classes from very wet to extremely dry – Tab. 10,
– correlations for only dry periods according to *SPI* (months were selected on the assumption that *SPI* < –1.0) – Tab. 11,
– correlations for only dry periods according to *RPI* (months were selected on the assumption that *RPI* < 75 % for one-month periods and *RPI* < 90 % for longer periods) – Tab. 12.

Table 10. Correlation coefficients between *RPI* and *SPI* for all classes of precipitation in the years 1954--1998

Locality	IV	V	VI	VII	VIII	IX	IV-IX
Bydgoszcz	0.97	0.97	0.95	0.96	0.94	0.96	0.98
Toruń	0.96	0.97	0.96	0.97	0.95	0.96	0.99
Płock	0.95	0.97	0.97	0.98	0.96	0.96	1.00
Koło	0.97	0.96	0.98	0.99	0.97	0.97	1.00
Poznań	0.97	0.98	0.97	0.97	0.96	0.97	0.99
Polanowice	0.95	0.98	0.97	0.97	0.97	0.97	0.99

Table 11. Correlation coefficients between *RPI* and *SPI* for dry periods (*SPI* < –1.0) in the years 1954--1998

Locality	IV	V	VI	VII	VIII	IX	IV-IX
Bydgoszcz	0.98	1.00	1.00	0.96	0.99	0.99	0.94
Toruń	0.99	1.00	1.00	1.00	0.98	1.00	1.00
Płock	0.99	1.00	0.83	0.85	0.76	0.79	1.00
Koło	1.00	0.99	1.00	1.00	1.00	1.00	1.00
Poznań	0.99	0.99	0.99	1.00	1.00	0.99	0.99
Polanowice	0.99	1.00	1.00	1.00	1.00	1.00	1.00

Table 12. Correlation coefficients between *RPI* and *SPI* for dry periods (*RPI* < 75 % for monthly periods and *RPI* < 90 % for multi-monthly periods) in the years 1954-1998

Locality	IV	V	VI	VII	VIII	IX	IV-IX
Bydgoszcz	1.00	0.99	1.00	0.91	0.99	0.98	0.99
Toruń	0.99	0.99	1.00	0.99	0.98	0.99	1.00
Płock	0.98	1.00	0.99	0.99	0.97	0.99	1.00
Koło	0.99	0.98	1.00	1.00	1.00	0.99	1.00
Poznań	0.99	0.99	0.98	0.98	0.99	0.98	1.00
Polanowice	0.98	0.99	0.99	0.99	1.00	0.98	0.99

High (0.9–1.0), positive and significant at $p < 0.01$ correlation coefficients between *RPI* and *SPI* (Tab. 10-12) indicate a good agreement between the two indices.

Comparison of data presented in Tabs 4 and 7 indicates significant differences in the frequency of drought classes. According to *SPI* there were 41 dry month in the region (total of all classes) which corresponds to 38 % frequency of drought classes according to *RPI*. In the respective classes the relationships were: 53 % (ss and es), 29 % (bs) and 42 % (s and us). The greatest difference was found in the bs class. In the s class nearly 58 % periods already classified as dry according to *RPI* and Kaczorowska's classes were prescribed by the *SPI* to the average periods. It is a result of the fact that *SPI* classifies precipitation deficits to appropriate drought classes more rigorously.

These differences were reflected in correlations between the frequency of occurrence of the drought classes according to *SPI* and *RPI* in the years 1954–1998 (Tabs 13 and 14). The highest positive correlations were found for classes ss and es and for bs and bs, the highest correlation coefficient (0.66) was calculated for Płock and than for Bydgoszcz (0.57), the lowest – for Polanowice (0.01). The coefficients were, however, insignificant. Significant correlations were also lacking in the remaining classes and in some cases the coefficients were negative which proved total disagreement of the values in a given class.

Table 13. Correlation coefficients between the frequencies of drought classes according to *RPI* and *SPI* in the years 1954–1998 at particular stations

Locality	*RPI*	*SPI*							
		es		bs		us		Σ(es+bs+us)	
		r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
1	2	3	4	5	6	7	8	9	10
Bydgoszcz	ss	0.57	0.17	–	–	–	–	–	–
	bs	–	–	–0.37	0.41	–	–	–	–
	s	–	–	–	–	–0.33	0.47	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	0.14	0.77
Poznań	ss	0.41	0.36	–	–	–	–	–	–
	bs	–	–	0.01	0.97	–	–	–	–
	s	–	–	–	–	0.23	0.61	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	–0.19	0.67
Koło	ss	0.47	0.29	–	–	–	–	–	–
	bs	–	–	–0.35	0.44	–	–	–	–
	s	–	–	–	–	0.05	0.91	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	0.22	0.63
Toruń	ss	0.33	0.46	–	–	–	–	–	–
	bs	–	–	0.02	0.97	–	–	–	–
	s	–	–	–	–	0.23	0.62	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	–0.18	0.69

cont. tab. 13

1	2	3	4	5	6	7	8	9	10
Płock	ss	0.66	0.11	–	–	–	–	–	–
	bs	–	–	0.60	0.16	–	–	–	–
	s	–	–	–	–	–0.81	0.02	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	–0.08	0.86
Polanowice	ss	0.21	0.64	–	–	–	–	–	–
	bs	–	–	–0.23	0.62	–	–	–	–
	s	–	–	–	–	0.21	0.66	–	–
	Σ(ss+bs+s)	–	–	–	–	–	–	0.29	0.53

Symbols: ss, bs and s as in Table 2, *r* – correlation coefficient, *p* – significance level.

Table 14. Correlation coefficients between the frequencies of drought classes according to *RPI* and *SPI* in the years 1954-1998 cumulatively at all stations

RPI	*SPI*							
	es		bs		us		Σ(es+bs+us)	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
ss	0.42	0.01						
bs			0.89	0.58				
s					-0.14	0.38		
Σ(ss+bs+s)							0.50	0.75

Symbols: ss, bs and s as in Table 2, *r* – correlation coefficient, *p* – significance level.

Correlation of the frequency between the classes of the driest periods calculated for all stations was positive (0.42) and significant at $p < 0.01$. In the remaining classes, in spite of high positive correlation coefficients, correlations were insignificant.

SUMMARY AND CONCLUSIONS

Analysed indices of precipitation deficit *RPI* and *SPI* are basic and necessary data that inform on a possibility of occurrence of other types of drought i.e. soil and hydrological droughts.

According to the *SPI* there were 41 dry months in the region of Bydgoszcz and Kujawy, which corresponded to 38 % frequency of the drought classes according to the *RPI* and the Kaczorowska's criteria. The greatest differences of the frequencies were found in the very dry class bs. According to the mean precipitation in the region and the values of *RPI* and *SPI* the vegetative period of 1989 was the driest in the whole analysed period. This confirms the finding of FARAT, KĘPIŃSKA-KASPRZAK and MAGER (1995) that the decade 1981-1990 had the highest frequency of the drought occurrence.

SPI is the standardised index i.e. it refers precipitation to a common reference level (as pressure is referred in meteorology to the sea level). Therefore, one can compare precipitation excess or deficit in various regions and seasons differing in precipitation. *RPI* refers the precipitation to the mean value and hence it is the index that should be used in comparing uniform precipitation sequences of similar mean values. At a high differentiation of the mean precipitation (e.g. 500 mm and 1000 mm) and the same *RPI* (e.g. 50 %), precipitation deficit can be assessed only in relation to the drought effects. Methodically, *SPI* is the better index than *RPI* for its objectiveness due to standardised precipitation dealt with as a random variable. It is also more useful for atmospheric drought monitoring due to its two features: a possibility of changing the temporal scale and unequivocal results of measurements.

Obtained results on the frequency of months and vegetation periods in the definite drought classes and correlations between *RPI*, *SPI* and the frequencies lead to the conclusions:

1. There was a good agreement in the course and changes of the *RPI* and *SPI* in the studied region and time period.

2. There was no agreement on classifying periods to a given drought class

3. There was no agreement on the occurrence of months of the vegetation period qualified to particular drought classes. The differences originate from the methods of classifying months and longer periods to particular drought classes. Kaczorowska's criteria based on the *RPI* are "milder" in assessing drought periods and therefore the frequency of occurrence of the dry periods is nearly three times higher than with the *SPI*.

4. *SPI* is based on more severe criteria of classifying precipitation deficits, especially to the first class of dry periods (s).

5. *SPI* is more rigorous in the drought assessment i.e. precipitation deficit must be larger to be classified to appropriate drought class.

6. There is a disagreement on threshold values of the drought classes.

Full assessment of the indices can be done in relation to the drought effects when one attempts to answer the question, which one better correlates with the soil or hydrological drought. The division of indices among classes should be further evaluated in reference to the aim and user of the information on the drought severity. The usefulness of analysed drought indices for the operational, current drought evaluation in shorter periods (week, ten-days) should also be estimated.

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STRESZCZENIE

Ocena intensywności susz przy użyciu wskaźnika względnego opad (*RPI*) i wskaźnika standaryzowanego opadu (*SPI*)

Słowa kluczowe*: susza, opad, wskaźnik względnego opadu (RPI), wskaźnik standaryzowanego opadu (SPI)*

Jednym z elementów monitorowania suszy jest ocena jej intensywności. Ocena ta, jak również częstość występowania okresów suchych w danej klasie intensywności, zależy od przyjętych kryteriów suszy, czyli od wybranego wskaźnika suszy. Na podstawie ciągów opadowych okresu wegetacji z lat 1954-1998, z 6 stacji pomiarowych leżących na obszarze Wielkopolski i Kujaw, obliczono wskaźniki względnego opadu *RPI* i standaryzowanego opadu *SPI*. Na podstawie stwierdzonego braku istotnych statystycznie różnic między średnimi sumami opadów na wybranych stacjach przyjęto, że wybrany region jest jednorodny pod względem wielkości opadów. Według *RPI* i kryterium Kaczorowskiej miesiące suche stanowiły 40% całego okresu wegetacji. Według wskaźnika standaryzowanego opadu *SPI*, miesiące suche stanowiły tylko 15%. W pra-

cy przeanalizowano przebieg wartości obu wskaźników i wzajemne związki statystyczne, zbadano przyczyny istotnej różnicy występowania miesięcy suchych w oparciu o te wskaźniki oraz oceniono każdy z nich pod kątem przydatności do monitorowania suszy.

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