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Comparative analysis of reference evapotranspiration from the surface of rainfed grass in central Serbia, calculated by six empirical methods against the Penman-Monteith formula

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Abstract: Five reference evapotranspiration (ET_o) methods and one adjusted method were compared with the Penman-Monteith formula, standardized by the Food and Agriculture Organization (FAO-56PM), using rainfed grass data from an agricultural weather station at the Radmilovac experimental site. The methods compared include four widely and commonly used empirical equations (Piestley-Taylor, Turc, Makkink, and Hargreaves-Samani), as well as a new equation recently proposed by Alexandris et al. (2006), namely the "Copais" equation. An adjusted Hargreaves equation for Southeast Europe proposed by Trajkovic (2007) was also included in the comparison. Daily ET_o values, obtained during two growing seasons (2005 and 2006) were compared, using linear regression and statistical indices of quantitative approaches to model performance evaluation. All the statistical indices were calculated on a daily basis. The soil water content of the rainfed grass field was adequate during the investigated period, as shown by soil moisture profiles (Petkovic et al., 2006). It was, therefore, assumed that rainfed grass evapotranspiration closely resembled hypothetical reference evapotranspiration. Because solar radiation (R_s) was the only radiation measured, the net radiation (R_{net}) variable was derived empirically, following the procedure outlined in the FAO-56 paper (Allen et al., 1998). The mean bias errors (MBEs), for estimates of grass crop evapotranspiration applying the Copais, Priestley-Taylor, Hargreaves-Samani, Turc, Makkink and Adjusted Hargreaves methods, and compared to FAO-56 PM estimations, were 0.019, -0.037, 0.741, -0.620, -0.186 and 0.158 mmday^{-1}, respectively, and the average FAO56-PM ET_o was 2.857 mmday^{-1}. In general, Priestley-Taylor and Copais models performed well for the study region and yielded results closest to the FAO56-PM method. Systematic overestimation of Hargreaves-Samani ET_o values was noted, while the other two methods, Turc and Makkink, produced underestimated results. The results of statistical comparisons provided a confident statistical justification for the ranking of the compared methods, based on performance indices.

Key words: reference evapotranspiration, empirical methods, methods comparison, Penman-Monteith formula, rainfed grass.

1. INTRODUCTION

Under the normal range of environmental conditions, water deficit is a major limiting factor of plant growth and production. In many areas of the world, where rainfall is too low or insufficient to meet the water demand of the crops, irrigation is a significant component of agricultural (cropping pattern) planning. In irrigated/rainfed agriculture, it is necessary to establish when and how much water to apply and, of course, determine the optimum sowing time to take advantage of the available soil moisture and precipitation. Irrigation water demand is usually determined through evapotranspiration estimation procedures. Apart from precipitation, ET is the most significant component of the hydrological budget. Calculations of crop reference evapotranspiration require that weather stations be sited on standardized vegetation surfaces (grass or alfalfa). Most Mediterranean areas and many other regions throughout the world do not have vegetation reference sites or installed ET_o-networks, due to high installation and maintenance costs. This leads to systematic use of inappropriate climatic data for ET_o calculations from non-ideal sites (those that do not conform to standardizations) and, consequently, to significant and systematic cumulative errors in irrigation scheduling, as well as confusing conclusions. During the past sixty years, empirical or physically based equations have been developed and used under various climatic regimes to estimate reference evapotranspiration. Testing the accuracy of these methods in a new environment requires costly equipment (lysimeters) and well-trained personnel or standardized reference surface conditions (protocols). In addition, many of these equations have a limited global validity. To minimize the differences associated with canopy characteristics, the FAO and working groups of the International Commission on Irrigation and Drainage, after extensive testing of different formulas among physically-based equations, recommended standardized Penman–Monteith reference evapotranspiration as the potential evapotranspiration for short grass or a tall reference crop (alfalfa), whose characteristics are well defined (Pereira et al., 1996; Walter et al., 2005; Allen et al., 1998, 2006). The objective of these studies is to provide guidance to irrigation engineers, hydrologists, agronomists, and meteorologists in the calculation of reference and crop evapotranspiration. They can be used for computing crop water demand for both irrigated and rainfed agriculture, and for computing water consumption by agricultural and natural vegetation (Allen et al., 1998). Although electronic data-logging weather stations are becoming the norm for some countries, this is not the case in many developing nations. However, empirical and less weather-data demanding equations provide an alternative way to derive accurate ET_o measurements, which are close to the selected standardized model with a short time step, under similar reference crop conditions (rainfed grass), using low-cost data acquisition systems. In this context, the main objective of this paper is to compare and evaluate the performance of four globally used methods for ET_o computation, namely: Makkink (1957), Turc (1962), Priestley and Taylor (1972), Hargreaves and Samani (1985), a new method - “Copais” (Alexandris et al., 2006), as well as a recently adjusted Hargreaves equation for Southeast Europe, proposed by Trajkovic, (2007). The ET estimated from daily climatic data by these methods is considered equivalent to the rate at which water is consumed by a well-watered grass reference crop. The importance of the empirical methods has been discussed by various researchers in many recent studies (Xu and Sinch, 2002; Pereira and Pruitt, 2004; Xu and Chen, 2005; Popova et al., 2006). Furthermore, we believe that in many extended rural areas in the near future, tested and validated empirical formulas could constitute a useful tool for more spatially and temporally representative and accurate values of evapotranspiration, in combination with valid remote-sensing data for common meteorological attributes, instead of single-point measurements by fully equipped and expensive ground stations.

2. SHORT DESCRIPTION OF THE EQUATIONS

2.1 FAO56 Penman -Monteith (Allen et al., 1998)

The FAO56-PM equation for predicting ET_o on a daily basis has the form:

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)} \tag{1}$$

where ET_o is the reference evapotranspiration $[\mathrm{mm\,day^{-1}}]$, R_n is the net radiation at the crop surface $[\mathrm{MJ\,m^{-2}day^{-1}}]$, G is the soil heat flux density $[\mathrm{MJ\,m^{-2}\,day^{-1}}]$, T is the mean daily air temperature at a height of 2 m $[^{o}\mathrm{C}]$, u_2 is the wind speed at a height of 2 m $[\mathrm{m\,s^{-1}}]$, e_s is the saturation vapor pressure $[\mathrm{kPa}]$, e_a is the actual vapour pressure$[\mathrm{kPa}]$, is the vapour pressure deficit $[\mathrm{kPa}]$, Δ is the slope of the vapour pressure curve $[\mathrm{kPa^{o}C^{-1}}]$ and γ is the psychrometric constant $[\mathrm{kPa^{o}C^{-1}}]$. The soil heat flux is ignored (G=0) in daily applications.

2.2. The Hargreaves-Samanı equation (Hargreaves and Samani, 1985)

The Hargreaves (1975) working formula, which was modified in 1985 for grass conditions and which requires temperature and solar radiation measurements, is:

$$ET_o = 0.0023 \cdot (T_{max} - T_{min})^{0.5} \cdot (T_m + 17.8) \cdot R_a \tag{2}$$

where ET_o is the reference evapotranspiration [mm day^{-1}], T_m is the mean daily air temperature [^oC]; T_{max} is the daily maximum air temperature [^oC], T_{min} is the daily minimum air temperature [^oC] and R_a is extraterrestrial radiation [mm day^{-1}]. The mean air temperature in the Hargreaves equation is calculated as an average of T_{min} and T_{max} and R_a is computed from information about the site (latitude) and the day of the year (DOY).

2.3 The Priestley-Taylor model (Priestley and Taylor, 1972)

The original model constitutes a modification of Penman's equation; it is used in areas of low moisture stress and described by the following equation:

$$ET_o = \alpha \cdot \frac{\Delta}{\Delta + \gamma} \cdot (R_n - G) \cdot \frac{1}{\lambda} \tag{3}$$

where, $\alpha = 1.26$, λ is the latent heat of vaporization [λ=2.45 MJ kg^{-1} at 20^{o}C] and all other terms are identical to those defined for Eq. (1). The assumptions made in this equation have been validated by a review of thirty studies which all conclude that in vegetated areas with very small water deficits, approximately 95% of evaporated demand is supplied by radiation (Stagnitti et al., 1989). Under these conditions, the mass transfer term in the Penman combination equation approaches zero and radiation terms dominate. Therefore, the aerodynamic term was represented by the coefficient, as suggested by Priestley- Taylor. This value was used in the present study since it is believed to be reasonable for most climates, as pointed out by McAneney and Itier (1996).

2.4 The Makkink formula (Makkink, 1957)

This is another simplified combination formula of the original Penman equation; it disregards the aerodynamic component and replaces the net radiation balance with incoming shortwave solar radiation (R_S). The equation is:

$$ET_o = 0.61 \cdot \frac{\Delta}{\Delta + \gamma} \cdot \frac{R_s}{\lambda} - 0.12 \tag{4}$$

where ET_o is the reference evapotranspiration [mm day^{-1}], R_S is solar radiation [MJ m^{-2} day^{-1}], and λ is the latent heat of vaporization [λ=2.45 MJ kg^{-1}]. Parameters Δ and γ are as defined for Eq.1.

2.5 The Turc method (Turc, 1961)

Turc (1961) developed an equation for the calculation of daily potential evapotranspiration as a function of air temperature, relative humidity and solar radiation. The Turc method is comprised of two equations; the one to be used depends on relative humidity (RH) of the air.

For RH > 50 % $$ET_o = 0.0133 \frac{T_m}{T_m + 15}(R_s + 50) \quad (5a)$$

For RH < 50 % $$ET_o = 0.0133 \frac{T_m}{T_m + 15}(R_s + 50)\left(1 + \frac{50 - RH}{70}\right) \quad (5b)$$

where ET_o is the reference evapotranspiration $[\mathrm{cal\,cm^{-2} day^{-1}}]$, T_m is the mean daily air temperature $[^oC]$, T_{max}, R_s is the incoming shortwave solar radiation $[\mathrm{mm\,day^{-1}}]$, and RH is the relative humidity [%].

2.6. The Copais formula (Alexandris et al., 2006)

The Copais equation was derived by surface bilinear polynomial regression (Alexandris et al., 2006) for Central Greece, using three meteorological attributes (solar radiation R_s, relative humidity RH, and air temperature T). The final working formula for daily ET_o is expressed by Eq. (6) below, in an implicit manner since C_1 and C_2 are functions of the attributes R_s, RH and T:

$$ET_o = m_1 + m_2 C_2 + m_3 C_1 + m_4 C_1 C_2 \quad (6)$$

where ET_o is the reference evapotranspiration $[\mathrm{mm\,day^{-1}}]$ with coefficients $m_1 = 0.057$, $m_2 = 0.277$ *, $m_3 = 0.643$, $m_4 = 0.0124$ and

$$C_1 = 0.6416 - 0.00784 \cdot RH + 0.372 \cdot R_s - 0.00264 \cdot R_s \cdot RH \quad (6a)$$

$$C_2 = -0.0033 + 0.00812 \cdot T + 0.101 \cdot R_s + 0.00584 \cdot R_s \cdot T \quad (6b)$$

2.7. Adjusted Hargreaves (Trajkovic, 2007)

The value 0.424 is proposed instead of the original 0.5 (Eq. 2), and should be used in the Hargreaves formula for Western Balkan locations under humid conditions. The adjusted Hargreaves exponent was derived from ten weather stations using monthly data. The proposed adjusted equation is:

$$ET_o = 0.0023 \cdot R_a \left(T_{max} - T_{min}\right)^{0.424} \cdot \left(\frac{T_{max} + T_{min}}{2} + 17.8\right) \quad (7)$$

All parameters are as defined for Eq.2.

3. MATERIAL AND METHODS

3.1. Study area and measures

The study was carried in out at the Radmilovac experimental field (0.9 ha) of the University of Belgrade/Faculty of Agriculture, 24 km southeast of Belgrade, in a small river basin. The total surface area of the catchment is about 80 ha. An automatic MetosCompact micro-meteorological

* Important note: In the original paper (Alexandris et al., 2006), the coefficient m_2 is 0.227 due to a misprint and should be replaced with the correct value 0.277.

station (Lat. $44^o 49' 14'' N$, Long. $20^o 27' 44'' E$, Elevation: 130m) was set up on a grass field (rainfed), where climatic data and measurements (*stored every 12 minutes*), related to water dynamics in the soil-plant-atmosphere-continuum, were recorded over two consecutive years (2005 and 2006). The data used in this paper are part of the research project WATERWEB (*Water Resources Strategies and Drought Alleviation in Western Balkan Agriculture*), financed by the EU. Meteorological data, such as air temperature (T_{mean}, T_{max}, T_{min}), wind speed (u_2), relative humidity, (RH_{mean}, RH_{max}, RH_{min}), solar radiation (R_s) and soil temperature (T_{soil}), were collected. An automated rain gauge, electronic barometer and wind direction sensor were also installed. The data were periodically downloaded from the acquisition system and subsequently processed to obtain hourly and daily averages. In the grass field, an electronic tensiometer (Watermark), used for continuous soil moisture measurements at a depth of 30 cm, and 15 profile probes installed in a neighboring vineyard were used to monitor volumetric soil moisture profiles at 3-10 day intervals. The soil water content of the vineyard was obtained from the following depths: 10, 20, 30, 40, 60, and 100 cm. The measurements were performed by a Delta T profile probe. Both the grass field and vineyard were well-supplied with water during both growing seasons (2005 and 2006), as shown in Figure 1.

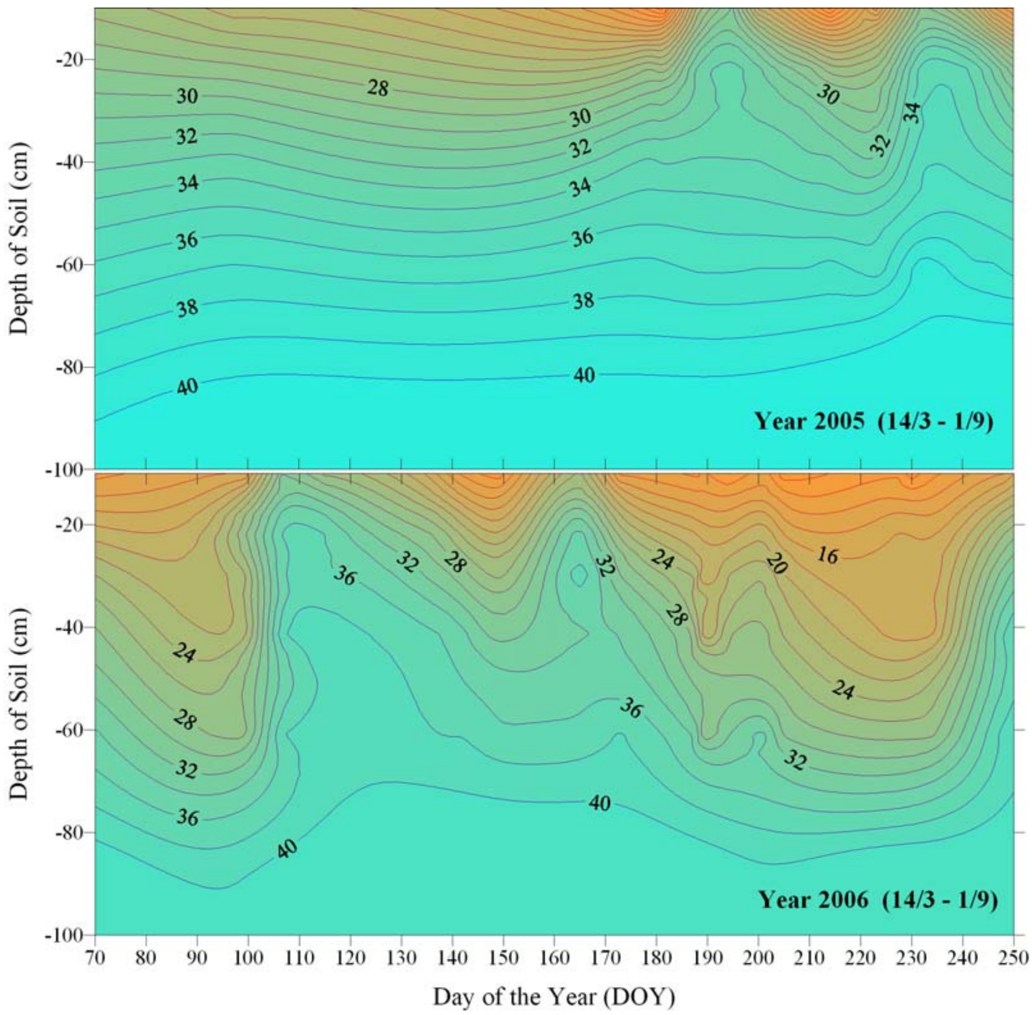

Figure 1. Spatial and temporal distribution of soil moisture content [% vol] (soil moisture concentrated contour lines) in the soil profile during the period from 14/3 to 1/9 for both years 2005 and 2006, using kriging method analysis from actual soil moisture measurements.

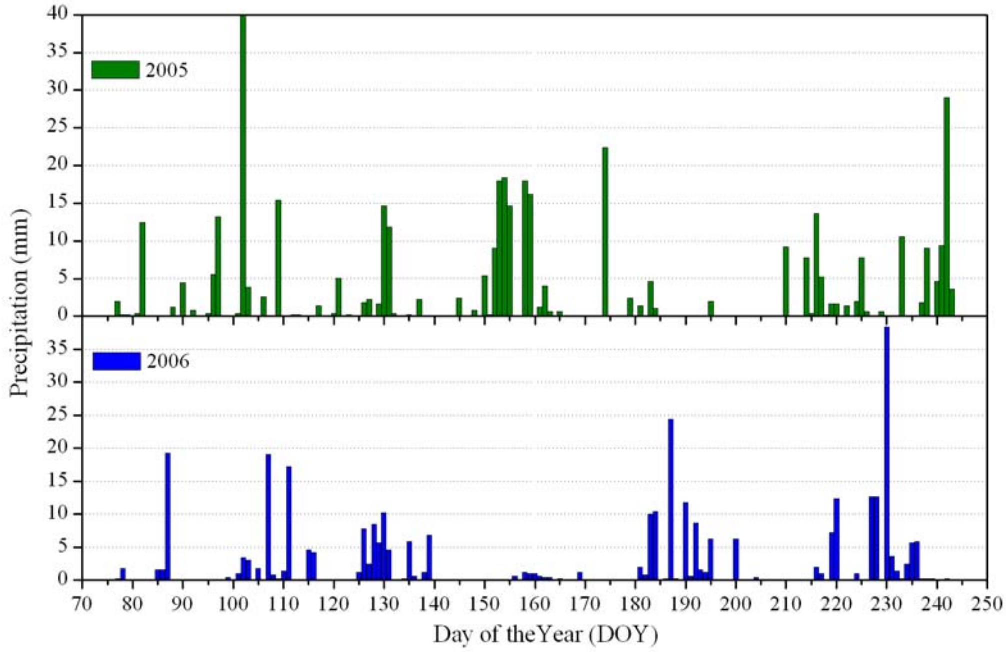

Figure 2. Distribution of precipitation (mm) in the growing season period for the years 2005 and 2006 at the Radmilovac experimental field.

Analysis of the data averaged over the entire growing season indicates that soil moisture (Figure 1) and precipitation (Figure 2) were very consistent and that precipitation was the dominant factor in soil moisture variation control. The rainfall in the summer of 2005 (152 - 243 DOY) was 254 mm, while in 2006 it was 56 mm less (22%). All rainfall events are illustrated in Figure 2.

Consequently, the grass field was well watered, even during the period when atmospheric demand was high (vapour pressure deficit >1.5 kPa).

3.2. Statistical analysis

Quantitative approaches to the evaluation of model performance were applied. To ensure a rigorous comparison of the methods, an extended analysis was performed using different statistical indices for the estimated values. Intercepts (b) and slopes (a) for the least squared regression analysis also were calculated and reported. It has been pointed out (Fox, 1981; Willmott, 1982) that commonly used correlation measures, such as (R) and (R^2), and tests of statistical significance in general, are often inappropriate or misleading when used to compare model predicted (P) and observed (O) variables. Model efficiency (EF) (Greenwood et al., 1985) is calculated on the basis of the relationship between observed and predicted mean deviations. The "Index of Agreement" (*d*), alternatively proposed (Willmott and Wicks, 1980; Willmott, 1981, 1982) as a descriptive measure which can be applied in order to make a cross-comparison between the models, is both a relative and bounded measure. Fox (1981) recommends, in essence, that four types of different measures be calculated and reported. Bias can be described by the mean bias error (MBE), while the variance of the distribution of differences (s_d^2) simply expresses the variability of the difference between predicted (P_i) and observed (O_i) values around the MBE. Alternatively, the average difference can be expressed by the root mean square error (*RMSE*) or the mean absolute error (MAE). *RMSE* and MAE are among the best overall measures of model performance because they summarize the mean difference between observed (O) and predicted (P) values. In spite of the fact that MAE and RMSE are similar measures, in many cases it is appropriate to report both indices. MAE is less sensitive to large forecast errors. MAE is preferred for small or limited data sets. RMSE is practical as it shows the errors in the same unit and scale as the parameter itself. Both MAE and RMSE can range from 0 to infinity and, of course, lower values are better. Furthermore, $RMSE_s$ and $RMSE_u$ are the systematic and the unsystematic component (Willmott, 1981), respectively, and are computed and reported in addition to $RMSE$. Systematic RMSE is determined by the distance between the linear regression best-fit line and the 1:1 line, while unsystematic RMSE is determined by the distance between the data points and the linear regression best-fit line. As discussed by Berengena1 and Gavilán (2005), the unsystematic component is representative of the "noise" level in the model being tested and is a measure of the scatter about the regression line; it can be interpreted as a measure of the potential accuracy. The systematic component is a measure of the space available for local adjustment. A good model is considered to have a very low unsystematic RMSE and the systematic RMSE close to the RMSE. Computational forms of all the indices are given below:

$$MBE = N^{-1}\sum_{i=1}^{N}\left(P_i - O_i\right) \tag{8}$$

$$MAE = N^{-1}\sum_{i=1}^{N}\left|P_i - O_i\right| \tag{9}$$

$$S_d^2 = \left(N-1\right)^{-1}\sum_{i=1}^{N}\left(P_i - O_i - MBE\right)^2 \tag{10}$$

$$RMSE = \left[N^{-1}\sum_{i=1}^{N}\left(P_i - O_i\right)^2\right]^{0.5} \tag{11}$$

$$RMSE_u = \left[N^{-1}\sum_{i=1}^{N}\left(P_i - \hat{P}_i\right)^2\right]^{0.5} \tag{12}$$

$$RMSE_s = \left[N^{-1}\sum_{i=1}^{N}\left(\hat{P}_i - O_i\right)^2\right]^{0.5} \tag{13}$$

$$EF = 1 - \frac{\sum_{i=1}^{N}\left(P_i - O_i\right)^2}{\sum_{i=1}^{N}\left(\bar{O} - O_i\right)^2}, \qquad 0 \le EF \le 1 \tag{14}$$

$$d = 1 - \frac{\sum_{i=1}^{N}\left(P_i - O_i\right)^2}{\sum_{i=1}^{N}\left(\left|P_i'\right| + \left|O_i'\right|\right)^2}, \qquad 0 \le d \le 1 \tag{15}$$

where O_i stands for observed values (*estimated by FAO56-PM*) and P_i stands for values predicted by the compared methods, $\hat{P}_i = aO_i + b$, $P_i' = P_i - \bar{O}$ and $O_i' = O_i - \bar{O}$.

4. RESULTS AND DISCUSSION

Comparisons for each empirical equation were made between daily reference evapotranspiration values and daily values calculated using the FAO56-PM method. FAO56-PM was selected as a benchmark method for comparison because it is a globally accepted model, used under a variety of climatic regimes and reference conditions. This paper places special emphasis on growing season comparisons because these are the most important periods for agriculture. The relationships (*regression equations*) between daily ET_o estimates for each method against the FAO56-PM ET_o and the cross-correlation coefficient (R^2) are shown in Figure 3, using the linear regression form $Y = bX + a$ and not regression through the origin ($Y = bx$).

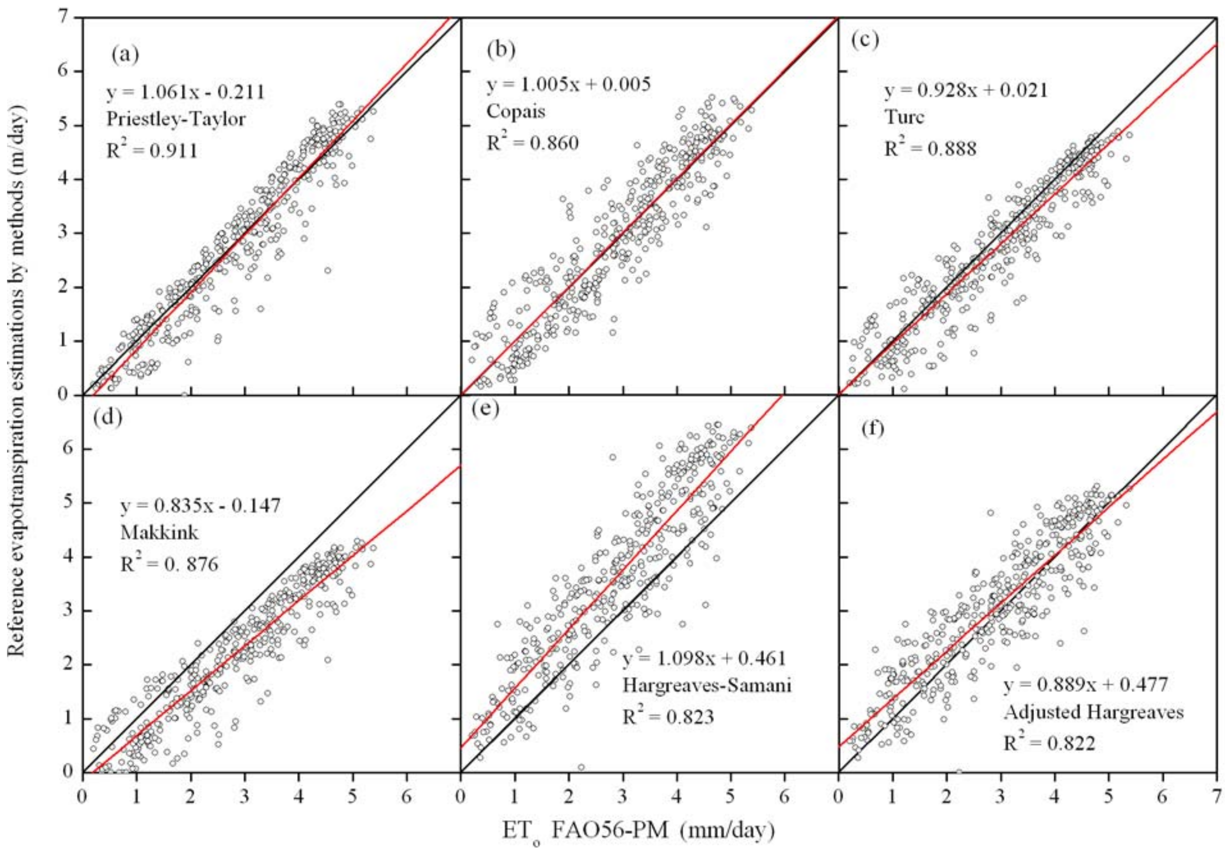

Figure3. Comparison of daily FAO56-PM ET_o versus respects values obtained from the other tested methods (N= 411 days).

In many studies researchers use linear regression through the origin (*intercept a = 0*) for model comparison, but there are a few curious aspects in this type of regression because residuals do not add up to zero and, additionally, the confidence band of the regression line and of individual observations does not expand from the center of the line but, instead, from the origin, where the variance is zero. In this case, a comparative evaluation of the models would not be fair since certain statistical indices would be false and would give an unreliable comparative picture. Priestley-Taylor and Copais methods correlated very well with the FAO56-PM method throughout the growing season under local conditions. With regard to regression equations, the Copais equation resulted in a slope close to unity (1.005) and an intercept close to zero (0.005), giving the best predicted values ($\hat{P}_i$). The second-best values were those obtained by the Priestley-Taylor method (b=1.061, a=0.211). The original dimensionless empirical multiplier (a=1.26), which is replaced by the Penman–Monteith aerodynamic term in the Priestley-Taylor equation, provides good estimates under low or no advective conditions, which prevailed in the study area. In other words, the advection component of the energy balance is not considered significant for local conditions on a daily basis. The Makkink method systematically produced the greatest underestimates (by as much as 16%), while the Turk method yielded the least underestimated values (7%). Conversely, the Hargreaves-Samani method systematically overestimated by as much as 20%, giving the worst estimates among all the tested methods. Similar behavior of the Hargreaves equation under humid conditions has been reported by Jensen et al. (1997), Temesgen et al. (2005), Droogers and Allen

(2002) and Garcia et al. (2004). The use of the adjusted Hargreaves exponent in Eq. 7 (value 0.424 instead of the original 0.5) results in improved ET_o estimations, changing the slope (b=0.889) of the regression line. However, this has no effect on the intercept value, which increases slightly (a=0.477), and there is a tendency to produce greater underestimates at higher rates of evapotranspiration, while at lower evaporative demand values the method tends to overestimate.

All statistical measures are in agreement with the illustrated results obtained by the regression analysis method. All relevant statistics and rankings of daily methods are listed in Table 1, where an attempt is made to rank the methods against FAO56-PM, taking into account all the above-mentioned statistical indices. In any complex evaluation system, a weighting coefficient for each statistical index should be determined separately. Considering the same symptomatic tendency and the behaviour of the indices, a simple grading of the determined index magnitude was made.

Table 1. Summary statistics of daily ET_o estimating methods tested against the FAO56-PM model. (*) Daily estimate rank number for each statistical index.

Indices	Priestley Taylor	(*)	Copais	(*)	Turc	(*)	Adjusted Hargreaves	(*)	Makkink	(*)	Hargreaves Samani	(*)
Ranking	1		2		3		4		5		6	
$\overline{P}$ (mm/d)	2.820	(2)	2.876	(1)	2.671	(4)	3.016	(3)	2.237	(5)	3.598	(6)
MBE (mm/d)	-0.037	(2)	0.019	(1)	-0.186	(4)	0.158	(3)	-0.620	(5)	0.741	(6)
MAE (mm/d)	0.331	(1)	0.429	(3)	0.350	(2)	0.469	(4)	0.669	(5)	0.843	(6)
s_d^2	0.194	(1)	0.281	(4)	0.194	(2)	0.313	(5)	0.215	(3)	0.458	(6)
RMSE (mm/d)	0.195	(1)	0.281	(3)	0.228	(2)	0.338	(4)	0.599	(5)	1.007	(6)
RMSE(s) (mm/d)	0.008	(2)	0.000	(1)	0.044	(3)	0.046	(4)	0.431	(5)	0.566	(6)
RMSE(u) (mm/d)	0.187	(2)	0.281	(1)	0.184	(4)	0.292	(3)	0.169	(6)	0.441	(5)
D	0.974	(1)	0.961	(3)	0.965	(2)	0.948	(4)	0.907	(5)	0.883	(6)
R^2	0.911	(1)	0.860	(4)	0.888	(2)	0.822	(5)	0.876	(3)	0.823	(6)
EF	0.886	(1)	0.835	(3)	0.866	(2)	0.802	(4)	0.648	(4)	0.409	(6)
b (slope)	1.061	(2)	1.005	(1)	0.928	(3)	0.889	(5)	0.836	(6)	1.098	(4)
a (intercept)	-0.211	(4)	0.005	(1)	0.021	(2)	0.476	(6)	-0.151	(3)	0.461	(5)

Another way to evaluate the performance of the methods is to compare the corresponding accumulated values of ET_o (mm), obtained by the various methods, with FAO56-PM accumulated estimates for a long period of high atmospheric water demand. The progressive daily cumulative values of $ET_{o,}$ as well as the cumulative difference (cumulative under/overvaluation) of all the tested methods, are shown in Fig. 4, separately for the two years (2005 and 2006) and for warm season months (10/4-1/9). The total evapotranspiration obtained by the FAO-56PM (benchmarked) method was 478.7 (2005) and 489.5mm (2006). As shown in the graph, the total underestimation of the Copais method for the 144 warmest days was only 15.2 mm (2005) and 9.5 mm (2006). The same level of accuracy was obtained by the Priestley-Taylor method, which produced overestimates by 10.8 mm and 12.8 mm for 2005 and 2006, respectively. The Hargreaves-Samani method yielded considerable overestimates (more than 25%) for both years. Total overestimation and under-estimation values in mm for the various methods are also shown in Fig. 4.

Table 2 presents a complete and clear picture of the monthly ET_o (summed daily values) for all the tested methods, including the variation of the mean percentage of over/underestimation for the summer months and for the two consecutive years (2005 and 2006). It is obvious that for a longer period (monthly average percent over/underestimation), the order of accuracy of the obtained results, compared with FAO56-PM estimates, is as follows: Copais (-3%), Priestley-Taylor (+5%), Turk (-5.3%), Adjusted Hargreaves (+9%), Makkink (-20%), and Hargreaves–Samani (30%).

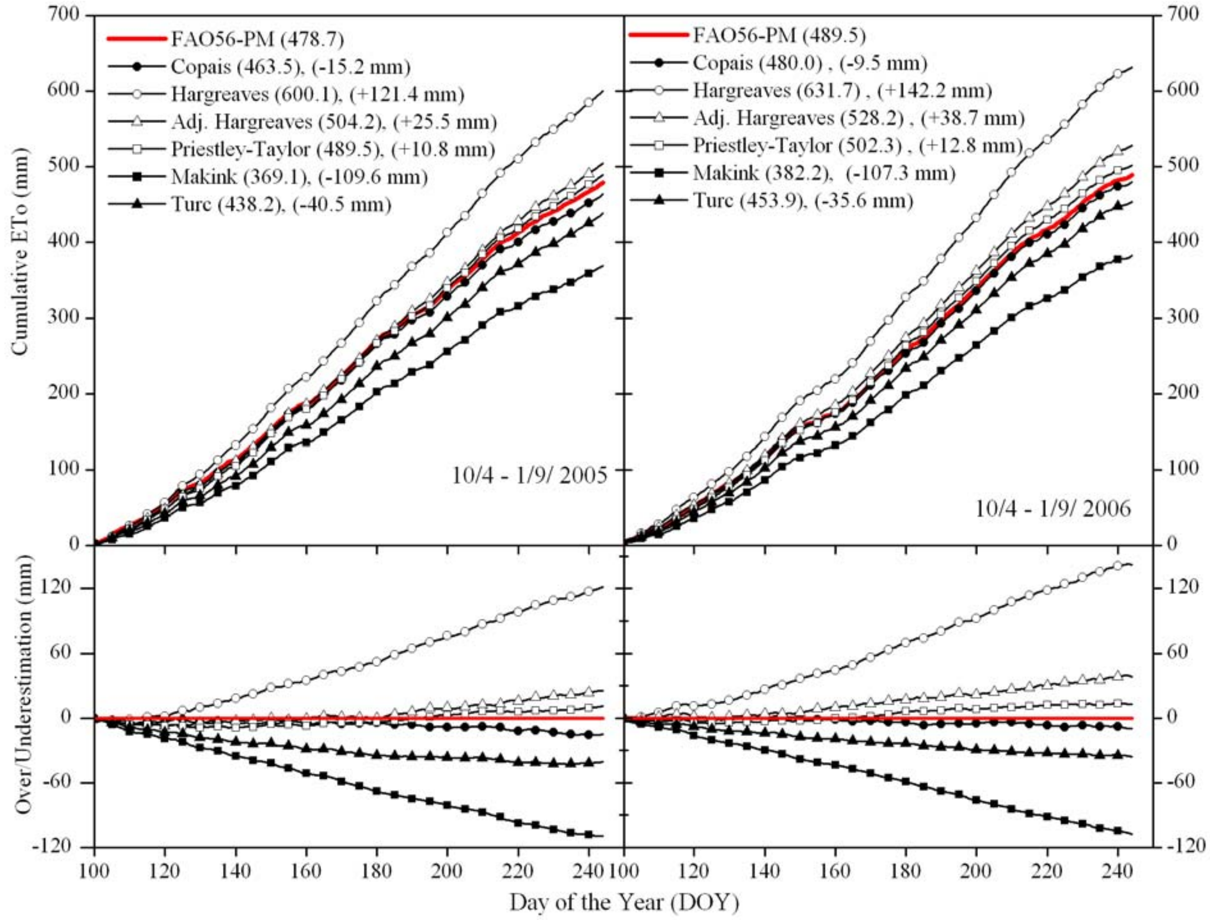

Figure 4. Cumulative ETo of evapotranspiration daily values and cumulative differences in relation with the FAO56-PM method (zero baseline) during the growing season period for the years 2005 and 2006..

Table 2.Monthly ETo values (summed daily) and monthly over/underestimation (± %) of methods relative to the FAO56-PM for the summer months of 2005 and 2006 respectively.

	FAO56 PM	**Copais**	**±**	**Hargreaves**	**±**	**Adjusted Hargreaves**	**±**	**Priestley Taylor**		**Makkink**	**±**	**Turc**	**±**
	mm/m	mm/m	%	mm/m	%	mm/m	%	mm/m	%	mm/m	%	mm/m	%
Summer 2005													
June	117.2	116.9	-0.3	141.1	20.4	118.0	0.7	119.7	2.2	91.4	-22.0	106.6	-9.0
July	112.8	110.0	-2.5	149.2	32.2	125.1	10.8	123.1	9.1	92.6	-17.9	110.2	-2.4
August	88.0	80.1	-9.0	119.2	35.4	101.0	14.7	91.8	4.3	67.6	-23.1	84.5	-4.0
Total	318.0	306.9	-3.5	409.4	28.7	344.1	8.2	334.6	5.2	251.6	-20.9	301.3	-5.3
Summer 2006													
June	104.9	100.7	-4.1	139.3	32.7	116.9	11.4	113.8	8.5	83.6	-20.3	98.7	-6.0
July	131.7	132.0	0.2	170.0	29.1	140.8	6.9	135.8	3.1	105.7	-19.8	124.0	-5.9
August	92.7	88.3	-4.8	125.5	35.3	105.4	13.7	95.7	3.2	72.4	-22.0	89.1	-3.9
Total	329.4	320.9	-2.6	434.8	32.0	363.1	10.2	345.3	4.8	261.7	-20.6	311.8	-5.3

5. CONCLUSIONS

The objective of this study was to provide guidance on the selection of the most appropriate ET equation for Serbia's climatic conditions. Six ET_o methods were evaluated relative to the FAO56-PM, under humid conditions which are prevalent in the Radmilovac area. The Food and Agriculture

Organization Penman-Monteith FAO56-PM equation was used as the basis for comparison with the other methods.

Overall results indicate that some of the simpler empirical equations compare reasonably well with the FAO-56 PM method during the warm months, while several other methods produced ETo estimates which significantly differ from those obtained by the FAO56-PM method. The Priestley-Taylor method ranked first among the methods evaluated. The Copais method ranked second with regard to statistical analysis on a daily basis data. The third and forth place were occupied by the Turc and Adjusted Hargreaves methods, respectively. The fifth was the Makkink method, which produced significant underestimates. Finally, the original Hargreaves-Samani equation was ranked below the other five methods due to its consistently high overestimates.

The results of this study are proposed as a reference tool; it can be used to provide practical guidance on which method to select, based on available data, for accurate and consistent estimates of daily ET_o relative to the FAO56-PM method, under humid conditions.

Optimum selection by the user among the tested methods depends on several factors. The most important are the accuracy of method and the availability of meteorological parameters. The latter factor alone should not be a unique selection criterion since some of the data can be estimated with acceptable accuracy from other meteorological variables (e.g., solar radiation during bright sunshine hours), to allow for better reference evapotranspiration estimation method to be used.

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