Development of an Operational Drought and Water Scarcity Monitoring System in Hungary

Fiala, Károly*; Dr. Barta, Károly**; Dr. Benyhe, Balázs*; Fehérváry, István*; Láng, István***; Lábdy, Jenő***; Dr. Sipos, György**; Dr. Győrffy, Lajos****

*: Lower Tisza District Water Directorate, H-6720 Szeged Stefánia 4.
**: University of Szeged, Department Physical Geography and Geoinformatics, H-6722 Szeged, Egyetem u. 2-6.
***: General Directorate of Water Management, H-1012 Budapest, Márvány u. 1/D
****: University of Szeged, Bolyai Institute, H-6720 Szeged, Aradi vértanúk tere 1.
(E-mail: *fialak@ativizig.hu, benyheb@ativizig.hu, fehervaryi@ativizig.hu*)

Abstract

The establishment of the present monitoring network has been started with the aim of supporting Hungarian drought management (recently starting to emphasise prevention) and water resource management. The system incorporates novel detection and evaluation methods, based on which operational plans and legislation procedures will be elaborated. During the research activity preceding the development of the network a new, daily resolution drought index was elaborated. At present the input data for the index is provided by 47 monitoring stations, which were installed between 2016 and 2018. In the near future in total 150 stations are planned to be operated within the network.

Beyond basic meteorological parameters the stations also provide soil moisture data from different depths, placing this way Hungarian water and drought management on new grounds. Novel information related to soil moisture can greatly support operational water resource management and the assessment of supplies and demands, being ultimately important for the agricultural sector to reach its goals concerning the development of irrigation and the facilitation of precision farming.

A highly emphasised aim of the monitoring system is to bring into effect operational drought monitoring in Hungary, meaning that similarly to flood and excess water management, data and conditions become adequate to determine intervention levels, and to define precisely operational activities and related measures for legislative harmonisation. The measured and calculated data provided by the monitoring network are published on a web portal, delivering information for decision makers, professionals or farmers free of charge, greatly supporting this was the everyday work of the most important stakeholders.

Keywords

drought, drought management, Hungarian Drought Index (HDI), water scarcity, water management, monitoring, soil moisture, irrigation

INTRODUCTION

Changing climate, changing challenges in water management

Looking at trends in global temperature change the climate of our planet – primarily due to intensifying human activity – is inevitably warming *(Riebeek 2010)*. Although there are certain areas where a long term temperature decrease is observed, the Danube Region is definitely not among these. In Hungary for example temperature rise reached 1.36 °C between 1901 and 2009 *(Lakatos and Bihari 2011)*. The long term data of precipitation is far less straight forward to interpret *(Lakatos et al. 2013)*. However, by considering the last more than a half century the number of periods with extreme precipitation distribution, such as dry spells and droughts, has inevitably increased since the last millennium *(Fiala et al. 2014)*.

In Hungary drought and water scarcity have become a significant risk factor, as both their frequency and severity have considerably increased in the past decades. Based on climate prediction models, drought hazard will further increase and beyond adaptation the consequent quantitative and qualitative changes of water resources will also call for prevention and improved water management planning.

Preliminaries of the drought management monitoring system

It is clear by now that the effective support of agriculture and the improvement of irrigation is not possible without being aware of soil moisture conditions, therefore, the development of a soil moisture monitoring network has become a priority in Hungarian drought management. Consequently, the General Directorate of Water Management (OVF) initiated the elaboration of a high technical standard monitoring system which is capable of detecting drought phenomena, supporting operational actions and providing adequate and relevant information for both professionals and different stakeholders by applying new methods and innovative technology. The system in general is based on three pillars: observation; evaluation; management and related legal regulation. For meeting these requirements in the order of execution the following activities have been proposed: (1) the planning and installation of the soil moisture monitoring network, (2) the development of a daily time step water shortage index (HDI), necessary for preventive drought detection and intervention levels, (3) the implementation of a GIS framework for supporting the monitoring activity and (4) based on the above activities the preparation of reports, remediation plans and intervention levels.

The system and the related methodology is developed by a team of professionals from the Lower Tisza District Water Directorate, the University of Szeged and GDI Hungary Ltd. The establishment of the network was preceded by a detailed scientific work in order to clarify the background and methodology of drought and water shortage monitoring. The main results of this investigation are summarised below.

THE MONITORING NETWORK

Factors determining the location of the stations, installation of the network

Given that the system, besides other potential applications, supports primarily water resource management and the determination of agricultural water demand the most important aspect during the placement of monitoring stations was the proximity of lands with agricultural activity. The exact location of stations was determined as a result of a GIS based optimisation procedure. First the entire land of Hungary was mapped, classified and ranked based on the combined presence, or lack of several significant factors of potential drought risk (agricultural land use, representative soil type, irrigation potential, topographical neutrality, excess water inundation hazard).

The implementation of the network has started during the autumn of 2016 by installing 16 test stations on the Great Hungarian Plain. This was followed by further 6 stations in 2017, still located on lowlands. During the latest campaign in 2018 another 25 stations were set up, but this time hilly areas were also included. At present in total 47 monitoring stations are functioning all over the country, but the extension of the network is continuous. At the end of 2018 further 32 stations are planned to be fitted on the Southern Hungarian Great Plains, and according to the plans, the envisaged number of stations (150) will be reached by the end of 2019 (Fig. 1).

Later, it will be possible for farmers to join the backbone network with their own auxiliary stations. The already existing monitoring system and the ensured software background will substantially decrease the technical demands against the voluntarily installed auxiliary stations, making the private investment cheaper. This can be an important incentive for farmers to shift to precision agriculture and at the same time extends and improves the monitoring activity of the water sector.

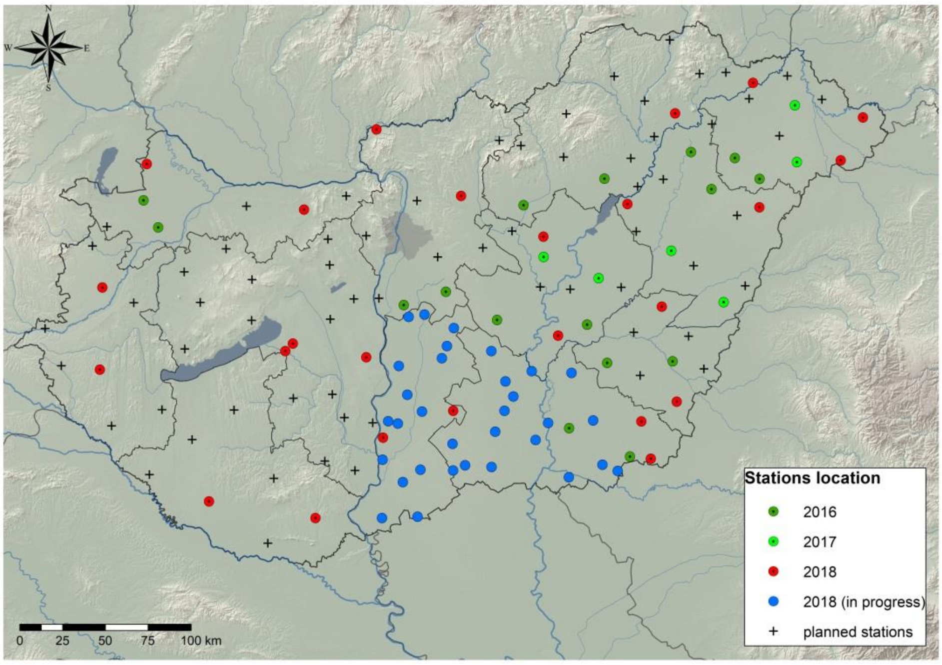

Figure 1: Location of the monitoring stations

Station components and delivered data

The equipment of the stations (Fig. 2) was selected by considering two main aspects. Firstly, the installed measurement facilities have to meet the WMO standards and have to provide the most relevant information concerning drought. Secondly, by applying a telemetry system and solar panels the stations have to operate automatically, requiring no direct read out and only limited onsite maintenance. Stations are communicating through GPRS, the telemetry box transmits data every 2 hours in the summer and every 6 hours in the winter. The system is controlled and supervised through a web portal. The components are the following:

- *Precipitation*
  OTT Pluvio 2
- *Air temperature and humidity*
  Adcon TR1
- *Soil moisture and temperature*
  Decagon 5TM (depths: 10, 20, 30 45, 60, 75 cm)

Figure 2: The equipment of a monitoring station

DAILY TIME STEP WATER SHORTAGE INDEX (HDI)

One of the main goals was to develop a robust drought index which can be refreshed on a daily base and requires only easily measurable meteorological data as input. A key aspect was the integration of soil moisture data retrieved from the implemented monitoring network. Consequently, the following versions of the Hungarian Drought Index (HDI) were developed:

HDI_0 – The baseline drought index, calculated using daily precipitation **(P)** and daily mean temperature **(T)**.

HDI_S – Heat stress adjusted drought index. Basic parameters are in line with the HDI_0. In this version it is assumed that during a heat wave the potential evapotranspiration **(PET)** is independent of water availability and losses are realised entirely.

HDI – A combined index including soil moisture values besides meteorological data. The calculation of the combined index requires the value of HDI_S, the measured soil moisture data and the knowledge of soil hydraulic properties.

The modular structure enables the calculation of the best possible version of the index at different levels of data availability. Consequently, for areas covered by the monitoring stations it is possible to calculate the combined HDI, but where no soil data are available the values of HDI_0 and HDI_S can be determined.

The procedure of HDI_0 calculation

Concerning its function the HDI_0 is analogous to other widely spread drought indices (e.g. SPI, PDSI). Its value and spatial variability is determined exclusively by meteorological parameters. The calculation of the HDI_0 is very similar to that of the water balance calculation of the Palmer index (PDSI), though it is novel in the sense that it operates using a daily time step.

During the calculation the positive side of the water balance is given by the value of daily precipitation, while the negative side is given by the estimated value of evapotranspiration **(ET)** being the function of PET, calculated from daily mean temperature and the water storage value of the preceding day **(WS_{i-1})**. The latter is the baseline component of the water balance, therefore an initial value has to be determined, then by summing up the positive and negative sides of the balance the WS value of the actual day can be determined.

Beyond the basic data (P, T) interim parameters derived from them are also necessary for the calculation of WS. As a first step the value of PET is estimated using a power function fitted to the T and related PET values determined by *Allen et al. (1998)* in their handbook published on the FAO website.

By taking a historical series of daily WS values, between 1981 and 2010 for the present study, an average value is determined for every calendar day $\left(\overline{\mathrm{WS}}\right)$. The ratio of $\overline{\mathrm{WS}}$ and WS gives then the value of HDI_0:

$$\boldsymbol{HDI_0} = \frac{\overline{WS}}{WS}$$

The value of HDI_0 is therefore the ratio of expectable (average) water storage and actual water storage on a given calendar day. It is a dimensionless parameter, and based on the minimum and maximum of WS and it takes values above 0 and below 10.

The procedure of HDI_S calculation

The climate of Hungary is arid enough for the development of significant drought events in the summer even in usual years. Consequently, the daily values of HDI_0 might indicate average conditions in critical periods too, despite of the heat stress originating from prolonged aridity. To overcome this problem we elaborated the HDI_S. It is determined similarly to HDI_0 but during the calculation of the water balance evaporation deficit (PET-ET), arising due to the low values of WS and the lack of precipitation, is also considered. A conditional temperature parameter was also introduced (T_{10} > 15 °C, i.e. the ten day mean temperature is above 15°C), otherwise the value of HDI_S would falsely indicate drought in the winter, which is irrelevant from an operational perspective. The 15 °C threshold temperature marks the transition between the summer and winter semesters.

The procedure of HDI calculation

HDI_0 and HDI_S rely merely on meteorological data, while soil moisture can also have a significant role in controlling the onset of drought. Therefore a complex index (HDI) incorporating soil data was also developed. This index is based on the values of HDI_S which is then multiplied by two conceptually elaborated factors comprising the actual water content, wilting point (WP) and field capacity (FC) of the represented soil layers.

Concerning the multiplication factors four expectations were made: (1) in an average, drought free period their value should be around 1, (2) in wet conditions they should decrease below 1, (3) as the drying of the soil intensifies their value should increase exponentially, (4) they must be soil specific, i.e. they need to integrate soil hydraulic properties. Finally, from meteorological parameters and correction factors derived from soil moisture data the complex water shortage index (HDI) can be calculated in the following way:

$$\boldsymbol{HDI} = HDI_s * k_{35} * k_{80}$$

where k_{35}, and k_{80} refer to the upper 35 cm soil layer and to the 35-80 cm soil layer, respectively.

PLACING DROUGHT MANAGEMENT TO NEW GROUNDS

In order to provide an adequate level of support for the widest possible circle of stakeholders the measured parameters and the time series of calculated data are made available online without any charge. The national drought monitoring system under development will provide immensely valuable data for the water sector, since drought and water shortage phenomena can be recognised more precisely, spatial and temporal differences can also be determined, and consequently, prevention and remediation activities can be focused on truly affected territories. By applying the results of the ECMWF model runs a 10 day drought forecast is published informatively to aid farmers in arranging preventive actions.

Future aims include the development of a soil moisture model, which can provide indispensable data for water resource management for planning division between users on the basis of directly measured data. The operation of the monitoring network and the processing of data are carried out by well trained personnel, therefore real time and supervised data and results are published for the end users.

Even simple meteorological data (precipitation, temperature, relative humidity) are important for agricultural planning and can improve the efficiency of production throughout the entire growing season. These parameters are also inputs for plant models with the help of which the development of plants can be monitored, plant protection and nutrition activities can be optimised and thus yields can be stabilised or increased. Further parameters measured (soil moisture and temperature) on the other hand can help to plan agro-technical activities and to determine the optimal time of sowing. By monitoring soil moisture the irrigational water demand can be calculated, consequently, precision irrigation and the efficiency of agriculture can be improved on a national scale.

References and further reading

Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements, FAO Irrigation and drainage paper 56., FAO, Rome.

Bergman, K.H., Sabol, P., Miskus, D. (1988). Experimental Indices for Monitoring Global Drought Conditions. Proceedings of 13th Annual Climate Diagnostics Workshop, U.S. Department of Commerce, Cambridge, MA.

Bussay, A., Szinell, Cs., Szentimrey, T. (1999). Az aszály magyarországi előfordulásának vizsgálata és mérhetősége. Égh. Agromet. T. 7. OMSZ. Bp.

Bhuiyan, C. (2004). Various Drought Indices for Monitoring Drought Condition in Aravalli Terrain of India. Proceedings of the XXth ISPRS Conference. International Society for Photogrammetry and Remote Sensing, Istanbul, Turkey.

Bálint, Z., Mutua, F.M., Muchiri, P. (2011). Drought monitoring with the combined drought index, FAO-SWALIM, Nairobi, Kenya. 3-25.

Faragó, T., Kozma, E., Nemes, Cs. (1988). Quantifying droughts. Identifying and Coping with Extreme Meteorological Events (eds.: Antal, E. – Glanz, M.H.). Országos Meteorológiai Szolgálat, Budapest.

Fiala, K., Benyhe, B., Dolinaj, D., Pálfai, I. (2014): A múlt és a jelen aszályai. In: Blanka, V. – Ladányi, Zs. (szerk.): Aszály és vízgazdálkodás a Dél-Alföldön és a Vajdaságban. SZTE. 87-96.

Gobron, N., Aussedat, O., Lavergne, T., Taberner, M., Pinty, B., Brito, F., Faber, O., Brockmann, C., Mélin, F., Robustelli, M., Snoeij, P. (2006). Validation of the operational MERIS fAPAR products. In: Danesy, D. (ed.) Proceedings of the 2nd Working Meeting on MERIS and ATSR Calibration and Geophysical Validation. 20-24 March 2006, Frascati, Italy of ESA Special Publication, European Space Agency, 1-8.

Hanyecz V. (2000). Öntözéses gazdálkodás az Alföldön. In: A víz szerepe és jelentősége az Alföldön, Pálfai I. (szerk.), A Nagyalföld Alapítvány Kötetei 6., Békéscsaba, 147-153.

Hayes, M. J., Svoboda, M. D., Wall, N., Widhalm, M. J. (2011). The Lincoln Declaration on Drought Indices: Universal meteorological drought index recommended., Bull. Am. Met. Society 92 (4): 485-488.

McKee, T.B., Doesken, N.J., Kleist, J. (1993). The relationship of drought frequency and duration to time scale. In: Proceedings of the Eighth Conference on Applied Climatology, Anaheim, California, 179-184. Boston, American Meteorological Society, 179-184.

Keetch, J.J., Byram, G.M. (1968). A Drought Index for Forest Fire Control. United States Department of Agriculture Forest Service Research Paper SE 38, Southeastern Forest Experiment Station, Asheville, NC.

Kozák, P., Pálfai, I., Herceg, Á. (2012). Palfai Drought Index (PaDI) – A Pálfai-féle aszályindex (PAI) alkalmazhatóságának kiterjesztése a délkelet-európai régióra. DMCSEE projekt tanulmány. 21-26.

Lakatos, M., Bihari, Z. (2011). A közelmúlt megfigyelt hőmérsékleti- és csapadéktendenciái. In: Bartholy, J., Bozó, L., Haszpra, L. (szerk). Klímaváltozás – 2011. MTA, ELTE. 146-169.

Lakatos, M., Kovács, T., Bihari, Z., Szentimrey, T. (2012). Az aszályindexek számítási lehetőségei és gyakorlata az Országos Meteorológiai Szolgálatnál. DMCSEE projekt tanulmány. 17-20.

Lakatos M., Szentimrey T., Bihari Z., Szalai S. (2013). Investigation of climate extremes in the Carpathian region on harmonized data, Environmental Changes and Adaptation Strategies, Skalica, Slovakia.

Mavromatis, T. (2007). Drought index evaluation for assessing future wheat production in Greece. Int.J. Climatol., 27, 911-924.

Narasimhan, B., Srinivasan, R. (2005). Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. Agricultural and Forest Meteorology, 133(1):69-88.

Niemeyer, S. (2008). New drought indices. Options Méditerranéennes. Série A: Séminaires Méditerranéens, 80., 267-274.

Monteith, J. L. (1973). Principles of Environmental Physics. Edward Arnold, London.

Pálfai, I. (2002). Magyarország aszályossági zónái, Vízügyi Közl., 3., 323-357.

Palmer, W. C. (1965). Meteorological Drought. Weather Bureau Res. Paper 45. U.S. Dept. of Commerce. 58.

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. Proc. Roy. Soc. London, A193, 120-146.

Riebeek, H. (2010). Global Warming, Feature Articles, NASA, Web.

Urbán, L. (1993). Az aszály fogalma és jelentősége. Beszámolók 1989. OMSZ. Budapest 113-135.

Wilhite, D.A., Glantz, M.H., (1985). Understanding the drought phenomenon: the role of definitions. Water Int. 10 (3), 111-120.

World Meteorological Organization (WMO) and Global Water Partnership (GWP), (2016). Handbook of Drought Indicators and Indices (Svoboda, M.D., Fuchs, B.A.). Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2. Geneva.

Zargar, A., Sadiq, R., Naser, B., Khan, F.I. (2011). A review of drought indices. Environmental Reviews 19. 333-349.