AGRICULTURAL DROUGHT DURING VEGETATION PERIOD IN THE CZECH REPUBLIC

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Climate of the Czech Republic is very variable, therefore random drought periods, including agricultural drought, are not uncommon. The level of agricultural drought risk in the Czech Republic during vegetation period in long-term has been analyzed for the period between 1961 and 2000. Selected outputs from daily data calculated by the AVISO model were used to assess the potential risk of agricultural drought occurrence. The main input data for calculations in daily intervals were technical series of basic meteorological parameters (air temperature and humidity given as water vapor pressure, sunshine duration, wind speed and precipitation) for a regular 10 x 10 km grid network (the whole area of Czech Republic is divided into 789 individual grid points). The long-term water availability in landscape, with particular emphasis on the potential occurrence of agricultural drought, has been assessed based on the difference between atmospheric precipitation and actual evapotranspiration from grassland. Two methods were used: actual water balance given as the difference between the above stated components, and actual water balance based on the index method.

***Keywords:** actual water balance, precipitation, actual evapotranspiration, model calculation, AVISO*

INTRODUCTION

Variability of the climate in the Czech Republic causes that there are years with flooding, as well as years with drought periods (Rožnovský, Kohut, 2000; Rožnovský, Kohut, 2004). In the last years, the years with drought periods have become more and more frequent, extensive droughts being observed for example in 2000, 2003 and also 2012. There have also been local droughts, for example in 2007 in the South Moravian region due to extremely low precipitation amount and very long, up to several weeks lasting, period with no rain at all. It must also be noted that climatological assessment on its own can often express the conditions relevant for organisms inaccurately (for example assessment purely based on calendar months or particular statistical parameters), or be even misleading. A classic example of such analysis is for example the analysis of precipitation amounts only using monthly values. From this perspective therefore, the soil conditions and agrotechnical methods are also important for the assessment of agroclimatological conditions, in particular data about time of sowing, planting and soil management.

What is also important is that the occurrence of drought in the Czech Republic is usually a random event. It occurs irregularly during periods with below-average or substantially below-average precipitation lasting from a few days up to several months in extreme cases. The occurrence of agricultural drought depends on the course and dynamics of soil moisture and in addition is also influenced by the soil type, soil management and of course the crop as well.

The issue of erosion has often been mentioned over the last few years, as it leads to damage of especially the plough horizon. This problem is often overlooked even in terms of insufficient soil moisture, in other words the occurrence of soil drought. It must therefore be emphasized that in real conditions, our results are modified by soil characteristics. In general, in areas with light soils, drought manifests earlier and is also more intense in comparison to heavy-soil regions.

This paper is concerned with the issue of agricultural drought in long-term in the Czech Republic. Many more or less complex methods are applied worldwide and in the Czech Republic to assess the potential risk of drought occurrence (including agricultural drought). Some only take into account the meteorological parameters (especially precipitation and air temperature), others also incorporate soil characteristics, but usually only as a model applied uniformly to the entire region assessed. Majority of the computational methods are based on meteorological data in monthly intervals or some other time interval (Kott, 1992). However, the method we used takes into account not just the meteorological factors, but also the real soil conditions as much as possible. Unlike other computational methods, we based our model entirely on outputs from meteorological data in daily and not monthly intervals.

The selected method of assessing potential occurrence of agricultural drought is based on a relatively simple principle of comparing precipitation (PREC) with actual evapotranspiration from grassland (AEVA_GL). The difference between these two components, ie. PREC-AEVA_GL, is referred to as actual water balance (AWB_GL) (in this particular case from grassland). Unlike the potential water balance, this parameter also takes into account soil water saturation. All the model results are therefore performed with the soil being divided based on its type and the most important hydrolimit was the available water capacity of that particular type.

If we disregard potential inflow and outflow (ie. purely hydrological parameters in water cycle in landscape), then the major input component of water is precipitation and output component evapotranspiration (the release of water from soils and plant cover) in the form of actual (real) values. To analyze the actual evapotranspiration, the AVISO model, which uses selected algorithms (modified Penman-Monteith method) and is a Czech alternative to the similar English model MORECS (The Meteorological Office Rainfall and Evaporation Calculation System) was used (Thompson, Barrie, Ayles, 1984; Hough, Palmer, Weir, Lee, Barrie, 1997; Hough, Jones, 1997). All calculations were performed for grassland, which is the basic surface of all measuring stations of CHMI.

The AVISO model was due to our specific conditions (input data type, soil variability, vertical variability of landscape etc.) modified and the values should therefore be referred to as modified values of actual evapotranspiration (in this case from grassland), calculated by a modified approach based on the Penman-Monteith method (Pal Arya, 2001; Novák, 1995). These modifications, however, do not have a substantial effect on the overall results.

MATERIALS AND METHODS

The main source of data for the model calculations of output component of water circulation in nature (evapotranspiration from grassland, AEVA_GL) were technical series of the main meteorological parameters in a regular grid of 10 x 10 km (one of the outcomes of the CECILIA project, which was partly being solved by the CHMI, Brno regional office). The Czech Republic is divided into a regular grid with 789 grid points. Daily precipitation amount (mm.day^{-1}) was obtained for each day of the year in the period between 1961 and 2000 for each of the grid points (all data sets were completed, homogenized and verified, always based on measurements from the network of climatological stations of CHMI). The above model was then used to calculate daily actual evapotranspiration (mm.day^{-1}) with model resolution based on prevailing soil types. Input data for the calculation of daily evapotranspiration amount from grassland were the basic meteorological parameters, i.e. the average daily air temperature [°C], average daily water vapor pressure [hPa] calculated from air temperature and humidity, daily sunshine duration [h], average daily wind speed [m.s^{-1}] and daily precipitation amount [mm].

Given that the values of actual evapotranspiration from grassland depend not just on the course of the weather, but also on the current water content in soil (from pedological perspective the dependency on soil type), it was necessary to take into account a suitable hydrolimit – in this case the available water capacity in soil (hereafter AWC, all values in mm), given as the difference between humidity at field water capacity (hereafter FWC) and at wilting point of soil (hereafter WP). The soil depth used corresponds to the depth of active rootings, in the case of grassland during vegetation period this was at most 100 cm.

It is now appropriate to further explain the method of increasing the accuracy of AWC for the individual points in the grid. The values of AWC of soil are quite important in this type of analysis (period between 1961 and 2000). GIS methods were used to increase the accuracy of this hydrolimit for each of the grid points based on map data from VÚOMP (in particular the digital map of available water capacity of soils in the Czech Republic with a resolution of 1:500 000 from 2007 by P. Novák, J. Vopravil, D. Vetišková, which distinguishes between 5 AWC intervals). The used map was one of the outcomes of the VAV project 1D/1/5/05 „Vývoj metod predikce stavů sucha a povodňových situací na základě infiltračních a retenčních vlastností půdního pokryvu ČR“, which was realized in previous years in collaboration with CHMI Prague, CHMI, Brno regional branch and VÚOMP Prague.

Available water capacity of soils (AWC) in the Czech Republic was divided in 1 km resolution into the following intervals:

- AWC ≥ 200 [l.m^{-2}] - soils with high AWC;
- 150 ≤ AWC ≤ 199 [l.m^{-2}] - soils with high-medium AWC;
- 110 ≤ AWC ≤ 149 [l.m^{-2}] - soils with medium AWC;
- 80 ≤ AWC ≤ 109 [l.m^{-2}] - soils with low-medium AWC;
- 79 ≤ AWC [l.m^{-2}] - soils with low AWC

Each of the 789 grid points was assigned this more accurate AWC value with the 3 following methods being tested:

- AWC exactly based on the location of the grid point, only one AWC value from one square with a 1 km side length was taken into account;
- AWC given as the average value from 9 squares with a side length 1 km (1 square containing the actual grid point and 8 surrounding squares);
- AWC given as the modal value from 9 squares with a side length 1 km (1 square containing the actual grid point and 8 surrounding squares).

Detailed analysis of the above methods proved the application of the modal AWC value to be the most suitable method. The calculations using the AVISO model were subsequently all based on these values.

The actual AVISO model calculation was realized in a daily interval (period 1961-2000) for a set of 789 grid points in the area of the Czech Republic and resolution based on the above stated AWC intervals. Apart from the middle value of AWC in the given interval, also the upper and lower limits of the interval were taken into account. This method allowed increasing the accuracy of the interval or area and it is highly likely that the evapotranspiration from grassland corresponds to the value in this interval for that particular grid point and AWC value. Daily actual evapotranspiration from grassland values are the average of all these three values, which were calculated by the AVISO model using all the 3 AWC values (lower, middle and upper value from AWC interval).

In the next stage, long-term daily precipitation amounts were analyzed and for modal AWC also long-term actual evapotranspiration from grassland, in both cases in mm.day^{-1} for the set of all the 789 grid points in the period between 1961 and 2000. The long-term daily values of both parameters were finally used to find long-term values of precipitation and current evapotranspiration from grassland for the vegetation period as a whole (usually April-September).

Long-term actual water balance from grassland (AWB_GL) (1961-2000) for the vegetation period was determined as the difference between the two major components, ie. AWB _GL = PREC – AEVA_GL [mm].

The actual analysis of the level of risk of agricultural drought in the Czech Republic was performed using two different approaches. In both cases they were based on AWB_GL for the vegetation period between April and September.

Approach 1 – level of agricultural drought risk in the Czech Republic based on actual water balance from grassland during vegetation period

The calculated long-term values of AWB_GL (mm) during vegetation period were divided into a total of 8 categories, out of which 6 were given by intervals of 50 mm and two tail intervals, i.e. below -150 mm and above +150 mm. In the final map, each interval was assigned a textual description based on the following intervals:

AWB_GL:	risk of drought:
< -150 mm	exceptional
-150 to -100 mm	extreme
-100 to -50 mm	very high
-50 mm to 0 mm	high
0 mm to +50 mm	moderate
+50 mm to +100 mm	low-moderate
+100 mm to +150 mm	low
+150 mm <	no danger

The reasons for choosing the above scale was first of all the distribution of the locations with negative balance, which are likely to be at a higher risk of facing drought and also the not so frequent, but very high positive values occurring usually only in high-altitude areas of the Czech Republic (approximately >800 m above sea level), where the risk of potential drought is in long-term minimal (category "no danger").

The resulting map of AWB_GL constructed using this approach is shown in Figure 1.

Approach 2 – level of agricultural drought risk in the Czech Republic based on values of actual water balance from grassland during the vegetation period in combination with the frequency of years with negative balance values (the so called "index" method)

This analysis was based on the annual values of AWB_GL calculated for the individual years between 1961 and 2000 for each of the 789 grid points.

The following approach was then used to find 2 indexes (A, B):

Index A: determined based on long-term AWB_GL (1961-2000) for each grid point in the vegetation period by assigning this index a value between 1 and 8 in 50 mm intervals ("1" = interval <-150 mm, "8" = interval > +150 mm).

Index B: determined based on AWB_GL values during vegetation period during the individual years analyzed for the period between 1961-2000. First, the number of years with negative actual water balance in vegetation period (AEVA_GL>PREC) was determined. Next, based on the frequency of years with negative actual water balance of the individual grid points (0-5, 6-10,....,31-35, 36-40) the index B was assigned using a scale from 1 to 8 (1 = 36 – 40 years with negative value, 8 = 0-5 years with negative value).

The final index C is calculated as the average of the two previously determined indexes, i.e. C = (A+B)/2. Again, a scale of 8 was used and each index C was assigned to one of these intervals so that the locations with significant negative values and meanwhile where the frequency of years with negative values in the analyzed period is high, are clearly distinguishable from areas with higher positive values of actual water balance and lowest frequency of years with negative values (category "no danger"). Textual description of the individual categories on the map is the same for both approaches used.

The map, which was constructed based on the index approach (Fig. 2) is in a sense a more accurate version of the first approach. The textual description of the intervals is same as for Fig. 1, the only difference being that the two intervals at the end with most negative values of actual water balance were grouped together. The similarity of the two methods proves the assumption that long-term actual water balance values are related to the frequency of individual years with negative balance. In other words, in almost all cases the lower the long-term value of actual water balance, the higher the number of years with negative water balance during the time period analyzed (1961-2000) and vice versa.

RESULTS

The final outcome of the analysis are maps, which show long-term level of risk of agricultural drought for regions of the Czech Republic. These maps are given in Fig. 1 and Fig.2.

Maps were constructed using GIS tools in the ESRI ArcView 3.2 environment and its extension Spatial Analyst. A grid layer was created based on the analyzed values of actual water balance and individual grid points assigned to it. Subsequently interpolation methods were used to calculate raster model of these values between the observed points and this was then used for constructing the actual map of the Czech Republic. The interpolation method used was a universal linear kriging, which took into account elevation of the individual points and raster pixels calculated. The spatial resolution of the final raster is 500 x 500 m. The cell values of the raster were subsequently re-classified based on the chosen intervals and in this way, each pixel of the raster was assigned to one of the intervals of level of risk of drought based on its value. The entire area of the Czech Republic was processed in this way and covered with raster cells corresponding to one of the intervals. This led to construction of compact regions with particular risk of drought. Raster was then used to generate a map in JPG format, which also contained lots of other additional information (region borders, large cities and rivers), and vector GIS layer in SHP format, where the individual regions with different level of risk are defined as closed polygons. The corresponding level of risk of drought for each individual polygon was also included as textual description in the layer attribute table. Vector layer is intended for further analyses using the GIS environment.

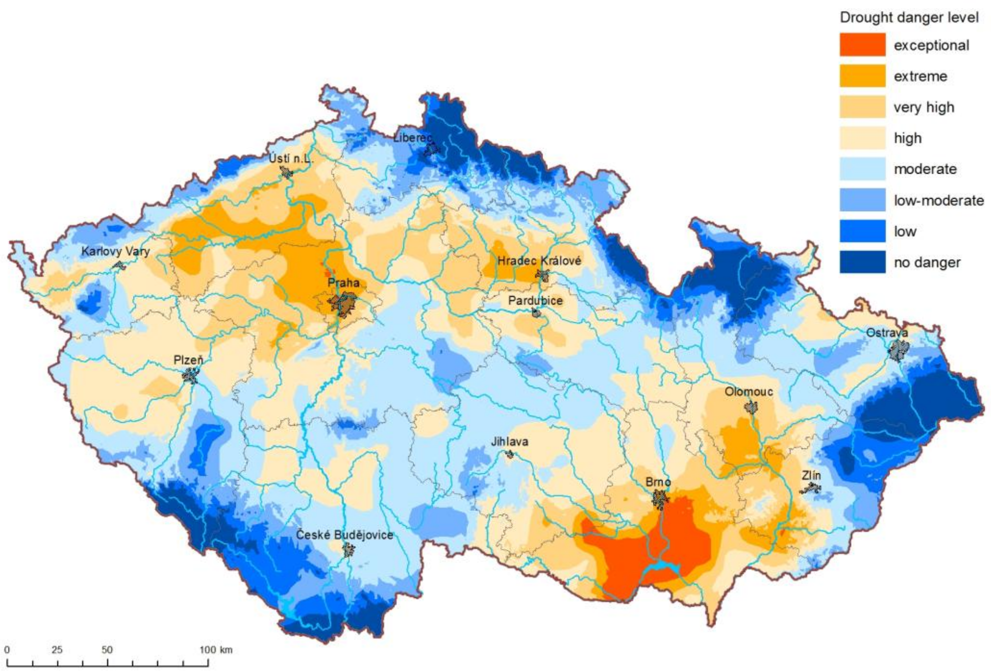

Fig. 1 Long-term agricultural drought in the Czech Republic during vegetation period, drought danger level based on the analysis of actual water balance from grassland for the period between 1961 and 2000

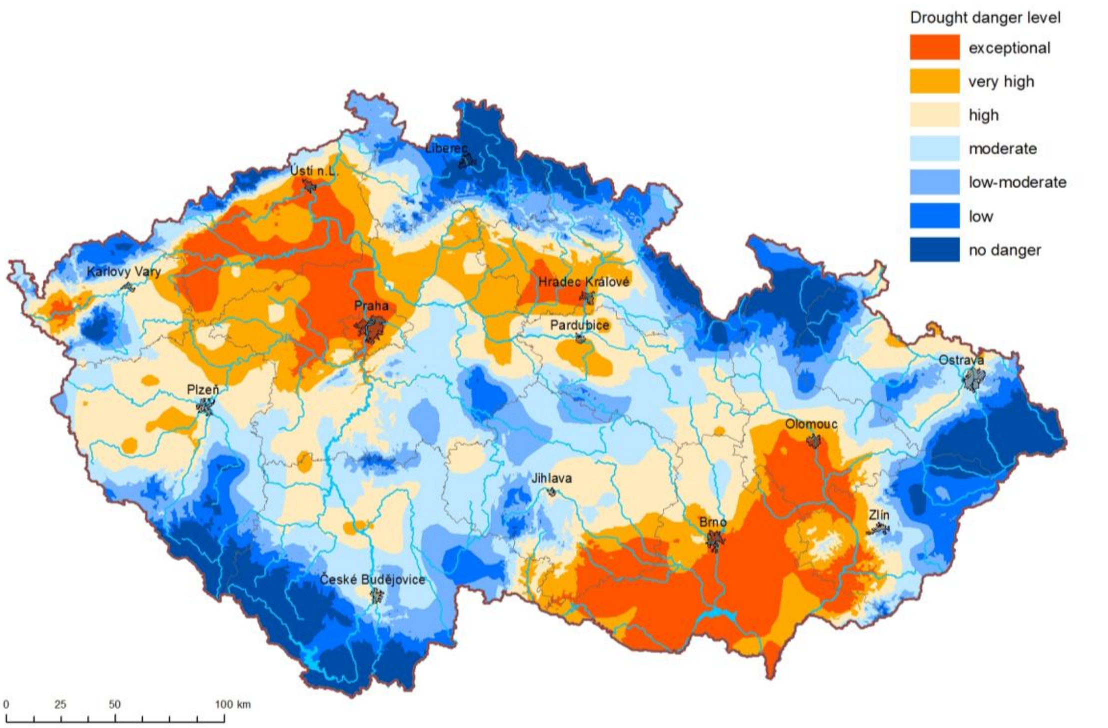

Fig. 2 Long-term agricultural drought in the Czech Republic during vegetation period, drought danger level based on the analysis of actual water balance from grassland for the period between 1961 and 2000, index method

CONCLUSION

The presented paper shows possible approaches to assessing potential occurrence of agricultural drought in long-term (1961-2000) in the Czech Republic. The analysis is based on a method designed by CHMI employees (Vráblík, Kohut, Chuchma, 2010) upon a request from the Ministry of Agriculture. Complete calculations of actual water balance from grassland were performed by the AVISO model using technical series of the main meteorological parameters with accuracy increased by taking into account soil hydrolimits (available water capacity of soil types).

When analyzing and using the resulting maps it is important to keep in mind several facts. Most of all, there is a certain level of subjectivity in the data analysis – the initial data and the actual calculations are objective, however the selection of method and drawing conclusions will always be slightly subjective given the nature of the problem analyzed. It must be emphasized that in general there are many other available methods with regards to analysis of drought, which in some cases can differ substantially (see Introduction). The approach we selected is unique, but still remains just "one of the available methods". The actual textual description of the individual categories is subjective and slightly vague, however necessary. For better understanding let´s now include a more detailed, mathematical description of the categories at both ends of the scale, which is based on the analysis of the calculated balance values:

- Category "exceptional danger" includes regions with long-term value of AWB_GL lower than -150 mm and with at least 90 % of years with negative balance in the period analyzed,
- Category "no danger" includes regions with long-term value of AWB_ GL above 100 mm and a maximum of 10 % of years with negative balance in the period analyzed.

The assessed regions have different level of risk of agricultural drought in long-term, but this difference and description must be understood from the perspective of the Czech Republic. Therefore the driest regions of the Czech Republic cannot be compared with the driest regions of Europe (for example the Southern part of Europe).

It is also important to note that the real impacts of drought in any of the regions in a given year are dependent not just on the factors analyzed (soil and weather conditions), but also on many other factors, which cannot be taken to account by our model, in particular:

- Land use of agricultural soils (parks, arable land, pastures),
- Type of crop and its water requirements and growing regime during the vegetation period,
- Application of measures to avoid drought (soil management, watering, suitable sowing methods),
- Economic possibilities of organizations to withstand the impacts of drought.

It must be emphasized that the basis for determination of agricultural drought in the individual regions is the level of drought given by soil dryability and agricultural management. This means that even in regions with highest level of risk intense agricultural production and satisfactory crop yield achieved in some years, though not on a regular basis.

Acknowledgement

The presented paper is based on the results of the QH92030 (NAZV) project „Hodnocení půd z hlediska jejich produkčních a mimoprodukčních funkcí s dopady na plošnou a kvalitativní ochranu půd České republiky".

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