Modelling of actual evapotranspiration and soil water content in Hungary

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1. Introduction

Evapotranspiration AET and root-zone soil water content Θ are neither operatively measured nor operatively calculated in Hungary, though they are basic flux and state quantities. The aim of this study is twofold: 1) to present a process oriented and as simple as possible method for estimating their monthly and annual values and 2) to determine the main factors regulating AET and Θ.

2. Data

Climate data (monthly precipitation P and air temperature T) refer to the period 1901-1950 (Kakas, 1960). These data agree well with the newest data presented in the Climate Atlas of Hungary. The soil texture categories used are as follows: sand, sandy loam, loam, clay loam and clay. The hydro-physical functions are parameterized after Nemes (2003). These soil data were provided by MTA TAKI GIS lab. The wilting point soil moisture content is calculated for pF = 4.2, while the field capacity for pF = 2.5.

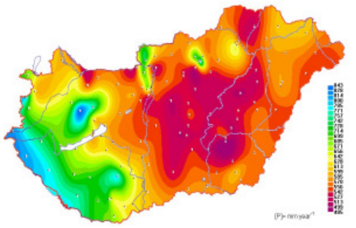

Fig.1: Areal distribution of the annual sum of precipitation in Hungary after Kakas (1960).

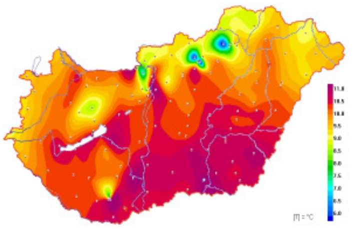

Fig.2: Areal distribution of the annual mean air temperature in Hungary after Kakas (1960).

3. Model

3.1 Inputs and outputs of the model

The input data are as follows: monthly and annual data of precipitation and air temperature, soil texture and the initial value of root-zone soil water content. The output data are as follows: monthly and annual values of root-zone soil water content (Θ), actual (AET) and potential (PET) evapotranspiration, water surplus, and deficit.

3.2 Bucket model

The core of the model is the bucket module serving for soil water content prediction. The bucket is 1m deep. The precipitation fills, while AET depletes it; no ground water moving is taken into account.

3.3 Parameterization

There are many evapotranspiration models (Szász et al., 2006). We used a common method for calculating AET:

$$AET = \beta \cdot PET$$

where β is a coefficient between 0 and 1.

3.3.1 Parameterization of PET

PET is parameterized after Thonthwaite (1948). Thornthwaite's method requires only monthly mean air temperature as input. A newer version of it is that of McKenny and Rosenberg (1993). According to this parameterization PET

$$PET = 1.6 \cdot \left(\frac{L}{12}\right) \cdot \left(\frac{N}{30}\right) \cdot \left(\frac{10 \cdot T_a}{I}\right)^a$$

where L is the average daytime length (hr), N is the number of days in a month, T_a is the mean monthly air temperature (°C). *I* is the thermal index, calculated as:

$$I = \sum_{j=1}^{12} \left(\frac{T_a}{5}\right)^{1.514}$$

and

$$a = 6.75 \cdot 10^{-7} \cdot I^3 - 7.71 \cdot 10^{-5} \cdot I^2 + 1.792 \cdot 10^{-2} \cdot I + 0.49239$$

3.3.2 Parameterization of β

There are also many parameterizations for β. In the study, Mintz & Walker's (1993) parameterization is used.

$$\beta = 1 - \exp\left(-6.8 \cdot \frac{\Theta - \Theta_w}{\Theta_f - \Theta_w}\right)$$

where Θ_w is the Θ at wilting point, Θ_f is the Θ at field capacity.

3.4 Numerical scheme

Different numerical schemes are applied for solving soil water prediction equation. According to our tests, a 2nd order implicit scheme (Kátai, 1976) seemed to be appropriate. To stabilize the scheme, Euler-method has been used in January.

4. Results

4.1 Verification

The performance of the model is tested in detail using measured soil water content data of the Agrometeorological Observatory of the University of Debrecen. These verification results are presented by Szász et al. (2006).

4.2 Statistical relationships

Relationships between AET, Θ and basic climatic variables have also been analyzed statistically for annual, growing season and monthly time periods taking each soil texture (sand, sandy loam, loam, clay loam and clay) separately. Results (regression line $y=a \cdot x+b$ with the highest value of R^2) obtained are presented in Table 1and 2. Results were obtained for sand, sandy loam, loam, clay loam and clay refer to 16, 9, 63, 21 and 6 data points, respectively. In the following the results will be separately discussed for different time periods and soil textures. In the tables only the cases with significant correlations are presented ($R_{AET}^2 \geq 0.55$; $R_{\Theta}^2 \geq 0.46$)

4.2.1 *Annual period*

The annual sums of AET and the annual average Θ are correlated well with P. Although only one case refers to the correlation between the AET and the Θ their R^2 is usually around 0.8 (not represented).

4.2.2 *Growing season*

The growing season sums of AET and the growing season average Θ are correlated well only with P. The relation between the AET and the Θ is similar to the case mentioned above.

4.2.3 *Monthly period*

In late autumn and in the winter months and in spring AET is well correlated with T especially for clay loam. In late autumn and in winter the AET is very small therefore Θ is determined by P. In spring, by rising of T AET is also rising and then T is the leading factor. In summer both P and Θ are important predictors for AET. In summer, P is large but high T causes high AET therefore Θ is decreasing. When Θ is smaller, the amount of water stored is significant factor. In summer, for Θ AET is also important. Note that for clay loam T is predictor from June to September.

4.2.4 *Soil texture*

There isn't difference in the relationships between the finer (loam, clay loam, clay) and courser (sand, sandy loam, loam) soil textures.

TIME	SAND		SANDY LOAM		LOAM		CLAY LOAM		CLAY	
	relation	R^2	relation	R^2	relation	R^2	relation	R^2	relation	R^2
January	-		-		-		-		-	
February	-		0.71T + 0.37	0.64	-		-		-	
March	3.03T + 3.79	0.93	1.88T + 9.88	0.81	2.60T + 6.12	0.84	3.21T + 2.64	0.95	2.52T + 5.39	0.98
April	2.28T + 26.08	0.93	2.03T + 28.68	0.9	2.36T + 25.01	0.86	2.91T + 19.41	0.97	2.77T + 20.38	0.88
May	3.00T + 45.44	0.68	-0.37P + 116.89	0.94	3.77T + 33.59	0.85	3.52T + 38.36	0.99	3.17T + 44.17	0.63
June	1.88Θ + 31.27	0.92	2.75T + 62.03	0.74	3.69T + 46.24	0.89	3.86T + 43.47	0.99	2.22T + 74.35	0.58
July	-		2.13P - 54.85	0.97	0.61Θ - 14.70	0.72	0.25Θ + 39.66	0.55	1.62Θ - 407.65	0.97
August	-		1.33P - 16.70	0.98	1.33P - 17.59	0.94	0.41Θ - 18.28	0.85	-	
September	-		0.94P + 2.66	1	0.94P + 2.76	0.99	1.06P - 2.09	0.92	-	
October	2.35T + 15.76	0.93	2.37T + 15.65	0.79	2.17T + 17.84	0.82	1.69T + 22.42	0.96	2.91T + 9.44	0.96
November	2.28T + 2.13	0.94	1.80T + 4.32	0.77	2.04T + 3.35	0.85	2.01T + 3.03	0.94	2.30T + 1.48	0.99
December	1.02T + 0.45	0.79	1.50T + 0.18	0.94	1.40T + 0.32	0.88	-		0.83T + 0.13	0.96
Growing Season	0.63P + 144.03	0.94	0.59P + 217.52	0.93	0.58P + 246.21	0.9	-		1.00P + 76.37	0.99
YEAR	0.52P + 144.44	0.93	0.47P + 223.79	0.9	0.50P + 235.17	0.88	-		0.98P - 10.29	0.98

Table 1.:AET versus Θ, T, P as represented by linear regressions for different soil textures and time periods.

TIME	SAND		SANDY LOAM		LOAM		CLAY LOAM		CLAY	
	relation	R^2	relation	R^2	relation	R^2	relation	R^2	relation	R^2
January	-		2.30P + 170.00	0.68	4.34P + 141.37	0.66	5.35P + 166.83	0.79	-10.91T + 366.87	0.61
February	-		-		-		2.19P + 299.45	0.53	-	
March	-		-		-		-		-	
April	0.19P + 69.07	0.75	0.16P + 263.86	0.64	0.14P + 323.47	0.52	0.28P + 370.71	0.51	-	
May	1.00P - 2.91	0.86	1.10P + 181.67	0.88	0.97P + 251.20	0.77	1.21P + 287.25	0.92	-	
June	0.49AET - 13.78	0.92	3.02P + 8.78	0.84	1.48P + 161.68	0.46	-16.25T + 612.03	0.81	0.91P + 327.31	0.76
July	-		1.09AET + 56.61	0.85	2.18P + 53.27	0.74	-27.91T + 812.96	0.9	0.60AET + 253.15	0.97
August	-		0.97AET + 62.91	0.87	1.39AET + 64.33	0.76	-22.71T + 647.38	0.87	-	
September	-		0.89P + 72.72	0.72	1.69P + 56.83	0.6	-20.21T + 511.17	0.81	-	
October	0.41P + 1.99	0.7	1.88P + 24.43	0.82	-		-21.99T + 417.89	0.76	-	
November	1.49P - 22.87	0.75	3.69P - 43.34	0.91	3.02P + 22.08	0.46	5.07P - 36.03	0.82	-	
December	-		3.86P + 43.97	0.96	5.57P + 6.89	0.68	6.09P + 40.22	0.79	-	
Growing Season	0.06P + 12.38	0.89	0.19P + 91.09	0.95	0.23P + 110.60	0.85	0.39P + 91.95	0.9	0.11P + 312.49	0.88
YEAR	0.04P + 29.77	0.86	0.15P + 110.91	0.96	0.21P + 114.77	0.89	0.32P + 102.60	0.91	0.14AET + 298.93	0.88

Table 2.: Θ versus AET,T,P as represented by linear regressions for different soil textures and time periods.

4.3 Areal distribution

4.3.1 *Annual characteristics*

The annual actual evapotranspiration (Fig.3a) is between 410-630 mm year^{-1}. AET is the largest in the western parts of country, in the mountain regions and on the hills. The effect of relief upon AET is obvious. Nevertheless, AET is determined not only by the relief but also by soil texture. This is especially valid for sandy soils. In sandy regions of Somogy, Kiskunság and Nyírség, AET is the smallest, it amounts about 420 mm year^{-1}. The average Θ is between 50-380 mmH_2O (Fig.3b). It changes in wide ranges because soil water holding capacity is different from area to area. The areal distribution of AET and Θ is very similar. The effect of sandy areas upon Θ is obvious like for AET. AET in western and southwest Hungary is larger because of the precipitation and temperature distribution (see Figs. 1 and 2), respectively.

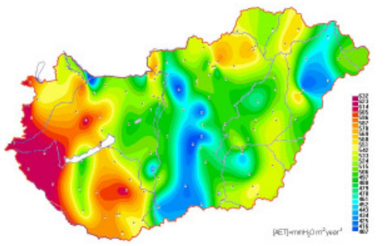

Fig.3a: Areal distribution of the annual actual evapotranspiration in Hungary.

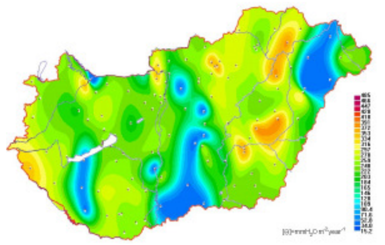

Fig.3b: Areal distribution of annual soil water content in Hungary.

4.3.2 *Monthly characteristics*

Monthly AET depends upon P, T and Θ. The areal distribution of AET in July (Fig.4a) is similar to the areal distribution of annual AET (Fig. 3a) and to the areal distribution of Θ in July (Fig. 5a). Monthly AET ranges between 50-130 mmH_2O m^{-2}, while monthly Θ between 15-370 mmH_2Om^{-2}. AET in July depends upon Θ, and P (see Table 1), but Θ has the strongest influence. As for AET, distribution of Θ in July (Fig. 5a) is very similar to the annual distribution of Θ (Fig. 3b).

The areal distribution characteristics in September (the driest month in autumn) are also interesting. The AET and Θ fields for September are presented in Fig. 3b and Fig. 4b, respectively. AET ranges between 40-75 mmH_2O m^{-2}, while Θ between 15-300 mmH_2Om^{-2}. The AET field is quite similar to the annual field of P (Fig. 1). AET is the smallest in Nagykunság and Jászság. On the contrary Θ depends upon T and does not have any effect upon AET. Nevertheless, this effect of T upon Θ cannot be viewed unequivocally because of the effect of soil texture.

Areal distributions in October are similar to that ones in September though it is much cooler (air temperature is 6 °C lower). AET ranges between 30-45 mmH_2O m^{-2} (Fig. 3c), while Θ between 20-315 mmH_2Om^{-2} (Fig. 4c). AET is mainly determined by T, though T is low (10°C). Since T is important predictor the areal distribution of AET is similar to the annual distribution of T (Fig. 2).The effect of T upon Θ is similar to that one in September.

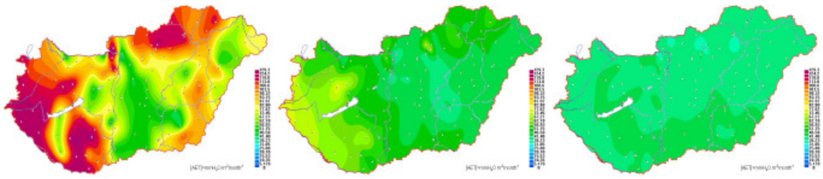

Fig.4: Areal distribution of AET in a) July; b) September; c) October.

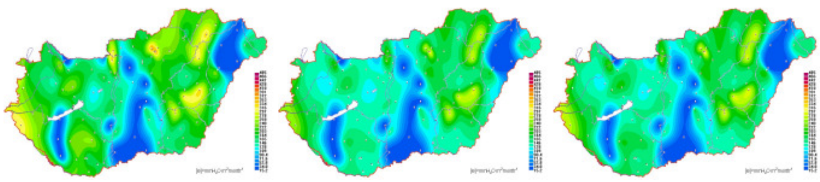

Fig.5: Areal distribution of Θ in a) July; b) September; c) October.

5. Conclusions

Thornthwaite's (1948) bucket model is applied for estimating annual and monthly fields of AET and Θ in Hungary. The fields are estimated taking into account the areal distribution of soil texture. The analysis refers to the period 1901-1950. The main findings are as follows:

- Annual AET ranges between 410-630 mm year^{-1}. Annual average of Θ ranges between 50-380 mmH_2O. Annual AET is the largest in the western parts of country and in the mountain regions.
- AET and Θ are determined not only by the relief but also by soil texture. This is especially valid for sandy soils. In sandy regions (Somogy, Kiskunság and Nyírség) AET amounts only about 420 mm year^{-1}.
- AET is mostly determined by T (red colour in Table 1) and P (blue colour in Table 1). For estimating AET, Θ does not seem to be as important as T and P.
- Θ is determined not only by P but also by T and AET (green colour in Table2).

The results obtained can be useful for estimating AET and Θ when only P and T measurements are available.

6. References

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