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20TH CENTURY VARIATIONS OF THE SOIL MOISTURE CONTENT IN EAST-HUNGARY

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Összefoglalás - A jelen tanulmány az első szerző PhD dolgozatának Téziseit[1] tartalmazza, néhány főbb eredményt ábrákon és táblázatokban illusztrálva. A Tézisek célja, hogy megbízható, hálózatszerű meteorológiai méréseken alapuló, korszerű klimatográfiai elemzést adjon a térség változatos hidrometeorológiai viszonyairól, amely egyszerre tér ki az évközi változékonyság pontszerű statisztikai jellemzőire és a hozzáférhető talajnedvesség térbeli és időbeli kapcsolódásaira, valamint a hosszabb távú változásokra és azoknak a nagytérségű éghajlati trendekkel való esetleges kapcsolatára. Vizsgálataink zömét öt kelet-magyarországi meteorológiai állomás: Miskolc, Nyíregyháza, Debrecen, Kecskemét és Szeged 1901 és 1999 közötti, Palmer-féle Aszály-szigorúsági Index (PDSI) adatsoraira végeztük el. A térbeli kapcsolatok elemzéséhez 17 állomás 1951 és 1992 közötti PDSI sorát állítottuk elő, ezúttal a Thornthwaite féle növény-független módszerrel, a nem-homogenizált kiindulási adatokból. Munkánk további célja, hogy a vizsgált térség nedvesség-anomáliáin alapuló objektív regionalizálással; objektív évtípusok jellemzőinek és kalendáriumának közreadásával; valamint számos éghajlati szempontból reprezentatív hosszúságú, száraz és nedves időszak kijelölésével segítse a talaj nedvességkészlete által befolyásolt agro-ökológiai problémák további tudományközi vizsgálatát.

Summary - The present study is an illustrated version of the Abstract of a PhD Theses prepared by the first author at the University of Szeged[1]. The aim of the Theses is to give a modern climatographical analysis on the varied hydrometeorological relations of the region, based on reliable observations of meteorological stations. The analysis includes statistical characteristics of the inter-annual variability, spatial and temporal correlation of the available soil moisture content and long-range changes, as well as their possible relation with climatic trends for greater regions. The above-mentioned aims are intended to be realised on the basis of the *Palmer's Drought Severity Index* (PDSI) data series. Monthly PDSI data series of five stations (Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged) were determined for the 20th century, in three versions. To study the spatial correlations short PDSI sets of 17 stations were calculated for the period between 1951 and 1992, with Thornthwaite's plant-independent method and without homogenisation. The objective and results of our work is to help further the inter-disciplinary study of agro-ecological problems, influenced by the soil moisture content, by performing objective regionalization based on soil moisture anomalies in the region; by publishing the characteristics and the calendar of the objective year-types; and also by determining climatically representative, long dry and wet periods.

Key words: Palmer's Drought Severity Index (PDSI), soil moisture content, time and space correlations, factor analysis, objective year-types, long term climate variations, method of "slices", Makra test

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[1] This Abstract and the scientific record of Sz. Horváth resulted in winning the "Young Scientist Award" conferred to her by the European Meteorological Society (EMS) in 2004.

INTRODUCTION

Hungary and the eastern part of the Great Hungarian Plain have always been characterised by significant hydrological extremities. Drought and inundation events followed each other, sometimes even within a year. On the other hand, couple of decades proved to be either dry or wet during the 20th century.

The most serious inundation events occurred between the years 1939-1942 and extended over 5700 km^2. The whole area threatened by inundation exceeds 18,000 km^2, which reaches nearly 60 % of the cultivated lands of the Great Hungarian Plain (*Pálfai*, 2000). Considering the 20th century, droughts at the beginning and the middle of the 1900s, as well as those in the early 1990s were the strongest ones. Furthermore, the drought of similar strength in 2000 can also be listed here. Frequency of drought and inundation events are similar in the Great Plain (total area: 45,000 km^2, cultivated lands: 32,000 km^2); however, the typical spatial extension of the former phenomenon is much larger than that of the inundation (*Pálfai*, 2000).

The aim of the study is to give a modern climatographical analysis on the varied hydrometeorological relations of the region, based on reliable observations of meteorological stations. The analysis includes statistical characteristics of the inter-annual variability, spatial and temporal correlations of the available soil moisture content and long-range changes, as well as their possible relations with climatic trends for greater regions. The objective of our work is to help further the inter-disciplinary study of agro-ecological problems, influenced by the soil moisture content, by performing objective regionalization based on soil moisture anomalies in the region; by publishing the characteristics and the calendar of the objective year-types; and also by determining climatically representative, long dry and wet periods.

The above-mentioned aims are intended to be realised on the basis of Palmer's Drought Severity Index (PDSI) data series, known world-wide in agroclimatic analysis (*Palmer*, 1965; *Alley*, 1984; *Karl,* 1986; *Briffa et al*., 1994; *Bussay and Szinell*, 1996; *Mika,* 1998; *Cook et al*., 1999; *Domonkos et al.,* 2000). Monthly PDSI data series of five stations were determined for the 20th century (99 years), in three versions: a) plant-covered surface (maize) and homogenised (i.e. against possible non-representative peculiarities of the stations or the observations); b) bare (not plant-specific) surface, homogenised; and c) plant-covered surface, but non-homogenised meteorological data. Among them, we consequently consider the first alternative, i.e. the homogenised datasets for plant-covered surface as the most important, basic version. Analysis of the other two versions aimed to examine whether our conclusions could be influenced by the homogenisation and by any hidden features connected to evapotranspiration of the selected plant.

The following questions were answered in the study:

- Is the seasonal and spatial independence of the PDSI, elaborated for another region, valid in the Great Hungarian Plain, too?
- Can the distributions of the monthly PDSI sets be considered normal ones?
- Have the PDSI series got significant correlation to parallel independent estimations of the soil moisture content, according to which the index can be reliably interpreted as a soil moisture indicator?
- Do the PDSI anomalies show regional differences or definite structures in the examined region of Eastern Hungary (36,000 km^2)?

- Until what time-lag is the autocorrelation, coming from the recursive definition of the PDSI, significant, and what kind of year-types can be defined on the basis of the significant autocorrelation?
- What kind of slow changes occurred in the course of PDSI in the 20th century?
- Did these local changes show statistical connection to the synchronous temperature characteristics of the Northern Hemisphere?
- Did any sufficiently long periods, occur in the 20th century, of which the PDSI indices differed significantly from those of the whole period in the given month?

DATABASE

Most of our analysis was performed on the Palmer's Drought Severity Index datasets of five meteorological stations found in Eastern Hungary [Miskolc, Nyíregyháza, Debrecen, Kecskemét and Szeged] for the period between 1901 and 1999. The input data of the index consist of monthly mean temperatures and monthly precipitation totals. The datasets mentioned above are disturbed by inhomogeneity, so the homogenised monthly datasets were the basis of our calculations (*Szentimrey*, 1999).

The basis of the analysis is Palmer's Drought Severity Index, produced from the monthly temperature and precipitation datasets (*Palmer*, 1965). The PDSI was devised by its author for the climatic conditions of North-America, in order to develop a numerically defined index, which is partly independent from local and seasonal features, and which partly shows the extremities of the soil moisture content always and everywhere on the same scale. (Owing to the different climatic conditions, the examinations started with the questions of place- and season-independence and with interpretation of the PDSI as a parameter of the soil moisture content.)

The Palmer-index numerically defines the soil moisture anomalies of the given month in five steps, beginning from the PDSI value of the preceding month. This PDSI value is multiplied by 0.9 and added to a term which is proportional to the difference between the precipitation of the given month and the computed precipitation that could definitely keep the actual soil moisture conditions unchanged. The proportionality coefficient weighting this difference before it is added to the PDSI is a temperature-related empirical factor calculated for the climatic conditions of the USA.

The above-mentioned steps of the calculation are performed in order to determine the precipitation amount, which is needed for preserving the soil moisture content. The stages of this process are the calculation of the elements of the potential (maximal, if there is enough water content) water balance and then establishing multiplicative factors for making normalisation, against the differences of local and seasonal climates.

A crucial point of calculating the PDSI is the choice of the formula and the reference-plant to estimate the potential evapotranspiration, which is performed in two versions. The basic solution was to choose Blaney-Criddle's plant-specific procedure, by assuming maize on the soil. This plant is characteristic for our region, and its evapotranspiration is fairly similar to that of many other plants, due to its quickly extending leaf surface. As an alternative, Thornthwaite's plant-independent PDSI series, based on climatic calculations, were also taken into account (*Thornthwaite*, 1948; *Alley,* 1984).

Considering the five stations used for representation of the region, it did not seem important that the soil types differ. Hence, the water capacity of 150 mm was taken into account in all versions of PDSI computation (*Stefanovits,* 1975). The above-described computation of PDSI leads to a non-dimensional index, qualitatively related to humidity conditions.

For studying the spatial correlation, the five stations are not enough, of course. Consequently, short PDSI sets of 17 stations were calculated for the period between 1951 and 1992, with Thornthwaite's plant-independent method and, in proper sense, without homogenisation. Differences between the water capacities of the characteristic soil-types of the arable land were taken into consideration at these 17 stations.

Besides the PDSI, two further datasets estimating the soil moisture content were used, kindly provided by the authors. Both sets use various combinations of the daily meteorological elements, influencing the water balance of the surface. Monthly correlation coefficients between the monthly values of the two series are between 0.7-0.9 in most part of the year, while they are only between 0.4-0.7 from May to September. Dunkel's dataset (*Dunkel,* 1994) was used between the years 1901-1990, while that of Bussay (*Lambert et al.,* 1993) was applied between the years 1901-1988. These parallel series were used to certify the PDSI as a quantitative indicator of the soil moisture content, and to establish the conversion of the PDSI into the soil moisture, as a physical parameter.

Besides these parameters, a version of Pálfai's Drought Severity Index was produced and used, operating with the monthly temperature and precipitation data, without numerically defined corrections of the daily extremities (*Pálfai*, 1991). The author, himself also suggests it as the PAI_0 Index. This index is a favourable tool for agro-hydrological examinations, the only disadvantage of which is that each year is characterised by one number only, integrating the period from October to the following August. The PAI_0, as a further independent index, supports our conclusion that PDSI can really be related to the soil moisture content.

Finally, connections of PDSI to the global climatic anomalies were based on series of the hemispheric mean temperatures and the continent-ocean air temperature contrast (*Mika,* 1988), as derived from air temperatures above the continents and the oceans of the Northern Hemisphere (*Folland et al.,* 1984; *Jones et al.,* 2000).

METHODS

In the study, the classical uni- and multivariate methods of the mathematical statistics are applied. Firstly, the first and second momentums of the monthly PDSI sets are determined then the place- and season-independence of the latter ones are examined with F-test, pair by pair. (The averages differ from zero because the reference period is not the whole 99 years but only the first 80 ones.)

The monthly PDSI sets, amalgamating all months and stations in one sample, as it is known from the special literature, do not fit the normal distribution. When dividing the whole set into monthly subsets for the separate stations, their normality is improving, examined by the Kolmogorov-Smirnov and the χ^2 tests.

The spatial and temporal correlation coefficients, calculated for short datasets of 17 stations in the region, are all significant when using the Z-test. On the basis of these, objective regions are determined using the rotated factor analysis (*Horel,* 1981). The results are compared to the classification of the hierarchical cluster analysis based on the Ward-method, using the Euclidean distances. The cluster analysis is also applied for determining objective year-types utilising the significant temporal autocorrelation. However, in the latter case, the method of K-means (*Hair et al.,* 1998) is chosen to classify the years into three year-types as dry, medium and wet ones.

The smoothing for detection of slow changes in the long data series is performed by the traditional moving averages and by the Gauss-filter, which does not deform the effect of any intermediate frequencies. The calculation window was 11 years in both cases.

Finally 1-1 methods of the supervisors are applied, which do not exceed the field of the methods represented in the first sentence of the current chapter. The parameters of the local changes and the hemispheric temperature; namely the connections between the mean temperature in the Northern Hemisphere and the continent-ocean air temperature contrast are defined numerically by the method of “slices” (*Mika*, 1988).

The essence of the method is slicing the original datasets into sub-periods of the same length (5, 9, 13, 17 and 21 elements) and then, using the averages of the sub-periods, a regression analysis is performed.

The method of “slices” is applied to the datasets between 1901 and 1988 and the conservation of the coefficients is tested for the independent period of 1989-1999. The correlation between the two hemispheric variables is negligible in the basic period, which makes it possible to avoid the so-called “multi-collinearity” of the two independent variables. The regression coefficients are estimated by the method of the “least squares”, while their statistical significance is checked with Student’s t-test.

Both the investigation of the slow changes, and the regression analysis performed with the hemispheric temperature characteristics referred to the substantial changes in the values of the PDSI, parallel with the global warming, considering the 20th century. Hence, the closing chapter of the study aimed to select climatically representative long periods, which can be used for impact studies on any problems depending on the soil moisture content.

In order to identify dry or wet sub-periods, averages of which are significantly lower or higher than that of the whole 99-year long dataset, a new interpretation of the classical two-sample test (*Makra et al.*, 2000, 2002; *Tar et al.,* 2001) was performed. The basic question of this test is whether or not a significant difference can be found between the averages of an arbitrary sub-sample of a given time series and the whole sample.

The normality of the distribution of monthly PDSI, which is found to be valid only partially, is a satisfactory condition to the application of the method. At the same time this is not a necessary condition, since in case of very large samples (99-99 data) the distribution of the density function for the sum of the elements is nearly normal, apart from the distribution of the basic sample. Besides that, a further condition is that the random variables be independent, which is realised for the succeeding PDSI values.

Most of our analysis was carried out on the monthly PDSI datasets of the whole year, while a smaller part of it was conducted on the four selected months of the growing season (April, June, August and October). The odd months in the latter case were omitted considering the strong and significant autocorrelation.

RESULTS

In the first eight points the results are summarised, based on Palmer’s Drought Severity Index datasets and calculated by the Blaney-Criddle method. Input data of this calculation are homogenised temperature and precipitation data series.

The differences of the PDSI data, generated by Thornthwaite's method of the potential evapotranspiration and homogenised data, from the above-mentioned sets are represented under point 9. On the other hand, the comparison of the PDSI based on partly homogenised, partly non-homogenised data, both calculated by Blaney-Criddle's method, can be found under point 10.

The results for the whole year are contained under points 1-5, while those for the growing season between April and October are found under points 6-8. Discussions of both points 9 and 10 follow this structure.

1. Place-independence of the PDSI, as a desirable condition, when elaborating the index for different climate conditions, is realised for the monthly values of the five stations in the Great Hungarian Plain. According to the F-test, the standard deviations of only one pair of stations differ significantly, which is far below the random proportion.
   Season-independence of PDSI, as another desirable feature, is only partly realised in the Great Plain, since the proportion of significantly different standard deviations is three times higher than that comes from pure chance. Standard deviation of the indices is considerably lower in May and June, than those of the other months. On the other hand, none of the standard deviations of the other ten months differ significantly from each other.
2. When putting the index values of i) the five stations, ii) the twelve months, iii) both aspects into one sample, the distributions of the PDSI differ significantly from the normal one in all of the three cases. The main reason of this result is the rare occurrence of the near-zero values, which is a well-known feature of the index, experienced in other regions as well. On the other hand, when analysing the PDSI sets of each station and month separately, then, according to the Kolmogorov-Smirnov test, distributions of all the 5 x 12 = 60 samples are normal. According to the χ^2-test, distributions of only ten samples are not normal at the 95 % probability level. This value (ten from the all sixty) is three times higher than the chance; nevertheless, the distribution of the samples for most stations and months can be considered normal.
3. The PDSI, as a standardised index without unit, has a close relation with the two (Dunkel's and Bussay's) calculations of the monthly soil moisture content, as well as with the Pálfai-index, characterising the water supply of the growing season from October to next August. According to this, the PDSI can correctly be interpreted as a characteristic of the soil moisture content. Furthermore, on the basis of the regression coefficients of linear connection, the index values can be expressed in physical unit of the water content of the upper 1 meter soil layer. Hence, the unit increase of PDSI corresponds to 8-19 mm surplus according to Dunkel's soil moisture estimates, and 5-17 mm surplus according to Bussay's one, depending also on season and place.
   Another feature of the regression coefficients, referring to the deep sense of the PDSI, is that if they are divided by the standard deviation of the soil moisture content, the following coefficients having no units result: 0.35 ± 0.05 in the datasets of the Dunkel's soil moisture content, while 0.25 ± 0.07 in those of Bussay's. Consequently, the unit change of the PDSI in each month and station equals to almost the same change in the unit of the soil moisture content standardised by the standard deviation.

4. The spatial correlation of the PDSI in each of the 15 station-pairs formed of the five stations and the 12 months exceeds the significance threshold value of 0.3 but does not reach the value of 0.9 in any case. From November to April all values are over 0.6, while from May to October they are lower than the winter values. In this period even the hydrological extremities of the region develop partly independently from each other.
   The significant spatial correlations makes it possible to determine objective sub-regions for the examined area. In the enlarged network with 17 stations, the rotated factor analysis of Thornthwaite's non-homogenised index series with shorter datasets results in at least two sub-regions in each month. The sub-regions are located along the north-east – south-west axis; whereas more stations and larger area belong to the southern sub-region. At the same time, during the seasonal alternation from drying out to filling up, between September and November, the procedure isolates an intermediate sub-region, too (*Horváth*, 2002; *Horváth et al.,* 2000). The independent method of the cluster analysis also confirmed the classification of the stations to the sub-regions received from the factor analysis.
5. The high autocorrelation, coming from the recursive definition of the PDSI, remains significant even at the time difference of two (0.7-0.9) and six months (0.3-0.7). Within these ranges, the somewhat lower values of the autocorrelations in the summer half-year come from the higher variability of convective precipitation.
   The high autocorrelations makes it possible to define so-called year-types objectively. The twelve months from November to the next October were classified into three types by cluster analysis. Each type occurred in a considerable part (14-57 %) of the 98 examined years. At all stations 1-1 year-type can be isolated, each month of which is definitely dryer or wetter than the average. At three stations, each month of the third type is around the average, while this type is characterised by a wet summer after a dry winter at Miskolc and Debrecen. The knowledge of the fact that a given month of a given year fell into which year-type, reduces the monthly variance of the PDSI with somewhat more than 50 %, as an average (*Horváth*, 2002). Proportion of the year-types differs from one decade to the other, in relation with the long-term changes of PDSI.
6. The PDSI datasets, calculated for the even months of the growing season, show significant linear trends only at three stations in April in the whole period of the 99 years. At the same time, the trends for each month and station are negative. Considering a hundred year time-span, its values are -0.7 and -3.1, respectively. Namely, the 20^{th} century was characterised by slow drying out. This definite tendency is reflected also in the datasets, smoothed with the moving average and Gaussian filters, detecting the non-monotonous and non-linear details of the slow inter-annual fluctuation.
7. The search for regression connection between the PDSI datasets and the average temperature and the continent-ocean temperature contrast of the northern hemisphere yields significant connection with at least one of the latter variables for 80 % of all months and stations, in the growing season. Most coefficients, relating to the hemispheric temperature, are negative. Namely, the drying out in the basic period between the years 1901-1988 is connected not only with the time, but the warming characterising the average of the northern hemisphere, too.
   The partial regression coefficients relating to the continent-ocean contrast (the rate of the warming) are mostly negative as well. The significant coefficients calculated

for a hemispheric warming of 0.5°C involve a decrease between -0.5 and -2.9 in the values of the PDSI, if the connection can generally be related to other periods, too. At the same time, this assumption is not supported by the behaviour of PDSI in the following independent 11 years (1989-1999), when the agreement of the actual PDSI anomalies and those calculated with the regression is not better than the chance (*Horváth*, 2002).

8. The break-point analysis makes it possible to detect sub-periods, PDSI averages of which differ significantly from that of the examined 99 years. Considering the growing season, the length of these significant sub-periods is many decades in most of the examined months and stations. The maximum difference of the sub-period's averages from that of the whole dataset decreases according to an exponential function, as the length of the sub-period increases. There are a number of sub-periods characterised by significant deviation from the overall mean being higher than the unit of the PDSI. Significant wet sub-periods are detected in the first half of the 20th century, while dry breaks occurred in the second half of the century. The averages of significant sub-periods with opposite signs show even more definite difference, than those between one-sided deviations and the overall mean (*Horváth, et al.,* 2000; *Horváth, et al.,* 2001; *Makra et al.,* 2002).

DISCUSSION

Main results concerned the PDSI values computed by the Blaney-Criddle method of potential evapotranspiration by using homogenised data. Here we discuss the behaviour of PDSI based on two alternatives, following the structure of the previous chapter.

The difference of the homogenised PDSI dataset, based on Thornthwaite's potential evapotranspiration from that calculated with the Blaney-Criddle method, are generally not substantial, but they can be summarised as follows:

i) The standard deviations in each month are somewhat higher than those determined assuming plants. There is no significant difference between the standard deviations of the month-pairs even including May and June.

ii) Distributions consisting of the largest datasets (5 stations*12 months*99 years; 5 stations, separately, 12 months*99 years) differ significantly from the normal distribution. Most monthly distributions per stations can be considered normal; nevertheless, the number of those monthly datasets, the distributions of which are not normal, is definitely higher than the chance.

iii) The strong linear connections between these PDSI datasets and the soil moisture content are to some extent weaker in most part of the year; though in May and June they are stronger.

iv) Most spatial correlation coefficients are higher than those determined by considering plants.

v) Most of the temporal correlation coefficients are higher than those determined by considering plants.

vi) The linear trends for the whole period decrease more intensely and the drying out according to the smoothed curves is steeper in this version. In other words, existence of plants slightly reduced the drying-out in the 20th century.

vii) The regressions relating to the hemispheric temperature are mostly negative in this version, too. The significant coefficients refer to a drying out higher than 20 %.
viii) The limits (the starting and the ending years) of the significant sub-periods are not independent of the method of calculating the PDSI. The ratio of the concurrently significant sub-periods in both versions is very little. Hence, before the possible application, it is worth to choose with care which method of PDSI to use for identification of the analogous periods.

The difference of the indices, using the Blaney-Criddle method and non-homogenous data series, from the above-mentioned basic behaviour are generally not substantial, but they can be characterised as follows:

i) There is no important difference compared with the results for the standard deviations of the homogenised dataset.
ii) The distributions consisting of the largest datasets differ significantly from the normal one in this case, too. Most of the monthly distributions per stations can be considered normal; nevertheless, the number of those monthly datasets the distribution of which is not normal is definitely higher than the chance in this case as well.
iii) The correlation coefficients between these PDSI datasets and the soil moisture content are stronger in this version, probably because this latter estimation is also performed on non-homogenised data.
iv) Most of the spatial correlation coefficients are lower than those calculated for the homogenised datasets.
v) Most of the temporal correlation coefficients are somewhat lower than those calculated for the homogenised datasets. The given homogenisation does not lead to considerable changes in centres of the year-types.
vi) Linear trends for the whole period decrease to a lesser extent and the drying out, according to the smoothed curves is also slighter in this version. In other words, the given homogenisation increased the drying-out characterising the 20^{th} century.
vii) Regressions relating to the hemispheric temperature are mostly negative in this version, as well. However, the significant coefficients refer to a drying out lower than 20 %. Hence, the homogenisation increased the drying out in this respect, too.
viii) Limits (the starting and the ending years) of the significant sub-periods are influenced by the homogenisation. The ratio of the concurrently significant sub-periods in both versions is very little. Hence, before the possible application, it is worth to choose with care which method of PDSI to use for identification of the analogous periods.

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