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AN EVALUATION AND COMPARISON OF REFERENCE CROP EVAPOTRANSPIRATION IN CLIMATIC CONDITIONS OF ALBANIA

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SYNOPSIS

In this study, a comprehensive comparison of major reference evapotranspiration equations for grass and alfalfa references was conducted using hourly and daily weather data from geographically diverse sites in Albania. Calculations were performed for both grass (ET_0) and alfalfa reference crop (ET_r) in a consistent manner using weather data passed integrity and quality assessment checks. In order to maintain consistency in computation of ET_0 and ET_r at all locations, the equations were applied using REF-ET, a software program for computing reference ET applying a variety of equations. The results were compiled and summarized so that comparisons could be made between: **(a)** daily values by a given method and daily values by the full-form ASCE-PM equation; **(b)** sum-of-hourly and daily values by a given ET method; **(c)** sum-of-hourly values by e given method and daily values by the full-form ASCE-PM. Comparisons were quantified as ratios and as Root Mean Square Differences (RMSD) among estimating methods The ASCE standardized equation (ET_{0s} and ET_{0r}) showed best agreement between sum-of-hourly and daily computations. ASCE-PM applied daily very closely, including that the adopted simplifications of the standardized equations will have minimum impact on ET estimates. The Hargreaves daily equation had the largest deviation from the ASCE-PM equation, followed by the 1963 Penman equation.

INTRODUCTION

Reference crop evapotranspiration computation forms an integral part of agricultural and urban landscape water management planning and regional water balance studies. Because direct measurement of ET_0 is difficult, time consuming, and costly, the most common procedure is to estimate ET_0 using climate data. Numerous methods have been introduced for computing ET_0, causing confusion among growers, consultants, extension educators, and decision and policymakers as to which method to select for ET_0 estimation. Reference ET equations range in sophistication from empirical solar radiation, or temperature based equations to complex resistance based equations. The widely used reference equations are of combination type and include various versions of the original Penman equation and Penman-Monteith ET equations. Another popular method is the empirical Hargreaves equation.

Studies have shown that reference ET computed using Penman-Monteith (PM) equation yields estimates close to observed reference ET values (Allen, 2001; Allen et al., 2000; Ventura et al. 1999; Howell et al. 2000; Wright et al. 2000). The FAO has recommended use of the PM method to compute reference ET from a grass surface and has standardized a form of the PM (FAO56-PM) as a grass reference equation (Allen et al., 1998). Among the empirical methods, the temperature based method of Hargreaves and Samani (1985) has provided good results for various regions (Jensen et al., 1990; Allen et al., 1998).

The numerous reference ET equations and versions in existence have resulted in some confusion as to appropriate equation to apply to particular climate and region. To facilitate a better understanding, sharing, and transfer of ET information, there is a need for a commonality in the quantification of reference ET among the various users of fresh-water resources for agricultural production and landscaping.

In order to highlight the above comments, this paper describes the methodology used and summarizes the results of the comparisons of five common different methods used for estimation of reference evapotranspiration in 21 geographically diverse sites in Albania.

MATERIALS AND METHODS

Weather data sets were obtained from 21 sites. One or two years of data were furnished per station. The data covered at least the growing season and, in many cases, the entire calendar year. Growing seasons were generally defined as April to October. The geographic and climatic diversity of the sites is evident (Table 1).

STUDY SITES AND CLIMATE DATA

This section describes requirements, equations, and procedures for calculations grass-reference evapotranspiration (ET_0) on a daily and hourly time step and over a relatively wide range of climates and over a range of elevations. These computations were made using carefully screened hourly weather data obtained from 21 regions having diverse climates. Hourly weather variables included rainfall, maximum and minimum air temperature, relative humidity, wind speed and direction, and solar radiation.

Table 1: Summary of the main characteristics of meteorological stations used in study.

Meteorological station	Longitude (degrees)	Latitude (degrees)	Elevation (m)	Mean annual precipitation (mm)	Peak-month mean ASCE-PM ET_0 (mm d^{-1})
Shkodër	42^0 06'	19^0 32'	43	1884	5.70
Kukës	42^0 02'	20^0 25'	354	910	5.68
Pukë	42^0 02'	19^0 54'	810	2102	4.98
Lezhë	41^0 47'	19^0 38’	20	1363	5.96
Peshkopi	41^0 41'	20^0 26'	657	995	5.18
Burrel	41^0 36'	20^0 00'	309	1197	4.92
Tiranë	41^0 20'	19^0 47'	89	1219	5.33
Durrës	41^0 18'	19^0 27'	15	931	5.17
Librazhd	41^0 11'	20^0 19'	250	1361	5.01
Elbasan	41^0 05'	20^0 03'	100	1148	5.36
Lushnjë	40^0 57'	19^0 42'	19	918	6.10
Pogradec	40^0 54'	20^0 39’	720	748	4.86
Fier	40^0 44'	19^0 31'	12	941	5.95
Berat	40^0 43'	19^0 57'	226	901	5.92
Korçë	40^0 36'	20^0 44'	899	765	5.70
Çorovodë	40^0 30'	20^0 13'	410	1000	5.15
Vlorë	40^0 28'	19^0 29'	2	892	5.99
Ersekë	40^0 20'	20^0 41'	1030	925	4.76
Përmet	40^0 14'	20^0 21'	240	1205	5.22
Gjirokastër	40^0 05'	20^0 09'	193	1833	6.53
Sarandë	39^0 52'	20^0 00'	23	1196	6.32

The accuracy of ET_0 computations depends on the quality and integrity of the weather data used. Following the procedures outlined by ALLEN et al. (1998), and WALTER et al. (2001) all datasets that were used in our analyses were acceptable for hourly ET_0 comparisons.

METHODS EVALUATED

In this paper performance of ET_0 and ET_r equations, is evaluated. A listing of the equations and a brief description is provided in following sub-sections.

ASCE PENMAN-MONTEITH METHOD. The well known ASCE Penman-Monteith equation (Jensen et al., 1990) is referred to here as full-form version of the ASCE Penman-Monteith equation, which can be applied to both grass and alfalfa reference surfaces using aerodynamic (r_a) and surface (r_s) resistance functions that vary with vegetation height. The resistance algorithms of the full-form ASCE-PM method and associated leaf area functions by ALLEN et al. (1998) predict r_s for a grass reference having 0.12 m height as 70 s m^{-1}, and r_s for alfalfa having 0.5 m height as 45 s m^{-1}. These parameters have been fixed at these values, only for a daily time step, in the standardized method describes below. The ASCE-PM equation can be used for hourly or daily time step. Several studies have shown the relatively good and consistent agreement of the ASCE-PM to measured ET values in various climates (Allen et al., 1998; Howell et al., 2000; Wright et al., 2000).

The Penman-Monteith form of the combination equation is:

$$ET_r = \left(\frac{\Delta(R_n - G) + K_{time}\, \rho_a\, c_p\, \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \right) / (\lambda\, \rho_w) \qquad (1)$$

where ET_r = reference evapotranspitarion (mm d^{-1}); R_n = net radiation (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}); G = soil heat flux (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}); (e_s – e_a) = vapor pressure deficit of the air (kPa); e_s = saturation vapor pressure of the air (kPa); e_a = actual vapor pressure of the air (kPa); ρ_a = mean air density at constant pressure (kg m^{-3}); c_p = specific heat of the air (MJ kg^{-1} $^0C^{-1}$); Δ = slope of the saturation vapor pressure temperature relationship (kPa $^0C^{-1}$); γ = psychrometric constant (kPa $^0C^{-1}$); r_s = (bulk) surface resistance (s m^{-1}); r_a = aerodynamic resistance (m s^{-1}); ρ_w = density of water (Mg m^{-1}); λ = latent heat of vaporization (MJ kg^{-1}), and ρ_w = density of water (MJ m^{-3}) taken as 1.0 Mg m^{-3}, and K_{time} = units conversion, equal to 86 400 s d^{-1} for ET in mm d^{-1} and equal to 3 600 s h^{-1} for ET in mm h^{-1}.

The aerodynamic resistance, applied for neutral stability conditions, is:

$$r_a = \frac{\ln[\frac{z_w - d}{z_{om}}]\, \ln[\frac{z_h - d}{z_{oh}}]}{k^2\, u_z}$$

where z_w = height of wind measurements (m); z_h = height of humidity and air temperature measurements (m); d = zero plane displacement height (m), = 0.67 h; z_{om} = roughness length governing momentum transfer (m), = 0. 123 h; z_{oh} = roughness length for transfer of heat and vapor (m) = 0.0123 h; u_z = wind speed at height z (m s^{-1}); k – von Karman constant (k = 0.41), and h = mean height of the vegetation (m).

Bulk surface resistance is:

$$r_s = \frac{r_l}{LAI_{active}}$$

where r_l = effective stomatal resistance of well-illuminated leaf (s m^{-1}), and LAI_{active} = active (sunlit) leaf area index [m^2 (leaf area) m^{-2} (soil surface)]. For ASCE calculation for dense vegetation, LAI active is calculated as:

LAI_{active} = 0.5 LAI

where LAI = leaf area index (m^2 of leaf per m^2 of soil surface). For clipped grass LAI = 24 h, and for alfalfa LAI = 5.5 + 1.5 ln (h), where h = vegetation height.

ASCE STANDARDIZED PENMAN-MONTEITH METHOD. The standardized equation is derived from the ASCE Penman-Monteith equation, by simplifying several terms within the equation. The standardized ASCE-PM equation is intended to simplify and clarify the application of the method and associated equations for computing aerodynamic and bulk surface resistance (r_a and r_s, respectively). As a part of the standardization, the full-form of the Penman-Monteith equation and associated equations for calculating aerodynamic and bulk surface resistance have been combined and reduced to a single equation having two constants. The standardized equation, with appropriate constants provided in an accompanying Table 2, is used to calculate evapotranspiration for the standardized short reference (ET_{0s}) and/or evapotranspiration for the standardized tall reference (ET_{rs}). The constants vary as a function of the reference surface and time step (hourly or daily). Equations were combined into a single expression for both grass and alfalfa-reference surface and for a 24h or an hourly time step by varying coefficients (Walter et al., 2001). Computation of standardized short grass ET_0 with a 24h time step uses a grass height 0.12 m and an r_s value of 70 s m^{-1}, which is the same as for the FAO56-PM equation (Allen et al., 1998). For hourly time step, r_s is set 50 s m^{-1} for daytime hours and to 200 s m^{-1} for nighttime hours.

The ASCE combined standardized reference equation is listed in Eq. (2), and values for C_n and C_d are listed in Table 3.

$$ET_{sz} = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{C_n}{T + 273}\,u_2\,(e_s - e_a)}{[\Delta + \gamma\,(1 + C_d\,u_2)]} \qquad (2)$$

where ET_0 = standardized grass-reference ET (mm d^{-1} or mm h^{-1}); Δ = slope of saturation vapor pressure versus air temperature curve (kPa $^0C^{-1}$); R_n = calculated net radiation at the crop surface (MJ m^{-2} d^{-1} for 24 h time step, or MJ m^{-2} h^{-1} for hourly time steps); G = heat flux density at the soil surface (MJ m^{-2} d^{-1} for 24 h time step, or MJ m^{-2} h^{-1} for hourly time steps); T = mean daily or hourly air temperature at 1.5 to 2.5 m (^0C); u_2 = mean daily or hourly wind speed at 2 m height (m s^{-1}); e_s= saturation vapor pressure at 1.5 to 2.5 m height above surface (kPa); e_a= actual vapor pressure at 1.5 to 2.5 m height above surface (kPa); $e_s - e_a$ = vapor pressure deficit (kPa); γ = psychrometric constant (kPa $^0C^{-1}$); C_n = numerator constant (in ^0C mm s^3 Mg^{-1} d^{-1}), and C_d = denominator constant (in s m^{-1}) that change with reference surface and calculation time (Table 3).

Table 2: ASCE Penman-Monteith term standardized for the standardized reference evapotranspiration equations.

Term	ET_0	ET_r
Reference vegetation height, h	0.12 m	0.50 m
Height of air and humidity measurements, z_h	1.5 – 2.5 m	1.5 – 2.5 m
Height of wind measurements, z_w	2.0 m	2.0 m
Zero plan displacrmrnt heigh, d	0.08 m	0.08 m
Heat of vaporization, λ	2.45 MJ kg^{-1}	2.45 MJ kg^{-1}
Surfice resistance, r_s, daily	70 s m^{-1}	45 s m^{-1}
Surface resistance, r_s, daytime	50 s m^{-1}	30 s m^{-1}
Surface resistence, r_s, nighttime	200 s m^{-1}	200 s m^{-1}
R_n to predict daytime	> 0	> 0
R_n to predict nighttime	≤ 0	≤ 0

Table 3: Values for C_n and C_d in Eq. 1.

Calculation time step	Short reference (ET_{0S})		Tall reference (ET_{rs})		Units for ET_{0S}, ET_{rs}	Units for Rn, G
	C_n	C_d	C_n	C_d		
Daily	900	0.34	1 600	0.38	mm d^{-1}	MJ m^{-2} d^{-1}
Hourly or shorter during daytime*	37	0.24	66	0.25	mm h^{-1}	MJ m^{-2} h^{-1}
Hourly or shorter during nighttime*	37	0.96	66	1.7	mm h^{-1}	MJ m^{-2} h^{-1}

* For application of the standardized equation, daytime is defined as when net radiation, R_n, for the period if greater or equal to zero; nighttime is defined as when R_n, for the period is less than zero.

FAO-56 PENMAN-MONTEITH METHOD. The FAO has adopted the FAO-56-PM equation as a standard for reference ET computation. The FAO-56-PM equation is a grass reference ET equation derived from the ASCE-PM by fixing parameter values for the grass reference surface (height = 0.12 m, r_s = 70 s m^{-1}, and albedo = 0.23) and specifying the measurement heights for weather parameters. The aerodynamic resistance (r_a) becomes a function of measured wind speed. The latent heat of vaporization (λ) is assigned a constant value of approximately 2.45 MJ kg^{-1}. The FAO-56-PM can be used for hourly or daily time steps based on a constant r_s. The form of the FAO56-PM equation for hourly time step (Allen et al., 1998) is:

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{37}{T+273} u_2\,(e_s - e_a)}{[\Delta + \gamma\,(1 + 0.34\,u_2)]} \qquad (3)$$

where ET_0, R_n and G are in MJ m^{-2} h^{-1}.

The 24h form and coefficients for the FAO56-PM method are the same as for the ASCE standardized equation (Eq. 1), where C_n = 900 and C_d = 0.34. The standardized ASCE-PM and FAO56-PM equations use essentially the same procedure for computing hourly and 24h values of G, R_n, and other parameters. The hourly G in both the ASCE-PM and FAO56-PM equations is estimated as a function of R_n for day and nighttime as (ASCE-EWRI, 2004):

$$G_{\text{h-daytime}} = 0.1\,R_n \qquad (4)$$

$$G_{\text{h-nighttime}} = 0.5\,R_n \qquad (5)$$

For more detailed information on the computation of hourly or 24 h time step ET_0 refer to the REF-ET user manual (Allen, 2001) and ASCE-EWRI (2004).

1963 PENMAN METHOD. The classical form of the Penman method (Penman, 1963) is:

$$ET = \left(\frac{\Delta}{\Delta+\gamma}(R_n - G) + K_w \frac{\gamma}{\Delta+\gamma}(a_w + b_w\,u_2)(e_s - e_a)\right) / (\lambda\,\rho_w)$$

where K_w = is a units constant; a_w and b_w = are wind function coefficients; u_2 = wind speed at 2 m (m s^{-1}); λ = latent heat of vaporization (MJ kg^{-1}), and ρ_w = density of water (Mg m^{-3}).

All other terms and definitions are the same as those using for the Penman-Monteith method. Parameter K_w = 6.43 for ET in mm d^{-1} and K_w = 0.268 for ET in mm h^{-1}.

HARGREAVES METHOD. The Hargreaves method (Hargeaves & Saman, 1985) for computing daily grass ET is a simple, empirical approach that has been used in case where the availability of weather data is limited. This method requires only measurements of maximum and minimum temperature, with extraterrestrial radiation calculated as a function of latitude and day of the year, and can be applied on 24 – hour, weekly, 10-day or monthly time steps. It has the form:

$$ET_0 = 0.0023\,(T_{max} - T_{min})\,0.5\,(T_{mean} + 17.8)\,R_a$$

where ET_0 = grass reference ET (mm d^{-1}); T_{max} = maximum daily air temperature (^{0}C); T_{min} = minimum daily air temperature (^{0}C); T_{mean} = mean daily air temperature, $T_{mean} = (T_{max} + T_{min})/2$; R_a = extraterrestrial radiation (mm d^{-1}).

DESCRIPTION OF EVALUATION

The equations above mentioned were evaluated using REF-ET (ASCE-EWRI, 2004). REF-ET is a software program capable calculating reference ET by using up to fifteen of the more common methods. Data evaluated was from 21 sites and covered site-years of data. It is made a concerted effort to insure that the data spanned a wide range of elevation (2 to 1030 m), mean annual precipitation (761 to 2102 mm), and peak monthly ET (4.76 to 6.53 mm d^{-1}). The significant benefit of using REF-ET was that the output was standardized which improved the efficiency of the analysis.

Daily and hourly ET amounts from all the sites were calculated. Then, the ET was compiled and several equation-to-equation comparisons were conducted. The comparisons were made for both ET_0 and ET_r. The ratio of each equation's ET estimate are analyzed (for both ET_0 and ET_r calculated with different methods) to that of ASCE-PM, the Root Mean Square Difference (RMSD), and the RMSD as percentage of mean ASCE-PM. For each of the site years, the statistics were summarized using the growing season ET and, if available, the full year ET.

For each site-year, reference ET computations were made for daily and, in most cases, hourly time steps once the weather data to be used were verified. Then the reasonableness of program outputs was checked. Hourly ET outputs were summed for each day to provide a daily total ET, referred to as sum-of-hourly outputs.

STATISTICAL ANALYSES

Simple statistics were calculated to describe both the sum-of-hourly and daily outputs for each site, year, and ET equation. These summary statistics included the maximum, minimum, mean, and standard deviation of ET calculations. This was done for the growing season and also for the full year if data were available. For the case of full year of data, the maximum, minimum, mean and standard deviation for 365 days values were determined. Parallel calculations were made for up to 365 days per year of sum-of-hourly data. Statistics were calculated for each ET_0 and ET_r equation. Concurrently, the root-mean-square difference (RMSD) was calculated for purposes of comparing one reference ET method to another, or for comparing sum-of-hourly to daily values. The RMSD was calculated as:

$$\mathrm{RMSD} = \left[\frac{\sum_{i=1}^{n} (x_i - y_i)^2}{n} \right]^{1/2}$$

where x_i is ET calculated by method x on day i; y_i = ET calculated by method y on day i, and n = total number of observations.

RESULTS AND DISCUSSION

Comparison and analysis of reference ET calculation were approached in several ways, given the various methods for calculating both ET_0 and ET_r, the option of hourly or daily time steps for most of these methods, and the site-years data. In this paper, emphasis is given to growing seasons comparisons because these are the periods of most interest in agriculture, in that they are characterized by active vegetation growth pertaining to the reference ET computation.

The comparison results for all the reference ET equations evaluated are divided into the following three sections:

- For each method, comparisons are made between the daily reference ET values and daily values calculated using the ASCE Penman-Monteith method. The ASCE-PM was chosen as a benchmark for comparison because it is a well-recognized equation that has been shown, at most locations, to accurately track ET measurements made under reference conditions.
- For each method, comparisons are provided between the sum-of-hourly reference ET values and the daily calculations by the same method. This provides a measure of the method's internal consistency when using two different time steps.
- For each method, comparisons are provided between the sum-of-hourly reference ET values and the daily values calculated using the full-form ASCE Penman-Monteith method. This comparison is essentially a hybrid of the first two comparisons.

Table 4 quantitatively summarizes the comparisons made between the values reference ET methods. In essence, the full-form ASCE-PM equation, applied daily, was used as a comparator basis for reference ET_0 and ET_r.

DAILY CALCULATED VERSUS DAILY ASCE-PM

The top third of Table 4 summarizes comparisons between a particular method's daily reference ET_0 and the daily ET_0 calculated by the full-form ASCE-PM method for sites. Table 4 includes a statistical summary of ratios and RMSDs. As an example for interpreting the Table 4, the ratios comparing daily FAO-56-PM ET_0 to the daily ASCE-PM ET_0 for annual growing seasons and had a maximum of 1.034, a minimum of 0.985, a mean of 0.993, and a standard deviation of 0.008 over all site-years. In other words, when averaged over the growing season for each of the sites-years, the daily FAO-56-PM ET_0 values were as much as 0.5 % higher for one site-year, and as much as 2.1% lower for another site-year, than the values calculated using the daily full-form ASCE-PM equation, with the average being about 0.8% lower. The mean RMSD for all site-years was 0.041 mm d^{-1}, with a maximum of 0.163 and a minimum of 0.006 mm d^{-1}. In the final column of Table 4 the mean RMSD for each site-year is expressed as a percentage of the mean daily ASCE-PM for the growing season, and then averaged over all site-years. This, in effect, normalizes the RMSD based on the magnitude of ET.

Table 4: Statistical summary of comparisons between various reference ET methods for growing season periods from site-years of daily and of hourly data.

Method	Ratio				RMSD (mm d^{-1})				RMSD as percentage of mean
	Max	Min	Mean	Standard deviation	Max	Min	Mean	Standard deviation	
(a) Daily ET_0 versus ASCE-PM ET_0									
FAO56-PM	1.034	0.985	0.993	0.008	0.163	0.006	0.041	0.042	0.9
ASCE Standardized	1.037	0.986	0.997	0.007	0.149	0.007	0.046	0.040	1.1
1963 Penman	1.236	0.998	1.077	0.041	0.785	0.187	0.451	0.096	10.6
Hargreaves	1.434	0.793	1.063	0.131	2.135	0.744	0.937	0.312	23.3
(b) Daily ET_r versus ASCE-PM ET_r									
ASCE Standardized	1.031	0.985	0.999	0.013	0.309	0.019	0.071	0.068	1.8
1963 Penman	1.115	0.904	0.997	0.051	1.695	0.158	0.566	0.259	10.4
(c) Sum-of-hourly ET_0 versus daily ET_0 (within method)									
ASCE-PM	1.054	0.923	0.967	0.056	0.887	0.207	0.387	0.145	9.5
FAO56-PM	1.049	0.917	0.963	0.048	0.886	0.206	0.915	0.157	10.4
ASCE Standardized	1.093	0.949	1.024	0.033	0.721	0.267	0.387	0.109	7.9
1963 Penman	1.197	0.961	1.046	0.044	1.354	0.198	0.488	0.203	11.2
(d) Sum-of-hourly ET_r versus daily ET_r (within method)									
ASCE-PM	1.042	0.936	0.957	0.045	1.564	0.232	0.599	0.245	12.4
ASCE Standardized	1.125	0.987	1.012	0.401	1.1014	0.402	0.561	0.208	10.1
(e) Sum-of-hourly ET_0 versus daily ASCE-PM ET_0									
ASCE-PM	1.058	0.932	0.962	0.048	0.912	0.214	0.394	0.154	9.6
FAO56-PM	1.052	0.913	0.986	0.051	0.998	0.269	0.421	0.654	10.2
ASCE Standardized	1.098	0.964	1.012	0.038	0.705	0.264	0.398	0.954	8.8
1963 Penman	1.215	1.025	1.164	0.521	1.134	0.399	0.713	0.187	16.7
(f) Sum-of-hourly ET_r versus daily ASCE-PM ET_r									
ASCE-PM	1.054	0.913	0.987	0.046	1.421	0.289	0.612	0.287	10.8
ASCE Standardized	1.124	0.954	1.068	0.039	1.123	0.368	0.598	0.196	9.9

As shown in Table 4, both the FAO56-PM and standardized ASCE-PM equation calculated ET_{0s} are very close to the ASCE-PM values. This is to be expected since the two equations are simplified versions of the full-form ASCE-PM. Estimates from the both the 1963 Penman and the Hargreaves equations tented to be higher (7.7

and 6.3%, respectively) than the ASCE-PM ET_0. The temperature-based Hargreaves method exhibited greater variability from the site to site relative to the ASCE-PM calculations, as indicated by the standard deviation of the ratio and the mean of the RMSD. For ET_r, the ASCE standardized had mean ratio very near 1.0. This is expected because the ASCE standardized equation is derived directly from the ASCE-PM.

Mean daily ET_0 calculations plotted in figure 1a show that the Hargreaves equation tended to predict greater ET_0 than ASCE-PM when mean daily ET_0 for growing season was relatively low, and predicted less ET_0 than the ASCE-PM when ET_0 was relatively high. The 1963 penman predicted an average 8% greater ET_0 than the ASCE-PM, and differences between the two methods seem to be independent of ET_0 magnitude. Figure 1b indicates that 1963 Penman ET_r estimates are slightly greater than ASCE-PM at location where ET is relatively low, and about 6% less than ASCE-PM at locations where ET is relatively high.

Most importantly, it is found that reduced forms of ASCE-PM, using constants for λ (heat of vaporization) and r_s (surface resistance), resulted in a limited loss in accuracy (+ or – 1% error).

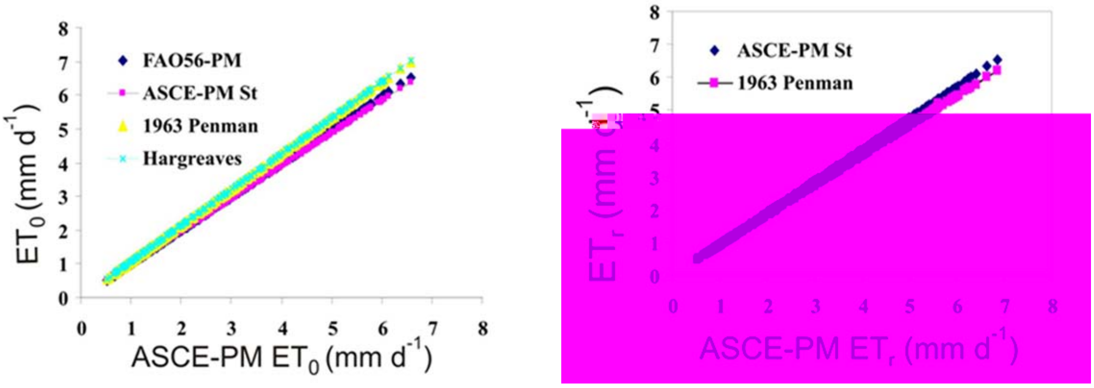

Figure 1: Mean daily reference ET for particular methods versus mean daily reference ET by ASCE-PM equation.

SUM-OF-HOURLY VERSUS DAILY (WITHIN METHOD)

Central portion of Table 4 summarizes comparisons made between the sum-of-hourly reference ET by a given method and daily calculations for the same method. Ratios represent seasonal average 24-h ET computed hourly to seasonal mean ET computed daily. The RMSD for the growing season was calculated as the RMSD between the sum-of-hourly values and their corresponding daily values. The results from analyses for all sites and years included ratios and RMSDs (entries for each site and each year having both hourly and daily data).

The center portion of Table 4 includes summaries for four ET_0 methods and two ET_r methods. Among the four ET_0 methods analyzed, the ASCE standardized reference equation (ET_{0s}) had best agreement between sum-of-hourly values of ET_0

(sum-of-hourly were 2.4% higher than daily ET_0 estimates, on average). Good agreement between sum-of-hourly and daily ET, based on means and standard deviations of ratios and means and standard deviations of RMSD, was one of the key factors (along with lysimeter measurements) in adopting surface resistance (r_s) values to use in hourly application of the standardized equations. The full-form ASCE-PM and FAO56-PM equations, which use the same resistance values for hourly as for daily, tended to calculate lower ET when applied hourly and summed daily than when applied to daily time steps. The opposite was true for the 1963 Penman equation, which showed the greatest inconsistency between sum-of-hourly and daily values.

With regard to ET_r, there was good agreement between sum-of-hourly and daily ET_r calculation for the ASCE standardized equation (summed hourly was about 1.2% higher than daily). The full-form ASCE-PM equation, which used the same r_s for hourly and daily time steps, showed greater differences (summed hourly was about 4% lower than daily across all sites), and the mean RMSD was slightly higher than for other two methods.

SUM-OF-HOURLY VERSUS DAILY ASCE-PM

The third type of comparison was made between the sum-of-hourly calculations using a particular method and daily calculations by the ASCE-PM equation. As summarizes in the bottom portion of Table 4, the sum-of-hourly predictions by the ASCE standardized PM equation agreed more closely with the daily full-form ASCE-PM method than did the sum-of-hourly base on full-form ASCE-PM. This is true for both ET_0 and ET_r, and is due to the use of lower values for daytime r_s in the standardized equation.

CONCLUSIONS

Analyses used hourly and daily weather data from geographically diverse sites in the Albania. Calculations were performed for both grass and alfalfa reference crop in a consistent manner, using weather data that passed integrity and quality assessment checks. Comparisons were made between reference ET computed by the various methods and ASCE Penman-Monteith equation used for a daily calculation time step. In addition, calculations using hourly time steps and summed daily were compared with daily calculations for the same method as well as the ASCE-PM method.

The statistical summary listed in Table 4 shows that the hourly summed ET versus daily ET for the standardized ASCE-PM performed as well or better than the ASCE-PM hourly summed ET versus to daily ET. Comparisons of daily ET_0 to daily ASCE-PM ET_0 and daily ET_r to daily ASCE-PM ET_r show a very small difference.

Therefore, the simplifications have a minimum impact on reference ET estimates. The third comparison of hourly sums of ET_0 and ET_r to daily ASCE-PM shows that the ET_0 and ET_r agree more closely to the ASCE-PM daily values.

Results showed that the standardized ASCE-PM equation agreed best with the full-form ASCE-PM. The results provide a basis for objectively assessing the relative performance of reference ET equation in a variety of climates. The reference evapotranspiration evaluation in this study found that the standardized ASCE-PM equation describes in this paper provides accurate estimates of ET_0 and ET_r.

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