Drought Monitoring in Hungary

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Abstract

The tools of the drought monitoring system used at the Hungarian Meteorological Service (HMS) are discussed in this chapter. A short description of the climate of Hungary is given. The status of seasonal forecasting is discussed in more detail, and a verification case study is presented. The mapping technique applied at HMS is examined. Research on drought indices, their trends, and the combined use of meteorological and hydrological indices is described. Recommendations for future work and cooperation are also presented.

Introduction

We do not mention Europe among the areas of the world most damaged by drought. However, drought is a quite frequent natural disaster in the Mediterranean region and the Balkan peninsula, and it does occur in different parts of the continent--for example, in the northern part in 1999, and in central Europe in 2000.

Hungary is situated in the Carpathian Basin. Its climate is determined mainly by the large-scale circulation patterns of maritime, continental, and Mediterranean air masses, modified by the topography of the basin. This is expressed in increased sunshine, less precipitation, diminished winds, greater amplitude of daily and yearly temperature variation range, and great spatial variability of precipitation (annual mean maximum is 879 mm, minimum is 453 mm). The mean annual temperature is about 10°C and exhibits a zonal pattern modified by the altitude. The distribution of precipitation over Hungary is uneven, as is apparent from Figure 1. The most humid parts of the country, in the west, receive somewhat less than 900 mm of rain per year, about twice the precipitation of the driest areas in the Hungarian Plain, which is the most important agricultural area of the country. In the Hungarian Plain, climate is characterized by a tendency for dryness and insufficient rain for agriculture during summer months. The highest monthly precipitation values are recorded in June (60-90 mm), and February is the driest month. Although monthly precipitation can exceed 100 mm or sometimes even 200 mm in any month, it is also possible that no monthly precipitation may be recorded at any given time of the year. The growing season (April-September) exhibits even larger variations in monthly precipitation sums.

Drought is a recurrent feature of Hungary's climate and can cause substantial damages to the nation's agriculture. Dunay and Czakó (1987) note that 36% of all agricultural losses are caused by drought, followed by hail, floods, and frosts, in order of importance. In the period from 1983 to 1995, every year, with the exception of 1987, 1988, and 1991, was a drought

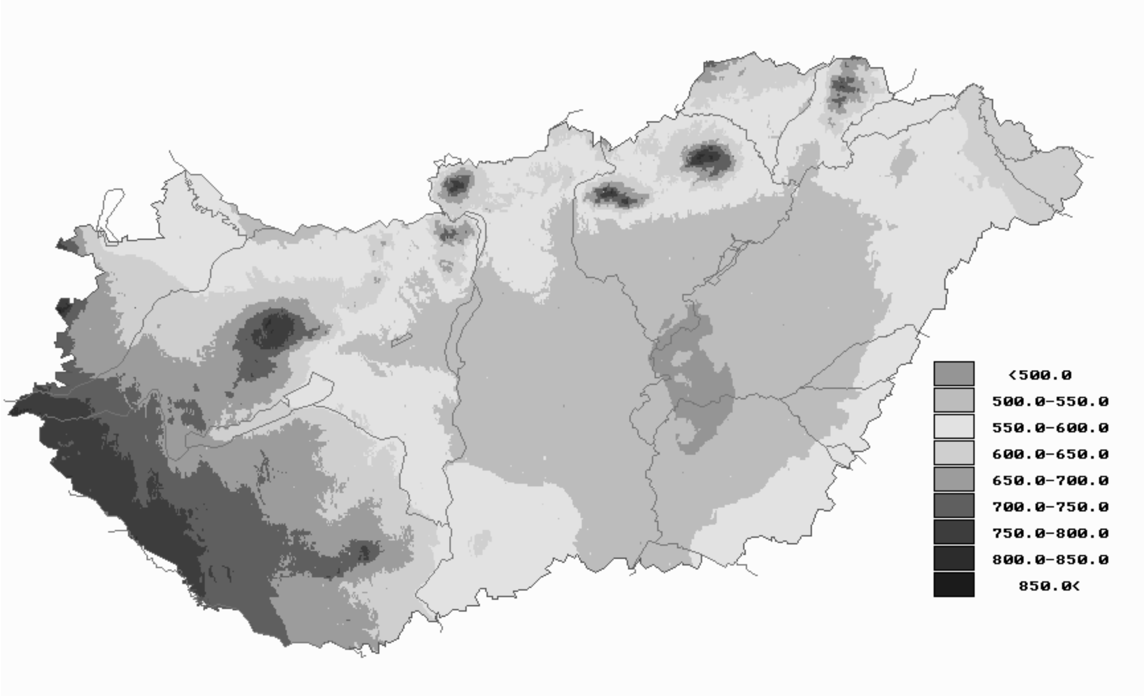

Figure 1. Mean annual precipitation in Hungary.

year. This long drought series was unprecedented in the 20th century in the region and comparable in length only to the 10-year period from 1943 to 1952 or in severity to the 1779-94 drought event (Gunst 1993). Because 8 of the 12 years were disastrous drought years, this eries of dry years has increased scientific and political interest in climate variability and climate change and the importance of drought as an extreme meteorological event.

Measuring Network

The largest national meteorological observing networks in Europe are operated by (hydro)meteorological services. Providing general data access is difficult, because of the combined financing systems of these institutes; budgets are partly governmental, partly commercial.

The national meteorological observing networks operate according to WMO recommendations. Another benefit of this system is that the hardware (sensors, data loggers, etc.) are the same throughout the network. This ensures that the data is measured, managed, and quality controlled in the same way. Here we have to point out the importance of quality control: different methods could lead to different results, even in the case of similarly measured data.

HMS's automated weather stations make measurements every 10 minutes, and most of the data are collected from the stations hourly. Therefore, most of the information is available in quasi-real time. HMS operates about 100 automated weather stations and more than 500 precipitation gauges throughout Hungary's 93,000 km^2. Figure 2 shows that these stations are evenly

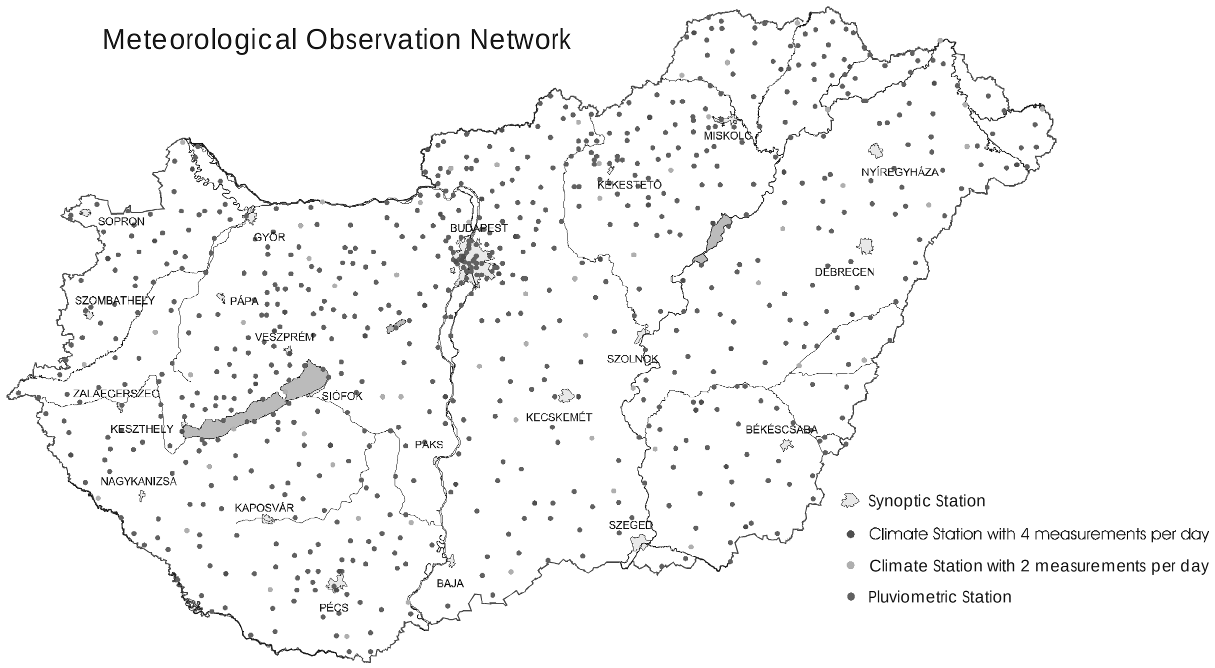

Figure 2. Meteorological Observation Network of HMS.

distributed. The main problem in the distribution of stations is that the mountainous areas have significantly fewer stations.

Long-Range and Seasonal Forecasts

One-month to one-year forecasts are based mostly on El Niño throughout the world. The investigations in this field do not support the existence of a simple teleconnection system of ENSO for Europe.

At the Hungarian Meteorological Service, an operational statistical (analogue) technique for long-range forecasting was developed and has been used for 20 years. The forecasts are generated for 6 months ahead. Temperature and precipitation forecasts are produced as one-month average values for 10 Hungarian towns. These forecasts have been issued on a monthly basis.

In 1998, we started to investigate the applicability of the European Centre for Medium Range Weather Forecasting's (ECMWF) dynamical seasonal forecasts for the Hungarian territory. These forecasts are available on the ECMWF's website for three overlapping 3-month periods, and they have been generated in every month. Forecasts of precipitation, surface air temperature, and mean sea level pressure are available both as ensemble mean anomalies and as probability plots. Sea surface temperature fields are available as ensemble mean anomalies only. We are developing programs for automatic data-reading from the forecasted fields, automatic data processing, and verification.

Verification Procedures

Ten Hungarian synoptic stations (Budapest, Győr, Sopron, Szombathely, Siófok, Pécs, Szeged, Békéscsaba, Debrecen, Miskolc) are evenly distributed over the country (Figure 3). We investigated surface air temperature and precipitation predictions, and we verified both ensemble mean anomalies and probability fields.

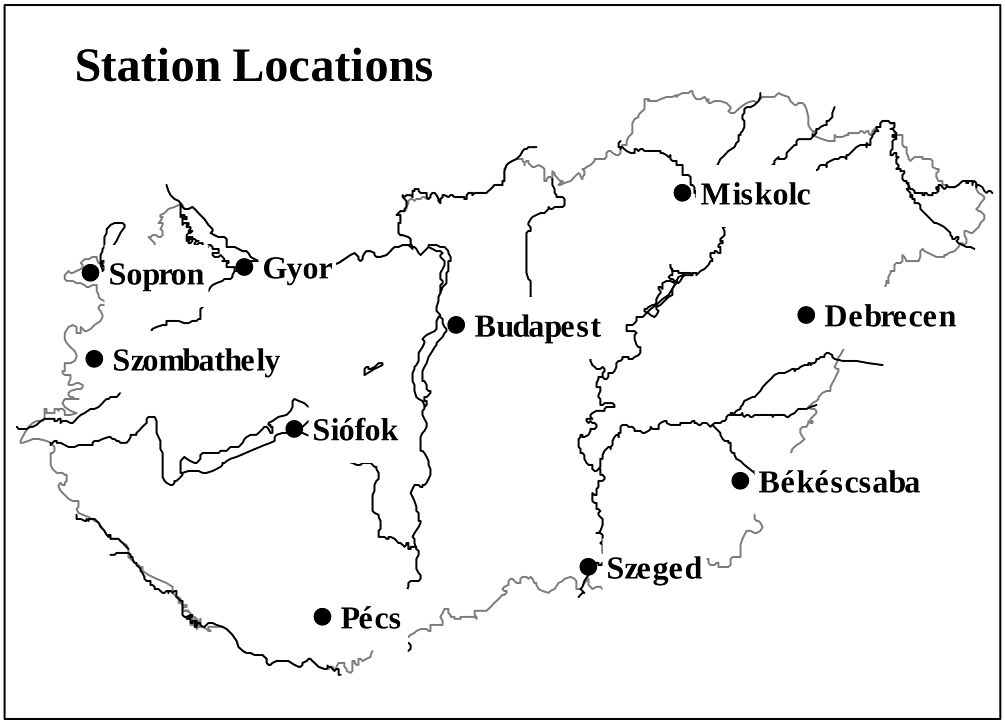

Figure 3. Stations used for the verification of ECMWF seasonal forecasts.

In the case of verification of ensemble mean plots, we used three categories (Table 1).

Table 1. Categories used in verification of ensemble mean plots.

Below normal	$\Delta T<-1K$	$\Delta P<-50mm$
Normal	$-1K<\Delta T<1K$	$-50mm<\Delta P<50mm$
Above normal	$1K<\Delta T$	$50mm<\Delta P$

The results of the verification for the period March 1998–December 1999 are shown in Table 2.

Table 2. Temperature/precipitation forecast verification for March 1998-December 1999.

	2-4 Months	3-5 Months	4-6 Months
Temperature forecasts	71%	65%	68%
Precipitation forecasts	52%	52%	52%

Probabilistic skill has been assessed by the use of the Relative Operating Characteristic (ROC). ROC values are suited to the comparison of the two different forecasts. The ROC scores were obtained at all 10 stations for the temperature and precipitation events that are above normal. The ROC values for the 10 stations are shown in Tables 3 and 4. The value 1 corresponds to a perfect forecast; values below 0.5 mean no skill. Climatological forecasts offer no skill. It can be seen that the skills of temperature forecasts, especially in the western part of Hungary, are promising.

Table 3. Skills of probabilistic temperature forecasts for the period March 1998-December 1999.

	2-4 Months	**3-5 Months**	**4-6 Months**
Sopron	0.74	0.51	0.43
Szombathely	0.74	0.52	0.43
Győr	0.73	0.57	0.50
Siófok	0.50	0.38	0.34
Pécs	0.58	0.43	0.54
Budapest	0.51	0.43	0.39
Miskolc	0.60	0.44	0.34
Szeged	0.63	0.55	0.52
Debrecen	0.47	0.44	0.36
Békéscsaba	0.57	0.45	0.50
Country wide mean	**0.61**	**0.48**	**0.44**

Table 4. Skills of probabilistic precipitation forecasts for the period March 1998-December 1999.

	2-4 Months	**3-5 Months**	**4-6 Months**
Sopron	0.56	0.56	0.38
Szombathely	0.59	0.55	0.43
Győr	0.57	0.57	0.38
Siófok	0.57	0.50	0.60
Pécs	0.61	0.50	0.57
Budapest	0.61	0.54	0.57
Miskolc	0.55	0.55	0.53
Szeged	0.47	0.43	0.43
Debrecen	0.53	0.56	0.56
Békéscsaba	0.56	0.56	0.53
Country wide mean	**0.56**	**0.53**	**0.48**

Drought Prediction

Another method of drought prediction used in Hungary was developed by Pálfai (Pálfai et al. 1998). This method calculates the possible situations until the end of the year under given conditions. A scenario-like calculation of drought is based on springtime conditions and three climatologically calculated scenarios (wet, normal, and dry) for the whole year. For a more effective calculation, the so-called Pálfai drought index was developed.

Yield Estimation

Two institutes develop yield estimation systems in Hungary. One system is based on the use of the NDVI index. The other is based on surface meteorological elements. Both systems are operational, but they are still primarily in the testing phase.

Climatological Scenarios

Climate Changes in the 20th Century in Europe

Many studies have investigated the current trends of climate variability. Herewith, we mention the study of the European Climate Support Network (ECSN 1995) for the climate of Europe. Data up to 1990 were used. The results show that almost all European stations experienced warming during the 20th century in what may be partly an urbanization effect. In the first part of the century, to around 1940, a warming trend occurred, followed by a cooling trend to the present. Relative cooling is found over the eastern Mediterranean, with another cold anomaly over the North Atlantic and Greenland. Long-records show that, at least in central and northern Europe, the temperature distribution in Europe around 1990 was at about the same level as it was 200 years ago.

Over the last century, an overall increase in precipitation can be observed over northern Europe, except Finland, where conditions are relatively unchanged, and southern and central Europe, where precipitation is decreasing or unchanged.

The last decade (1981-90), compared to 1951-80, shows general drying over much of southern Europe and large parts of northern Europe, with Scandinavia in contrast, becoming relatively wetter.

Climate Change Predictions

The following discussion of climate change prediction is based on the recent study of the Hadley Center.

With unmitigated emissions, global average temperature is predicted to increase by 3° C by the 2080s. Under this scenario, land areas would warm twice as fast as oceans, and winter high latitudes are also expected to warm more quickly than the global average, as are areas of northern South America, India, and southern Africa. Large changes in precipitation, both positive and negative, would be seen, largely in the Tropics. Large changes are also predicted in the availability of water from rivers. Substantial decreases would be seen in Australia, India, southern Africa, most of South America and Europe, and the Middle East. Increases would be seen across North America, Asia (particularly central Asia), and central eastern Africa.

Water resource stress due to climate change by the 2080s is predicted to worsen in many countries (for example, in northern Africa, the Middle East, and the Indian subcontinent), but will improve elsewhere (for example, in China and the United States). Overall, about 3 billion people will suffer from this increased water stress. Reductions in emissions leading to stabilization at concentrations of 550 ppm CO_2 would reduce this number to about 1 billion. Stabilization at 750 ppm has little effect on the total.

By the 2080s, climate change and CO_2 increases due to unmitigated emissions are estimated to increase cereal yields at high and mid latitudes, such as North America, China, Argentina, and much of Europe. At the same time, cereal yields in Africa, the Middle East, and, particularly, India are expected to decrease.

Spatial Interpolation

The AUREHLY method is the most frequently used method at HMS. This method was developed at the French Meteorological Service by Benichou and Le Breton (1987). This two-step method first describes the meteorological field as a function of the land surface via multiple linear regression equations. Second, the resulting surface of differences between the calculated and measured meteorological values is smoothed by ordinary kriging.

Simple regression is normally applied for site elevation. Therefore it is beneficial to apply multiple regression, since it can also account for other surface characteristics, provided that the given surface is depicted by principal component analysis.

The product surface S(x,y,T) is determined by the following formula:

$$S(x,y,T) = S(T) + ß(x,y),$$

where S(T) is determined by the orography via multilinear regression and ß(x,y) is the residual smoothed by kriging.

For calculations, a digital map of Hungary has been used with about 1 km x 1 km resolution. Each grid point was characterized by its elevation and the elevation differences between the central point and 120 neighboring points (on an 11 x 11 grid section). Therefore each grid was assigned 121 data values. This immense amount of information has been condensed by principal component analysis; thus the grid points are represented by their elevation and the appropriate values of the first 15 principal components, which account for about 90% of the orography variance, preserving sufficient accuracy.

The first five principal components (PC) can easily be interpreted geometrically:

PC1 indicates peaks (positive values) and valleys (negative values)

PC2 indicates east-west slopes
PC3 indicates north-south slopes
PC4 indicates north-south saddle
PC5 indicates northeast-southwest saddle

The next step is to develop relationships between the surface structures and meteorological fields. In determining the multilinear regression, the observation locations and the nearest grid points formed data pairs. Five principal components revealing the strongest simple linear regressions with observations were chosen and included in developing the multilinear regression equation.

After determining S(T), this function was applied to estimate the value of the meteorological element at the observation location, and the differences between estimated and measured values were calculated. These discrepancies were interpolated by kriging. The calculations are made by a program prepared by FAO (Bogaert, Mahau, and Beckers 1995).

The accuracy of the kriging method depends largely on the selection of variograms, which describe spatial dependence existing between variables at different locations. In our experience, the linear variogram was found to be the most appropriate for mean temperature; for precipitation, a combination of nugget and linear variograms was the most suitable (Dittmann 1999).

Drought History and Indicators

To consider drought severity on a country-wide scale, both the index values and their spatial extent are important. The following categories were used to evaluate drought severity: drought is *moderate* if PDSI values of <-2.0 extend over more than 50% of Hungary, *severe* if PDSI values of <-3.0 extend over 33% of the country, and *extreme* if PDSI values of <-4.0 cover at least 20% of the nation. These categories, while somewhat arbitrary, were selected because more severe droughts have a lower probability of affecting larger areas. Moderate and severe droughts have occurred almost continuously during the period 1983-95 (Figure 4).

Trends of Drought Events

General trends of PDSI series were tested by regression analysis and by the Mann-Kendall test. In general, both tests resulted in the same figures. Results of the Mann-Kendall test are presented in Table 5. The consistent results of the regression analysis and the Mann-Kendall test support the assumption of a drying tendency and lower PDSI values in the later years. A decrease in PDSI values for different stations and months was in the range of -1.3 to -2.4 PDSI/100 years.

The majority of the values fulfill the criteria of a 1% significance level. Moreover, for more than one-third of the stations, the test statistics showed a decrease in PDSI in all the months at the 1% level. Eleven of the fifteen PDSI station series in all the months have experienced a significant decrease (1-10%). Only two stations revealed no significant change in the PDSI series in the majority of the months. The index series of May, October, and November at all stations decreased significantly (i.e., at least 10%). Moreover, for October a significant decrease was found at fourteen of the fifteen stations on a 1% level and at one station on a 5% level. In July, three series did not indicate statistically significant change. Test statistics exceeding 4 refer to an exceptionally strong trend, which was found at Buda (in three months), Nyíregyháza (five months), Sopron (three), Szeged (three), Szombathely (ten), Túrkeve (one), and Pécs (ten), but in the latter case, four series even exceeded 5 (Figures 5, 6) (Bussay et al. 1999).

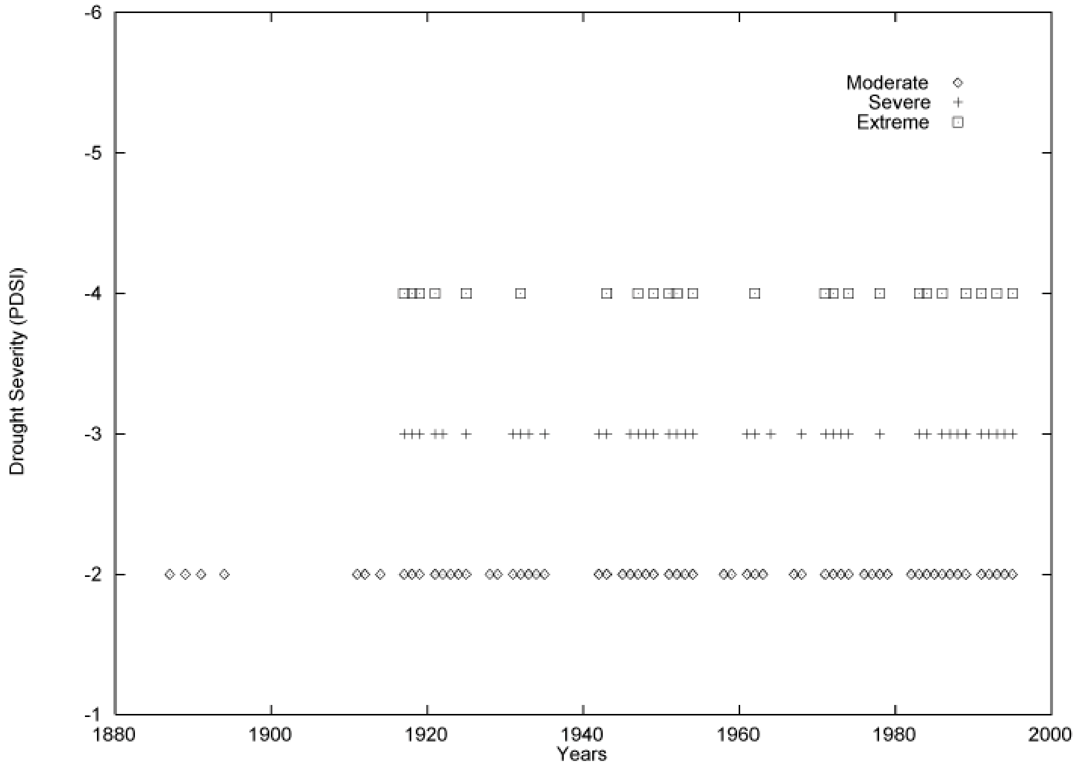

Figure 4. Occurrence of moderate, severe, and extreme droughts, 1880-2000.

Table 5. Results of the Mann-Kendall test. Sign of significancy levels: 10% italic, 5% bold, 1% bold italic.

Baja	***-2.835***	***-2.705***	***-3.285***	***-3.063***	***-3.309***	***-2.710***	**-2.429**	**-2.284**	**-2.366**	***-3.295***	***-2.589***	**-2.115**
Buda	***-3.614***	***-2.951***	***-3.546***	***-4.479***	***-4.904***	***-3.899***	***-3.764***	***-3.198***	***-3.793***	***-4.764***	***-3.938***	***-3.570***
Debrecen	**-2.299**	**-1.999**	**-2.526**	**-2.033**	**-2.076**	**-2.159**	**-2.260**	**-2.183**	***-2.671***	***-3.077***	***-3.024***	***-2.816***
Kalocsa	**-2.347**	**-2.018**	**-2.540**	**-2.497**	***-2.618***	**-2.072**	-1.448	*-1.665*	**-2.139**	***-2.821***	**-2.139**	*-1.632*
Kecskemét	**-2.802**	***-2.163***	**-3.092**	**-3.295**	**-3.261**	**-2.632**	*-1.951*	***-2.966***	***-3.183***	***-3.831***	***-3.208***	***-2.719***
Keszthely	-0.906	-0.742	-1.438	-1.443	**-2.018**	-0.960	-1.240	*-1.810*	**-1.994**	***-2.627***	*-1.873*	-1.404
M.óvár	**-2.323**	-1.491	*-1.757*	***-2.922***	***-3.145***	***-2.758***	***-2.729***	***-1.970***	***-2.623***	***-3.179***	***-2.627***	***-2.420***
Nyíregyháza	***-3.971***	***-3.657***	***-4.005***	***-4.266***	***-3.894***	***-3.826***	***-3.967***	***-3.121***	***-3.560***	***-4.435***	***-4.150***	***-4.295***
Pécs	***-4.750***	***-5.219***	***-5.349***	***-5.586***	***-5.852***	***-4.624***	***-4.213***	***-3.913***	***-3.817***	***-4.987***	***-4.426***	***-4.421***
Sopron	***-2.714***	*-1.651*	*-1.815*	***-2.632***	***-2.792***	**-2.463**	***-3.256***	***-4.639***	***-4.576***	***-4.537***	***-3.739***	***-3.667***
Szarvas	***-3.502***	***-3.391***	***-3.478***	***-3.967***	***-3.971***	***-3.541***	***-3.270***	***-3.425***	***-3.696***	***-4.363***	***-4.121***	***-3.817***
Szeged	***-3.672***	***-3.938***	***-4.155***	***-4.179***	***-4.165***	***-2.937***	***-2.681***	***-2.197***	***-2.743***	***-3.851***	***-3.657***	***-3.217***
Szombathely	***-4.083***	***-3.710***	***-4.286***	***-4.972***	***-4.228***	***-3.735***	***-4.170***	***-4.450***	***-4.721***	***-4.817***	***-4.489***	***-4.411***
Túrkeve	***-3.101***	***-2.884***	***-3.174***	***-3.478***	***-2.714***	***-3.314***	***-2.951***	***-2.850***	**-2.555**	***-4.141***	***-3.764***	***-3.517***
Zalaegerszeg	-1.385	-1.665	-1.960	-2.603	-1.777	-1.593	-1.409	-1.303	-1.661	-2.110	-1.293	-1.245

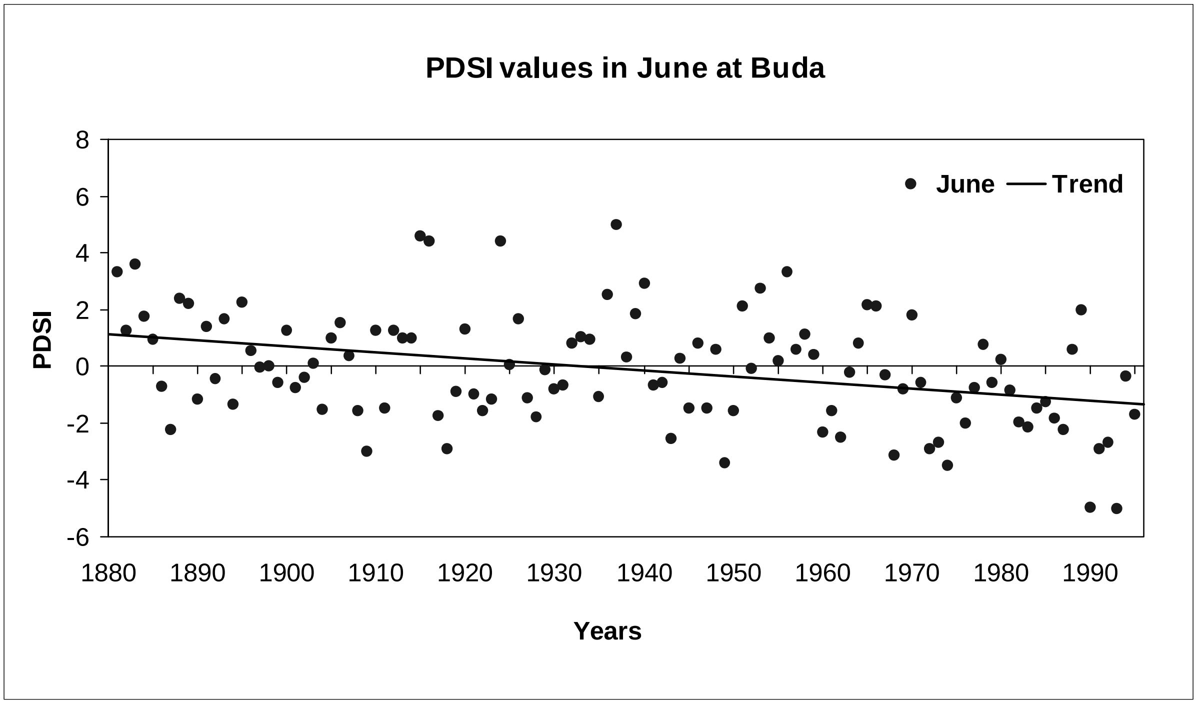

Figure 5. PDSI values in June at Buda.

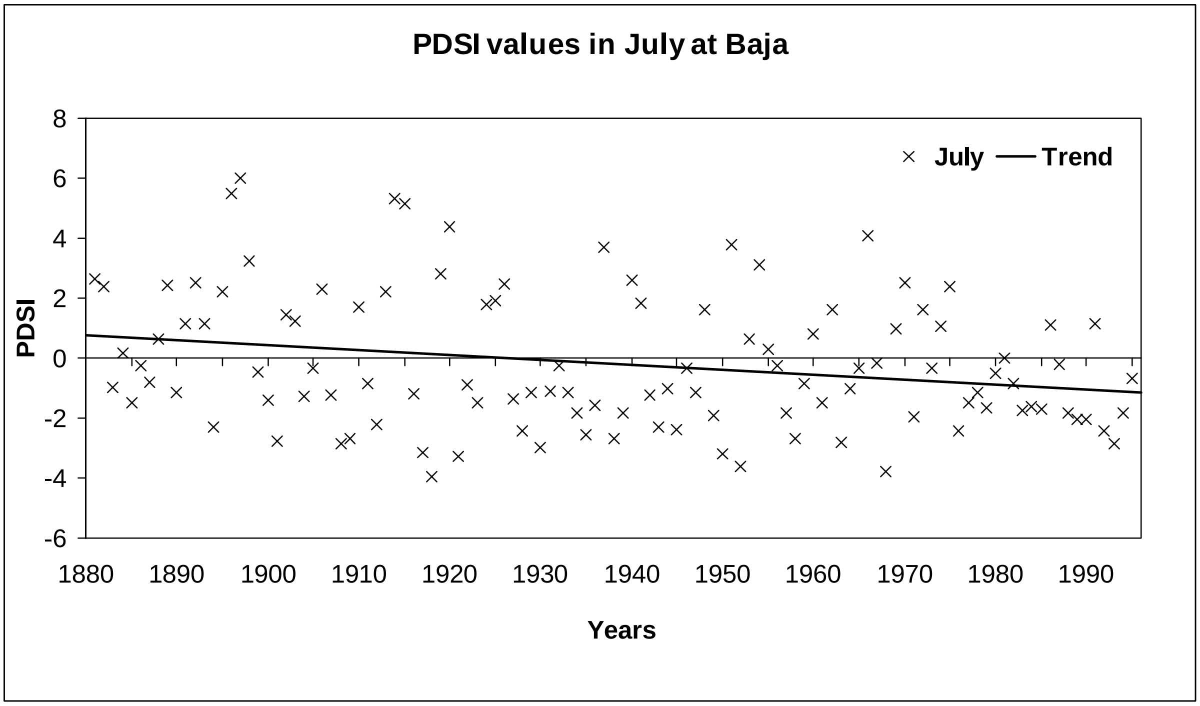

Figure 6. PDSI values in July at Baja.

Drought Frequency Investigations

Two statistical tests were used to detect changes in drought frequency. The first test is based on the Wilcoxon test, and it addresses the question of whether drought occurrence in a specific intensity category has systematically changed or not. If there is a trend in the occurrence, it is that drought events concentrate at one end of the time series. The limiting distribution of the test statistics is normal, so its values can be easily checked for significance. The second test investigates whether occurrence of droughts in a particular category reveals periodicity over the years. For this, the number of threshold crossings are counted when two subsequent elements of the time series are on different sides of a certain threshold—e.g., when the PDSI falls from -2.8 to -3.2 and the threshold is -3. This test statistic has binomial distribution, and therefore the significance of the results should be compared to a table. Both tests are described in detail by Szinell et al. (1998).

Results of the Tests

The two tests were first applied to the PDSI and SPI index series ending in 1995, then to the series ending in 1999. For the PDSI, the tests indicated significant (1% to 5%) increasing drought frequency at a number of stations, mostly on the Hungarian Plains. The second test indicated that droughts tend to occur in spells of years even when the first test failed to indicate a drying tendency. This result suggests that successive years in which PDSI values under certain thresholds recur are more probable than individual occurrences. Tests 1 and 2 when applied to the PDSI series ending in 1999 resulted in a similar outcome. In accordance with the expected behavior, the test statistics are smaller and their significance is sometimes less than in the previous case because of the recent spell of wet years. However, the general characteristics remained the same (Figure 7).

SPI index series of 3-, 6-, 9-, and 18-month time scales have been calculated. SPIs of shorter time scales can characterize water supply changes for short time periods. One advantage of using the SPI is its explicit time scale in contrast to the PDSI, which responds to moisture anomalies on the scale of 6-12 months (e.g., Guttman 1998).

The 3-month SPI revealed different patterns from those of the PDSI discussed above. They also indicated existing drying tendencies, but at more defined periods of the year. According to these series, drying occurs mostly in the late spring and early summer months and during late autumn. Both periods play a very important role in agriculture, as the first is the time of germination and sprouting and the second is after harvest, when soils should fill up with moisture for the next vegetative period. Therefore drying during these important phases can have crucial effects on agricultural production. Tests on longer SPI series also indicated that the recent period has been drier, but, similar to the PDSI results, the significant results occurred at longer time scales within the year.

Test 2 when applied to the SPI series resulted in far fewer significant test statistics than when applied to the PDSI series. This suggests that the clustering feature found earlier could be associated with the PDSI characteristic, that it has a tendency to be stuck at negative or positive values (e.g., Guttman 1998; Bussay et al. 2000).

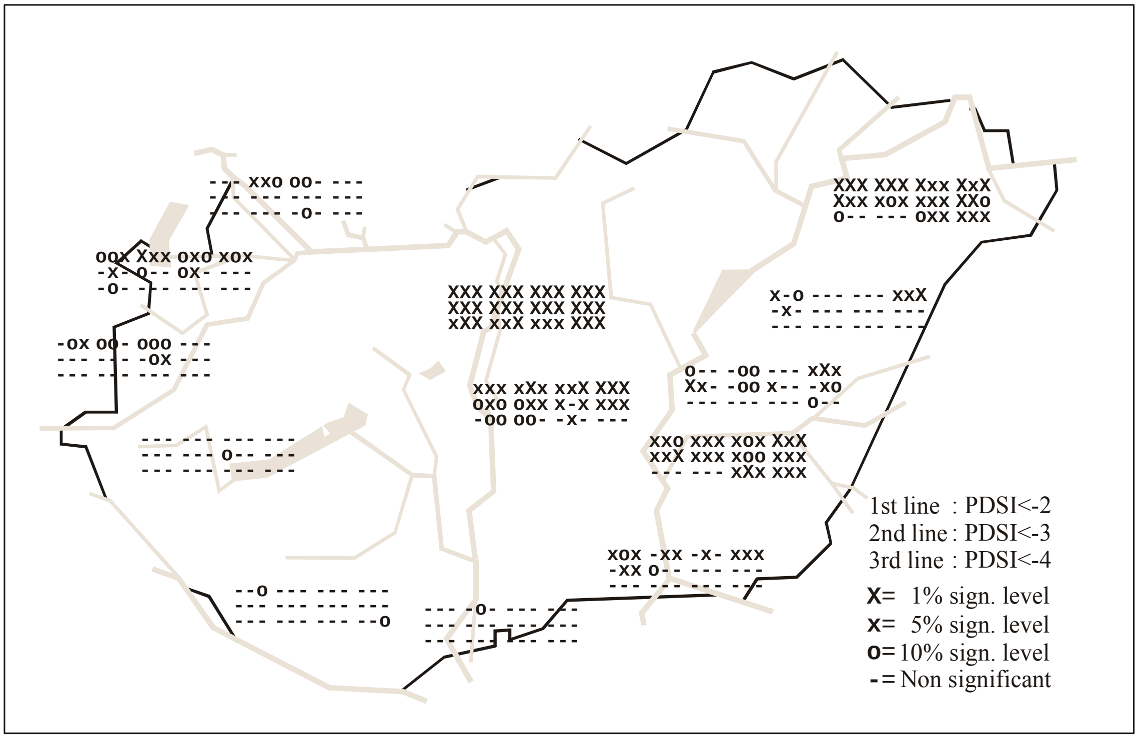

Figure 7. Significance of Test 1 for PDSI through 1999 for 13 locations in Hungary.

Combination of Different Drought Indices (Bussay et al. 2000)

SPI and Hydrological Droughts

Because the SPI is based on precipitation amounts, it is a natural for examining meteorological droughts. The flexibility of the multiple time scale component of the index means that it may be useful for hydrological applications as well. Several questions need to be addressed: Can the SPI identify and characterize hydrological droughts? How strong is the connection of the SPI with hydrological features such as streamflow and ground water levels? What is the appropriate SPI time scale for these features? Finally, what are the limitations of using the SPI for hydrological applications? Very few studies have examined the capability of the SPI to monitor hydrological drought conditions.

SPI Relationship with Streamflows

The first hydrological relationship examined will be between SPI and streamflows. Rainfall certainly has an impact on streamflows through runoff, based on the distribution in space and the intensity of the rainfall. Runoff, however, is influenced by many additional factors, such as the size and topography of the catchment area, soil characteristics, and frozen ground and snow cover. All of these factors affect the relationship between the SPI and streamflow.

Figure 8 shows the relationship between the 2-month SPI and streamflows in the southwest. Although the scatter is quite large, an exponential relationship identifying low streamflows with negative SPI values and high streamflows with positive SPI values is evident. The fitted curve is convergent at the large negative SPIs with minimal runoff, while large runoff values are scattered along an extended SPI range. Additional examination reveals that all of the very high streamflow values occurred during the late winter and early spring and were associated with the quick melting of a thick snow cover. To find the appropriate SPI time scale, regression coefficients (*r*) were calculated for the relationships between streamflows and the series of SPI time scales for the four river basins (Table 6). As in Figure 8, an exponential relationship was used. Results were similar in each basin, with the short time scales having the highest correlation values. The 2-month SPI had the highest relationship for the Black-Körös, Kapos, and Zala rivers, while the relationship was best with the 6-month SPI for the Zagyva River. The PDSI was also included in Table 6, and the regression coefficients between the PDSI and streamflow were lower, in general, compared to the SPI, except for the Zagyva River. Several factors could be affecting these relationships, but it does appear that for these small Hungarian basins, the 2-month or 3-month SPI values could provide the best information about streamflow levels.

SPI Relationship with Ground Water

Relationships can also be examined between the SPI and ground water levels measured at the well sites. Figure 9 shows the relationship between the 5-month SPI and the depth to the water table at Keszthely in western Hungary.

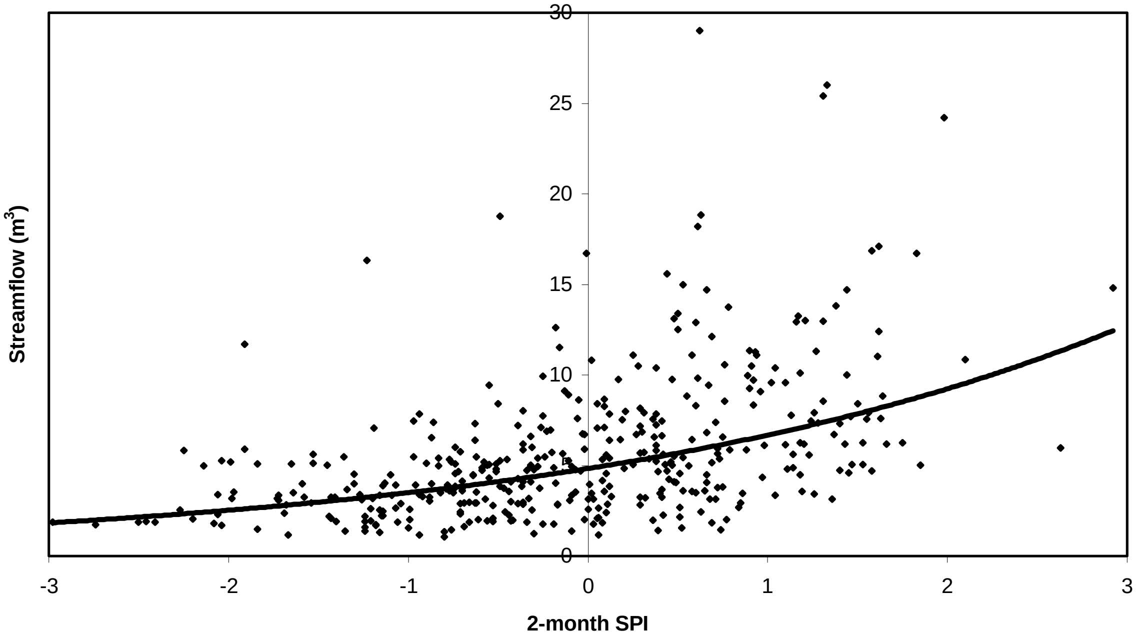

Figure 8. Relationship between the 2-month SPI and streamflows in the southwest.

Table 6. Relationships between streamflow and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are in italic; 1%, bold.

	Correlation Coefficient (r)							
River	SPI1	SPI2	SPI3	SPI6	SPI12	SPI18	SPI24	PDSI
Black-Körös	**0.3324**	**0.4493**	**0.4418**	**0.3274**	**0.2062**	**0.3531**	**0.3681**	**0.3463**
Kapos	**0.4471**	**0.5139**	**0.5093**	**0.4591**	**0.4441**	**0.4363**	**0.3912**	**0.4810**
Zagyva	**0.3471**	**0.4639**	**0.4894**	**0.5133**	**0.4607**	**0.2278**	**0.1783**	**0.5226**
Zala	**0.4232**	**0.4573**	**0.4127**	**0.2728**	**0.2590**	**0.1606**	**0.1280**	**0.3233**

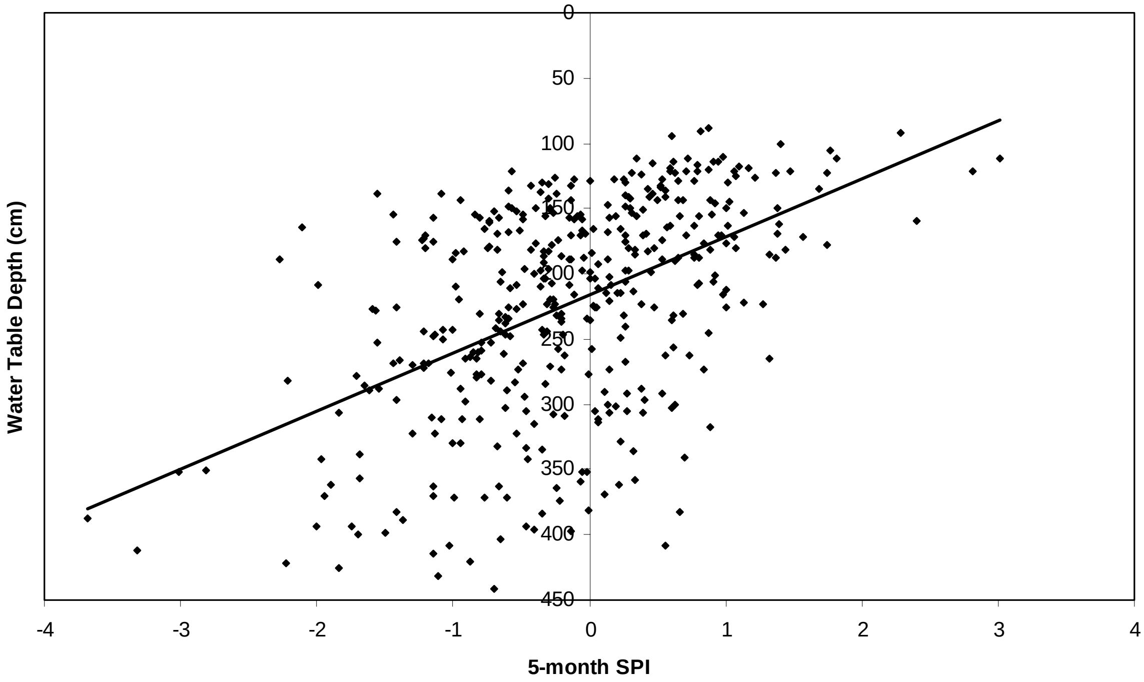

Figure 9. Relationship between the 5-month SPI and the depth to the water table at Keszthely.

The SPI and the Ground Water Table

Generally, the most positive SPI values occur at the same time that the ground water table is closest to the surface, and SPI values are below zero when the ground water table is farther below the surface. As for streamflows, a table of the regression coefficients (*r*) was constructed showing the relationship between ground water measured by well levels at the four locations and the SPI for various time periods (Table 7). The strongest relationships are at longer time scales: 5, 12, 18, and 24 months for the different areas. Some of the differences in time may be accounted for by the distance between the well and the station. They are close at Keszthely and farther apart at Kaposvár. The PDSI is also included in the table, but those relationships are not as strong as the particular SPI relationships.

Table 7. Relationships between the depth of the ground water table and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are in italic; 1%, bold.

				Correlation Coefficient (r)			
Well Location	SPI3	SPI5	SPI6	SPI12	SPI18	SPI24	PDSI
Southeast	*0.1200*	**0.1612**	**0.1688**	**0.1895**	**0.2404**	**0.2387**	**0.1470**
Southwest	**0.1356**	*0.1204*	*0.1225*	0.0574	**0.3079**	**0.3877**	**0.1411**
Central	**0.2938**	**0.3895**	**0.4297**	**0.5265**	**0.5083**	**0.5148**	**0.4596**
West	**0.4613**	**0.5249**	**0.5135**	**0.4972**	**0.4163**	**0.3471**	**0.4719**

Figures 8 and 9 appear to indicate that the SPI can be used qualitatively to identify hydrological drought. Correlations of the SPI with streamflows were similar, while for ground water levels the best correlations were found at widely different time scales. This behavior can be the result of other factors, since hydrological parameters, such as streamflow or ground water, depend on several different soil and ground characteristics. Therefore, one meteorological parameter (rainfall) and its derivative (SPI) can only be used as a tool for identifying tendencies in the evolution of these hydrological variables.

SPI and Agricultural Droughts

To determine the usefulness of the SPI for detecting and monitoring agricultural drought, the soil moisture component was investigated. Soil moisture is one of the most important limiting factors of plant production in Hungary.

For this investigation, the winter half of the year (October to March) was excluded. Generally there is very little evaporation from the soil, and soils are usually saturated at the end of winter regardless of the amount of winter precipitation. Monthly soil moisture data were used for April through September at a depth of 0.5 m. Table 8 shows the regression coefficients (r) between the monthly soil moisture from April through September and four SPI time periods. Table 9 shows the same, except that only soil moisture is considered for the main summer months of June, July, and August. The r values show the strongest relationships to be with the 2-month SPI. The relationships between soil moisture and PDSI are also shown in both tables, and the relationships are poor. Figure 8 shows the relationship between soil moisture in June, July, and August and the 2-month SPI at Szolnok. There is a large scatter of soil moisture values around the relationship, indicating that nonmeteorological factors (e.g., agronomic factors) also play a role in determining soil moisture.

Table 8. Relationships between April through September soil moisture (0.5 m) and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are italic; 1%, bold.

			Correlation Coefficient (r)		
Station	SPI1	SPI2	SPI3	SPI6	PDSI
Southeast	**0.3587**	**0.4880**	**0.4390**	**0.3763**	0.1217
Southwest	**0.3752**	**0.5173**	**0.5217**	**0.4384**	**0.4770**
Central	**0.4152**	**0.5352**	**0.4873**	**0.4507**	0.0663
West	**0.5383**	**0.5877**	**0.5532**	**0.3575**	0.1100

Table 9. Relationships of June, July, and August soil moisture (0.5 m) and SPI for several time scales. Underlined values are the maximums. Test statistics of 5% significance are italic; 1%, bold.

	Correlation Coefficient (r)				
Station	SPI1	SPI2	SPI3	SPI6	PDSI
Southeast	**0.4465**	**0.5960**	**0.5479**	**0.4691**	0.1616
Southwest	**0.3697**	**0.5842**	**0.5585**	**0.5095**	0.0300
Central	**0.5223**	**0.6938**	**0.5799**	**0.5253**	0.1652
West	**0.5348**	**0.6788**	**0.5912**	**0.4592**	0.1334

Irrigation Advisory System

It is clear from the above investigation that different types of information about precipitation in Hungary are necessary. Therefore, an automated irrigation advisory system was developed with the financial support of the Ministry for Agriculture and Rural Development.

The system calculates daily evapotranspiration (Penman-Monteith formula) and uses these results and precipitation measurements to derive the accumulated actual daily water shortage. From the water shortage we can calculate the water demand of different plants.

This system is the first automated, interactive, and freely accessible system on the Internet in Hungary. As a next step, we would like to expand this system, with more detailed calculations of water demand, a mapping system, and more information about the situation of the atmosphere and pedosphere.

International Cooperation

Many international activities are connected with drought. The International Commission on Irrigation and Drainage has a special working group investigating this question, and the south European division of this group published a paper on the drought mitigation issue, in English and Hungarian.

The network of European climatological services (ECSN) has a special project on drought. The tasks of this project are more practical than theoretical. The participants of the project use the same software, which is very important, especially for the PDSI index. The value of this cooperation is shown by the growing number of participants.

The first meeting involving regional cooperation was held in Hungary in spring 2000. The participating countries agreed to strengthen their common activity for the better management of drought on the regional level (National Drought Mitigation Center 2000).

Conclusions

1. There is a growing frequency of drought in Hungary, even if we calculate the recent wet years.
2. Hungary has a relatively small area, but drought tendencies differ significantly in the various regions of the country.
3. Comparable data are necessary for drought monitoring. This means standardizing the networks of different authorities and countries.
4. In the case of surface measurements, a good mapping procedure is necessary.
5. The SPI index describes the evolution of drought events quite well, and it shows good correlations (but on different time scales) with parameters of different types of drought (other than meteorological).

Therefore, it is beneficial

1. to use common data management systems,
2. to use combinations of different drought indices,
3. to have international cooperation, especially within one geographical unit, and
4. to use a unified methodology for calculation of the cost/benefit ratio of drought management.

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