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Determination of Reference Evapotranspiration Using Penman-Monteith Method in Case of Missing Wind Speed Data under Subhumid Climatic Condition in Hungary

Zoltán Varga-Haszonits, Éva Szalka, Tamás Szakál

Department of Water and Environmental Sciences, Széchenyi István University of Győr, Mosonmagyaróvár, Hungary
Email: vargahz@t-online.hu

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Abstract

The reference evapotranspiration was calculated using Penman-Monteith method proposed. This method was evaluated on data measured by lysimeter in Szarvas experimental station in Hungary. The results of the two methods were in good agreement. However, this method requires an amount of data which is not available at all sites of meteorological measurement. Therefore it was necessary to investigate which elements influencing evapotranspiration are important and which elements are less important. With the help of investigation was indicated that radiation and vapor pressure deficit play important role in determination of reference evapotranspiration. Taking into account this there was two possibilities to calculate evapotranspiration. One of these is to use Penman-Monteith formula with constant wind speed as advised by Allen. Another one is to neglect wind speed data. Both methods were investigated and the method with constant wind speed was found better in a subhumid climatic condition of Hungary.

Keywords

Reference Evapotranspiration, Global Radiation, Vapor Pressure Deficit, Sub Humid Climate, Irrigation Requirements of Crops

1. Introduction

Evapotranspiration can be used in three forms, such as potential evapotranspiration, reference evapotranspiration and actual evapotranspiration. The potential evapotranspiration is the evaporation under conditions of non-limiting water supply, reference evapotranspiration is the evaporation from a hypothetical crop surface and actual evapotranspiration is evaporation under available soil moisture conditions. Potential evapotranspiration means the maximum rate of evaporation that is induced by the vaporizing power of the atmosphere from a crop's surface that is well supplied with water. However, when the rate of evapotranspiration of the crops was measured this definition proved to be contradictory, because the rate of the evapotranspiration of tall crops exceeded the rate of potential evapotranspiration (Doorenbos and Pruitt) [1]. The specific crops' surface is a hypothetical reference plant surface with specific characteristics. Evaporation from this surface exclusively depends on the local meteorological conditions of the atmosphere. As a result, the reference evapotranspiration represents a climatic parameter that expresses the evaporating power of the atmosphere (Katerji and Rana [2], Walter *et al.* [3]). The purpose of the reference surface is to find a surface that is the same under all climate conditions, and only atmospheric conditions affect the evaporation determined for the given surface. Because of the diversity of soils and crops, such a surface does not exist. Therefore it is necessary to use a hypothetical surface whose characteristics are known and do not change. Evaporation determined for this hypothetical surface expresses the evaporation power of the atmosphere. As the crop evapotranspiration is proportional to reference evapotranspiration, crop evapotranspiration can be determined with the help of a proportion factor. Therefore, knowing the reference evapotranspiration from a hypothetical surface and a crop surface, with the help of a coefficient, we can calculate the evaporation rate of other surfaces as well. According to an FAO Expert Committee, a hypothetical plant surface can be identified as: "A hypothetical reference crop has a crop height of 12 cm, a fixed surface resistant of 70 $s \cdot m^{-1}$ and an albedo of 0.23". This resembles an extensive surface of green grass of uniform height, completely shading the ground and with adequate water supply. The FAO Penman-Monteith method was selected to determine the evapotranspiration of this reference surface (ET_0), because this method can unambiguously be applied for every region and climate type by Allen *et al.* [4]. The Penman-Monteith method includes the energy needed for evaporation, the temperature affecting the intensity of evaporation, the saturation deficit, which elevates the vapour into the air and wind speed, which transports the vapour from the wet surface. This method requires a large amount of data, so it is advisable to check which factors exert the greatest influence on evaporation and take into consideration only those factors to determine evapotranspiration. In this case, the main question will be the accuracy of the calculation.

2. Materials and Methods

The effect of four most important factors used in Penman-Monteith formula were investigated using a database of 25 years of data from fourteen meteorological stations in the Hungarian network. The selected stations are listed in the first two columns of **Table 3** and their geographical locations can be seen in **Figure 1**.

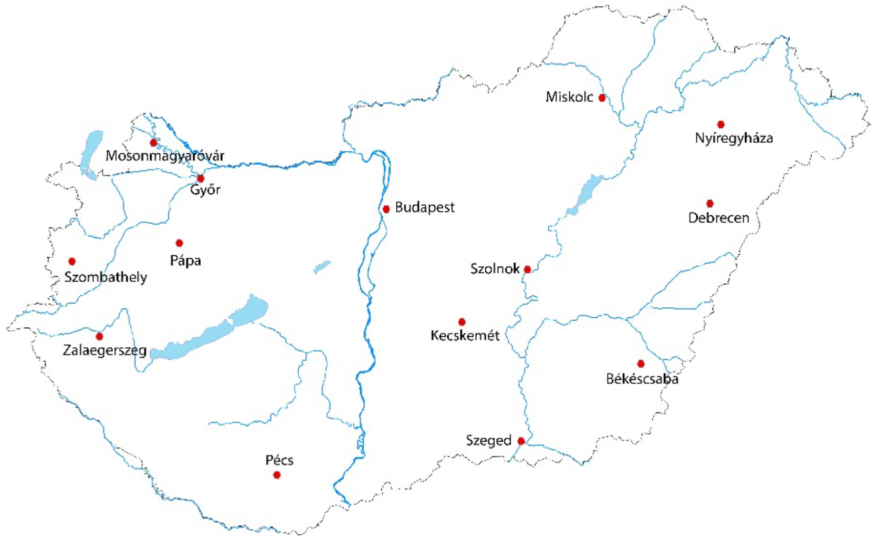

Figure 1. Selected stations.

2.1. The FAO Penman-Monteith Method

The method can be described in following way:

$$\text{PMET}_{\text{ref}} = \frac{0.408\cdot\Delta\cdot(R_n - G) + \gamma\left(\frac{900}{T_k + 273}\right)\cdot u_2\cdot(e_s - e_a)}{\Delta + \gamma\cdot(1 + 0.34\cdot u_2)}$$

where ET_{ref} is the reference evapotranspiration (mm/day), 0.408 $\text{MJ}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ converting the latent heat at 20˚C into mm/day value, Δ slope of vapour pressure curve ($\text{kPa}\cdot{}^\circ\text{C}^{-1}$), R_n net radiation at crop surface ($\text{MJ}\cdot\text{m}^{2}\cdot\text{day}^{-1}$), G soil heat flux ($\text{MJ}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$), that can be neglected if the soil is totally shaded by grass surface, γ psychometric constant ($\text{kPa}\cdot{}^\circ\text{C}^{-1}$), considering the altitude of Hungarian meteorological stations it equals 0.066, T_{mean} the mean air temperature, u_2 wind speed at 2 m height e_s – e_a vapour pressure deficit (kPa). The elements of FAO Penman-Monteith equation were determined with the help of methods applied type by Allen *et al.* [4] and Walter *et al.* [3]. This method was evaluated on the data measured by lysimeter in Szarvas experimental station in Hungary. Calculated data by Penman-Monteith method and measured data by Lysimeter in Szarvas were in good agreement Varga-Haszonits *et al.* [5].

The slope (Δ) of the curve of temperature-saturation vapour pressure:

$$\Delta = \frac{2503\left(\frac{17.27T_{\text{mean}}}{T_{\text{mean}} + 237.3}\right)}{(T_{\text{mean}} + 237.3)^2}$$

The T_{mean} mean temperature calculated from maximum and minimum temperatures is:

$$T_{\text{mean}} = \frac{T_{\max} + T_{\min}}{2}$$

Radiation balance (R_n):

$$R_n = (1-\alpha) R_{gl} - R_{nl}$$

where α commonly used crop albedo (0.23);

R_{gl} global radiation determined by Angström formula;

$$R_{gl} = \left(0.25 + 0.50 \frac{n}{N}\right) R_a$$

R_a extraterrestrial radiation can be estimated from solar radiation data:

$$R_a = \frac{24(60)}{\Pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos\delta \sin\omega_s\right]$$

where R_a is the extraterrestrial radiation ($MJ \cdot m^{-2} \cdot day^{-1}$);

G_{sc} is the solar constant (4.92 $MJ \cdot m^{-2} \cdot hour^{-1}$);

d_r inverse relative distance Earth-Sun;

ω_s sunset hour angle (rad), φ s latitude (rad) and δ solar declination (rad);

R_{nl} net outgoing longwave radiation as can be described as

$$R_{nl} = \sigma\left(\frac{(T_{\max,K})^4 + (T_{\min,K})^4}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_{gl}}{R_{gl0}} - 0.35\right)$$

where R_{nl} net outgoing long wave radiation ($MI \cdot m^{-2} \cdot day^{-1}$);

σ Stefan-Boltzmann constant (4.903×10^{-9} $MJ \cdot K^{-4} \cdot m^{-2} \cdot day^{-1}$);

$T_{\max,K}$ and $T_{\min,K}$ a max. and min. temperature in Kelvin;

e_a actual vapour pressure (kPa), R_{gl} global radiation ($MJ \cdot m^{-2} \cdot day^{-1}$);

R_{gl0} ($MJ \cdot m^{-2} \cdot day^{-1}$) clear sky solar radiation max possible ($MJ \cdot m^{-2} \cdot day^{-1}$).

The saturation deficit, which is the difference of saturation vapour pressure (e_s) and actual vapour pressure (e_a), determines the aerodynamic vapour transportation.

To estimate saturation vapour pressure, Allen *et al.* [4]:

$$e_s = \frac{e^0(T_{\max}) + e^0(T_{\min})}{2}$$

The $e^0(T_{\max})$ and $e^0(T_{\min})$ can be estimated based on the equation below if we use values off a $T_{\max}$ and $T_{\min}$:

$$e^0(T) = 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)$$

Actual vapour pressure can be estimated with the dewpoint temperature (T_{dew}):

$$e_a = 0.6108 \exp\left(\frac{17.27 T_{\text{dew}}}{T_{\text{dew}} + 237.3}\right)$$

If there are no dewpoint temperature data available, we can calculate the actual vapour pressure values from the minimum temperature values under the subhumid climatic conditions of Hungary with reasonable accuracy (Varga-Haszonits) [6].

Wind speed is measured at different heights, not at 2 meter height, where the other meteorological elements are measured. Wind speed measured at different heights can be adjusted with the help of logarithmic wind profile to 2 m above ground level (Campbell and Norma) [7].

The Penman-Monteith formula requires wind speed data measured at 2 m above ground level to determine other elements at the same height, and can be adjusted according to the following equation (Allen *et al.*) [4]:

$$u_2 = u_z \cdot \frac{4.87}{\ln(67.8 \cdot z - 5.42)}$$

where u_2 is the wind speed at 2 m height (m/s), u_z is the wind speed at z height (m/s), and z is the height of measurement (m).

2.2. FAO-56 Penman-Monteith Formula with Constant wind Speed Data

The method suggests an average wind speed of 2 m/s in regions with low constant wind speed data if there are no wind speed data available (Allen *et al.*) [4], then the Penman-Monteith formula can be described as:

$$\text{PMET}_{\text{cw}} = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \left(\frac{900}{T_k + 273} \right) \cdot 2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot 2)}$$

where PMET_{cw} (cw = constant wind speed).

2.3. FAO-56 Penman-Monteith Formula without Wind Speed Data

When there are no wind speed data available, Penman-Monteith formula can be expressed exclusively using radiation, temperature and vapour pressure data:

$$\text{MET}_{\text{rtv}} = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \left(\frac{900}{T_k + 273} \right) \cdot (e_s - e_a)}{\Delta + \gamma}$$

where PMET_{rtv} (rtv = radiation, temperature, vapour pressure) is the reference evapotranspiration calculated from the radiation, temperature and vapour pressure data.

2.4. Relationship between PMET_{ref} and Meteorological Elements

The relationship between FAO-PMET and the climatic factors was determined using linear regression. It is well known, that the higher the value of the determination coefficient of the linear relationship (r^2), the more the measured climatic factor explains the changes in evapotranspiration. Furthermore, the form of the line $y = a + bx$ shows how closely the calculated relationship approximates the original one. Namely, if b is close to 1 and a to 0, then the result gives a close approach, but if $b = 1$ and $a = 0$, then $y = x$. In this case, it may be necessary to examine only those factors that most intensively influence the evaporation. It needs to take into consideration, however, Wilks [8] revealed the ambiguity of these expectations. Namely, the regression relationship quantitatively expresses the nature and closeness of the relationship between two variables, but does not give information regarding causality. Nevertheless in the agro- and hydroclimatology the effecting factors and the dependent variables can be satisfactorily distinguished. The regression relationship between the climatic factors affecting evaporation and the FAO $PMET_{ref}$ values was analysed in a way where except the selected factors all the other values were kept constant.

3. Results

The Penman-Monteith formula was calculated for the period between 1975-2000 using the database of 14 meteorological stations of Hungary. In the first step, the connection between meteorological elements and reference evapotranspiration calculated by Penman-Monteith formula was investigated. **Sensitivity analysis:** Penman-Monteith formula considers the effect of four meteorological factors. These factors exert effects on reference evapotranspiration with different intensities. The important point is which element produces significant effects and which element produces no significant effect. The results can be seen in Table 1. Table 1 shows that three factors have the greatest effect: global radiation, saturation deficit and temperature. Wind speed has minimal effect on evapotranspiration. There are two ways to arrange this problem. We can calculate with an average wind speed considering the low wind speed data, or we do not use wind speed data at all.

3.1. A FAO-56 Penman-Monteith Formula with Constant Wind Speed

To analyse the effect of wind speed at 2 m above ground level and under Hungary's climatic conditions, the wind speed data of the 14 meteorological stations

Table 1. $PMET_{ref}$ and meteorological factors. Determination coefficients (r^2).

Meteorological stations	Global radiation	Temperature	Saturation deficit	Wind speed
Békéscsaba	0.9822	0.8924	0.9592	0.0448
Bp-Pestszentlőrinc	0.9803	0.8792	0.9585	0.0001
Debrecen	0.9805	0.8834	0.9654	0.0327
Győr	0.9816	0.8709	0.9676	0.1239
Kecskemét	0.9791	0.8828	0.9672	0.0013
Miskolc	0.9810	0.8745	0.9657	0.0589
Mosonmagyaróvár	0.9765	0.8779	0.9731	0.0819
Nyíregyháza	0.9857	0.8838	0.9811	0.0048
Pápa	0.9807	0.8791	0.9615	0.0545
Pécs	0.9836	0.8834	0.9809	0.1582
Szeged	0.9830	0.9075	0.9601	0.1199
Szolnok	0.9812	0.8960	0.9587	0.0442
Szombathely	0.9797	0.8670	0.9666	0.0053
Zalaegerszeg	0.9878	0.9576	0.9798	0.0005

are presented in **Table 2**. **Table 2** shows that the average wind speed values of the months do not reach 3 m/s and they fall under the value of 1.5 m/s for only some months. Data vary around 2 m/s. It is, therefore, reasonable to examine what values we get if we apply the Penman-Monteith formula and calculate with 2 m/s average wind speed. Allen *et al.* [4] also advise to calculate reference evapotranspiration with a constant 2 m/s value if there are no wind speed data available, Allen *et al.* [4].

The Penman-Monteith formula was calculated in original form and in modified form using 2 m/s wind speed data for 14 meteorological stations for the time period between 1976-2000. The relationship between the results of the two methods was expressed in a form of regression equations. The result is shown in **Table 3**.

Table 3 shows a very high correlation between the two formulas, If the form and relationship of the linear equation are expressed as $y = bx + a$ and $b = 1$ and $a = 0$, then $x = y$; Therefore the received result is more accurate if b is much closer to 1 and a to 0. In **Table 3**, the value of a can be regarded as 0 and b shows that the received value is a few tenths lower than the original Penman-Monteith formula.

3.2. FAO-56 Penman-Monteith Formula in Case of Missing Wind Speed Data

We compared the results of calculations without wind speed data with the results received with the application of the original formula (**Table 4**).

Table 4 shows if we apply $PMET_{rtv}$ formula to estimate the reference ET with

Table 2. Monthly average wind speed (m/s) (months are marked with numbers in upper line).

Stations	Latitude	Longitude	1	2	3	4	5	6	7	8	9	10	11	12
Békéscsaba	46.7	21.1	2.2	2.2	2.5	2.5	2.2	2.0	2.0	1.8	2.0	1.9	2.1	2.3
Bp-Pestszentlőrinc	47.5	19.2	2.1	2.1	2.3	2.3	2.0	2.0	2.0	1.8	1.9	1.8	1.9	2.0
Debrecen	47.5	21.6	2.1	2.1	2.4	2.4	2.1	1.9	1.8	1.7	1.8	1.7	1.8	2.1
Győr	47.7	17.7	2.0	2.0	2.2	2.2	1.9	1.8	1.7	1.5	1.6	1.7	1.9	2.0
Kecskemét	46.9	19.8	2.3	2.3	2.6	2.6	2.3	2.3	2.3	2.0	2.1	2.1	2.1	2.2
Miskolc	48.1	20.8	1.2	1.4	1.8	1.8	1.5	1.4	1.4	1.3	1.3	1.2	1.2	1.2
Mosonmagyaróvár	47.9	17.3	2.5	2.6	2.6	2.8	2.4	2.3	2.1	2.0	2.0	2.1	2.4	2.4
Nyíregyháza	48.0	21.4	1.9	2.1	2.4	2.4	2.1	1.9	1.8	1.7	1.7	1.7	1.8	2.0
Pápa	47.4	17.5	2.1	2.2	2.4	2.5	2.1	2.0	1.9	1.7	1.8	1.9	2.2	2.2
Pécs	46.0	18.2	2.3	2.4	2.6	2.6	2.1	2.0	1.9	1.8	1.8	2.0	2.1	2.4
Szeged	46.3	20.1	2.5	2.5	2.8	2.8	2.5	2.2	2.1	2.0	2.0	2.2	2.4	2.5
Szolnok	47.2	20.3	1.8	1.8	2.1	2.0	1.7	1.6	1.6	1.5	1.6	1.5	1.7	1.8
Szombathely	47.3	16.6	2.4	2.6	2.8	3.1	2.6	2.3	2.3	2.1	2.1	2.1	2.4	2.5
Zalaegerszeg	46.9	16.8	1.6	1.7	1.9	2.1	1.8	1.6	1.5	1.4	1.4	1.5	1.6	1.6

Table 3. Relationship between values of $PMET_{cw}$ and of $PMET_{ref}$.

Stations	Equations	r^2
Békéscsaba	$PMET_{ref} = 0.9994 * PMET_{cw} + 0.0299$	0.9975
Bp-Pestszentlőrinc	$PMET_{ref} = 0.9910 * PMET_{cw} + 0.0306$	0.9976
Debrecen	$PMET_{ref} = 0.9890 * PMET_{cw} + 0.0070$	0.9975
Győr	$PMET_{ref} = 0.9724 * PMET_{cw} + 0.0461$	0.9969
Kecskemét	$PMET_{ref} = 0.9991 * PMET_{cw} + 0.0401$	0.9970
Miskolc	$PMET_{ref} = 0.9793 * PMET_{cw} + 0.0226$	0.9973
Mosonmagyaróvár	$PMET_{ref} = 0.9926 * PMET_{cw} + 0.0731$	0.9975
Nyíregyháza	$PMET_{ref} = 0.9849 * PMET_{cw} + 0.0226$	0.9957
Pápa	$PMET_{ref} = 09763 * PMET_{cw} + 0.0925$	0.9948
Pécs	$PMET_{ref} = 0.9715 * PMET_{cw} + 0.0906$	0.9953
Szeged	$PMET_{ref} = 1.0007 * PMET_{cw} + 0.0936$	0.9952
Szolnok	$PMET_{ref} = 0.9610 * PMET_{cw} + 0.0273$	0.9962
Szombathely	$PMET_{ref} = 1.0020 * PMET_{cw} + 0.0687$	0.9943
Zalaegerszeg	$PMET_{ref} = 0.9811 * PMET_{cw} + 0.0032$	0.9966

Table 4. Relationship between values of $PMET_{rtv}$ and of $PMET_{ref}$.

Monitoring site	Equation of the line	r^2
Békéscsaba	$PMET_{ref} = 0.9457 * PMET_{rtv} + 0.0909$	0.9980
Bp-Pestszentlőrinc	$PMET_{ref} = 0. 9633 * PMET_{rtv} + 0.1012$	0.9983
Debrecen	$PMET_{ref} = 0.9413 * PMET_{rtv} + 0.0585$	0.9989
Győr	$PMET_{ref} = 0.9201 * PMET_{rtv} + 0.118$	0.9986
Kecskemét	$PMET_{ref} = 0.9604 * PMET_{rtv} + 0.0861$	0.9982
Miskolc	$PMET_{ref} = 0.9306 * PMET_{rtv} + 0.0303$	0.9986
Mosonmagyaróvár	$PMET_{ref} = 0.9145 * PMET_{rtv} + 0.1468$	0.9968
Nyíregyháza	$PMET_{ref} = 0.9701 * PMET_{rtv} + 0.0921$	0.9971
Pápa	$PMET_{ref} = 0.9453 * PMET_{rtv} + 0.1556$	0.9971
Pécs	$PMET_{ref} = 0.963 * PMET_{rtv} + 0.167$	0.9973
Szeged	$PMET_{ref} = 0.9974 * PMET_{rtv} + 0.1596$	0.9965
Szolnok	$PMET_{ref} = 0.9573 * PMET_{rtv} + 0.0823$	0.9978
Szombathely	$PMET_{ref} = 0.9735 * PMET_{ref} +0.9961$	0.9961
Zalaegerszeg	$PMET_{re}f = 0.9427 * PMET_{rtv} + 0.0614$	0.9985

the application of $PMET_{ref}$ then the coefficient of b changes between 0.92 and 0.96, which indicates a good approach. The line's a constant of 0.03 and 0.16 mm shows differences of only 0 and 0.2 mm.

3.3. Frequency of Error of Estimating Formulas

If the amount of irrigation water need has to be calculated, then it is very important to know the difference between the values of the original reference evapotranspiration and the values of evapotranspiration estimated with modified formulas. From a practical perspective, it is very useful to know not only the value of error but its frequency as well. Therefore when assessing the usefulness of the modified formulas we looked at the frequency of errors and chose the method which produced the smallest errors with the highest frequency.

Table 5 shows the frequency of errors in the case of formulas estimated at 2 m constant wind speed. It can be seen from the data of **Table 5** that differences close to 0 occur mostly at the measuring sites. Zero is the most frequent difference at most sites. There are only 4 of the measuring sites where the most frequent values fall into the interval of 0.1. Differences between −0.2 and +0.2 mm are the most frequent in relation to all measuring sites. **Table 5** also shows differences of −0.1 and +0.1 mm, which have the most frequent occurrence. They show rates of 70% or higher at all measuring sites. Their frequency of occurrence is the lowest in Miskolc, where it is exactly 70% and the highest rate is in Mosonmagyaróvár, with 95%. As a result, it may be concluded that considering wind speed conditions in Hungary $PMET_{cw}$ formula can be applied to estimate reference evapotranspiration in regions where there are no wind speed data available. Another approach was where wind speed data was completely excluded. **Table 4** shows this formula which produced very good results, so we compared this formula of $PMET_{rtv}$ with the results of the original $PMET_{ref}$ formula (**Table 6**).

The most frequent estimation errors fall into the interval of −0.1 and +0.2.

Table 5. Estimation error of $PMET_{cw}$ (%).

Stations	Error of estimation (mm)													
	0.3	−0.5	−0.4	−0.3	−0.2	−0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Békéscsaba				0	1	7	42	22	17	10	1	0		
Bp-Pestszentlőrinc				0	0	16	50	21	13	1	0			
Debrecen				0	0	1	34	28	21	15	1			
Győr				0	0	11	33	19	14	22	2	0		
Kecskemét				0	0	12	42	30	14	2	0	0		
Miskolc				0	0	0	19	31	20	22	7	0.27		
Mosonmagyaróvár				0	1	17	32	19	13	11	5			
Nyíregyháza				0	3	16	49	19	9	4	0	0	0	
Pápa			0	1	5	23	36	17	13	6	1	0	0	
Pécs		0	1	1	8	34	33	16	7	1	0	0	0	
Szeged	0	0	3	5	17	38	31	5	0	0	0	0		
Szolnok				0	1	9	40	25	15	8	1	0	0	0
Szobathely		0	0	2	7	33	35	16	6	2	0	0		
Zalaegerszeg				0	0	2	32	25	19	19	2	0	0	

Table 6. Estimation error of $PMET_{rtv}$ (%).

Stations	Error of estimation (mm)													
	0.3	−0.5	−0.4	−0.3	−0.2	−0.1	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
Békéscsaba				0	1	7	42	22	17	10	1	0		
Bp-Pestszentlőrinc				0	0	16	50	21	13	1	0			
Debrecen				0	0	1	34	28	21	15	1			
Győr				0	0	11	33	19	14	22	2	0		
Kecskemét				0	0	12	42	30	14	2	0	0		
Miskolc				0	0	0	19	31	20	22	7	0.27		
Mosonmagyaróvár				0	1	17	32	19	13	11	5			
Nyíregyháza				0	3	16	49	19	9	4	0	0	0	
Pápa			0	1	5	23	36	17	13	6	1	0	0	
Pécs		0	1	1	8	34	33	16	7	1	0	0	0	
Szeged	0	0	3	5	17	38	31	5	0	0	0	0		
Szolnok				0	1	9	40	25	15	8	1	0	0	0
Szobathely		0	0	2	7	33	35	16	6	2	0	0		
Zalaegerszeg				0	0	2	32	25	19	19	2	0	0	

The estimation error of +0.2 mm is also relatively frequent. These results fit well with the results achieved with other alternative formulas in humid and sub-humid regions (Fisher and Pringle) [9].

4. Conclusion

Fourteen stations of Hungary were selected to determine reference evapotranspiration the by Penman-Monteith method. All necessary data was available in these stations to use the Penman-Monteith method. This made it possible to compare modified formulas with the original formula. The aim of this comparison was to investigate whether the modified formulas can be used to calculate reference evapotranspiration with acceptable accuracy in the case of missing wind data. The results of the comparisons show that both modified formulas can be used to calculate reference evapotranspiration with acceptable accuracy at sites in the country where wind speed data are not available. This is important for irrigation because it helps to estimate the reference evapotranspiration in regions without wind speed data for longer periods as well as back to the start of meteorological measures. Furthermore, it becomes possible to estimate crop reference evapotranspiration using crop coefficients as well. In this way, irrigation requirement of crops may be estimated with adequate accuracy in all regions of the country. Comparing the b coefficients and a constants of the equations in **Table 3** and **Table 4** it can be concluded that $PMET_{cw}$ formula produces a more accurate approach. Furthermore, **Table 5** and **Table 6** show that the most frequent errors fall into intervals of −0.1 and +0.1 mm. Estimations with $PMET_{rtv}$

formula show the most frequent error in the intervals is between −0.1 and +0.2 mm. $PMET_{rtv}$ formula shows a relatively frequent estimation error in intervals of +0.2 as well. The application of $PMET_{cw}$ formula is favourable for sub-humid climates because the average wind speeds vary around 2 m/s at 2 m above ground level (**Table 2**). These examinations have revealed that the sub-humid climate of Hungary and the average wind speed of 2 m/s at 2 m above ground level, make it possible to estimate the reference evapotranspiration at an adequate level of accuracy if we apply the Penman-Monteith equation calculated at 2 m/s constant wind speed in regions where wind speed data is missing.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Doorenbos, J. and Pruitt, W.O. (1977) Guidelines for Predicting Crop Water Requirements FAO Irrigation and Drainage Paper, No 24. Revised. Food and Agriculture Organization of the United Nations, Rome, 144 p.

[2] Katerji, N. and Rana, G. (2011) Crop Reference Evapotranspiration A Discussion of the Concept, Analysis of the Process and Validation. *Water Resources Management*, **25**, 1581-1600. https://doi.org/10.1007/s11269-010-9762-1

[3] Walter, I.A., Allen, R.G., Elliot, R., Itenfisu, D., Brown, P., Jensen, M.E., Mecham, B., Howell, T.A., Snyder R., Ehongs, S., Spofford, T., Hattendorf, M., Martin, D., Cuenca, R.H. and Wright, J.L. (2005) The ASCE Standardized Reference Evapotranspiration Equation. Final Report. Environmental and Water Resources Institute of American Society of Civil Engineers, USA.

[4] Allen, R.G., Pereira, L.S., Raes, D. and Smith, D. (1998) Crop Evapotranspiration (Guidelines for Computing Water Requirements). FAO Irrigation and Drainage Paper 56. Food and Agricultural Organization of the United Nations, Rome, 299 p.

[5] Varga-Haszonits, Z., Lantos, Z., Vámos, O., Kalocsai, R. and Szakál, T. (2019) A referencia evapotranszspiráció meghatározása FAO Penman-Monteith módszerrel. *Acta Agronomica Óvariensis*, **60**, 107-126.

[6] Varga-Haszonits, Z. (2019) Az agro-és hidrometeorológiai adatgyűjtés és adatkezelés módszerei. Széchenyi István Egyetem, Universitas Győr Nonprofit Kft., 195 p.

[7] Campbell, G.S. and Norma, J. M. (1998) An Introduction to Environmental Biophysics. 2 Edition, Springer, New York, 286 p. https://doi.org/10.1007/978-1-4612-1626-1

[8] Wilks, D.S. (2006) Statistical methods in Atmospheric Science. 2 Edition, Academic Press, Amsterdam, 630 p.

[9] Fisher, D.K. and Pringle, H.C. (2013) Evaluation of Alternative Methods for Estimating Reference Evapotranspiration. *Agricultural Sciences*, **4**, 51-60. https://doi.org/10.4236/as.2013.48A008