SPATIOTEMPORAL CHARACTERISTICS OF DROUGHT EPISODES IN CZECHIA*

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This paper presents the results of a study on the assessment drought episodes in Czechia. The assessment is conducted on 47 years (1961–2007) of meteorological information from 50 weather stations including monthly rainfalls and temperature series recorded at the Czech Hydrometeorological Institute (CHMI). The drought episodes were determined by three methods: according to the values of Standardized Precipitation Index (*SPI*), percent of long-terms precipitation (*r*) and on the basis of aridity index (*Si*). The *Si* combined effects of temperature and precipitation in drought monitoring, while the *SPI* is based solely precipitation data. The *r* is permitting quite very effective estimate of drought episodes when used for a single region or a single season. Consequently, it combining of indices *SPI*, *Si* and *r* as tools in identification of severity, frequency and extend of drought episodes has been used**.** Having analysed the characteristic features of the drought in the CR, we can state that approximately every 5th year suffers from severe drought during the spring and/or summer. In the meantime, severe intensity droughts are most frequent in April and July (it occurring throughout most of the entire country with a guarantee of 95%), while in June droughts are mostly middle and moderate. However, the spatial distribution of drought episodes can be very diverse. The extreme drought episodes usually affected wide areas of Czechia, but sometimes a drought episode affects one region, whilst other areas are subject to humid conditions. According to Poisson's law an increased frequency of the widespread and very widespread droughts has been noticed, together with diminishing intervals between them.

SPI; aridity index *Si*; register of droughts

INTRODUCTION

This complex study of drought brings important theoretical contributions, since it allows a more detailed and causal knowledge of this event and of its role in the characterization of the climate of the territory. Also, the study of droughts has a special practical importance since, it offers the reference material for the redistribution of crops in the territory, i.e. the development of the most suitable agricultural technology and the choice of the species that can resist and produce most under the given conditions.

An increasing frequencies and magnitude of drought event, thereby it is the focus of current research from the local to global scale. This tendency has been recorded in the 20th century and particularly in the last decade 1990–2000, which likewise was the warmest decade in the past century (IPCC, 2007). Over the past decade, significant progress has been made in drought studies worldwide. An increasing number of studies are focusing on drought risk and vulnerability assessment, drought monitoring and early warming, drought policy and mitigation activities (National Drought Mitigation Center, Wilhite, 2000b). With respect to studies of drought episodes pattern in Czechia, many climatologists have studied the frequency, intensity and duration of this event using diverse methods (Dubrovsky et al., 2005; Trnka et al., 2006; Kožnarová, Klabzuba, 2002; Brázdil et al., 2008; Potop, Türkott, 2007; Potop et al., 2008). The intensifying warming of the global climate leads to an increase in the probability of manifestation of climatic risks at regional level. Drought is the costliest and slow-onset cumulative climate hazard of the world and affects more people than any other natural disaster (Wilhite, 2000a). The recent wave of drought episodes was experienced not only in Southern Europe but also throughout Central Europe during 2000, 2003, 2006 and 2007 (Vicente-Serrano, Cuadrat-Prats, 2007). The drought of 2000 was relatively short in duration but had a significant impact, especially on early sown spring crops. The next event of 2003, which was much more pronounced in a lot of regions of Europe, clearly demonstrated that prolonged periods of rainfall deficit, combined with extremely high summer temperatures, might have influenced the full range of ecosystem services starting with the elimination of fodder production (Dubrovsky et al., 2005; Schaumberger et al., 2006) and ending with the negative carbon sequestration of European biosphere (Ciais et al., 2005).

Droughts differ from one another in three essential characteristics: intensity, duration, and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall. It is generally measured by the departure of some climatic index from normal and is closely linked to duration in the determination of impact. Based on previous research (Guttman, 1998, 1999), we chose the *SPI* index as indicator for measuring the drought for a different time scale in Czechia. Thus, *SPI* quantifies the precipitation deficit

* This research was supported by Research Project MSM No. 6046070901.

for multiple time scales and reflects the impact of drought on the availability of different types of water resources. For example, the moisture stored in the soil is highly affected by the short-term precipitation anomalies, whereas stream flow, groundwater and reservoir storage respond slowly to longer-term precipitation anomalies (H a y e s et al., 1999). Wetter and drier climates can be represented by *SPI* in the same way, because it is a normalized index. However, the spatial and temporal analysis of droughts using the *SPI* has some advantages regarding the use of precipitation series because the *SPI* series are comparable in both time and space (K e y a n t a s h , D r a c u p , 2002; L a n a et al., 2002; T r n k a et al., 2006).

The percentage of the long term mean precipitation (*r*) is one of the simplest measurements of rainfall for a location. It is calculated by dividing actual precipitation by the long term mean precipitation and multiplying it by 100%. This can be calculated for a variety of time scales. One of the disadvantages of using the percentage of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50% of the precipitation occurrences in a long-term climate record. Another tool can be used in the identification of drought spells is the aridity index *Si*. He is of the greatest interest in terms of climate change, since it incorporates the values of temperatures, precipitation and amount of moisture of soil in the form of normalized observations, thus permitting the objective comparison of the trends displayed by various stations during different months.

MATERIALS AND METHODS

In our analyses, the drought event has been estimated separately for each month of the warm period of the year (April–September). For the study of the regional drought the following items have been carried out: the analysis and evaluation of the drought indices and the selection of the most informative ones for the characterization of drought in Czechia; the development of a register of droughts of various magnitudes; the evaluation of the temporal and spatial distribution of droughts.

The assessment of drought was based on 50 climatic-stations situated in various physical-geographical regions and different elevations, from mountain sites to medium-elevations and lowland sites. The stations are spread within 158 m and 1321 m above sea level with a mean altitude of 400 m, which is close to the country mean altitude (430 m). The climatological database for all weather stations has a series of observational data on 47 years (1961–2007), containing the monthly precipitation amounts and monthly average temperature. Data series was homogenized and checked at the section climatology from CHMI; the list of uses station is given in Table 6. In our paper, we proposed to identify drought episode not basing only one index (e.g. using *SPI*), but combining several indices which complement each other; this is due to the fact that the indices are not perfect, although they have their advantages and disadvantages. When the numerical values of most of the indices coincided, the year was considered a drought year and therefore, it was included in the register. Thus, if 2–3 indices determined moderate to extreme drought, that year was dry. As an example from Table 2, drought of the year 1962 is identified by only the *Si* index for a moderate magnitude drought. Therefore 1962 was not considered a drought year. Thus, the drought episodes were determined by three methods: according to the values of *SPI*, *r* and *Si*. The *Si* combined effects of temperature, precipitation and moisture of soil in drought monitoring, while the *SPI* and *r* are based solely precipitation data. The *r* is permitting quite very effective estimate of drought episodes when used for a single region or a single season. Thereby, it combining of indices *SPI*, *Si* and *r* as tools in identification of severity, frequency and extend of drought episodes has been used.

In our opinion, a highly individual solution for the principle of climatological drought was reflected in *Si*:

$$Si(\tau) = \frac{\Delta T}{\sigma T} - \frac{\Delta R}{\sigma R} - \frac{\Delta E}{\sigma E} \tag{1}$$

It presents a difference of monthly anomalies of temperature ($\Delta T = t - t_n$), precipitation ($\Delta R = r - r_n$) and amount of moisture in the soil ($\Delta E = e - e_n$), to their standard deviations (σT, σR and σE), where *i* and τ are a selected station and period (P e d , 1975). So, this index determines drought conditions, if values of parameters are following: $\Delta T > 0$ or $\Delta T/\sigma T > 0$; $\Delta R < 0$ or $\Delta R/\sigma R < 0$; $\Delta E < 0$ or $\Delta E/\sigma E < 0$, then $Si > 0$. If $Si > 0$, one observes a mild atmospheric drought; while $1 \le Si < 2$ is moderate; $2 \le Si < 3$ severe; and $Si \ge 3$ is extreme. The *Si* may also be calculated by three methods. Firstly, in case identifying of meteorological drought can be calculated only first and second parameters of the index:

$$Si(\tau) = \frac{\Delta T}{\sigma T} - \frac{\Delta R}{\sigma R} \tag{2}$$

Secondly, agricultural drought can be formulate:

$$Si(\tau) = -\frac{\Delta E}{\sigma E} \tag{3}$$

Third, drought as complex event may also be identified by equation 1. In our analysis, we input in this index a precipitation-temperature series for a set of weather stations and/or single test-station (Žatec). The application of normalized values allows the use of this index for comparing purposes in various situations, since it describes a specific meteorological situation regarding some mean level. Conditions of both (–) humidity content and heat content (–) can be characterized by the application of the *Si* since, it reflects an alternating quantity: – positive values of *Si* correspond to dry periods, negative to humid ones. Another interpretation may be made as follows: – positive values of *Si* correspond to a warmer thermal regime during some period, whereas negative ones reflect a colder thermal regime. The criteria of the index *Si* are useful for estimating monthly droughts. Certain researchers disagree with this conclusion, since droughts can appear in one month and extend into the following month. Drought develops gradually and impacts accumulate as conditions persist for month, several months or seasons after the termination of the event. It has therefore been proposed to determine drought by means of the *Si* and to use an alternative approach. This approach, if we consider the data of the neighbouring months to be independent, requires that we take $Si \geq \frac{2}{\sqrt{r}}$, where *r* is the number of combined months (Bagrov, 1995). The application of the above access approach has been put to test in the assessment of droughts in Czechia, both for the entire warm period and for individual seasons. In this case, for the warm period the computation was carried out with the following data:

$$Si \geq \frac{1}{\sqrt{6}};\ Si \geq \frac{2}{\sqrt{6}};\ Si \geq \frac{3}{\sqrt{6}};\ Si \geq \frac{4}{\sqrt{6}},$$

that provided the thresholds given in Table 1. In the evaluation of drought during the spring and autumn seasons, the period of vegetation was taken into account and hence the calculation was carried out for only two months. The criteria obtained for these seasons were

$$Si \geq \frac{1}{\sqrt{2}};\ Si \geq \frac{2}{\sqrt{2}};\ Si \geq \frac{3}{\sqrt{2}};\ Si \geq \frac{4}{\sqrt{2}}.$$

For the summer, when drought was calculated for three months, the following data was obtained:

$$Si \geq \frac{1}{\sqrt{3}};\ Si \geq \frac{2}{\sqrt{3}};\ Si \geq \frac{3}{\sqrt{3}};\ Si \geq \frac{4}{\sqrt{3}}.$$

In our paper, use this approach allows analysis technique to identify drought event in Czechia on bases following time scale: 1 month (*Si*-1), 2 month (*Si*-2), 3 month (*Si*-3) and 6 month (*Si*-6). This index describes the intensity of drought as compared to the long-term average drought condition at different station or a single station and different period.

An estimate of territories affected by drought was made for every month from the vegetation period of each drought year (Table 4). The drought observed on the surface of up to 10% of the territory of the Czech Republic is classified as a local one. The droughts that cover 11–30% of the territory are related to widespread droughts. But the droughts that cover a territory of 31–50% are considered very widespread and over 50% are classified as most ex-

Table 1. The new criteria of drought proposed for different indices

Indices	Drought severity classification			
	mild	moderate	severe	extreme
Si at time scale 6 months	0.41 ≤ *Si* < 0.81	0.81 ≤ *Si* < 1.22	1.22 ≤ *Si* < 1.63	*Si* ≥ 1.63
Si at time scale 3 months	0.58 ≤ *Si* < 1.15	1.15 ≤ *Si* < 1.73	1.73 ≤ *Si* < 2.31	*Si* ≥ 2.31
Si at time scale 2 months	0.71 ≤ *Si* < 1.41	1.41 ≤ *Si* < 2.12	2.12 ≤ *Si* < 2.86	*Si* ≥ 2.86
Si at time scale 1 months	0 ≤ *Si* <1	1 ≤ *Si* <2	2 ≤ *Si* <3	*Si* ≥ 3
SPI	0 to –0.99	–1.00 to –1.49	–1.50 to –1.99	≤ –2.00

Table 2. An example of the application of a set of indices to identify April drought events for Žatec. D – drought year, M – mild, m/e – moderate, S – severe, E – extreme; *n* – number of drought of diverse intensity for each indices, total – is on the whole number droughts for every indices

Year	D	*Si*				*SPI*				*r*			
		M	m/e	S	E	M	m/e	S	E	M	m/e	S	E
1961	+			2.86		–0.71							
1962	–		1.11										
1967	–										58.28		
1971	+		1.07								57.62		
1974	+		1.40				–1.33					32.78	
1975	+						–1.24					39.09	
1982	+						–1.04					47.35	
1985	+		1.19								51.32		
1988	+		1.63				–1.33					32.78	
1993	+				3.40			–1.71					13.25
1998	+			2.41							51.99		
2000	+				3.17						52.32		
2004	+		1.87				–1.18					40.40	
2007	+				3.33			–1.79					9.20
n		0	6	2	3	0	5	2	0	0	5	5	2
Total	12	11				7				12			

Table 3. The droughts register of Žatec for the years 1961–2007. The table includes the assessment of drought (grey cell), normal (white table cell) and damp (d) month for each index. The marks are type of drought: M – mild, m/e – moderate, S – severe, E – extreme

Rok	April			May			June			July			August			September		
	r	SPI	Si	r	SPI	Si	r	SPI	Si	r	SPI	Si	r	SPI	Si	r	SPI	Si
1961		m/e	S			d						d				m/e	m/e	m/e
1962			m/e			d			d			d	m/e					
1963							d	d	d			d						
1964				S		m/e	S	S	S	E	S	S	S			S	m/e	m/e
1965	d		d	d	d	d				d		d	m/e	m/e		d	d	d
1966				S	m/e							d						
1967	m/e			d	d	d	d	d	d							d	d	d
1968	d			S			d			m/e	m/e							
1969	d		d			m/e	d		d	S	m/e	m/e						
1970			d			d				m/e			d	d	d	m/e		
1971	m/e		m/e	d	d	d			d	S	S	m/e						
1972													m/e					
1973			d	m/e									E	m/e	m/e	S	m/e	S
1974	S	m/e	m/e			d			d	m/e	m/e					d	d	d
1975	S	m/e													m/e			
1976							m/e		m/e			m/e						
1977			d				d	d	d				d	d	d			
1978				d	d	d			d									
1979	d	d	d	S	m/e	m/e			m/e			d	m/e			d	d	d
1980			d								d	d	m/e			d		
1981							S	S	S	d	d	d						
1982	S	m/e														S	m/e	S
1983	d	d	d				S		m/e	S	m/e	E	d	d	d			
1984	d	d	d			d				d		d						
1985	m/e		m/e	S	m/e	S			d	d			d	d		S	m/e	m/e
1986				d	d	d	m/e	m/e	m/e	m/e			d	d	d			
1987	d					d			d							d	d	
1988	S	m/e	m/e	S	m/e	S				d						d	d	
1989	d	d	d	m/e		m/e												
1990				S		m/e	d			E	S	m/e			m/e			
1991						d	d	d	d	m/e		S						m/e
1992	d			S	m/e	S	d			d	d		S		S			
1993	E	S	E	d		m/e	d		d			d						
1994	d	d	d	d	d		m/e	S	S			S	d					
1995				d		d	d	d	d			m/e						
1996							d	d	d			d	d		d			
1997			d	m/e		m/e				d	d	d	m/e		m/e	m/e		m/e
1998	m/e		S	E	m/e	S										d	d	d
1999				m/e		m/e						m/e						m/e
2000	m/e		E			m/e	m/e		S						m/e			
2001						m/e	m/e	S							m/e	d		d
2002						m/e			m/e	d			d	d	d	d	d	d
2003						m/e	m/e	m/e	S	d	d		E	m/e	S	S	S	m/e
2004	S	m/e	m/e	d		d												
2005				d	d	d	m/e	m/e										
2006	d	d	d									m/e					m/e	m/e
2007	E	S	E						m/e									

tensive (P o t o p , 2003). The surface affected by drought was calculated as a percentage, with the total number of stations being 100%.

RESULTS AND DISCUSSION

Since the Žatec weather station is situated in the rain shadow of the "Krušné hory" mountain chain, it was adopted as a standard for the evaluations of the droughts

Table 4. The droughts register of the Czech Republic for the years 1961–2007 was based on data from 50 weather stations. The estimation areas affected with local drought, widespread drought, very widespread drought and most extensive drought. The table includes the drought years for every season of the warm period. % – the surface affected by drought, "+" marks the drought, "–" marks the absence of drought in that month

	Spring				Summer				Autumn			
	April		May		June		July		August		September	
		%		%		%		%		%		%
1961	+	14	–	–	+	12	+	10	+	22	+	34
1962	+	14	–	–	+	72	+	24	+	64	–	–
1963	+	44	–	–	+	10	+	60	–	–	–	–
1964	+	22	+	26	+	24	+	44	–	–	+	48
1965	–	–	–	–	+	4	–	–	+	22	–	–
1966	–	–	+	14	–	–	–	–	–	–	+	40
1967	–	–	–	–	+	8	+	24	+	20	–	–
1968	+	8	–	–	+	10	+	20	–	–	–	–
1969	+	32	+	18	–	–	+	56	+	6	+	56
1970	–	–	+	26	+	20	+	54	–	–	+	30
1971	+	18	+	16	+	6	+	84	+	22	–	–
1972	–	–	–	–	+	26	+	12	+	38	–	–
1973	–	–	+	10	+	28	–	–	+	66	+	46
1974	+	74	–	–	–	–	+	4	+	28	+	22
1975	+	26	+	6	–	–	+	12	+	16	+	52
1976	+	62	+	20	+	92	+	38	+	32	–	–
1977	–	–	+	24	+	28	–	–	–	–	–	–
1978	+	22	–	–	+	56	+	10	+	6	–	–
1979	–	–	+	80	–	–	+	16	+	18	–	–
1980	–	–	+	54	+	6	–	–	+	54	+	10
1981	+	36	+	8	+	64	–	–	+	26	–	–
1982	+	46	+	22	+	8	+	20	+	12	+	66
1983	–	–	–	–	+	44	+	82	+	30	+	8
1984	+	6	–	–	+	46	–	–	+	22	–	–
1985	+	30	+	8	+	14	–	–	–	–	+	54
1986	+	32	–	–	+	46	+	16	–	–	+	50
1987	+	22	–	–	+	8	+	6	+	10	–	–
1988	+	74	+	56	+	22	+	6	+	6	–	–
1989	–	–	+	48	+	16	+	16	+	28	–	–
1990	–	–	+	54	+	16	+	74	+	50	+	4
1991	+	56	+	22	–	–	+	18	+	10	+	48
1992	+	16	+	94	+	16	+	24	+	48	+	26
1993	+	74	+	28	–	–	+	12	+	36	–	–
1994	–	–	–	–	+	66	+	50	–	–	–	–
1995	–	–	–	–	–	–	+	30	–	–	–	–
1996	+	18	–	–	–	–	+	10	–	–	–	–
1997	+	8	+	26	+	30	–	–	+	50	+	50
1998	+	42	+	72	–	–	–	–	+	50	–	–
1999	+	20	+	26	+	14	+	6	+	52	–	–
2000	+	66	+	14	+	66	–	–	+	58	+	12
2001	–	–	+	20	+	20	–	–	–	–	–	–
2002	+	22	+	40	+	8	+	6	–	–	+	6
2003	+	36	–	–	+	66	–	–	+	84	+	36
2004	+	30	+	20	–	–	+	24	+	38	–	–
2005	+	26	–	_	+	48	–	–	–	–	+	24
2006	–	–	–	–	+	8	+	70	–	–	+	76
2007	+	96	–	–	–	–		–	–	–	–	–
Months		31		27		35		32		31		22

years (also tested *Si*). According to the obtained data, within the interval under consideration, droughts were observed in 34 years (with 53 months) in warm periods, 20 years in spring (23 months), 19 years in summer (22 months) and 8 years (8 months) experienced autumn droughts (Table 3). For Žatec, the most frequent drought events occurred in April (12 cases) and May (11 cases). The less frequent drought years occurred in August (5 cases). According to *Si*, it was establishing 3 months with extreme drought, 17 months – severe drought and 44 months moderate and mild drought. The most extreme drought months for entire reference period were recorded in following cases: June (2003), July (1983) and April (1983, 2007, 2000). The longest drought spells were recorded during four months (1964 and 2003). Table 3 describes only the data that relate to the Žatec weather. Data for all other parts of the country have been processed in the same way. For each of the 50 weather stations the numerical values of the drought indices have been calculated, which then allowed us to evaluate the years according to drought intensity and surface affected. Having analysed the characteristic features of the drought in the whole territory of the country, we can state that approximately every 5th year suffers from severe drought during the spring and/or summer. In the meantime, moderate and severe intensity droughts are most frequent in April and July, while in June (35 cases) droughts are mostly middle and moderate. The spatial distribution of droughts can be observed in Table 4. From the total number of drought months (168) in the warm period, 65% of the months are June, July and April. The lack of precipitation in the vegetation period in drought years corresponds 200 to 300 mm.

When the register of the droughts that have occurred during the period of approximately 47 years is analysed we can highlight the tendency of increased frequency of the given phenomena. According to all indices and the majority of weather stations the longest drought periods were noticed at the beginning of the 1980's and 1990's, reaching their highest points in the decade of 1990–2000. After the 1990's, the frequency of intense droughts increases. Similarly, during the last 20 years in 9 cases of drought, 4 were registered as being of both a severe intensity degree and an extreme intensity degree. For example for Žatec the linear trend of drought months with level significant p = 0.02 have a positive trend (D = 15.87 + 0.0089 * t). Analogous results had published by Sládek (2001), Blinka (2004) or Trnka et al. (2006, 2007).

Droughts also differ in terms of their spatial characteristics. The areas affected by severe drought evolve gradually, and regions of maximum intensity shift from season to season. The local droughts are a characteristic of the north-west and southern areas, while the widespread ones have been observed in the southern and south-eastern parts of the country. The very widespread droughts cover a large territory of up to 50% of the area and are frequent in the southern, south-eastern and north-east parts of the Czech Republic. In the above mentioned territory droughts of severe intensity occurred in dry regions of the country i.e. South Moravia and the rain shadow of the "Krušné hory" mountain chain. However, in the rest of the area, droughts of a moderate and mild degree of intensity have been noticed. The extensive droughts cover the whole territory except the mountain stations. For example, a extensive drought in 2007 was registered. During April of this year, the drought covered 96% of the territory of the Czech Republic and was of a severe and/or extreme intensity (Fig. 1). Similarly, the driest months from 2006 which covered 70% from the territory were July and September, which affected the principal agricultural production areas in the Czech Republic. The register of droughts makes it possible to obtain extensive information concerning both the intensity and the intervals of their manifestation (Tables 3–4). It shows that the manifestation of drought has a random character, which follows a Poisson-type distribution. The statistics were based upon the data from the droughts register that allowed us to produce a new statisti-

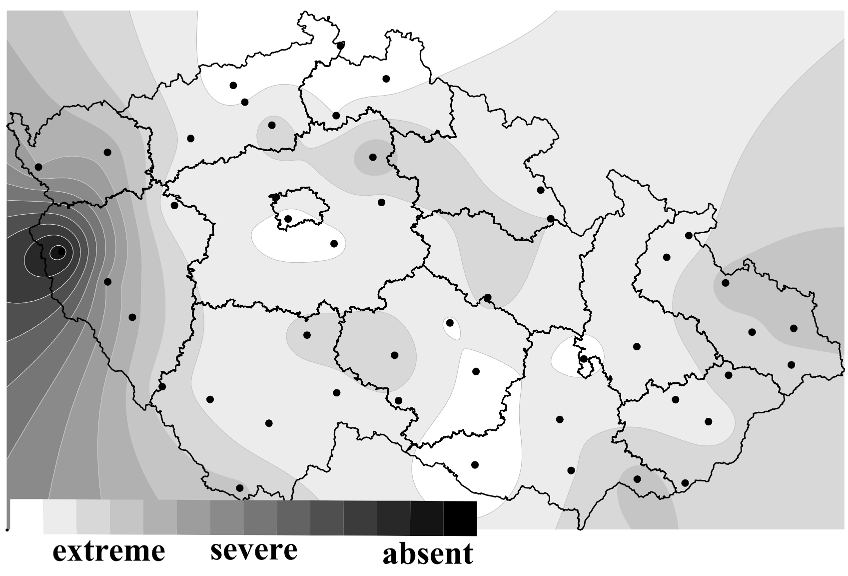

Fig. 1. Estimation of the territories affected by drought in the Czech Republic (in April 2007). The black colour indicates the territory without drought event

Table 5. The model Poisson and values of the time intervals between droughts are identified testing using χ^2 for individual months from the warm period in the Czech Republic. "–" is $\chi_e^2 < \chi_t^2$

Months	Number of drought events in time interval 47 years, *n*	Average of time interval between drought events, avg(x)	Predicted drought frequency, λ, 1/avg(x)	Pearson criterion $\chi_e^2 < \chi_t^2$	
				χ_e^2	χ_t^2 (α = 0,05)
	local (up to 10% of the territories affected by drought)				
April	3	15.7	0.06	–	–
May	4	11.8	0.08	–	–
June	10	4.7	0.21	5.99	18.30
July	7	6.7	0.15	0.01	14.06
August	5	9.4	0.11	3.87	11.07
September	4	11.8	0.08	–	–
	widespread drought (11–30%)				
April	15	3.1	0.32	9.44	24.99
May	15	3.1	0.32	9.44	24.99
June	14	3.4	0.29	8.03	23.69
July	14	3.4	0.29	8.03	23.69
August	12	3.9	0.26	5.47	21.03
September	3	15.7	0.06	–	–
	very widespread drought (31–50%)				
April	7	6.7	0.16	0.01	14.06
May	2	23.5	0.04	–	–
June	4	11.8	0.08	–	–
July	3	15.7	0.06	–	–
August	7	6.7	0.15	0.01	14.06
September	8	5.9	0.17	0.55	15.51
	most extensive drought (< 50%)				
April	7	6.7	0.15	0.01	14.06
May	6	7.8	0.13	0.54	12.59
June	6	7.8	0.13	0.54	12.59
July	7	6.7	0.15	0.01	14.06
August	6	7.8	0.13	0.54	12.59
September	5	9.4	0.11	3.87	11.07

cal series, which was then analysed according to the Poisson model. This means that the number of droughts in the time period of length *N* will be a Poisson variable, *n*. The Poisson distribution is used to model an expected number of drought event occurring within a given time interval:

$$f(n;\lambda) = \frac{\lambda^n \cdot \exp(-\lambda)}{n!} \quad (4)$$

If the expected number of occurrences in an interval is λ, then $f(n;\lambda)$ is the probability of how many occurrences of drought there will be (n being a non-negative integer).

To assess how well a given distribution describes the data, it is possible to compare the empirical cumulative probability distribution with the corresponding theoretical cumulative probability distribution. The statistical series thus obtained was tested by the criteria of χ^2 (Pearson criterion) goodness-of-fit test. For the respective evaluation of the time distribution of drought according to Poisson's law and its parameters, according to the known rules, the experimental histograms of the distribution of intervals between them have been drawn, and the correlation degree between the empirical and theoretical data was thus established (Table 5). According to Pearson's test (χ_e^2), the phenomenon obeys the same rule when the empirical data (χ_e^2) are smaller than the theoretical (χ_t^2) ones. Chi-square is calculated by finding the difference between each empirical and theoretical frequency for each possible outcome, squaring them, dividing by theoretical frequency, and taking the sum of results:

$$\chi_e^2 = \sum_i^k \left[\left(P_{e,i} - P_{t,i} \right)^2 / P_t \right] \quad (5)$$

where: $P_{e,i}$ – an empirical frequency, $P_{T,i}$ – a theoretical frequency, *i*, *k* – number of possible outcomes of each event.

The χ^2 test divides the range of individual types of drought into nonoverlapping intervals and compares the number of observations in each class to the number expected, based on the fitted distribution. Since the smallest

Table 6. List of weather stations

	Indicative	WMO	Name station	Latitudinal, deg.	Longitudinal, deg.	Altitudinal, m a.s.l.
1	B1HOLE01	11774	Holešov	49.1907	17.3424	224
2	B1VIZO01	11777	Vizovice	49.1323	17.5038	315
3	B2BTUR01	11723	Brno, Tuřany	49.0935	16.4144	241
4	B2KMYS01	11636	Kostelní Myslová	49.0936	15.2621	569
5	B2KUCH01	11698	Kuchařovice	48.5257	16.0511	334
6	B2VMEZ01	11687	Velké Meziříčí	49.2114	16.0031	452
7	B2VPAV01	11725	Velké Pavlovice	48.5431	16.4928	196
8	C1CHUR01	11457	Churáňov	49.0406	13.3654	1118
9	C2CBUD01	11542	České Budějovice	48.5742	14.2805	388
10	C2TABO01	11582	Tábor	49.2449	14.4009	440
11	C2TREB01	11589	Třeboň	49.0032	14.4621	429
12	C2VBRO01	11549	Vyšší Brod	48.3859	14.1850	559
13	H1VELI01	11678	Velichovky	50.2116	15.5019	320
14	H2USTI01	11679	Ústí nad Orlicí	49.5849	16.2520	402
15	H3CHTU01	11624	Chotusice	49.5631	15.2309	235
16	H3PARD01	11652	Pardubice	50.0058	15.4426	225
17	H3SEC003	11620	Seč	49.5041	15.3853	529
18	H3SVRA01	11683	Svratouch	49.4406	16.0201	737
19	H4PODE01	11617	Poděbrady	50.0826	15.0800	189
20	L1KLAT01	11455	Klatovy	49.2327	13.1808	430
21	L1PLZB01	11446	Plzeň, Bolevec	49.4721	13.2312	328
22	L2KRAL01	11442	Kralovice	49.5916	13.2928	468
23	L2PRIM01	11423	Přimda	49.4010	12.4041	742
24	L3CHEB01	11406	Cheb	50.0407	12.2328	483
25	L3KVAL01	11414	Karlovy Vary	50.1207	12.5438	603
26	O1CERV01	11766	Červená	49.4638	17.3231	749
27	O1LUCI01	11784	Lučina	49.4351	18.2633	300
28	O1LYSA01	11787	Lysá hora	49.3246	18.2652	1322
29	O1OPAV01	11763	Opava, Otice	49.5511	17.5234	270
30	O1SVET01	11736	Světlá Hora	50.0159	17.2404	593
31	O1ZARY01	11761	Město Albrechtice, Žáry	50.0906	17.3319	483
32	O2LUKA01	11710	Luká	49.3908	16.5712	510
33	O2OLOM01	11742	Olomouc, Holice	49.3433	17.1704	210
34	O3PRER01	11748	Přerov	49.2526	17.2423	203
35	O3VALM01	11769	Valašské Meziříčí	49.2749	17.5827	334
36	P1NEUM01	11522	Neumětely	49.5111	14.0214	322
37	P1PRUZ01	11518	Praha-Ruzyně	50.0603	14.1528	364
38	P2SEMC01	11561	Semčice	50.2202	15.0016	234
39	P2TUHA01	11562	Tišice	50.1639	14.3254	168
40	P2TUHA01	11562	Turaň	50.1750	14.3120	160
41	P3NRYC01	11632	Nový Rychnov	49.2309	15.2154	624
41	P3ONDR01	11572	Ondřejov	49.5426	14.4705	485
43	P3PRIB01	11659	Přibyslav, Hřiště	49.3458	15.4545	530
44	U1DOKS01	11509	Doksany	50.2730	14.1013	158
45	U1KATU01	11438	Tušimice	50.2236	13.1941	322
46	U1KOPI01	11433	Kopisty	50.3239	13.3724	240
47	U1ZAT001	11468	Žatec	50.2052	13.3300	210
48	U2DOKY01	11558	Doksy	50.3405	14.4003	284
49	U2LIBC01	11603	Liberec	50.4612	15.0127	398
50	U2VARN02	11551	Varnsdorf	50.5431	14.3622	365

P-value amongst the tests performed is less than 0.05, we can reject the idea, that local droughts occurring in June, July and August comes from a Poisson distribution with 95% confidence. For other months, such as April, May and September, there were insufficient data to conduct the χ^2 test. The χ^2 test was not run because the number of observations was too small. As the results in Table 5 show, the average time intervals between local droughts for June–July are 4.7 and 6.7 years. By contrast, in April, May and September the number of local drought diminished from 3 to 4 cases with an average time interval of 11.8 and 15.7 years. Examination of distributions of the widespread drought has shown that in the all spring and summer months number of drought years increases with a greater probability, but decrease the intervals between them. Thus, every third year widespread drought was recorded. Throughout the whole period of study, were about 8 and 5 very widespread and extensive droughts in September, which can be expected once in 6 years respectively, once in 9 years. According to the obtained results, the droughts from April and July, with a guarantee of 95%, are occurring throughout most of the entire country. Thus, according to Poisson's law an increased frequency of the widespread and very widespread droughts has been noticed, together with diminishing frequency between them. Moreover, quite frequently the droughts extended over 2–3 successive years.

It combining a set of indices *SPI*, *Si* and *r* as tools in identification of severity, frequency and extend of drought episodes has been used. At the same time, the both indices PDSI and Z-index has become one of the most widely used tools for assessment-drought in Czechia. However, mainly obstacle in implementer these indices is a limitation on input meteorological information about amount of moisture in the soil for majority weather stations from network within country. For this reason, in our paper those indices were not possible used.

CONCLUSION

This study describes the drought episodes in the Czech Republic from 50 weather stations, including monthly rainfalls and temperature measurements obtained during periods of 47 years. It was to determine the frequency of occurrence, the intensity and extend of drought episodes. Firstly, the registers of the droughts have been identified and processed. Secondly, the frequency and tendency of the drought episodes have been evaluated. Thirdly, the occurrences of drought, as well as their spatial distribution, have been estimated by Poisson model. Three meteorological indices are applied to ascertain a month as a drought period. In this paper drought intensity categories are based on three key indices, including the well known *SPI* is an interesting strategy, which can be used to determine if a particular month suffers from a drought event. In this study, we propose new criteria for the *Si* index, to be used together with the *SPI*, which is well known around the world, plus the *r* index, which is already used in Czechia. The *Si* index exhibits significant advantages over the other indices by including the values of temperatures and precipitation in the form of normalized observations, thus allowing the objective comparison of the trends displayed by various observation stations during different months. The *r* may also be used with great success in regions, where rainfall is normally received at enough frequent intervals and droughts or dry spells appear in short periods.

The register of the droughts for individual month from warm period (April–September) has been identified and elaborated. We are proposing a new methodology for the creation of the register of droughts. It is a known fact, that a single index on its own is not able to identify all the drought years in a given region. Therefore it is recommended to evaluate a complex of several indices, which complement one another. Thus, for instance, a combination of several indices will determine the severity of a drought. An analysis of extreme drought events shows that the *r* provides a better spatial distribution than the *SPI*. By contrast, *SPI* is the most informative index in the identification of mild and moderate droughts for all seasons. On the other hand, the *Si* and *r* are better indices for the identification of severe magnitude droughts. As a result of the analysis of the drought catalogue for a period of over 45 years, an increase in the tendencies of frequency of the studied phenomena after the 1980's was discovered. The both longest and most severe drought periods were noticed early 1980's and 1990's, reaching their highest points in the decade of 1990–2000. Already at the beginning 21st century was registered three drought years (2003, 2006, 2007), while 2003 year had extreme and very widespread drought. The next severe spring drought was occurred in 2007, which started in consequence poor winter snow and little spring rain. While even much more pronounced during April, the drought covered 96% of the territory of Czechia. Due to fact, that drought was not occurred in time during the reproductive stages for crops, thereby yields was not radical affected. According to result by Brázdil et al. (2008) are concluded that in Czechia drought an increasing tendency towards longer and more intensive dry episodes in which, for example, droughts that occurred in the mid-1930s, late 1940s–early 1950s, late 1980s–early 1990s and early 2000s were the most severe.

Based on the analysis of the data from the observation stations across Czechia, we determined the areas affected of drought. As a result of the droughts' classification, according to the territory in which they covered, we may say that it is characteristic for the territory of Czechia to pass through widespread drought (11–30%) during the spring and summer seasons; while in the autumn season the very widespread (31–50%) and extensive droughts are more frequent. However, during the months of April and July the widespread and very widespread droughts have an important frequency that covers almost the whole territory of Czechia. The extreme drought episodes usually affected wide areas of Czechia, but sometimes a drought episode affects one region, whilst other areas are subject to humid conditions. The contribution of the present work is mainly restricted to methodology, which allows a deeper knowledge at the characteristics of drought process. Furthermore, it can help to decide which measures should be taken in order to prevent the problem. Also, improved understanding of a region's drought climatology will provide critical information on the frequency and intensity of historical events. Thereby, the characteristics of frequency and spatial extent of past droughts provide benchmarks for projecting similar conditions into the future.

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Received for publication on March 5, 2008
Accepted for publication on July 2, 2008

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Časové a prostorové distribuce suchých období v ČR.

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Příspěvek se zabývá využitím některých metod při analýze časové a prostorové distribuce suchých období v ČR. Sucha jsou definována jako atmosférický jev z klimatologického hlediska pro teplý půlrok (IV–IX) z datového souboru 50 klimatologických stanic za časový interval 1961–2007.

Byla vytvořena databáze hlavních meteorologických prvků a tří agrometeorologických indexů pro vymezení such se zaměřením na správnost výběru nejvýraznějšího indexu a na kompatibilnost hodnot kritérií indexů s vlastnostmi podnebí regionu. Na základě námi navrženého nového postupu tvorby katalogů such byl vytvořen katalog pro jednotlivé měsíce teplého půlroku.

Je známo, že není možné identifikovat suchý rok jen podle jednoho indexu. Proto je vhodné použít komplex vzájemně se doplňujících indexů. Pokud minimálně dva indexy určí hodnocené období (měsíc) jako suché, můžeme konkrétní rok označit za rok s výskytem sucha.

Analýzou dat klimatických stanic v ČR jsme určili prostorové rozložení sucha. Hodnocením sucha a jeho prostorového rozšíření jsme došli k závěru, že průměrný časový interval ve výskytu lokálního sucha je pro měsíce červen a červenec 4,7 a 6,7 let. Naproti tomu v měsících květen a září se lokální sucho vyskytlo pouze ve čtyřech případech s průměrným intervalem výskytu 11,8 let a v měsíci dubnu ve třech případech s průměrným intervalem výskytu 15,7 let. Analýzou distribuce sucha bylo zjištěno, že všechny jarní a letní měsíce mají vyšší výskyt rozsáhlých such a zároveň menší intervaly mezi nimi (každý třetí rok jsme zaznamenali rozsáhlé sucho). V měsících duben, srpen a září bylo v hodnoceném období území ČR postiženo velmi rozsáhlým suchem (31 až 50 % území). Podle Poissonova modelu lze rozsáhlá sucha očekávat s pravděpodobností 95 % v časovém intervalu 5,9 až 6,7 let. Katastrofická sucha v teplém půlroku lze dle modelu očekávat v intervalu 6,7 až 9,4 let.

Podle Poissonova pravidla při zvýšené četnosti výskytu plošných such dochází ke snížení intervalů mezi nimi. Toto platí za předpokladu, že empirická pravděpodobnost (χ_e^2) je menší než pravděpodobnost teoretická (χ_t^2). V našem případě však toto neplatí pro lokální sucha v měsících duben, květen a září. Pro rozsáhlá sucha v měsíci září a pro velmi rozsáhlá sucha v měsících květen, červen a červenec, kdy $\chi_e^2 < \chi_t^2$.

SPI; index aridity *Si*; katalog such

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