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Temperature-based Evapotranspiration in the WSVI Drought Index Implementation

Case Study: Pannonian Basin

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Abstract

Drought is a natural hazard that affects environmental and socio-economic development. In this study, the Water Surplus Variability Index (WSVI), which is based on both precipitation and Penman-Monteith (PM) evapotranspiration (ET) estimates, was used to quantify drought. The application of the WSVI is not possible in some locations because of the missing data for estimating ET. The key objectives of this research were to 1. compare the different temperature-based WSVIs for the 1-, 3-, 6- and 12-month timescales with the original PM-based WSVI; 2. improve the WSVI by replacing the full-set PM equation with the corresponding temperature-based ET equation, such as Hargreaves, adjusted Hargreaves, Thornthwaite, modified Thornthwaite or temperature-based PM; and 3. compare the best temperature-based WSVI with the Standardized Precipitation Index (SPI). The set of meteorological data was obtained from several stations from Pannonian Basin (Budapest, Debrecen, Novi Sad and Sombor). According to statistical indicators, the Hargreaves-based WSVI (WSVIH) was ranked first or second for each time period at all locations. The WSVIH was additionally tested using the SPI for each location and each timescale. The obtained results indicated the capability of the WSVIH to quantify drought frequency, duration and severity identified by the SPI. Finally, the WSVI can be recommended using the Hargreaves equation instead of the full-set PM equation in future WSVI implementations in the Pannonian Basin.

Keywords

drought, evapotranspiration, temperature, WSVI, Pannonian Basin, SPI

1 Introduction

Drought is a natural hazard that affects water resources, agricultural production and natural ecosystems. Deficit irrigation and drought-tolerant crops can become a sustainable strategy in a drought-prone environment [1–3]. Many drought indices have been introduced to characterize drought conditions. One of the most explored is the precipitation-based index, the Standardized Precipitation Index (SPI) [4]. Although precipitation is one of the main drought indicators, temperature is also an important factor that can characterize drought as it controls evapotranspiration (*ET*). Many indices use *ET* and precipitation in the process of drought assessment, monitoring and prediction: the Palmer Drought Severity Index (PDSI) [5], the Reconnaissance Drought Index (RDI) [6], the Standardized Precipitation Evapotranspiration Index (SPEI) [7], the Water Surplus Variability Index (WSVI) [8, 9], the Standardized Evapotranspiration Deficit Index (SEDI) [10], the Crop Reconnaissance Drought Index (CRDI) [11]. Many of these indices (PDSI, RDI, SPEI) use the temperature-based Thornthwaite equation [12] to estimate *ET*. However, the WSVI enforces the Penman-Monteith method (PM) [13] to calculate *ET*. The Food and Agriculture Organization of the United Nations (FAO) recommends PM as the standard *ET* equation. This equation requires numerous input data such as wind speed, temperature, solar radiation, and relative humidity. Therefore, the WSVI is not applicable in many sites because of missing data for estimating *ET*. There are many studies on applying different *ET* estimation methods to numerous drought indices [14–22]. The results suggested that the method used to estimate *ET* can have a significant role in quantifying drought for many regions of the world. If all input data are available, the Penman-Monteith equation is recommended for worldwide implementation of

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the Standardized Precipitation Evapotranspiration Index (SPEI), else the Hargreaves or Thornthwaite equations are recommended [23]. In the Loess Plateau (China), the two-source evapotranspiration method or Penman-Monteith equation is proposed instead of the Thornthwaite equation in the calculation of the SPEI [24]. The key objectives of this research were to:

1. compare the different temperature-based WSVIs for the 1–, 3–, 6– and 12– month timescales with the original PM-based WSVI;
2. improve the WSVI by replacing the full-set PM equation with the adequate temperature-based ET equation; and
3. compare the best temperature-based WSVI with the Standardized Precipitation Index (SPI).

Drought trends in Serbia (Novi Sad and Sombor) from 1980 to 2015 and Hungary (Budapest and Debrecen) from 1971 to 2010 were evaluated using five temperature-based versions of the WSVI. These WSVIs were calculated using ET values obtained by the various temperature-based equations (Hargreaves, adjusted Hargreaves, Thornthwaite, modified Thornthwaite and temperature-based Penman-Monteith).

2 Methodology and material

2.1 Study area

In this research, four meteorological stations in Serbia and Hungary were selected. The time series of the monthly mean of daily actual vapor pressure (e_a), sunshine hours (n), minimum temperature ($T_{\min}$), maximum temperature ($T_{\max}$), wind speed (U_2) and precipitation (P) during the period 1980–2015 were used for the Serbian stations (Novi Sad and Sombor). The time series of the monthly mean of daily sunshine hours (n), minimum temperature ($T_{\min}$), maximum temperature ($T_{\max}$) and precipitation (P) during the period 1971–2010 were used for the Hungarian stations (Budapest and Debrecen). The average temperature ranged from 10.2 °C to 12.2 °C, and the mean RH for these locations varied from 72% to 77%. The mean annual U_2 ranged from 1.25 m s^{-1} to 2.82 m s^{-1}. Sunshine hours varied from 4.7 h day^{-1} to 5.7 h day^{-1}. The mean annual sum of P ranged from 563 mm to 710 mm.

2.2 Water surplus variability index

WSVI is calculated as:

$$\mathrm{WSVI}_k^{(i)} = \frac{D_k^{(i)} - \mu}{\sigma} \quad (1)$$

where WSVI = water surplus variability index, k = month, i = year, D = monthly water surplus or deficit, μ = mean and σ = standard deviation.

Water surplus $D_k^{(i)}$ is estimated as:

$$D_k^{(i)} = \sum_{j=1}^{k} \left(P_{ij} - ET_{ij} \right) \quad (2)$$

where P_{ij} = precipitation and ET_{ij} = ET of month j for year i.

2.3 Penman-Monteith equation

The PM equation was explained in detail in [13]:

$$ET_0 = \frac{0.408 \times \Delta \times \left(R_n - G\right) + \gamma \frac{900}{T + 273} U_2 \times \left(e_s - e_a\right)}{\Delta + \gamma \left(1 + 0.34 \times U_2\right)} \quad (3)$$

where ET_0 = reference evapotranspiration (mm day^{-1}), T = mean temperature (°C), R_n = net radiation (MJ m^{-2} day^{-1}), U_2 = wind speed at a 2 m height (m s^{-1}), G = soil heat flux density (MJ m^{-2} day^{-1}), e_s = saturation vapor pressure (kPa), Δ = slope of the saturation vapor pressure function (kPa °C^{-1}), γ = psychometric constant (kPa °C^{-1}) and e_a = actual vapor pressure (kPa).

2.4 Temperature-based PM equation

Alternative procedures for missing weather data estimation were proposed by [13]. When radiation data are missing, the temperature data are applied for the radiation estimation:

$$R_s\left(T\right) = K \left(T_{\max} - T_{\min}\right)^{0.5} R_a \quad (4)$$

where $R_s(T)$ = temperature-based solar radiation (MJ m^{-2} day^{-1}), $T_{\max}$ = maximum temperature (°C), $T_{\min}$ = minimum temperature (°C), R_a = extraterrestrial radiation (MJ m^{-2} day^{-1}) and K = adjustment coefficient. The extraterrestrial radiation is the solar radiation at the top of the atmosphere and depends only on latitude and day or month of the year. If the vapor pressure data are lacking, the minimum temperature can be used to calculate vapor pressure:

$$e_a\left(T\right) = 0.611\, e^{\left[\frac{17.27\, T_{\min}}{T_{\min} + 237.3}\right]} \quad (5)$$

where $e_a(T)$ = temperature-based actual vapor pressure (kPa), $T_{\min}$ = minimum temperature (°C).

If the wind speed data are missing, the average wind speed can be used instead of measured wind speed values. Allen et al. [13] suggested using the global mean wind speed where U_{2g} = 2.0 m s^{-1}. The temperature-based PM equation (PMT) used in this research is:

$$ET_0(T) = \frac{0.408 \times \Delta \times R_n(T) + \gamma \dfrac{900}{T+273} U_{2g} \times \left(e_s - e_a(T)\right)}{\Delta + \gamma\left(1 + 0.34 \times U_{2g}\right)} \quad (6)$$

2.5 Hargreaves equation

The frequent absence of weather data encouraged Hargreaves to present a simple temperature-based equation [25]:

$$ET_{0,H} = 0.0023 \times \left(T_{max} - T_{min}\right)^{HE} \left(\frac{T_{max} + T_{min}}{2} + 17.8\right) \quad (7)$$

where $ET_{0,H}$ = Hargreaves-based ET_0 (mm day^{-1}) and HE = empirical Hargreaves exponent, T_{max} = maximum temperature (°C), T_{min} = minimum temperature (°C). Two Hargreaves approaches were presented in this study: H (HE = 0.5 [25]) and AH (HE = 0.424 [26, 27]).

2.6 Thornthwaite equation

Thornthwaite equation can be written as [12]:

$$ET_{0,i} = \frac{16 N_i}{360} \left(\frac{10 T_i}{\sum_{i=1}^{12} \left(0.2 T_i\right)^{1.514}}\right)^{0.016 \sum_{i=1}^{12} \left(0.2 T_i\right)^{1.514} + 0.5} \quad (8)$$

where N = maximum sunshine duration (hours) and T = mean temperature (°C).

Equation (8) can be improved by using an "effective" temperature (T_{ef}) instead of the mean temperature [28]. The effective temperature can be estimated as:

$$T_{ef} = 0.5 k \left(3 T_{max} - T_{min}\right) \quad (9)$$

where T_{ef} = effective temperature (°C), T_{max} = maximum temperature (°C), T_{min} = minimum temperature (°C) and k = empirical coefficient. Camargo et al. [28] suggested k = 0.72 for Brazilian locations. Different values of k were tested in [29] and [30]. Pereira and Pruitt [29] proposed to replace T_{ef} with adjusted effective temperature (T^*_{ef}).

$$T^*_{ef} = T_{ef} \frac{N}{24 - N} \quad (10)$$

with the following restriction: $T \leqq T^*_{ef} \leqq T_{max}$. Two Thornthwaite approaches were used in this study: TH with mean temperature (T) [12] and ATH with adjusted effective temperature (T^*_{ef}) [29].

2.7 Evaluation criteria

In this study, the root-mean-square error (RMSE) and mean absolute error (MAE) were used as statistical indicators:

$$\text{MAE} = \frac{\sum_{j=1}^{K} \left(\left|\text{WSVI}_{pm,j} - \text{WSVI}_{eq,j}\right|\right)}{K} \quad (11)$$

$$\text{RMSE} = \left[\frac{\sum_{j=1}^{K} \left(\left|\text{WSVI}_{\text{PM},j} - \text{WSVI}_{eq,j}\right|\right)^2}{K}\right]^{0.5} \quad (12)$$

where WSVI_{PM} = PM-based WSVI, WSVI_{eq} = temperature-based WSVI and K = the number of data.

3 Results and discussion

The statistical summary of WSVI values calculated by the various ET methods for the 1–, 3–, 6– and 12–month timescales is presented in Table 1.

The Hargreaves-based WSVI (WSVIH) for each timescale was found to be in excellent agreement with the PM-based WSVI (WSVIPM) at all sites.

The RMSE for the 1–, 3–, 6– and 12–month timescales was in the range of 3.8 – 7.1 × 10^{-3}, 3.9 – 7.8 × 10^{-3}, 4.3 – 8.5 × 10^{-3} and 4.0 – 9.2 × 10^{-3}, respectively. WSVIH yielded the smallest RMSE nine times (at one station for 1–month timescale, two stations for 3-month timescale, three stations for 6–month timescale, and three stations for 12–month timescale) and the second smallest RMSE seven times. In other words, WSVIH was ranked as the first or second for each timescale at all stations. The temperature-based PM WSVI (WSVIPMT) yielded very good agreement with the WSVIPM at all sites with the RMSE for the 1–, 3–, 6– and 12–month timescales ranging 3.8 – 7.1 × 10^{-3}, 3.8 – 7.9 × 10^{-3}, 4.0 – 8.6 × 10^{-3} and 4.2 – 9.4 × 10^{-3}, respectively.

The WSVIPMT yielded the smallest RMSE four times in the case of Novi Sad (1–month time scale) and Debrecen (1–, 3–, and 6–month timescales) and the second smallest RMSE eight times.

The adjusted Hargreaves-based WSVI (WSVIAH) was reasonably good at all sites with the RMSE for the 1–, 3–, 6– and 12–month timescales ranging 4.1 – 6.9 × 10^{-3}, 4.5 – 8.3 × 10^{-3}, 4.8 – 9.2 × 10^{-3} and 5.1 – 10.0 × 10^{-3}, respectively. The WSVIAH yielded the smallest RMSE values only two times in the case of Sombor (1–month timescale) and Novi Sad (3–month timescale) and the second smallest RMSEs three times at Budapest (3–, 6– and 12–month timescales).The adjusted Thornthwaite-based WSVI (WSVIATH) was the second lowest ranking approach thirteen times with the RMSE for the 1–, 3–, 6– and 12–month timescales varying 6.0 – 8.0 × 10^{-3},

Table 1 Statistical summary of WSVIs calculated by the various ET_0 methods for 1–, 3–, 6– and 12–month timescales

Method	Budapest		Debrecen		Novi Sad		Sombor	
	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE
WSVIPMT–1	4.01	1.61	**3.84**	1.47	**6.60**	3.75	7.09	4.61
WSVITH–1	6.62	4.11	7.03	4.50	7.58	4.68	8.19	5.37
WSVIATH–1	6.21	3.64	5.99	3.47	7.18	4.33	8.02	5.56
WSVIAH–1	4.08	2.04	5.06	2.50	6.85	3.91	**6.92**	4.28
WSVIH–1	**3.76**	1.87	4.15	1.75	6.70	3.84	7.07	4.49
WSVIPMT–3	4.82	2.32	**3.81**	1.45	7.35	4.56	7.91	5.42
WSVITH–3	6.62	4.11	6.93	4.36	8.23	5.23	8.83	5.79
WSVIATH–3	6.23	3.66	5.86	3.32	7.78	4.98	9.01	6.26
WSVIAH–3	4.52	2.04	4.67	2.12	**7.28**	4.47	8.31	5.56
WSVIH–3	**4.33**	1.87	3.92	1.54	7.35	4.56	**7.81**	5.26
WSVIPM–6	4.98	2.48	**4.01**	1.61	7.94	**5.27**	8.62	6.49
WSVITH–6	6.07	3.46	7.71	5.10	8.84	6.14	9.91	7.24
WSVIATH–6	5.81	3.32	6.03	3.63	8.13	5.34	9.38	6.60
WSVIAH–6	4.81	2.31	4.98	2.48	7.95	5.29	9.17	6.96
WSVIH–6	**4.50**	2.03	4.31	1.86	**7.85**	5.32	**8.52**	6.42
WSVIPMT–2	5.61	3.15	4.21	1.78	8.29	5.82	9.37	7.22
WSVITH–12	6.42	4.13	7.36	4.73	9.43	6.60	10.77	8.31
WSVIATH–12	6.15	3.61	5.43	2.95	**8.18**	5.75	9.90	7.62
WSVIAH–12	5.43	2.95	5.11	2.61	8.49	5.89	9.99	7.93
WSVIH–12	**5.05**	2.49	**4.01**	1.60	8.29	5.82	**9.22**	7.17

Note: Bold values indicate the most successful methods at each station for each timescale. RMSE and MAE are multiplied by 10^{-3}.

$5.9 - 9.0 \times 10^{-3}$, $5.8 - 9.4 \times 10^{-3}$ and $5.4 - 9.9 \times 10^{-3}$, respectively. The Thornthwaite-based WSVI (WSVITH) yielded the largest RMSE values fifteen times and the second largest RMSE in only one case (Sombor, 3-month timescale). In other words, the Thornthwaite-based WSVI was the lowest ranking for each timescale at all locations except WSVITH–3 for Sombor.The obtained WSVIs demonstrate that the Hargreaves equation performed much better than the other temperature-based equations. Overall, the results suggest using the Hargreaves equation instead of the full-set Penman-Monteith equation in calculating the WSVI drought index. In addition, the WSVIPM and WSVIH were compared with the Standardized Precipitation Index (SPI) for each location and for each timescale. The precipitation-based SPI index has been recommended by the World Meteorological Organization (WMO) as the standard meteorological drought index [31]. The characteristics of SPI, WSVIPM and WSVIH for the 1–, 3–, 6– and 12–month timescales during 1980–2015 at the Sombor station are presented in Table 2. The results indicate a perfect agreement between WSVIPM and WSVIH in both the wet and drought periods. Both WSVI versions were found to be in very good agreement with the SPI for each timescale. Results showed that the WSVI yielded a lower severity during drought episodes and a higher severity during wet episodes compared to the SPI.

The WSVI and SPI presented very similar drought frequencies and durations in each timescale. Similar results were obtained at the other locations. The drought indices that referred to six months of the growing season from April to September (WSVIPM–6, WSVIH–6 and SPI–6) for each year at the Sombor station are presented in Fig. 1. The perfect agreement between the two versions of WSVI and an excellent agreement between the SPI and WSVI for the most months are shown in this Fig. 1. The WSVI slightly overestimated the SPI during extreme wet periods and underestimated SPI during extreme drought periods, with the conclusion that the main differences in severity between the SPI and WSVI (Table 2) originated from extreme drought and wet episodes. The WSVI underestimation of extreme droughts is caused by the introduction of evapotranspiration in the WSVI estimation. The variation in the time series of precipitation (*P*) is higher compared to the time series $P\text{-}ET_0$. Similar results were obtained using other *ET*-based drought indices [8, 9, 32].

Table 2 The characteristics of SPI, WSVIPM and WSVIH during 1980–2015 at the Sombor station

Index		Drought episodes				Wet episodes			
		1-month	3-month	6-month	12-month	1-month	3-month	6-month	12-month
SPI	Frequency	16.7	15.6	14.5	14.3	14.8	16.0	16.2	14.0
	Duration	1.3	2.3	3.9	7.5	1.2	2.3	2.6	5.2
	Severity	–1.59	–1.61	–1.61	–1.70	1.49	1.47	1.47	1.60
WSVIPM	Frequency	15.0	15.6	14.3	14.5	14.8	16.5	16.4	14.0
	Duration	1.3	2.3	3.8	6.8	1.2	2.2	2.6	5.4
	Severity	–1.26	–1.40	–1.45	–1.55	1.81	1.62	1.57	1.72
WSVIH	Frequency	15.3	15.6	14.3	14.5	14.8	16.7	16.4	14.0
	Duration	1.2	2.3	3.8	6.8	1.2	2.2	2.5	5.4
	Severity	–1.26	–1.40	–1.45	–1.54	1.81	1.61	1.58	1.73

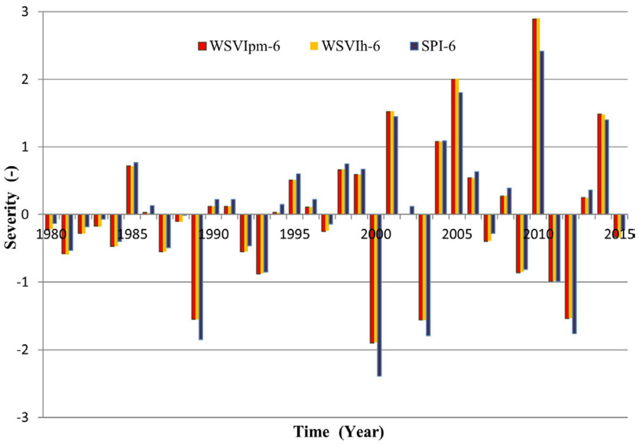

Fig. 1 Drought indices for the 6-month timescale from April to September (growing season) at Sombor

4 Conclusions

Evapotranspiration variability can play a significant role in quantifying drought. The key objective of this study was to present a simpler and more flexible approach to implement WSVI in the Pannonoan basin by introducing the temperature-based instead of the PM-based *ET* estimation. Data from four meteorological stations in Serbia (Novi Sad and Sombor) and Hungary (Budapest and Debrecen) were used as the basis for computing the WSVI drought index. Thus, the five temperature-based *ET* equations (Hargreaves, adjusted Hargreaves, Thornthwaite, modified Thornthwaite, and temperature-based PM) were tested against the standard PM equation. The temperature-based *ET* WSVIs were compared to the original WSVIPM. The Hargreaves-based WSVI (WSVIH) yielded excellent agreement with the WSVIPM. This approach was the first ranking approach nine times and the second ranking seven times (out of the altogether 16 evaluated cases when counting stations and timescales). This means that the WSVIH was ranked first or second for each timescale at each location.

These results indicate that the WSVIH performed better than the other selected temperature-based WSVIs. The WSVIPM and WSVIH were additionally tested using the SPI. Overall, these results demonstrate the capability of WSVIPM and WSVIH to quantify the drought frequency, duration and severity identified by the SPI. The drought severity, duration and frequency of the WSVIH and WSVIPM are almost equal. Both versions of the WSVI presented a moderate severity compared to the SPI. The drought duration and frequency identified by the WSVIPM and WSVIH were quite similar to those obtained by the SPI.

One can conclude that using the Hargreaves equation instead of the full-set Penman-Monteith equation will not compromise the reliability of the WSVI drought index. In the future research, the same procedure can be performed for more Pannonian stations to confirm the obtained results in the present study. Also, in the future research, any missing weather variable could be estimated using numerical weather reanalysis.

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References

[1] Hao, B., Xue, Q., Marek, T. H., Jessup, K. E., Becker, J. D., Howel, T. A. "Grain yield, evapotranspiration, and water-use efficiency of maize hybrids differing in drought tolerance", Irrigation Science, 37(1), pp. 25–34, 2019. https://doi.org/10.1007/s00271-018-0597-5

[2] Kozma, Z., Jolánkai, Z., Kardos, M. K., Muzelák, B., Koncsos, L. "Adaptive water management-land use practice for improving ecosystem services – a hungarian modelling case study", Periodica Polytechnica Civil Engineering, 66(1), pp. 256–268, 2022. https://doi.org/10.3311/PPci.18369

[3] Zhang, K., Pang, B., Kisekka, I., Zhang, M., Rogers, D., Wang, D. "Effect of irrigation on physicochemical properties and bioethanol yield of drought tolerant and conventional corn", Irrigattion Science, 36(2), pp. 75–85, 2018. https://doi.org/10.1007/s00271-017-0563-7

[4] McKee, T. B., Doesken, N. J., Kleist, J. "The relationship of drought frequency and duration to time scales", [pdf] In: Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 1993, pp. 179–184. Available at: https://www.droughtmanagement.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_Scales_1993.pdf

[5] Palmer, W. C. "Meteorological Drought", [pdf] US Deparment of Commerce, US Weather Bureau, Washington, D.C., USA, 45, 1965. Available at: https://www.droughtmanagement.info/literature/USWB_Meteorological_Drought_1965.pdf

[6] Tsakiris, G., Vangelis, H. "Establishing a Drought Index Incorporating Evapotranspiration", [pdf] European Water, 9(10), pp. 3–11, 2005. Available at: http://www.ewra.net/ew/pdf/EW_2005_9-10_01.pdf

[7] Vicente-Serrano, S. M., Beguería, S., López-Moreno, J. I. "A Multiscalar Drought Index Sensitive to Global Warming: the Standardized Precipitation Evapotranspiration Index", Journal of Climate, 23(7), pp. 1696–1718, 2010. https://doi.org/10.1175/2009JCLI2909.1

[8] Gocic, M., Trajkovic, S. "Drought Characterization Based on water surplus variability index", Water Resources Management, 28(10), pp. 3179–3191, 2014. https://doi.org/10.1007/s11269-014-0665-4

[9] Gocic, M., Trajkovic, S. "Water surplus variability index as an Indicator of Drought", Journal of Hydrologic Engineering, 20(2), 04014038, 2015. http://doi.org/10.1061/(ASCE)HE.1943-5584.0001008

[10] Kim, D., Rhee, J. "A drought index based on actual evapotranspiration from the Bouchet hypothesis", Geophysical Research Letters, 43(19), pp. 10277–10285, 2016. https://doi.org/10.1002/2016GL070302

[11] Tigkas, D., Vangelis, H., Tsakiris, G. "Implementing crop evapotranspiration in RDI for farm-level drought evaluation and adaptation under climate change conditions", Water Resources Management, 34(14), pp. 4329–4343, 2020. https://doi.org/10.1007/s11269-020-02593-6

[12] Thornthwaite, C. W. "An Approach toward a Rational Classification of Climate", Geography Review 38(1), pp. 55–94, 1948. https://doi.org/10.2307/210739

[13] Allen, R. G., Pereira, L. S., Raes, D., Smith, M. "Crop evapotranspiration – Guidelines for computing crop water requirements", Food and Agriculture Organization of the United Nation, 1998. ISBN 92-5-104219-5

[14] Vangelis, H., Tigkas, D., Tsakiris, G. "The effect of PET method on Reconnaissance Drought Index (RDI) calculation", Journal of Arid Environments, 88, pp. 130–140, 2013. https://doi.org/10.1016/j.jaridenv.2012.07.020

[15] Yuan, S., Quiring, S. M. "Drought in the U.S. great plains (1980–2012): A sensitivity study using different methods for estimating potential evapotranspiration in the Palmer Drought Severity Index", Journal of Geophysical Research, 119(19), pp. 10996–11010, 2014. https://doi.org/10.1002/2014JD021970

[16] Ficklin, D. L., Letsinger, S. L., Gholizadeh, H., Maxwell, J. T. "Incorporation of the Penman-Monteith potential evapotranspiration method into a Palmer Drought Severity Index Tool", Computers & Geosciences, 85, pp. 136–141, 2015. https://doi.org/10.1016/j.cageo.2015.09.013

[17] Vicente-Serrano, S. M., Van der Schrier, G., Beguería, S., Azorin-Molina, C., Lopez-Moreno, J. I. "Contribution of precipitation and reference evapotranspiration to drought indices under different climates", Journal of Hydrology, 526, pp. 42–54, 2015. https://doi.org/10.1016/j.jhydrol.2014.11.025

[18] Zarei, A. R., Mahmoudi, M. R. "Evaluation of changes in RDIst index effected by different Potential Evapotranspiration calculation methods", Water Resources Management, 31(15), pp. 4981–4999, 2017. https://doi.org/10.1007/s11269-017-1790-7

[19] Shi, L., Feng, P., Wang, B., Liu, D. L., Yu, Q. "Quantifying future drought change and associated uncertainty in southeastern Australia with multiple potential evapotranspiration models", Journal of Hydrology, 590, 125394, 2020. https://doi.org/10.1016/j.jhydrol.2020.125394

[20] Zhou, J., Wang, Y., Su, B., Wang, A., Tao, H., Zhai, J., Kundzewicz, Z. W., Jiang, T. "Choice of potential evapotranspiration formulas influences drought assessment: A case study in China", Atmospheric Research, 242, 104979, 2020. https://doi.org/10.1016/j.atmosres.2020.104979

[21] Wang, Y., Wang, S., Zhao, W., Liu, Y. "The increasing contribution of potential evapotranspiration to severe droughts in the Yellow River basin", Journal of Hydrology, 605, 127310, 2022. https://doi.org/10.1016/j.jhydrol.2021.127310

[22] Báder, L., Szilágyi, J. "Widening gap of Land Evaporation to reference evapotranspiration implies increasing vulnerability to droughts in Hungary", Periodica Polytechnica Civil Engineering, 67(4), pp. 1028–1037, 2023. https://doi.org/10.3311/PPci.21836

[23] Beguería, S., Vicente-Serrano, S. M., Reig, F., Latorre, B. "Standardized precipitation evapotranspiration index (SPEI) revisited: Parameter fitting, evapotranspiration models, tools, datasets and drought monitoring", International Journal of Climatology, 34(10), pp. 3001–3023, 2014. https://doi.org/10.1002/joc.3887

[24] Zhang, B., Wang, Z., Chen, G. "A sensitivity study of applying a two-source Potential Evapotranspiration Model in the Standardized Precipitation Evapotranspiration Index for drought monitoring", Land Degradation & Development, 28(2), pp. 783–793, 2017. https://doi.org/10.1002/ldr.2548

[25] Hargreaves, L. G., Hargreaves, G. H., Riley, J. P. "Irrigation water requirements for Senegal River Basin", Journal of Irrigation and Drainage Engineering, 111(3), pp. 265–275, 1985. https://doi.org/10.1061/(ASCE)0733-9437(1985)111:3(265)

[26] Trajkovic, S. "Hargreaves versus Penman-Monteith under humid conditions", Journal of Irrigation and Drainage Engineering, 133(1), pp. 38–42. 2007. http://doi.org/10.1061/(ASCE)0733-9437(2007)133:1(38)

[27] Trajkovic, S., Gocic, M., Pongracz, R., Bartoly, J. "Assessment of reference evapotranspiration by regionally calibrated Temperature-based equations", KSCE Journal of Civil Engineering, 24(3), pp. 1020–1027, 2020. https://doi.org/10.1007/s12205-020-1698-2

[28] Camargo, A. P., Marin, F. R., Sentelhas, P. C., Picini, A. G. "Ajuste da equação de Thornthwaite para estimar evapotranspiração potencial em climas áridos e superúmidos, com base na ampliturde térmica diária" (Adjust of the Thornthwaite's method to estimate the potential evapotranspiration for arid and superhumid climates, based on daily temperature amplitude), [pdf] Revista Brasileira de Agrometeorologia, 7(2), pp. 251–257, 1999. Available at: http://www.leb.esalq.usp.br/agmfacil/artigos/artigos_sentelhas_1999/1999_RBAgro_7(2)_251-257_ETPThTefetiva.pdf (in Portuguese)

[29] Pereira, A. R., Pruitt, W. O. "Adaptation of the Thornthwaite scheme for estimating daily reference evapotranspiration", Agricultural Water Management, 66(3), pp. 251–257, 2004. https://doi.org/10.1016/j.agwat.2003.11.003

[30] Trajkovic, S., Gocic, M., Pongracz, R., Bartoly, J. "Adjustment of Thornthwaite equation for estimating evapotranspiration in Vojvodina", Theoretical and Applied Climatology, 138(3), pp. 1231–1240, 2019. http://doi.org/10.1007/s00704-019-02873-1

[31] Hayes, M., Svoboda, M., Wall, N., Widhalm, M. "The Lincoln Declaration on drought indices: Universal meteorological Drought Index recommended", Bulletin of the American Meteorological Society, 92(4), pp. 485–488, 2011. https://doi.org/10.1175/2010BAMS3103.1

[32] Park, J., Lim, Y. J., Kim, B. J., Sung, J. H. "Appraisal of Drought characteristics of representative Drought Indices using meteorological variables", KSCE Journal of Civil Engineering 22(5), pp. 2002–2009, 2018. http://doi.org/10.1007/s12205-017-1744-x