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Hydrological Impacts of Various Land Cover Types in the Context of Climate Change for Zala County

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Abstract – The water balance of Zala County was analyzed using remote-sensing based actual evapotranspiration (ET_A) and runoff (R) in the context of land cover types. The highest mean ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forests have higher values than agricultural areas, and the lowest rates belong to artificial surfaces. Mean annual runoff is the largest on artificial surfaces (89 mm/year). For climate change impact analysis a Budyko-model was used in spatially distributed mode. The parameter of the Budyko model (α) was calculated for pixels without surplus water. For the extra water affected pixels a linear model with β parameter (actual evapotranspiration / pan evapotranspiration) was used. These parameters (α and β) can be used for evaluating future ET_A and R in spatially distributed mode. According to the predictions, the mean annual evapotranspiration may increase about 27 mm while the runoff may decrease to one third of the present amount by end of the century.

evapotranspiration / runoff / land cover / Budyko-model / climate change

Kivonat – Különböző felszínborítások vízforgalomra gyakorolt hatása a klímaváltozással összefüggésben Zala megye példáján. Zala megye területi vízmérlegének elemzése távérzékelési adatokon alapuló aktuális evapotranszspiráció (ET_A) és lefolyás (R) alapján, a felszínborítás függvényében történt. A legmagasabb átlagos párolgásértékek a vizek (658 mm/év) és a vizenyős területek (622 mm/év) esetében jelentkeztek. Az erdők magasabb párolgással jellemezhetők, mint a mezőgazdasági területek, a legalacsonyabb értékek a mesterséges felszínekhez tartoznak. Az éves átlagos lefolyás a legnagyobb a mesterséges felszíneken (89 mm/év). A klímaváltozás hatásának vizsgálata egy térben osztott Budyko féle modell használatával történt. A Budyko modell kalibrációs paramétere (α) a többletvízhatástól független pixelekre került kiszámításra. A többletvízhatású pixelek esetében egy lineáris β paraméterű modellt (aktuális párolgás / kádpárolgás) vezettünk be. A két paraméter (α és β) segítségével becsülhető a jövőbeli ET_A és R, térben osztott módon. Az előrejelzés alapján az éves átlagos aktuális párolgás 27 mm-el növekedhet, míg a lefolyás a harmadára csökkenhet a század végére.

evapotranszspiráció / lefolyás / felszínborítás / Budyko-modell / klímaváltozás

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1 INTRODUCTION

More precipitation evaporates than runs off and stored on the land surface (Hewlett 1982). Generally, in Hungary about 90% of precipitation evaporates and only 10% goes to streams, soil and groundwater storage. Due to the high latent heat of vaporization value of water evapotranspiration (ET) is a very effective indicator for mass and energy () transfer between the land- or vegetation surface and the ambient atmosphere (Szilágyi – Józsa 2009).

Obtaining spatially distributed ET estimates is crucial in most water balance calculations for identifying mass and energy fluxes across the area of interest (Szilágyi – Kovács 2011). Monthly actual evapotranspiration (ET_A) has been mapped for Hungary by Kovács (2011) over the 2000-2008 period. On an annual scale − using ET_A and precipitation data − the spatially distributed runoff can be calculated using the long-term water-balance equation:

$$R = P - ET_A \tag{1}$$

where P is the precipitation, ET_A is the evapotranspiration and R is the runoff (each members in mm/period). The spatially distributed ET_A and R maps are suitable to analyze the data in the context of land cover types (CLC 2006).

2 MATERIAL AND METHODS

2.1 Description of the ET mapping technique

Morton et al. (1985) presented an algorithm (called the WREVAP model) − based on Bouchet's (1963) complementary relationship − for estimating regionally representative ET_A rates for periods longer than 5 days. Szilágyi – Józsa (2009), Szilágyi et al. (2011) devised a method of disaggregating the regional ET_A values into spatially variable ET_A rates. It is based on the assumption that at a large enough scale (for example 1 km) where surface heterogeneities of a terrain become largely smoothened out, surface temperatures are proportional to the ET_A rates, since evaporation is an endothermic process, providing an effective cooling (due to the high latent heat of vaporization) of the evaporating surface.

The spatial disaggregation of the regionally representative ET_A rates is based on a linear transformation of the 8-day composite MODIS (Moderate Resolution Imaging Spectroradiometer) daytime surface temperature (T_s) values into ET_A rates (Szilágyi – Józsa 2009). The transformation requires specifying two anchor points in the T_s – ET plane (*Figure 1*). The first is defined by the spatially averaged daytime surface temperature (T_s) and the corresponding regionally representative ET_A rate (from WREVAP, using spatially averaged values of the required climate variables). The second anchor point comes from a spatial average of the coldest pixel values for well watered cells within the region (T_{WS} – wet surface temperature) and the corresponding wet environment evaporation rate (ET_W), out of consideration that the coldest pixels are the wettest (Szilágyi – Kovács 2010). The two points define the linear transformation of the T_S pixel values into ET_A rates for the examined period (for example a month).

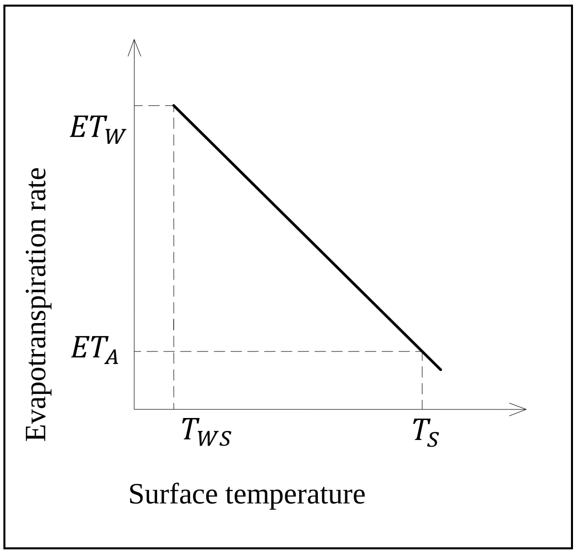

Figure 1. Schematic representation of the linear transformation of the MODIS daytime surface temperature values into ET rates (after Szilágyi et al. 2011)

The 8-day composited MODIS daytime T_s data for Hungary over the 2000–2008 period was collected and the T_s maps were averaged for each month to yield one surface temperature map per month by Kovács (2011). Further necessary data for calculation (mean annual precipitation, mean monthly air temperature, specific humidity as well as sunshine duration values) were provided by the Hungarian Meteorological Service. The monthly ET_A maps were prepared from March till November each year, because in the winter-time with possible patchy snow cover on the ground the quasi-constant surface net energy assumption of the T_s versus ET_A transformations break down (due to the snow cover's vastly different albedo from that of the land) (Szilágyi – Józsa 2009). ET in Hungary is small from December through February, the sum total is about 20 mm (Kovács 2011). We made calculations for total water years (from November 1 to October 31), so a 20 mm correction was added for all pixels of each mean annual ET maps (1999 November was prepared as the average of the other Novembers). The mean annual ET maps were averaged for the period of 1999-2008.

2.2 The Budyko type model

The Budyko curve (Budyko 1974) is often used to estimate the actual evaporation as a function of the aridity index. In any location, depending on the dryness of the climate, either the available water or the available energy is the limiting factor (Gerrits et al. 2009).
The Budyko curve is based on two balance equations, the water balance and the energy balance:

$$\Delta S = P - ET_A - R \tag{2}$$

$$Q_{nT} = L \cdot ET_A + H + G \tag{3}$$

where ΔS is the water storage change over time (m/year), P the precipitation (m/year), ET_A the actual evaporation (m/year), R the runoff (m/year), Q_{nT} the net radiation (J/m^2/year), L the latent heat of vaporization (J/m^3), H the sensible heat flux (J/m^2/year), and G the ground heat flux (J/m^2/year).

On an annual time scale we can assume (Arora 2002) that the water storage change is negligible (ΔS = 0) and that the net ground heat flux approaches zero (G = 0), thus:

$$P = ET_A + R \tag{4}$$

$$Q_{nT} = L \cdot ET_A + H \tag{5}$$

By dividing *Eq. 5* by *Eq. 4* we obtain:

$$\frac{Q_{nT}}{P} = \frac{L \cdot ET_A}{P} + \frac{H}{P} \tag{6}$$

Arora (2002) interprets potential evaporation as (different from the above ET_P):

$$ET_0 = \frac{Q_{nT}}{L} \tag{7}$$

Displacement of *Eq. 6* by *Eq. 7*:

$$\frac{ET_0}{P} = \frac{ET_A}{P} + \frac{(H/L)}{P} \tag{8}$$

If we define the Bowen ratio as $B_r = H/L \cdot ET_A$ (Gerrits et al. 2009), we obtain:

$$\frac{ET_0}{P} = \frac{ET_A}{P} + \frac{B_r \cdot ET_A}{P} = \phi = \frac{ET_A}{P}(1 + B_r) \tag{9}$$

with ϕ the aridity index.

Since the Bowen ratio can also be expressed as a function of the aridity index ($B_r = f(\phi)$) (Arora 2002), *Eq. 9* can be rewritten as:

$$\frac{ET_A}{P} = \frac{\phi}{1+f(\phi)} = f(\phi) \tag{10}$$

So, the evapotranspiration ratio $\left(\frac{ET_A}{P}\right)$ is a function of aridity index.

A lot of studies have been done on finding this relation. The best-kown classical studies were done by Schreiber, Ol'dekop, Turc, Pike, Budyko and Porporato et al. (Gerrits et al. 2009). Their equations are summarized in *Table 1*.

Table 1. Equations for the relation of the evapotranspiration ratio $\left(\frac{ET_A}{P}\right)$ and the aridity index (ϕ) (after Gerrits et al. 2009)

Equation	Reference
$\frac{ET_A}{P} = 1 - \exp(-\phi)$	Schreiber (1904)
$\frac{ET_A}{P} = \phi \tanh(1/\phi)$	Ol'dekop (1911)
$\frac{ET_A}{P} = \frac{1}{\sqrt{0.9+(1/\phi)^2}}$	Turc (1954)
$\frac{ET_A}{P} = \frac{1}{\sqrt{1+(1/\phi)^2}}$	Pike (1964)
$\frac{ET_A}{P} = [\,\phi \tanh(1/\phi)(1 - \exp(-\phi))]^{0.5}$	Budyko (1974)
$\frac{ET_A}{P} = 1 - \frac{\phi \cdot \gamma^{\frac{\gamma}{\phi}-1} \exp(-\gamma)}{\Gamma\left(\frac{\gamma}{\phi}\right) - \Gamma\left(\frac{\gamma}{\phi}, \gamma\right)}$	Porporato et al. (2004)

From the above models we are using the Schreiber equation (Schreiber 1904), because of its simplicity. The actual evapotraspiration estimated by Schreiber's method (hereinafter the evapotranspiration, the precipitation and the runoff are understood in mm/year instead of m/year):

$$ET_A = P(1 - \exp(-\phi)) = P\left(1 - \exp\left(-\frac{ET_0}{P}\right)\right) \tag{11}$$

The determination of runoff by Schreiber (Fraedrich 2009):

$$R = P - ET_A = P \exp\left(-\frac{ET_0}{P}\right) \quad (12)$$

After rearrangement we get the following equation for potential evapotranspiration:

$$ET_0 = -P\left(\ln\left(\frac{R}{P}\right)\right) \quad (13)$$

ET_0 can also be expressed as a function of pan-evaporation (ET_{pan}), according to the general relation for Hungary (Nováky 2002):

$$ET_0 = f(ET_{pan}) = -\alpha ET_{pan} = -\alpha\left(36400\frac{T}{P} + 104\right) \quad (14)$$

where α is a calibration parameter, which aggregates all of the factors affecting ET (dominantly the surface cover) (Keve – Nováky 2010), and T is the mean annual temperature (°C).

Knowing the above equations, α can be calculated:

$$\alpha = -\frac{ET_0}{ET_{pan}} \quad (15)$$

According to Nováky, the spatially distributed version of the Budyko model is applicable to analyze the climatic impacts (Nováky 1985, 2002). The spatially-distributed determination of α parameter was the following: ET_0 (*Eq. 13*) and ET_{pan} (the part in parentheses of *Eq. 14*) values of Zala county were calculated for the 1999-2008 period (in the same resolution as the ET_A maps), and they were substituted for *Eq. 15*.

When the ET_A value was higher than the P value of the pixel, so R became negative, the α parameter could not be determined, because the natural logarithm of a negative number is undefined (*Eq. 13*). For these pixels another calibration parameter (β) was calculated according to the next formula (McMahon et al. 2012):

$$\beta = \frac{ET_A}{ET_{pan}} \quad (16)$$

α and β parameters must be calculated in spatially distributed mode (maps). The parameter maps (α and β) are suitable to analyze this data in the context of land cover types. They can be used for evaluating future ET and R in spatially-distributed mode, for that only temperature and precipitation predictions are required.

The calculations were done with the help of DigiTerra Map software, the temperature and precipitation data were available in the "Agroclimate 2 (VKSZ_12-1-2013-00-34)" project.

3 STUDY SITE DESCRIPTION

Zala County is situated in the south-western part of Hungary (*Figure 2*). It is one of the smallest counties of Hungary. It covers 3784 km^2. The population was 282 179 people in 2011 (less than the 3% of the total population of Hungary). The mean population density is 75 people per km^2 (KSH 2011).

The county has a varying landscape of hills and valleys. The settlement density is one of the highest in Hungary, although the average size of the settlements is less than the half of the national average. It has no distinctive isolation from adjacent territories. It is a transition through a series of grades. The highest point of the county is 445 m (Köves-tető) in the Keszthelyi Mountains on the eastern edge of the county.

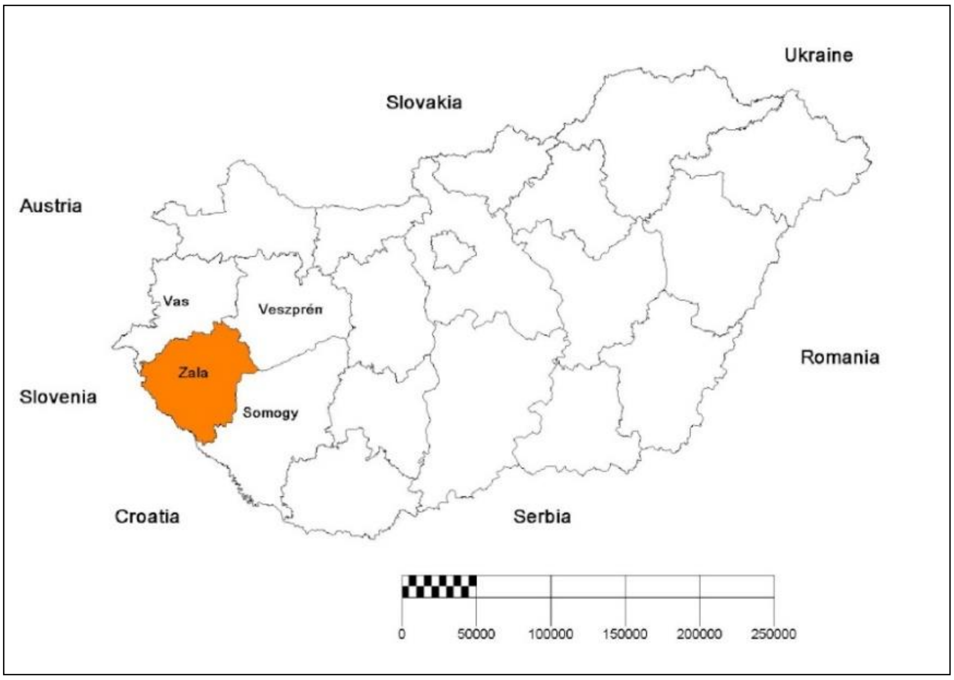

Figure 2. Location of Zala County within Hungary

The climate is moderated by atlantic effects, so the mean annual temperature was about 11.6 °C between 1999 and 2008. Winters are relatively mild and summers tend to be cooler than the norm for the Carpathian Basin. It is one of the wettest parts of the country. The average annual rainfall during this period was about 700 mm in the west, and 600 mm in the east.

Agriculture is the dominant land use (54%) in the County, with a significant presence of forest and semi natural areas, which cover more than 37% of the total area (*Figure 3 and Table 2*).

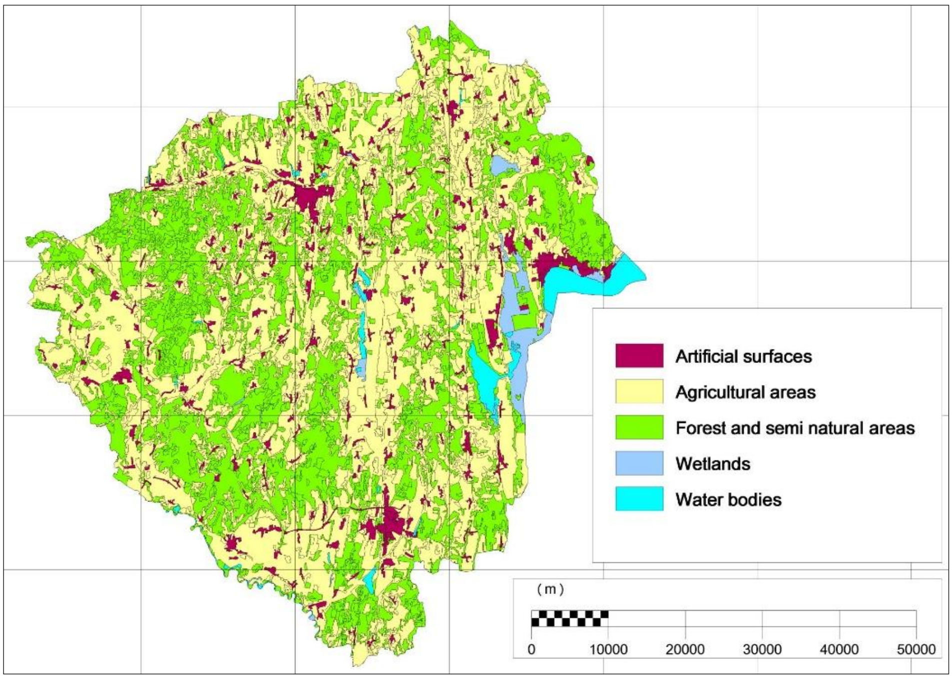

Figure 3. Land cover of Zala County (CLC 2006)

Table 2. Land cover distribution of Zala County

Land cover type	Area (km^2)	Percentage (%)
Artificial surfaces	195.90	5.18
Agricultural areas	2040.71	53.94
Forest and semi natural areas	1406.01	37.16
Wetlands	62.97	1.66
Water bodies	77.94	2.06
Total	3783.54	100.00

4 RESULTS

The averaged (1999-2008 period) mean actual evapotranspiration and runoff for Zala County were analyzed in the context of land cover types. Moreover, the Budyko type α and the β parameters were calculated, mapped and analyzed too.

4.1 Evaluation of evapotranspiration

The mean annual actual evapotranspiration over Zala County (1999-2008) is displayed in *Figure 4*. The average ET_A of the County was 577 mm/year, which is 88% of the mean annual precipitation (655.7 mm/year). The brown pixels show lower rates on the map. The bigger cities are distinctly visible as brown patches. Higher ET_A values (blue pixels) belong to water bodies and wetlands,.

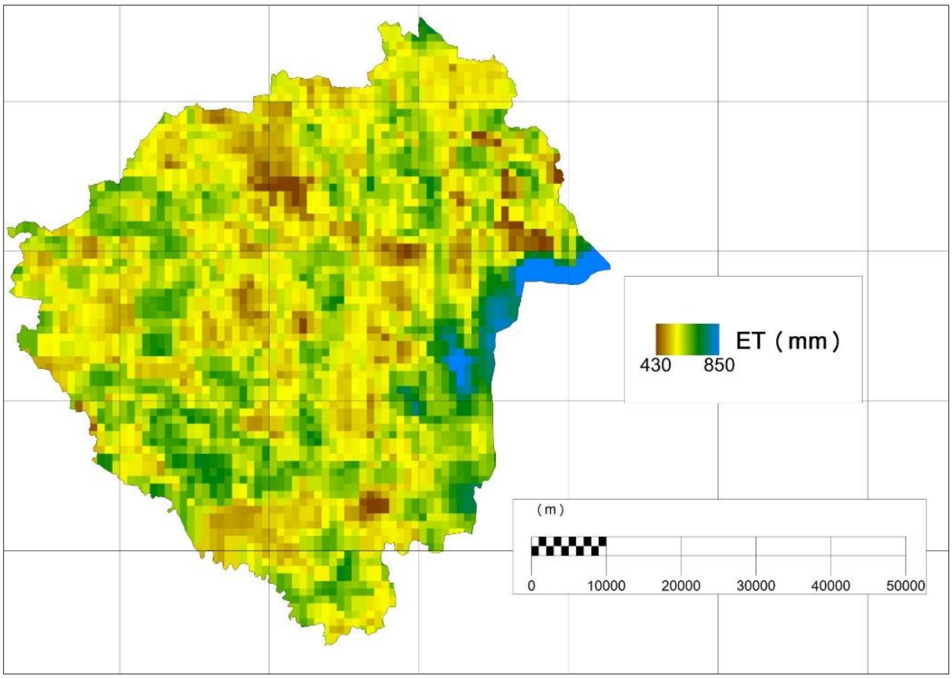

Figure 4. Mean annual ET_A rates over Zala County (1999-2008)

Table 3 contains the ET_A values belonging to the each Corine Land Cover (CLC 2006) type. The evapotranspiration, the runoff, the Budyko α and the β parameter maps have a 1·1 km resolution. They were examined with a vector land cover map, so more land cover types might belong to one pixel. The value of these 'mixed pixels' were counted in more land cover types, so it distorts the differences between the categories.

The highest mean annual ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forest and semi natural areas have higher values than agricultural areas and the lowest rates belong to artificial surfaces. Standard deviation is the highest in case of water bodies (97 mm).

Table 3. Mean annual ET_A rates of different land cover types over Zala County (1999-2008)

Land cover type	Mean annual ET (mm)				
	Min	Max	Average	P%*	Std. dev
Artificial surfaces	450	703	562	86	38
Agricultural areas	434	721	569	87	35
Forest and semi natural areas	434	828	582	89	37
Wetlands	461	729	622	95	53
Water bodies	486	846	658	100	97

* In the percentage of the mean annual precipitation

Figure 5 shows the mean annual ET_A over forest and semi natural areas. In the north-eastern part of Zala County the ET_A values of forest are generally lower than the south-western part and the neighborhood of wetlands.

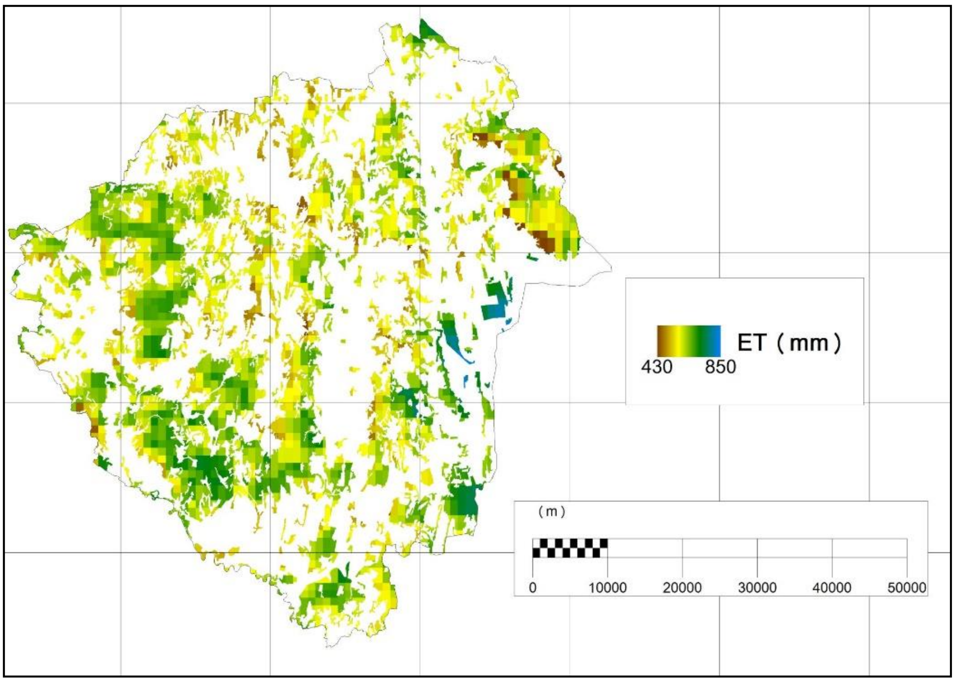

Figure 5. Mean annual ET_A rates over forest and semi natural areas in Zala County (1999-2008)

4.2 Evaluation of runoff

The mean annual runoff (R, 1999–2008) was calculated from the water-balance equation, as the difference of annual precipitation and mean annual actual evapotranspiration ($R = P - ET_A$). The 10×10 km spatial resolution precipitation map was downscaled for 1×1 km using the bicubic convolution interpolation technique, and after it was validated by field measurements. (The data from field measurements were not used for preparation of the original map.)

Figure 6 shows the mean annual runoff over Zala County and *Table 4* contains the rates of the different types of land cover. The average runoff was 78 mm/year, which is 12% of the mean annual precipitation (655.7 mm/year). The runoff is the highest on artificial surfaces, and it decreases in the other categories. It is especially low for wetlands, and negative for water bodies, where the ET_A is generally higher than the precipitation. Moreover, the standard deviation is the highest over water bodies (119 mm).

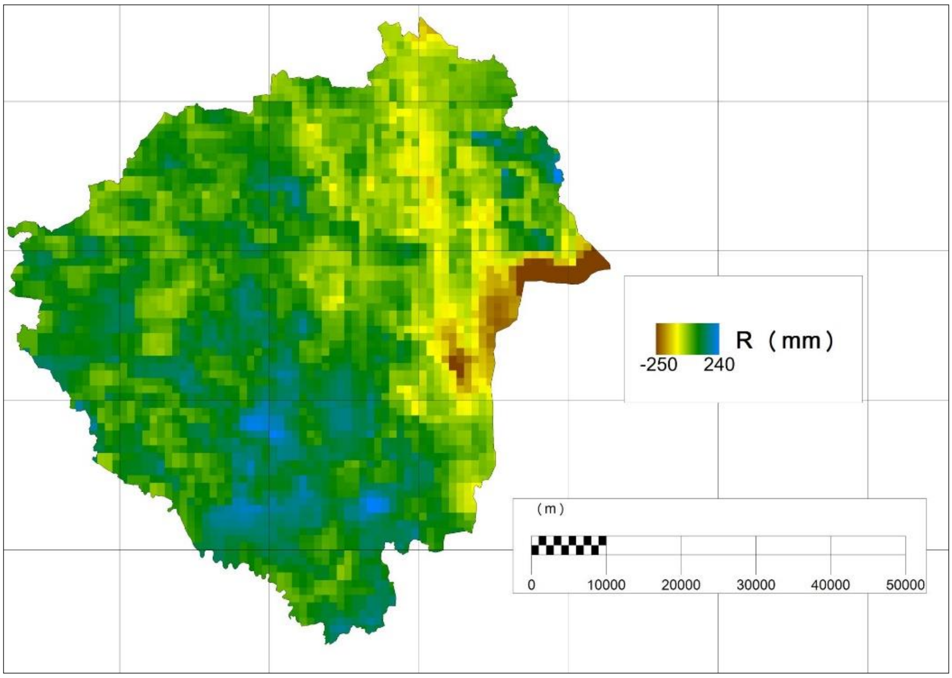

Figure 6. Mean annual R rates over Zala County (1999-2008)

Table 4.Mean annual runoff rates of different land cover types over Zala County (1999-2008)

Land cover type	Mean annual R (mm)				
	Min	Max	Average	P%*	Std. dev
Artificial surfaces	–86	231	89	14	48
Agricultural areas	–88	231	87	13	45
Forest and semi natural areas	–181	214	77	12	46
Wetlands	–98	140	2	0	58
Water bodies	–250	211	–19	–3	119

* In the percentage of the mean annual precipitation

4.3 Evaluation of α and β parameters

The calculated Budyko type α parameter can be seen in *Figure 7*, and the values belonging to the each land cover type are in *Table 5*.

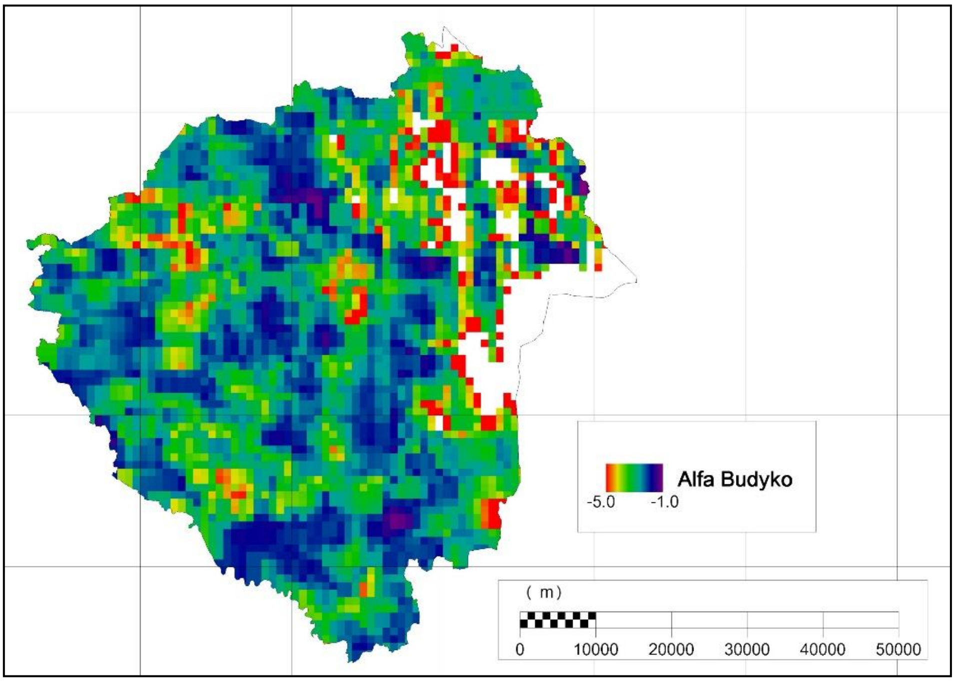

Figure 7. The calculated Budyko type α parameter rates in Zala County

Table 5. The calculated Budyko type α parameters (absolute values) of different land cover types over Zala County

Land cover type	α parameter			
	Min	Max	Average	Std. dev.
Artificial surfaces	1.03	4.59	1.80	0.42
Agricultural areas	0.96	7.48	1.86	0.46
Forest and semi natural areas	0.96	7.48	1.98	0.51
Wetlands	1.08	5.88	2.42	1.05
Water bodies	1.15	6.30	2.16	0.87

Compared to the α values determined by Keve – Nováky (2010), the comparable categories according to land cover types show similar tendencies (*Table 6*), but the differences between the categories are smaller. High absolute α values are calculated for forest, lower for agricultural areas and much lower for artificial surfaces. The α parameters are not comparable for wetlands and water bodies. The deviation from the values estimated by Keve and Nováky arises from two sources. The first reason is the different climatic conditions because they modelled a plain catchment basin, second is that the values of their parameters were not based on calculations but on estimations considering the land cover.

Table 6. α values determined by Keve – Nováky (2010)

Description	α
Artificial surface, with channel	2.3
More channels in the area	2.4
Big channel in the area	2.5
Agricultural area, with channel	2.7
Agricultural area, without channel	2.8
Area far from channel, forest	2.9

We calculated the β parameter (which gives the relationship between ET_{pan} and ET_A) for those pixels, where ET_A value was higher than P value, because the Budyko type model for this type of pixels is not valid. Typically this is the case for wetlands and water bodies. The β parameter map is displayed in *Figure 8*, and the rates of the different land cover types can be seen in *Table 7*. From agricultural areas to water bodies, β shows increasing values. (For artificial surfaces it is inadequate, because the pixel number of the category was very small.) The highest maximum values were detected over water bodies (1.08) as well as forest and semi natural areas (1.07), exceeding the calculated pan-evaporation (U-pan) rates by 7–8%.

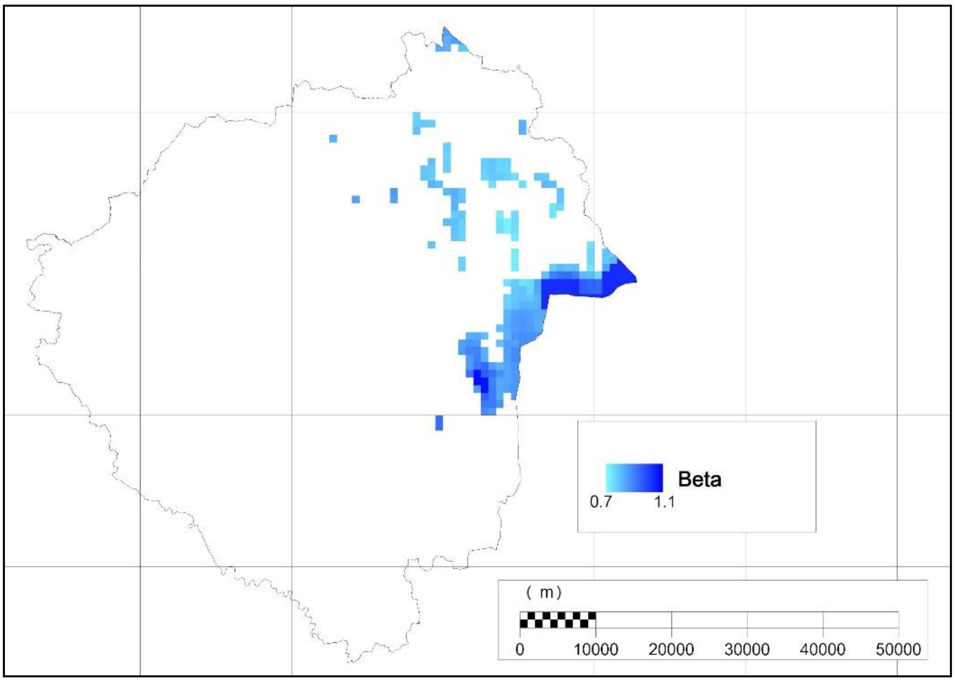

Figure 8. β parameter pixels and rates in Zala County

Table 7. The calculated β parameter rates of different land cover types over Zala County

Land cover type	β parameter			
	Min	Max	Average	Std. dev.
Artificial surfaces	0.71	0.91	0.80	0.05
Agricultural areas	0.71	0.93	0.79	0.05
Forest and semi natural areas	0.71	1.08	0.80	0.06
Wetlands	0.72	0.98	0.82	0.05
Water bodies	0.76	1.08	0.92	0.10

5 EVAPOTRANSPIRATION AND RUNOFF PREDICTIONS

Temperature and precipitation data were required for estimating future ET_A and runoff of Zala County, besides the prepared Budyko-α and β parameter maps. They were obtained for three periods (2011–2040, 2041–2070, 2071–2100) by averaging of 12 Regional Climate Models data (RCM, *Table 8*, Csóka 2013). The original grid size of the RCM maps was 25×25 km. They were disaggregated to 1×1 km spatial resolution by the bicubic convolution interpolation technique.

Table 8. Main parameters of the Regional Climate Models (Csóka 2013)

Nr.	Institute	Model	Scenario	Resolution
1.	C4I	RCA3	A1B	25 km
2.	MPI-M	REMO	A1B	25 km
3.	ETHZ	CLM	A1B	25 km
4.	KNMI	RACMO2	A1B	25 km
5.	DMI	HIRHAM5	A1B	25 km
6.	DMI	HIRHAM5	A1B	25 km
7.	SMHI	RCA	A1B	25 km
8.	SMHI	RCA	A1B	25 km
9.	SMHI	RCA	A1B	25 km
10.	HC	HadRM3Q0	A1B	25 km
11.	HC	HadRM3Q3	A1B	25 km
12.	HC	HadRM3Q16	A1B	25 km

The *11, 14, 15* and *16 Equations* were used for calculating spatially distributed future ET_A. The runoff data were obtained as the difference of precipitation and ET_A. These calculations were done for Zala County, not on a catchment scale.

Figure 9 shows the estimated mean annual ET_A values belong to the period 1999–2008 and the three predicted periods (2011–2040, 2041–2070, 2071–2100) in the context of climatic index (100·T/P, Nováky 1985). According to the predictions a mean annual temperature increase of about 3 degrees (from 11.6 °C to 14.6 °C) and a 25 mm decrease in precipitation can be expected by the end of the century. The mean annual evapotranspiration may increase by about 27 mm, from 577 mm to 604 mm (from 88 to 96 percent of the precipitation).

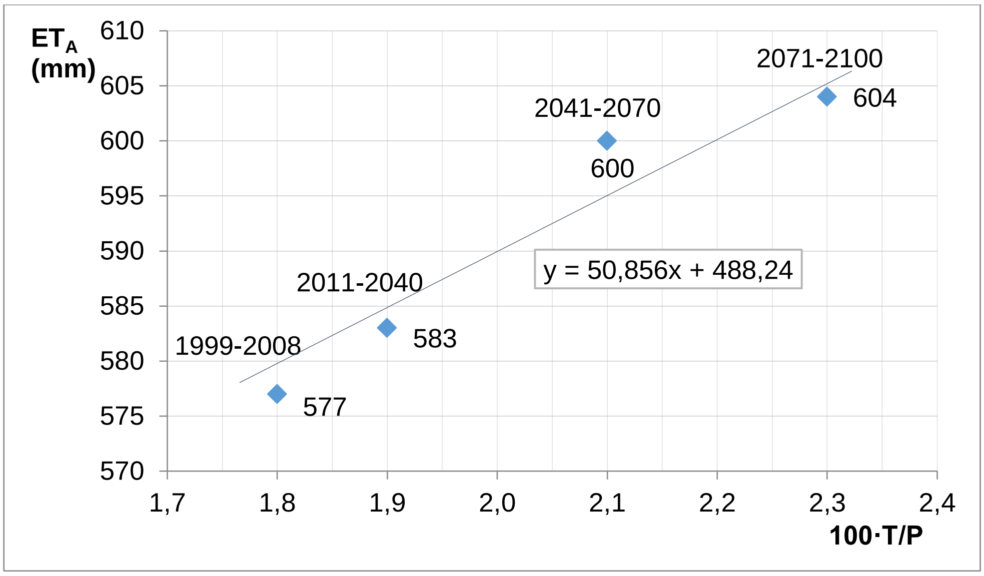

Figure 9. The trend of the mean annual evapotranspiration in the context of the climatic index (100·T/P)

Table 9 contains the estimated mean annual ET_A values belonging to each land cover type. The largest increase (90–100 mm) can be expected in wetlands and water bodies. The

ET_A increments are similar for artificial surfaces, agricultural areas, forest and semi-natural areas.

Table 9. The annual actual evapotranspiration of different land cover types, and annual precipitation, mean annual temperature and climatic index for the 1999–2008 period and for three future periods

Period	Mean annual ET_A (mm)					P (mm)	T (°C)	100·T/P
	AS*	ACA	FSN	WL	WB			
1999–2008	562	569	582	622	658	655.7	11.6	1.8
2011–2040	567	574	586	646	684	642.6	12.3	1.9
2041–2070	583	590	602	677	718	648.7	13.5	2.1
2071–2100	585	592	604	714	759	630.4	14.6	2.3
Slope#	45.730	43.524	44.213	167.610	182.730	–	–	–

* AS: artificial surfaces, ACA: agricultural areas, FSN: forest and semi natural areas, WL: wetlands, WB: water bodies.
#Slope of the trend line.

Figure 10 shows the mean annual runoff values belonging to the 1999-2008 period and the three predicted periods in the context of climatic index. The mean annual runoff may significantly decrease (from 78 mm/year to 27 mm/year, from 12 to 4 percent of the precipitation) by the end of the 21st century.

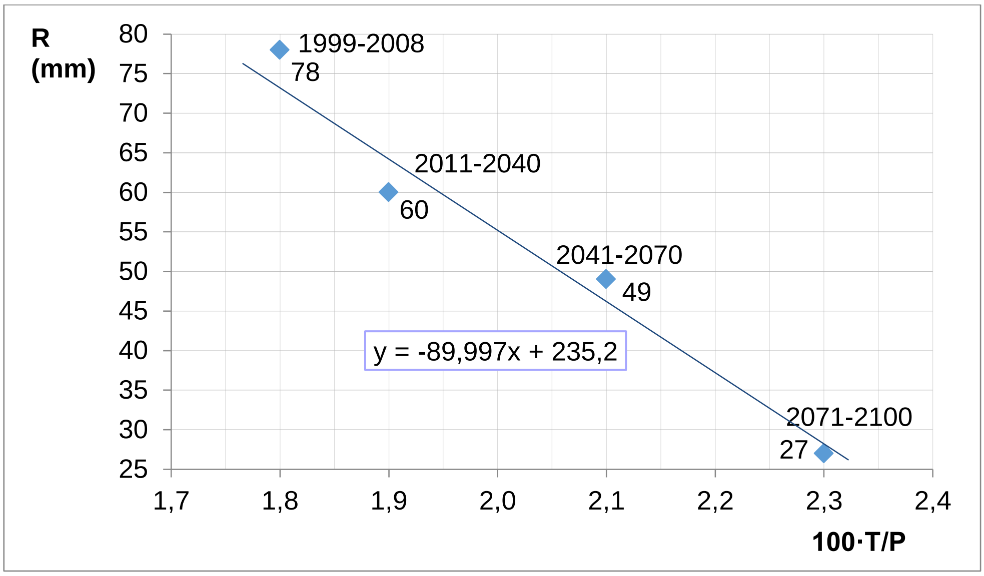

Figure 10. The trend of the mean annual runoff in the context of the climatic index (100·T/P)

The estimated mean annual runoff values belonging to the each land cover type are shown in *Table 10.* Obviously the increasing evapotranspiration prevails in case of the wetlands and water bodies: –144 mm and –115 mm negative water balance can be detected for future. If we compare artificial surfaces, agricultural areas as well as forest and semi natural areas, for the latter the lowest annual runoff is calculated.

Table 10. The annual runoff of different land cover types, and annual precipitation, mean annual temperature and climatic index for the period of 1999–2008 and for three future periods

Period	Mean annual R (mm)					P (mm)	T (°C)	100·T/ P
	AS*	ACA	FSN	WL	WB			
1999–2008	89	87	77	2	–19	655.7	11.6	1.8
2011–2040	71	69	59	–36	–58	642.6	12.3	1.9
2041–2070	61	59	50	–61	–86	648.7	13.5	2.1
2071–2100	40	39	29	–115	–144	630.4	14.6	2.3
Slope[#]	–84.625	–83.215	–83.281	–205.770	–220.090	–	–	–

* AS: artificial surfaces, ACA: agricultural areas, FSN: forest and semi natural areas, WL: wetlands, WB: water bodies.

[#] Slope of the trend line.

6 CONCLUSIONS

The spatially-distributed ET_A and runoff maps are suitable to analyze the data in the context of land cover types. The average ET_A of Zala County from 1999-2008 was 577 mm/year, or 88% of the mean annual precipitation (655.7 mm/year). The highest mean annual ET_A rates were determined for water bodies (658 mm/year) and wetlands (622 mm/year). Forest and semi natural areas have higher values than agricultural areas. The lowest rates belong to artificial surfaces. The mean annual runoff is the largest on artificial surfaces (89 mm/year), and it decreases on the other land cover types.

We used the Budyko type model (α parameter) and a linear model with β parameter for evaluating the effects of climate change on evapotranspiration. The β parameter was used for the extra water affected pixels. These calculations were not done on a watershed, but in the future the α and β parameters can be validated on a catchment scale using historical precipitation and streamflow measurements. By using the two parameter maps and future data of climate models (mean annual temperature and precipitation) evapotranspiration and runoff predictions have been made until the end of the 21st century. According to the predictions, the mean annual evapotranspiration may increase about 27 mm while the runoff may decrease to the one third of the present amount by the end of the century.

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REFERENCES

ARORA, V. K. (2002): The use of the aridity index to assess climate change effect on annual runoff. J. Hydrol., 265, 164–177.

BOUCHET, R. J. (1963): Evapotranspiration reelle, evapotranspiration potentielle, et production agricole. [Actual evapotranspiration, potential evapotranspiration, and agricultural production.] Ann. Agron., 14, 543–824. (in French)

BUDYKO, M. I. (1974): Climate and Life. Academic, Orlando, Fla.

CLC (2006): Corine Land Cover. European Environment Agency, European Topic Centre for Spatial information and Analysis, Copenhagen, Denmark. Online: http://sia.eionet.europa.eu/CLC2006

CSÓKA, G. (2013): A klímaváltozás vízgazdálkodási hatásainak vizsgálata éghajlat-lefolyási modellekkel. [Analysis of climate change effects on water management using climate-runoff models.] MSc thesis, University of West Hungary, Sopron. (in Hungarian)

FRAEDRICH, K. (2010): A Parsimonious Stochastic Water Reservoir: Schreiber's 1904 Equation. J. Hydrometeor., 11, 575–578.

GERRITS, A. M. J. – SAVENIJE, H. H. G. – VELING, E. J. M. – PFISTER, L. (2009): Analytical derivation of the Budyko curve based on rainfall characteristics and a simple evaporation model. Water Resources Research 45:4.

HEWLETT, J. D. (1982): Principles of forest hydrology. The University of Georgia Press, Athens

KEVE, G. – NOVÁKY, B. (2010): Klímaváltozás hatásának vizsgálata a Bácsbokodi-Kígyós csatorna vízgyűjtőjén Budyko modell alkalmazásával. [Effects of climate change in the catchment of Bácsbodoki-Kígyós channel by using Budyko-model.] XXVIII. National Conference of Hungarian Hydrological Society, Sopron, 7–9th July, 2010. (in Hungarian)

KOVÁCS, Á. (2011): Tó- és területi párolgás becslésének pontosítása és magyarországi alkalmazásai. [Specifying lake and areal evapotranspiration rates in Hungary.] PhD thesis, Budapest University of Technology and Economics, Budapest. (in Hungarian)

KSH (2011): Regional data – Zala County. Hungarian Central Statistical Office, Budapest, Hungary. Online: http://www.ksh.hu/nepszamlalas/tables_regional_20

MCMAHON, T. A. – PEEL, M. C. – LOWE, L. – SRIKANTHAN, R. – AND MCVICAR, T. R. (2012): Estimating actual, potential, reference crop and pan evaporation using standard meteorological data: a pragmatic synthesis. Hydrol. Earth Syst. Sci. Discuss., 9, 11829-11910, doi:10.5194/hessd-9-11829-2012

MORTON, F.I. – RICARD, F. – FOGARASI, S. (1985): Operational estimates of areal evapotranspiration and lake evaporation – Program WREVAP. National Hydrological Research Institute Paper #24, Ottawa, Ontario, Canada

NOVÁKY, B. (1985): A lefolyás éghajlati adottságai a Zagyva-Tarna vízrendszerben. [The runoff climatic facilities in the Zagyva-Tarna water system.] Vízügyi Közlemények, 1.: 78–93. (in Hungarian)

NOVÁKY, B. (2002): Mapping of mean annual actual evaporation on the example of Zagyva catchment area. Időjárás (Quarterly Journal of the Hungarian Meteorological Service), 3–4, 227–238.

SCHREIBER, P. (1904): Über die Beziehungen zwischen dem Niederschlag und der Wasserführung der Flüsse in Mitteleuropa. Z. Meteorol., 21(10), 441–452.

SZILÁGYI, J. – JÓZSA, J. (2009): Estimating spatially distributed monthly evapotranspiration rates by linear transformations of MODIS daytime land surface temperature data. Hydrol. Earth System Sci. 13(5), 629–637.

SZILÁGYI, J. – KOVÁCS, Á. (2010): Complementary-relationship-based evapotranspiration mapping (CREMAP) technique for Hungary. Periodica Polytechnica - Civil Engineering, 54(2), 95-100.

SZILÁGYI, J. – KOVÁCS, Á. (2011): A calibration-free evapotranspiration mapping technique for spatially-distributed regional-scale hydrologic modeling. J. Hydrol. Hydromech., 59, 2011, 2, 118–130.

SZILÁGYI, J. – KOVÁCS, Á. – JÓZSA, J. (2011): A calibration-free evapotranspiration mapping (CREMAP) technique. In: L. Labedzki (ed.): Evapotranspiration, InTech, Rijeka, Croatia