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The impact of drought incidence on yield variability of cereals in Slovakia as influenced by climate change

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Abstract

Spatial variability of drought incidence in Slovakia was evaluated on the basis of data from 10 weather stations and selected soil parameters of the sites. Palmer Drought Severity Index was used as indicator of dry and wet periods to compare the impact of climate on yield variability of winter wheat, spring barley and maize in two climatic normals, 1951 – 1980 and 1981 – 2010. The highest increase in yield variability was found in the case of maize yield; the lower variability for wheat yield. The impact of climate change resulted in increase of yield variability in the second climatic normal (1981 – 2010). As concerning spatial aspect, the occurrence of drought was more frequent in lowland areas of Slovakia. A significant connection of drought to the variability in yield was not detected.

Key words: PDSI, winter wheat, spring barley, maize

Introduction

Drought can be seen as the cause of natural disasters. Shortage of water sources during the dry periods in the conditions of changing climate can negatively affect agriculture, forestry, watercourse regime as well as natural ecosystems in Central Europe (ŠKVARENINA et al 2009, BRÁZDIL et al. 2009). One of the methods for evaluating draught is the Palmer Drought Severity Index (PALMER, 1965). PDSI calculation takes into account not only the climate but also soil characteristics. Over the past years its use gradually spread to the areas of meteorology, hydrology, forestry, economics and agriculture

(LITSCHMANN, 2001, TRNKA, 2008). In terms of agriculture the water balance during the months April to June plays a key role in the estimation of total yield of most of the major crops. A significant disruption of the water balance in the mentioned period April to June occurs on average in a 20 year interval. The likelihood of this occurrence can however rise up to five times until 2050. That would mean that the water balance in the period April to June would be disrupted once every four years (HLAVINKA et al. 2009). Extensive changes in the water balance in the period April to June can be expected in whole of the Central Europe (ŠIŠKA – TAKÁČ, 2009).

Materials and methods

For the evaluation of drought Palmer Drought Severity Index (PDSI) was used (PALMER, 1965). The index is standardized for various regions and time periods. Therefor it is usable for the evaluation of drought in various areas with various climates (DUNKEL, 2009). The calculation of PDSI was carried out by a program developed at the University of Nebraska – Lincoln. It was written in FORTRAN by Tom Heddinghaus (TURŇA, 2014). The input data consists of: average monthly precipitation totals, average monthly air temperatures, average temperatures during the evaluated period, latitude and available water capacity. The climate data was provided by SHMI. Available water capacity was provided by the Soil Science and Conservation Research Institute in Bratislava. For the evaluation of drought ten sites were chosen: Bratislava, Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad, Košice, Milhostov and Kamenica nad Cirochou (figure 1). The sites were chosen to cover the altitude profile of the agricultural production area of Slovakia. The key stations are Hurbanovo (Danube Lowland), Čadca (northern Slovakia), Poprad (below Tatra Mountains) and Milhostov (Eastern Slovak Lowland). The evaluation was carried out on two 30-year time periods, 1951 – 1980 and 1981 – 2010. In this paper periods covering more than 10 continual dry months are recognized as long-term drought periods.

Figure 1: Evaluated sites: 1 – Bratislava, 2 – Piešťany, 3 – Hurbanovo, 4 – Čadca, 5 – Sliač, 6 – Boľkovce, 7 – Poprad, 8 – Košice, 9 – Milhostov, 10 – Kamenica nad Cirochou

Table 1: PDSI classification

PDSI value	Characteristics of the evaluated month
≥ 4,00	extremely moist
3,00 to 3,99	very moist
2,00 to 2,99	moderately moist
1,00 to 1,99	slightly moist
0,50 to 0,99	weakly moist
0,49 to -0,49	neutral
-0,50 to -0,99	weakly dry
-1,00 to -1,99	slightly dry
-2,00 to -2,99	moderately dry
-3,00 to -3,99	severely dry
≤ -4,00	extremely dry

For the assessment of variability of biomass production of agricultural crops winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*) and maize (*Zea mays*) were chosen. The evaluation was based on variability of PDSI values (table 1) and the production of the crops. MARKECHOVÁ, STEHLÍKOVÁ and TIRPÁKOVÁ (2011) indicate that the variability according to the value of

the coefficient of variation can be: modest (0% – 4%), normal (5% – 44%), high (45% – 64%), very high (65% – 84%), extreme (85% – 104%) or anomalous (105% and more). The variability of production of the crops was evaluated individually for Western, Central and Eastern Slovakia. The data on crop yields were provided by the Statistical Office of the Slovak Republic.

Results

In Bratislava during 1951 – 1980 most months were classified as slightly dry at 16.9%. Overall, 50.3% of the months were recognized as dry according to the PDSI classification. There has been recorded four long-term drought periods in 1951 – 1980. In the period 1981 – 2010 most of the months were classified as slightly dry at 15.6%. The amount of extremely dry months increased by 0.6% compared to the first evaluated period (from 2.5% to 3.1%). Overall, 52.5% of the months were recognized as dry according to the PDSI classification (an increase by 2.2%). Only one long-term drought period was recorded in 1981 – 2010 (a decrease by 3).

In Piešťany during 1951 – 1980 most months were classified as slightly moist at 16.1%, followed by neutral at 11.7% and slightly dry at 11.4%. Extremely dry months represented 3.9%. Overall, 42.2% of the months were recognized as dry according to the PDSI classification. There has been recorded 6 long-term drought periods. In 1981 – 2010 most of the months were classified as slightly moist at 16.7%, followed by slightly dry at 15%. Overall, 43.6% of the months were recognized as dry according to the PDSI classification (an increase by 1.4%) with 6.7% being extremely dry. There has been recorded 5 long-term drought periods (a decrease by 1).

In Hurbanovo during 1951 – 1980 (figure 2) most months were classified as neutral at 17.2%. During the period 46.4% of the months were recognized as dry according to the PDSI classification, with 1.1% being extremely dry. There has been recorded 3 long-term drought periods. The period 1981 – 2010 (figure 3) was mostly represented by slightly dry and moderately dry months, both at 16.1%, followed by neutral months at 15.8%. Overall, 48.6% of the months were recognized as dry according to the PDSI classification (an increase by 2.2%)

with 1.9% being extremely dry. There has been recorded 6 long-term drought periods (an increase by 3).

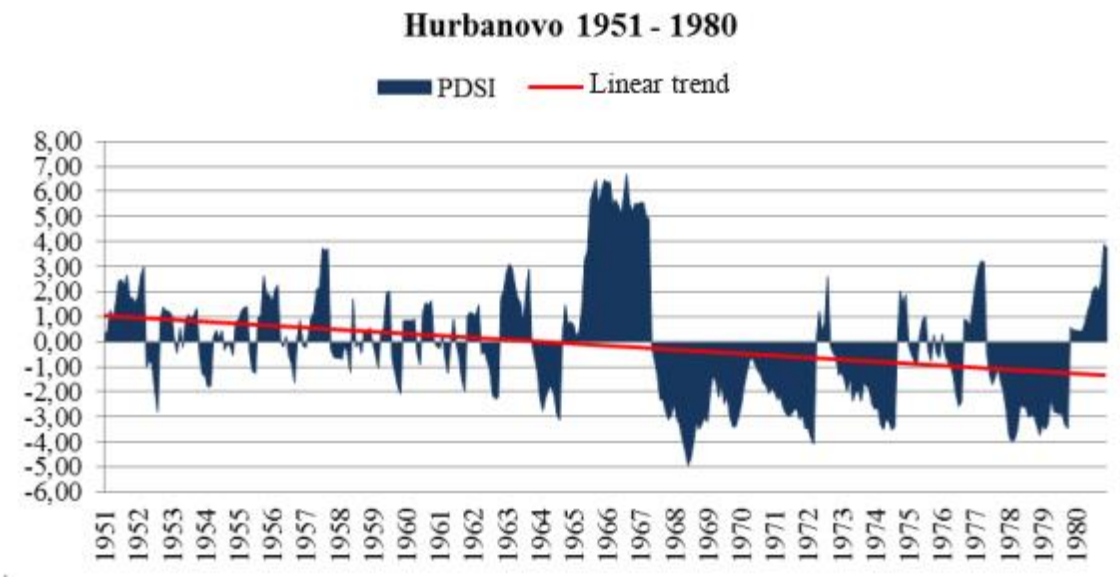

Figure 2: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Hurbanovo

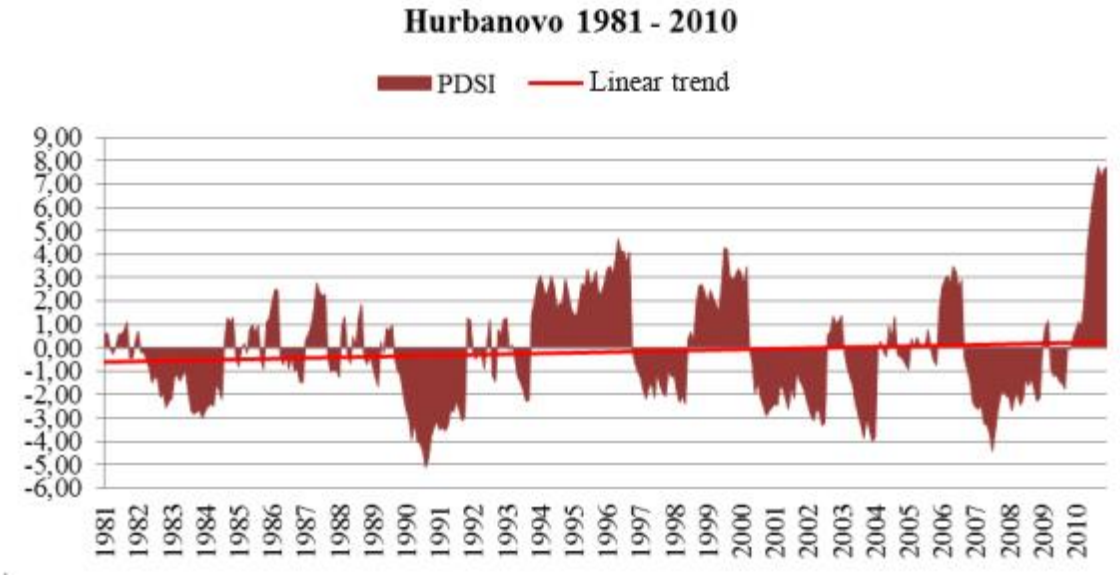

Figure 3: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Hurbanovo

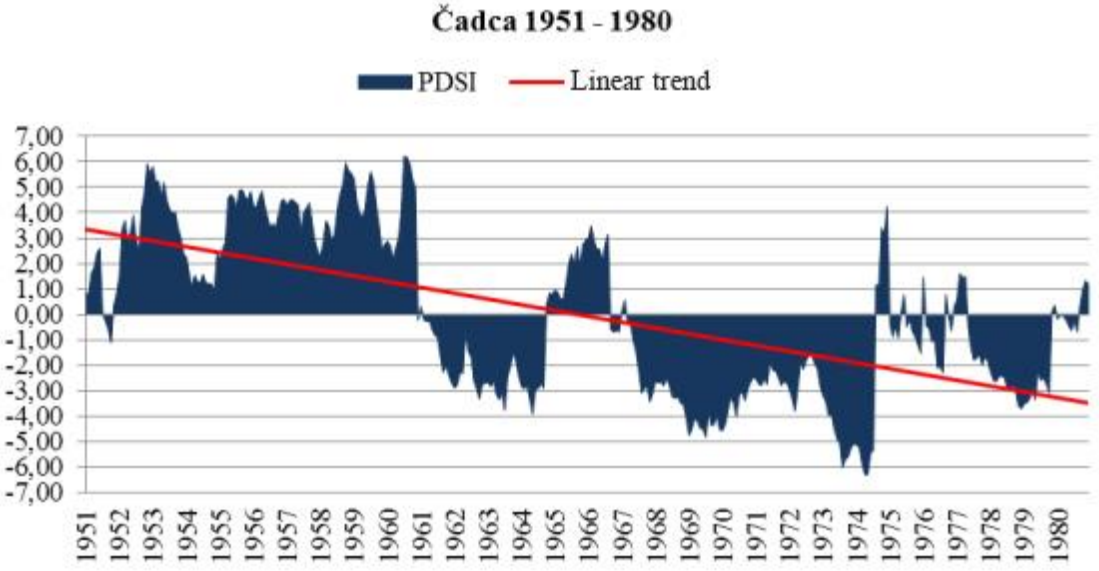

Figure 4: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Čadca

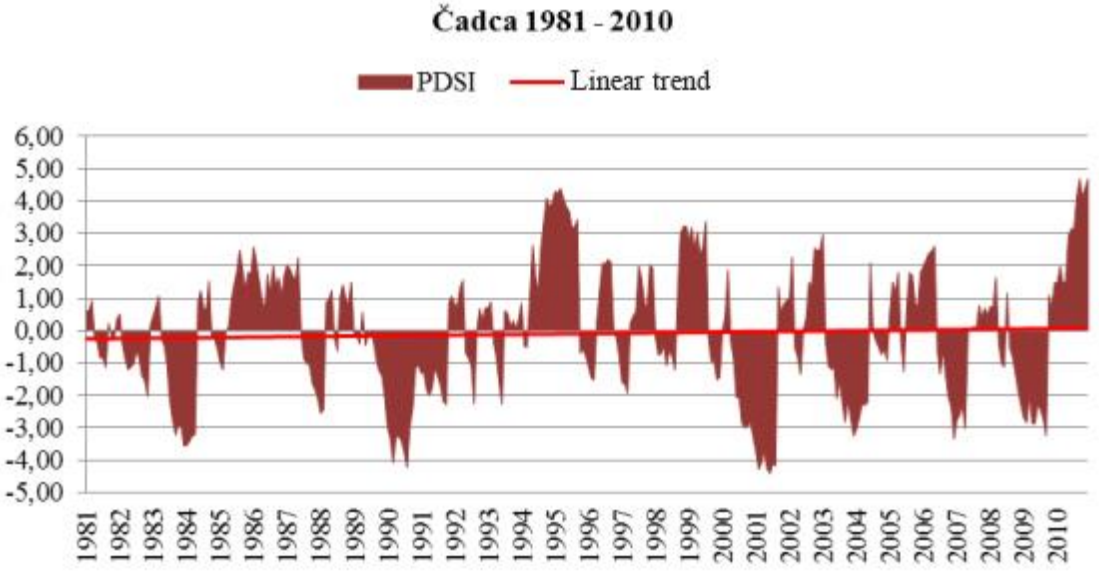

Figure 5: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Čadca

In Čadca during 1951 – 1980 (figure 4) most months were classified as moderately dry at 19.4%. Extremely dry months figured at a significant amount of 8.1% as well as extremely moist months with the amount of 15.6%. Overall, 49.5% of the months were recognized as dry according to the PDSI classification. There has been recorded 3 long-term drought periods out of

which the longest one lasted over 7 continual years. However, in 1981 – 2010 (figure 5) only 2.2% of the months were classified as extremely dry and only 2.8% as extremely moist.This period was represented mostly by neutral months at the amount of 15.6%. Overall, 43.1% of the months were recognized as dry according to the PDSI classification (a decrease by 6.4%). There has been recorded 4 long-term drought periods (an increase by 1).

In Sliač during 1951 – 1980 most months were classified as neutral at 17.8%, followed by slightly dry at 15.3% and slightly moist at 14.4%. Overall, 42.2% of the months were recognized as dry according to the PDSI classification with 1.1% being extremely dry. There has been recorded 4 long-term drought periods. In 1951 – 2010 most of the months were classified as neutral and slightly dry, both at 15.6%. Overall, 45.3% of the months were classified within the range from weakly dry to extremely dry (an increase by 3.1%), with 1.4% being extremely dry. There has been recorded 5 long-term drought periods (an increase by 1).

In Boľkovce during 1951 – 1980 most months were classified as slightly dry at 14.7%. Overall, 45% of the months were recognized as dry according to the PDSI classification with 2.2% being extremely dry. There has been recorded 5 long-term drought periods. In 1981 – 2010 most months were classified as slightly dry at 17.8%. Overall, 49.7% of the months were recognized as dry according to the PDSI classification (an increase by 4.7%) with 2.2% being extremely dry. There has been recorded 4 long-term drought periods (a decrease by 1) with one lasting almost 4 years.

In Poprad during the period 1951 – 1980 (figure 6) most months were classified as neutral at 18.3% followed by slightly dry at 13.6%. Extremely moist months were represented by 2.5% and extremely dry months by 2.2%. Overall, 38.6% of the months were recognized as dry according to the PDSI classification. There has been recorded 4 long-term drought periods in 1951 – 1980. In the period 1981 – 2010 (figure 7) most of the months were classified as neutral at 16.7%, followed by slightly moist at 14.7% and moderately moist at 13.3%. The amount of extremely dry months has increased by 1.1% compared to the

previous period, from 2.2% to 3.3%. Overall, 43.3% of the months were recognized as dry according to the PDSI classification (an increase by 4.7%). 3 long-term drought periods were recorded in 1981 – 2010 (a decrease by 1), two of which were significantly longer compared to those in 1951 – 1980.

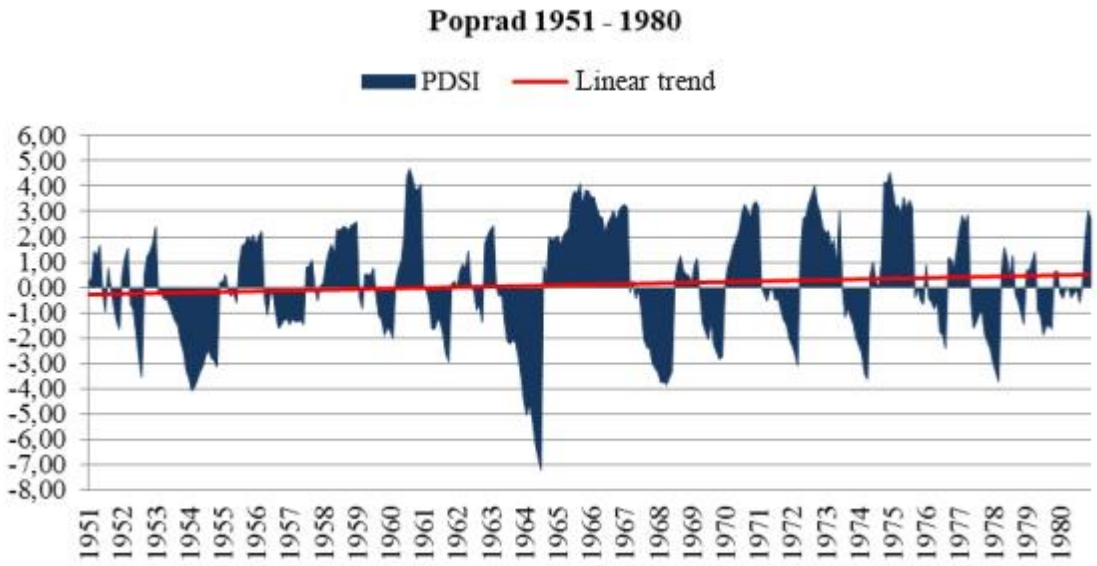

Figure 6: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Poprad

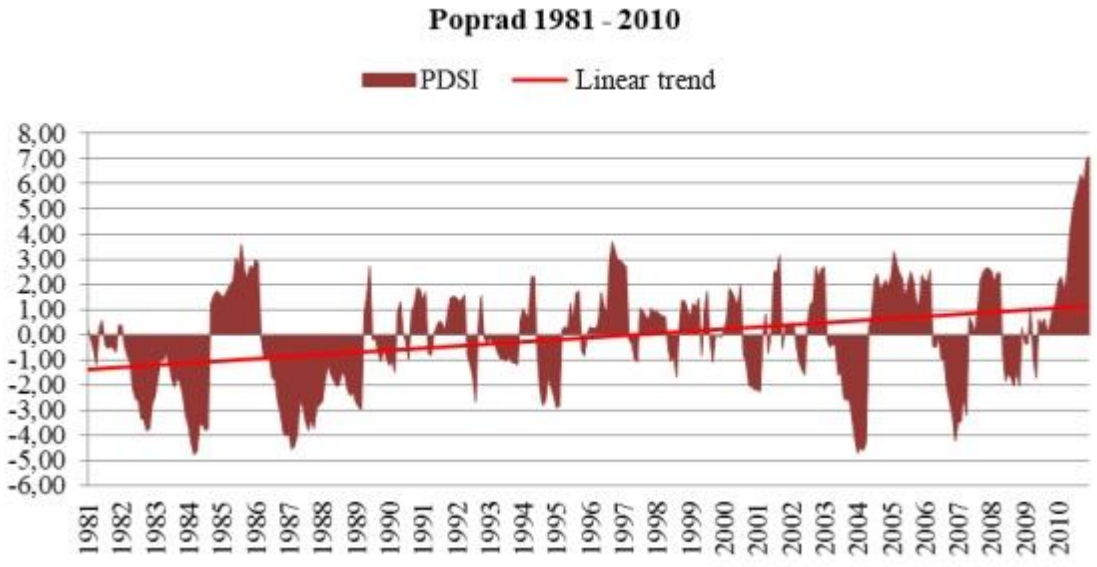

Figure 7: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Poprad

In Košice during 1951 – 1980 most of the months were classified as slightly dry at 13.9%, followed by moderately moist at 13.3%. Extremely dry months were represented by 2.8%. Overall, 48.6% of the months were recognized as dry according to the PDSI classification. There has been recorded 6 long-term drought periods. In 1981 – 2010 the most frequent month classification was neutral at 16.9%, followed by slightly dry at 16.7%. Overall, 46.1% of the months were recognized as dry according to the PDSI classification (a decrease by 2.5%) with 3.1% being extremely dry. There has been recorded 5 long-term drought periods (no change).

In Milhostov during 1951 – 1980 (figure 8) most of the months were classified as neutral at 15.3%. During the period 46.7% of the months were recognized as dry according to the PDSI classification with 3.1% as extremely dry. There has been recorded 6 long-term drought periods. The period 1981 – 2010 (figure 9) was mostly represented by slightly dry months at 19.7%, followed by neutral months at 16.7%. Overall, 49.4% of the months were recognized as dry according to the PDSI classification (an increase by 2.7%) with 1.4% being extremely dry. There has been recorded 5 long-term drought periods (a decrease by 1).

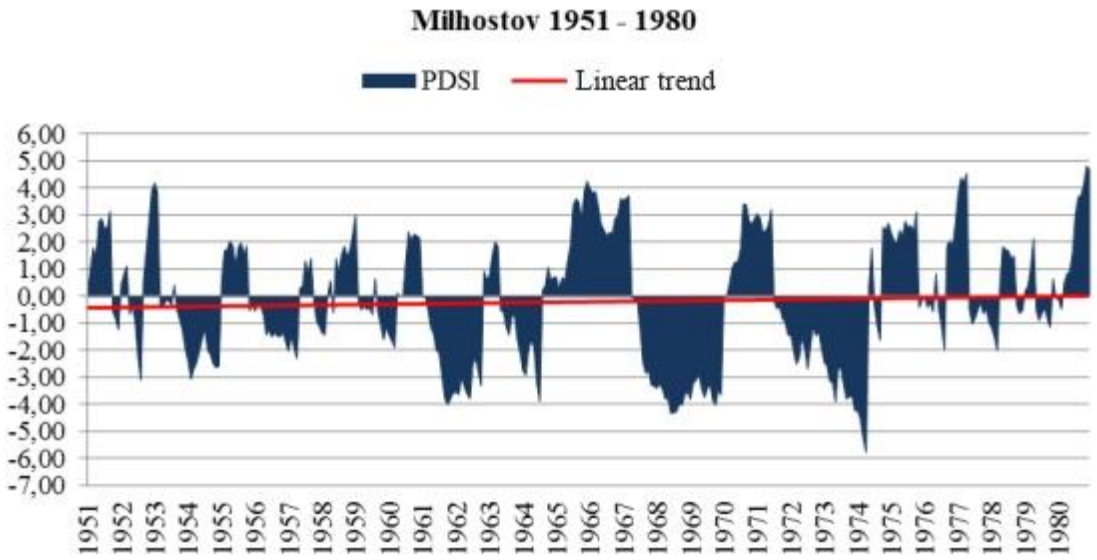

Figure 8: Graphic interpretation of PDSI index course in the period 1951 – 1980 in Milhostov

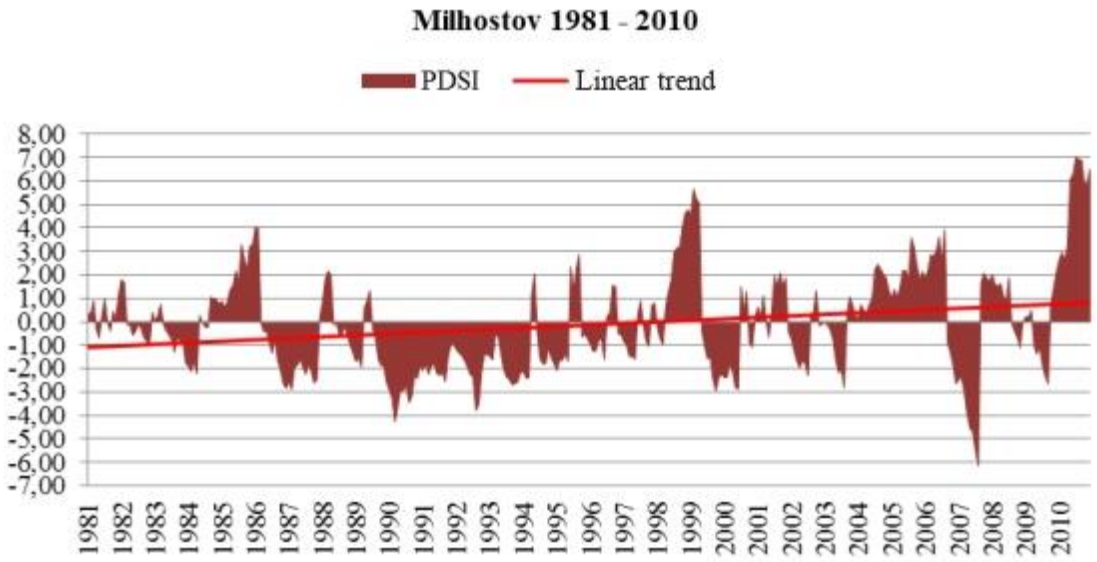

Figure 9: Graphic interpretation of PDSI index course in the period 1981 – 2010 in Milhostov

In Kamenica nad Cirochou during 1951 – 1980 most of the months were classified as neutral at 15.8%, closely followed by slightly moist at 15.6%. Extremely dry months represented 8.1% which represented the highest amount from all observed sites in both evaluated periods. Overall, 41.1% of the months were recognized as dry according to the PDSI classification. There has been recorded 4 long-term drought periods. In 1981 – 2010 the most frequent classification was neutral at 14.7%, followed by weakly moist and moderately dry, both at 12.2%. Overall, 44.2% of the months were recognized as dry according to the PDSI classification (an increase by 3.1%) with 2.8% being extremely dry (a decrease by 5.3%). There has been recorded 4 long-term drought periods (no change).

The growing season of spring barley is shortest and that of winter wheat the longest of the evaluated crops. This fact could affect the relationship between drought and crop production, whereas some of the dry months were not included in the growing seasons. The coefficients of variation of crop production divided into two periods (1951 – 1980, 1981 – 2010) are given in tables 2 to 4.

Table 2: Coefficients of variation of crop production as a percentage for Western Slovakia

1951 – 1980		**1981 – 2010**	
crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	50	winter wheat	69.3
spring barley	36.7	spring barley	37.7
maize	47.4	maize	58.2

In Western Slovakia the coefficient of variation of winter wheat production was 50% in 1951 – 1980. In 1981 – 2010 the coefficient of variation was 19.3% higher (at 69.3%) while the coefficient of variation of spring barley production showed an increase by 1% and the coefficient of variation of maize production showed an increase by 10.8% in 1981 – 2010 compared to 1951 – 1980. This implies that the distribution of the dry months during the growing season of spring barley during 1981 – 2010 did not change significantly compared to the period 1951 – 1980. Coefficient of variation in the case of other crops is the opposite.

Table 3: Coefficients of variation of crop production as a percentage for Central Slovakia

1951 – 1980		**1981 – 2010**	
Crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	60.6	winter wheat	49.9
spring barley	47.2	spring barley	48.4
maize	29.1	maize	57.4

In Central Slovakia the coefficient of variation of winter wheat production showed a decrease by 10.7% in the period 1981 – 2010 in comparison to the period 1951 – 1980. This was the only case in this study where the coefficient of variation was lower in 1981 – 2010. The reason on this phenomenon was due to moister winters in 1981 – 2010 compared to those in 1951 – 1980. The coefficient of variation of spring barley was higher by 1.2% in 1981 – 2010. As in the case of maize, it was higher by 28.3%. This means that a situation similar

to that in Western Slovakia was observed. However, the growing season of maize was affected by the dry growing season more significantly than the growing season of spring barley.

Table 4: Coefficients of variation of crop production as a percentage for Eastern Slovakia

1951 – 1980		**1981 – 2010**	
crop	Coefficient of variation	crop	Coefficient of variation
winter wheat	37	winter wheat	59.6
spring barley	10.9	spring barley	35.6
maize	38.6	maize	40.5

In Eastern Slovakia higher values of the coefficients of variation were recorded in the period 1981 – 2010 for all of the evaluated crops, by 22.6% for winter wheat, by 24.7% for spring barley and 1.9% for maize production compared to the period 1951 – 1980. On this location a change was observed compared to the Western and Central Slovakia in a significantly higher increase of the coefficient of variation of spring barley production and a significantly lower increase of the coefficient of variation of maize production. This means that the growing season of spring barley during the period 1981 – 2010 in comparison to that in 1951 – 1980 was affected by drought to a higher extent than the growing season of maize.

Discussion

The most significant drought periods mutual for all of the ten evaluated sites were observed in 1954 (except in Čadca), 1964, 1968, 1973, 1974 and 2007.

The variability of the results of other papers compared to this study is most probably caused by different evaluated periods. The 30-year periods were designed to cover the closest past. In the methods of PDSI calculations one of the inputs is the average temperature over the evaluated period. As some of the other inputs represent latitude and available water capacity it is not suitable to compare the results of this study with other papers.

It is important to mention the fast that 2010 was very rich in the means of precipitation totals which could be responsible for the positive trend on seven of the ten evaluated sites. As VIDO (2012) mentions, this can lead to the misinterpretation of reality. Therefor one must be very cautious when trying to interpret draught. HLAVINKA, TRNKA, SEMERÁDOVÁ et al. (2009) state that the correlation between drought (PDSI values) and the production of crops was not as big in the case of maize compared to the cases of spring barley and winter wheat. This study shows that the variability of production in relation to drought is the smallest in the case of spring barley. This could be caused with the shorter growing season of spring barley compared to the growing season of maize which was annually not affected as much as spring barley.

Based on the values of the computed coefficients of variation in both of the evaluated periods it can be stated that the production variability of the selected crops in relation to drought was normal to high. The production variability of winter wheat and maize was high in Western Slovakia in both evaluated periods. The production variability of spring barley in relation to drought was normal. In Central Slovakia the production variability of maize in relation to drought was normal in the period 1951 – 1980, the production variability of maize in 1981 – 2010 was high same as of the other evaluated crops.

For Eastern Slovakia normal production variability in relation to drought was typical for all crops in both evaluated periods. The only exception was winter wheat where in 1981 – 2010 its production variability was classified as high.

By comparing the two evaluated periods it can be stated that the variability in 1981 – 2010 is higher than in 1951 – 1980. This could have been caused also by the year 2010 being overly rich on precipitations which logically lead to damage to the yields of crops.

Conclusion

Based on the distribution of the months according to the PDSI classification it was shown that period 1981 – 2010 featured more months classified as dry (in the range from weakly dry to extremely dry) than the period 1951 – 1980. This was proven in eight of the ten evaluated sites. The exceptions were the two

sites Čadca and Košice. This could have been caused by the influence of continental climate.

From the comparison of the trends between the evaluated periods it was observed that in the period 1951 – 1980 seven out of the ten sites shown a negative (drying) trend. The mentioned sites are: Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad a Milhostov. The drying trend was only observed in three sites in the period 1981 – 2010, in Bratislava, Košice and in Kamenica nad Cirochou. The most common linear trend of the period 1981 – 2010 was mainly caused by the significantly moist year 2010 which represented the last year of the evaluated period. The influence of drought presence in relation to production variability of winter wheat (*Triticum aestivum*), spring barley (*Hordeum vulgare*) and maize (*Zea mays*) on the basis of their coefficients of variation can be evaluated as normal to high. The production variability in relation to drought was higher in the period 1981 – 2010 than in the period 1951 – 1980. This was caused by distribution of dry and moist years in the period 1981 – 2010 and by the extremely wet year 2010.

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Summary

Štúdia bola zameraná na zhodnotenie stavu sucha na Slovensku v podmienkach meniacej sa klímy. Pre hodnotenie sucha bola vybraná metóda prostredníctvom Palmerovho indexu závažnosti sucha (PDSI). Tento spôsob hodnotenia sucha sa odlišuje od predchádzajúcich používaných spôsobov hodnotenia tým, že využíva aj dáta o pôdnych pomeroch (dostupnej vodnej kapacite). Pre hodnotenie bolo zvolených desať lokalít (Bratislava, Piešťany, Hurbanovo, Čadca, Sliač, Boľkovce, Poprad, Košice, Milhostov a Kamenica nad Cirochou) a dva časové rady (1951 – 1980 a 1981 – 2010). Bolo pozorovaných niekoľko spoločných období sucha na všetkých sledovaných lokalitách. Boli to obdobia v rokoch 1954 (s výnimkou Čadce), 1964, 1968, 1973, 1974 a 2007. Niektoré predstavovali časť daného roka, v iných prípadoch boli suché obdobia v spomínaných rokoch súčasťou dlhších suchých období (trvajúcich viac ako 1 súvislý rok).

Na základe percentuálneho podielu mesiacov od kategórie obdobia začínajúceho sucha až do kategórie extrémne suché mesiace možno konštatovať, že väčší podiel, a teda suchšie obdobie, predstavoval časový rad 1981 – 2010. To sa preukázalo v prípade ôsmich lokalít. Výnimku predstavovali len dve lokality, a to Čadca a Košice, v ktorých suchšie obdobie predstavovalo časový rad 1951 – 1980. Príčinou mohol byť vplyv kontinentálnej klímy. Vplyv výskytu sucha na variabilitu produkcie pšenice letnej formy ozimnej (*Triticum aestivum*), jačmeňa jarného (*Hordeum vulgare*) a kukurice siatej (*Zea mays*) na základe variačných koeficientov možno zhodnotiť ako normálny až veľký. Variabilita produkcie v závislosti od sucha bola vyššia v rokoch 1981 – 2010 ako v rokoch 1951 – 1980. Príčinou bolo rozdelenie suchých a vlhkých mesiacov počas druhého sledovaného obdobia zakončené extrémne vlhkým rokom 2010.

Odporúčanie pre hospodárenie na Slovensku v podmienkach meniacej sa klímy predstavuje aplikáciu doplnkových závlah, ktoré sú osvedčeným opatrením pre stabilizáciu produkcie vybraných obilnín.

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