ASSESMENT OF METEOROLOGICAL DROUGHT IN BOHEMIAN-MORAVIAN HIGHLANDS USING PALMER DROUGHT INDICES

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As the climate change is underway, the frequency, intensity and duration of heat waves increase over Europe. Higher temperatures and heat waves episodes increase evaporation and thus intensify droughts when they occur. Recently, in the Czech Republic, increased global radiation and air temperature together with decreased relative humidity led to increases in the reference evapotranspiration in all months of the growing season. This is going to be a serious issue for agricultural production to deal with in following years. First step in mitigating drought impacts is the definition of drought-threatened areas, by applying appropriate drought assessment indices. In this study we picked Palmer drought severity index (PDSI) to document the occurrence of drought episodes in the region of Bohemian-Moravian highland and illustrate its severity in recent years. Firstly, the PDSI was calculated based on long-term meteorological data and then applied on dataset from years 1961-2014 to identify drought periods and its severity.

Keywords: PDSI, Z index, drought indicator

INTRODUCTION

Drought is a recurring phenomena that has plagued civilization throughout history. It affects natural habitats, ecosystems, and many economic and social sectors, from the foundation of civilization—agriculture—to transportation, urban water supply, and the modern complex industries (Heim Jr, 2002). After floods, droughts represent the most disastrous natural events in the Czech Republic, moreover, the areas with the most pronounced drying trend are located in the most productive agricultural areas (Brázdil et al., 2007; Trnka et al., 2014). Droughts are, by nature, regional phenomena (Alley, 1984). The wide variety of sectors affected by drought, its diverse geographical and temporal distribution, and the demand placed on water supply by human-use systems make it difficult to develop a single definition of drought (Heim Jr, 2002). Drought may be defined as a negative deviation of water balance from the climatological norm over a given area. This implies that drought is a result of deficiency in precipitation over an extended period of time, whereas other meteorological elements (such as increased air temperature, global radiation and wind, as well as decreased air humidity) drive up water demand through increased evapotranspiration (Allen et al., 1998). The World Meteorological Organization (WMO) defines a drought index as "an index which is related to some of the cumulative effects of a prolonged and abnormal moisture deficiency" (Heim Jr, 2002). It is possible to define drought in terms of meteorological, hydrological, agricultural, and socio-economic conditions (Lloyd-Hughes and Saunders, 2002). For this reason, several indicators exist that attempt to encapsulate drought severity on a regional basis. Perhaps the best known is the Palmer Drought Severity Index (PDSI) (Alley, 1984; Palmer, 1965; Sheffield et al., 2012). The method takes into account precipitation, evapotranspiration and soil moisture conditions (Alley, 1984). It applies a two-layer bucket-type model for soil moisture computations with three assumptions related to soil profile characteristics: (i) the water-holding capacity of the surface layer is set at a maximum of 25 mm, (ii) the water-holding capacity of the underlying layer has a maximum value that depends on soil type, (iii) water transfer into or out of the lower layer only occurs when the surface layer is full or empty. The PDSI itself can be described as an accumulative departure relative to local mean conditions in atmospheric moisture supply and demand at the surface (Palmer, 1965) and it is considered a good representation of episodes of prolonged drought. Moreover, the PDSI calculation includes an intermediate term known as the Palmer moisture anomaly index (or Z-index), which is a measure of surface moisture anomaly for a given month without the consideration of the antecedent conditions so characteristic of PDSI. It is basically the moisture departure, adjusted by a weighting factor known as the climatic characteristic. The Z-index can be used to track drought events on a monthly basis as it responds relatively quickly to changes in soil moisture. The capacity of the Z-index to rank the dryness or wetness of individual months makes it especially useful as one of the indicators of short spells of drought (Brázdil et al., 2014; Palmer, 1965). Thus, the Palmer (1965) indices, computed on a monthly timescale show short-term (Z Index) and cumulative long-term (PDSI) drought and wet spell conditions (Brázdil et al., 2014; Heim Jr, 2002; Palmer, 1965).

The aim of this study is drought assessment using drought indices PDSI, Z Index and basic trend analysis over period 1961-2014 under conditions of Bohemian-Moravian highlands.

MATERIALS AND METHODS

Presented drought indices were calculated for area of research field locality Domanínek (Czech Republic, 49°521'N; 16°235'E, altitude 578 m a. s. l.), near the town of Bystřice nad Pernštejnem. The site is located in the eastern part of Bohemian-Moravian Highland, with mean annual precipitation 609.3 mm and mean annual temperature 7.2 °C (1981-2010) and the mean annual reference evapotranspiration 650 mm (Fischer et al., 2013). For calculations we used homogenized and interpolated monthly temperature means and precipitation totals in period 1961-2014. The computation of Palmer's indices was performed through following steps: 1) Calculation of monthly values of precipitation, evapotranspiration (Thornthwaite, 1948), soil moisture loss and recharge, and runoff. Potential and actual values were computed for the last four. Means of the potential and actual values for these parameters were computed over a calibration period 1961-2014. 2) Summary the results to obtain coefficients (of evapotranspiration, recharge, runoff, and loss) that are dependent on the climate of the location being analyzed. These coefficients were computed by dividing the mean actual quantity by the mean potential quantity. 3) Re-analyzing the series using the derived coefficients to determine the amount of moisture required for "normal" weather during each month. 4) Computation of the precipitation departure for each month, then conversion the departures to indices of moisture anomaly (Z Index). This moisture anomaly index has come to be known as the Palmer Z Index and reflects the departure of the weather of a particular month from the average moisture climate for that month, regardless of what has occurred in prior or subsequent months (Palmer, 1965). 5) Analysis of the index series in order to determine the beginning, ending, and severity of the drought periods. In Palmer's computations, the drought severity for a month depends on the moisture anomaly for that month and on the drought severity for the previous and subsequent months (Heim Jr, 2002; Lloyd-Hughes and Saunders, 2002). The trend analysis of the long term course of PDSI and Z Index was performed using Statistica 10 software.

RESULTS

The Fig. 1 show comparison of two monthly Palmer drought indices – the PDSI and the Z Index. The magnitude of PDSI range between -4.65 to 5.72. The longest period of drought according PDSI index lasted 4 years since March 1968 until March 1972, with most severe drought during winter 1969-1970 with PDSI index as low as -4.65 in February 1970 and average PDSI value -2.5. This drought period was interrupted by slightly positive values during growing season 1972, but then drought took over until May 1974. The second longest drought period persisted since April 1988 until October 1991. As the most critical of this period seem to be the entire year 1990 with first 5 months of year 1991, during which period the PDSI remained below -3, which represents "severe drought" (Alley, 1984; Palmer, 1965). During winter 1991-1992 the PDSI was slightly positive, but it became negative soon in April 1992 and remained so until July 1994 with average PDSI -2. The third largest drought started in February 2011 and continues through the end 2014 (end of database), which is almost 4 years. Average PDSI for this period is –2.2.

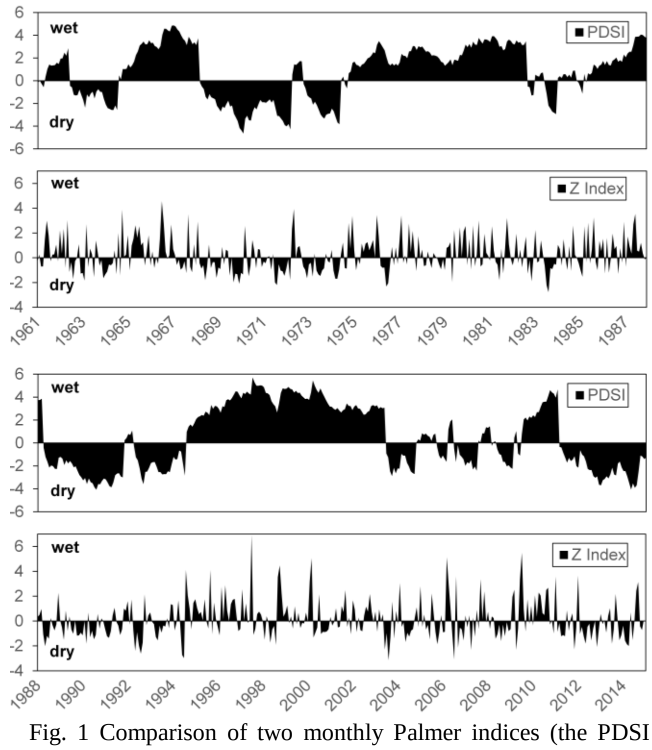

Fig. 1 Comparison of two monthly Palmer indices (the PDSI and the Z Index) over period 1961-2014 at Domanínek locality.

Apart from drought, there were also distinctly wet periods, e.g. August 1964 to February 1968, with average PDSI 3.1. The longest and most intense wet period prevailed since August 1992 until May 2003, with average PDSI 3.58 and the highest PDSI value of the whole period 1961-2014, 5.72 in July 1997. Also the Z index reaches its maximum value 6.91 for July 1997. This month is remarkable, since eastern half of Czech Republic has been stricken by extraordinary rainfall (207.8 mm for Domanínek), followed by catastrophical floods (Brázdil et al., 2007). The second longest wet period lasted almost 8 years since October 1974 until August 1982, with average PDSI 2.82.

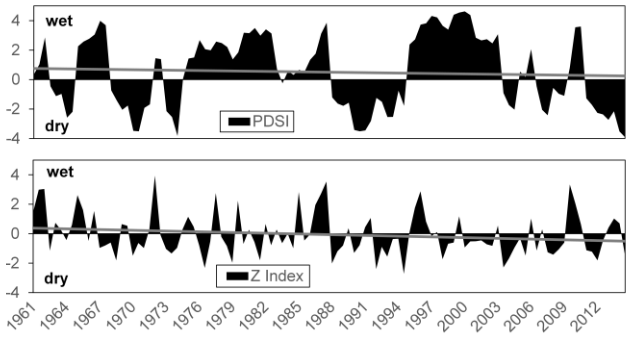

Fig. 2 Comparison of PDSI and Z Index in months May and June over period 1961-2014 at Domanínek locality with marked trend lines.

The Z index ranged between -3.15 to 6.91 and exhibited high interannual variability, compared to PDSI, as this index characterizes each month separately from other months. If we rank 10 months with lowest Z index (< -2.28) within period 1961-2014, 8 out of 10 driest months happened to be in recent 3 decades and the top three driest months (Z index < -2.98) in last 2 decades, namely July 1994, August 2003 and July 2006.

Fig. 2 depicts comparison of PDSI and Z Index (1961-2014), where only values for May and June are shown. May and June represent the most sensitive period in terms of agricultural crop vegetative season (Hlavinka et al., 2009). There can be seen decreasing trend in both indices (increasing dryness), which is more pronounced in case of Z Index.

Tab. 1 Trend analysis of Z Index in particular months during period 1961-2014.

Z Index	April	May	June	July	April-May	March-August	April-July	May-July	May-June
R^2	0.09	0.19	0.17	0.01	0.08	0.10	0.16	0.15	0.23
p value	0.52	0.18	0.21	0.93	0.59	0.46	0.24	0.29	**0.09**

Tab. 1 shows statistical trend analysis of Z Index in particular month/months of growing seasons 1961-2014. The most pronounced drying trend was found for period May-June, however the statistical analysis did not prove its significance ($p = 0.09$). This result is in accordance with Brázdil et al. (2014), who found clearly negative and statistically significant trends for PDSI in months March-May and June-August, for period 1806–2012 in Czech Republic.

CONCLUSION

In this study we calculated and evaluated two Palmer drought indices - the PDSI and Palmer's Z index for period 1961-2014 for the area of Bohemian-Moravian highlands. The PDSI ranged between -4.65 to 5.72 and Z index -3.15 to 6.91. The most positive and negative value for Z index fits well with extreme climate events in recent years - the heat wave in Europe in year 2003 (Z index -3.15 in August) and one of the worst floods in hundred years in Czech Republic, in July 1997 (Z index 6.91). We also found negative decreasing trend for Z Index in months May and June, although it was not statistically significant ($p = 0.09$). This suggests increasing drought risk in the most sensitive part of growing season for agricultural crops.

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