Estimating Reference Evapotranspiration Using Two Different Models of Penman-Monteith Method for Climatic Conditions of Albania

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Abstract

In this study two different models of Penman-Monteith method are used to estimate grass-reference evapotranspiration (ET_0) over a range of climate at six locations based on hourly and daily (24 h) weather data time periods: FAO-56 Penman-Monteith (FAO56-PM) and standardized ASCE Penman-Monteith (ASCE-PM). Hourly ET_0 computations were summed over 24 h periods and reported as sum-of-hourly. The sum-of-hourly ASCE–PM ET_0 values ($ET_{0,h,ASCE}$) were compared with the 24 h time step ASCE-PM ET_0 values and with the sum-of-hourly FA056-PM (respectively $ET_{0,d,ASCE}$, $ET_{0,h,FAO56}$). The $ET_{0,h,ASCE}$ values were used as the basis for comparison. The values $ET_{0,h,FAO56}$ correlated well with values $ET_{0,d,ASCE}$ ($r^2 \geq 0.990$), but estimated lower than $ET_{0,h,\ ASCE}$ at all location by 4% to 9 %. This was due to the impact of higher surface resistance during daytime periods. Summing the ET_0 values over multiple days and longer periods for peak ET_0 months resulted in inconsistent differences between the two time steps. The results suggest a potential improvement in accuracy when using the standardized ASCE-PM procedure applied hourly rather than daily. The hourly application helps to account for abrupt changes in atmospheric conditions on ET_0 estimation in advective and other environments when hourly climate data are available.

Keywords: *Albania, climate, evapotranspiration, Penman-Monteith, ASCE, surface resistance.*

Introduction

Reference crop evapotranspiration computation forms an integral part of agricultural and urban landscape water management planning and regional water balance studies. Accurate and consistent determination of ET in irrigated agriculture is becoming increasingly important for better planning and efficient use of water resources, especially in arid and semi-arid environments where lack of precipitation usually limits crop growth and yield. Accurate quantification of ET is also crucial to irrigated crop production, water allocation, irrigation scheduling, evaluating effects of changing land use on water yield, environmental assessment to protect surface and ground water quality.

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.

In May 1990, FAO organized a consultation of high-level experts and researchers in collaboration with the International Commission for Irrigation and Drainage and with World Meteorological Organization, on review the FAO methodologies on crop water requirements and to advice on the revision and update of procedures. The panel of experts recommended FAO-56 Penman-Monteith method (Allen et al., 1998) as a new standard for reference evapotranspiration and as a sole method for determining ET_0. The method has been selected because it closely approximates grass ET_0 at the location evaluated, is physically based, and explicitly incorporates both physiological and aerodynamic parameters. Moreover, procedures have been developed for estimating missing climatic parameters. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data.

The American Society of Civil Engineering (ASCE) established a Task Committee on "Standardization of Reference Evapotranspiration Calculation", which recommended the use of the standardized ASCE Penman-Monteith method as the basis for "standardized" ET_0 computation (ASCE-EWRI, 2004). Equation parameters differ for hourly and 24 h (daily) data. The advantages of adapting a specific procedure as a standardized method were discussed by Allen et al. (2000) and Walter et al. (2001). Two important advantages are: providing commonality in computing ET_0, and enhancing the transferability of crop coefficients.

A literature review reveals that ET_0 methods are being mainly utilized for computation with a 24 h time step and not on a sum-of-hourly basis. Meanwhile, van Bavel (1966) suggested that the Penman equation was only valid for instantaneous or hourly data. He argued that sum-of hourly approach should provide a better representation of the effect of climatic conditions (solar radiation, air temperature, wind speed, and vapor pressure deficit) on daily ET_0. Allen et al. (2000) stated that computing ET_0 on an hourly or shorter time step has advantages of improved accuracy in locations where diurnal changes in wind speed and direction or cloudiness occur that are not typical of patterns at locations where 24 h ET_0 methods have been developed. Tanner and Pelton (1960), Pruitt and Lowrence (1966) recommended the use of hourly data for daily ET_0 estimation. Pruitt and Doorenbos (1977), Snyder and Pruitt (1985), and Ortega-Farias et al. (1995) pointed out the uncertainty exists when applying Penman-type equations using daily or longer-period mean weather data. Interaction between input parameters, including the daily-night distribution of wind speed, vapor pressure deficit, and level of solar and/or net radiation, can produce errors in computation of daily ET_0. Magnitude of the error depends on the trends and interactions among wind speed, vapor pressure deficit, temperature and radiation during the 24 h period. Differences in ET_0 computed using hourly and 24 h time steps are likely larger in environments where strong advection occurs (for example, during hot, dry and windy summer months in arid and semi-arid climates) as opposed to humid or sub-humid locations where wind speed are lower and advection is less severe.

It was also needed the evaluation of differences in ET_0 values caused by time step and method over growing seasons and calendar years. In addition, evaluations of the differences in ET_0 during the peak months is needed to assess the impact on peak values of reference ET that are needed for design and management of irrigation and drainage systems and water resources infrastructure. Furthermore, the variations between hourly and daily time step ET_0 computations with location are not known. It is important to emphasize the possible consequences of higher or lower estimations of ET. Lower estimations of ET will cause growers to underirrigate and this might impose stresses on the crops, thus negatively affecting plant growth and yield quantity and/or quality. Higher estimations of the ET will cause overirrigation and wasting of resources, with attendant increase in nutrient and pesticide leaching to the groundwater or other water bodies.

This study quantifies differences associated with using 24 h time step ET_0, as compared with sum-of-hourly computations with the standardized ASCE-PM and FAO56-PM methods for calendar years and peak months, for a selection of climate within the Albania.

Materials and Methods

a. 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. These computations were made using carefully screened hourly weather data obtained from six regions having diverse climates. Hourly weather variables included rainfall, maximum and minimum air temperature, relative humidity, wind speed and direction, and solar radiation.

The study sites provided an opportunity to compare performance of the ASCE-PM, and FAO56-PM computation procedures, and hourly and daily time steps, over a relatively wide range of climates and over a range of elevations. The geographic and climatic diversity of the sites is evident: site elevations ranges from 899 m at Korça to 4 m at Vlora, and mean annual precipitation from 760 mm at Korça to 2000 mm at Gjirokastra station. The mean ET_0 calculated for the peak month varies from 4.89 to 6.53 mm d^{-1}.

The accuracy of ET_0 computations depends on the quality and integrity of the weather data used (Allen et al., 1996; Itenfisu et al., 2003). Following the procedures outlined by Allen (1996), Allen et al. (1998), Temesgen et al. (1999), Walter et al. (2001), Droogers and Allen (2002), and Irmak et al. (2003), all datasets that were used in our analyses were acceptable for hourly ET_0 comparisons.

b. Statistical analyses

The standardized ASCE-PM sum-of-hourly ET_0 computations were used as the basis for comparison of ET_0 values. The reason for selecting this method as the basis was because several studies (Allen et al., 1966; Todorovic, 1999; Wright et al., 2000; Steduto et al., 2003) have shown that, in reality, for daytime hourly periods, r_s is less than 70 s m^{-1} for the standardized height of 0.12 m, which is used in FAO56-PM for clipped grass, and that lower r_s values (e.g., 50 s m^{-1} used in the standardized ASCE-PM method) would better represent clipped grass hourly r_s values under the field conditions.

The hourly ASCE-PM ET_0 were summed over each day to obtain daily values of ET_0 ($ET_{o,h,ASCE}$, were “h” stands for sum-of-hourly). Daytime and nighttime ET_0 values were summed. Comparison and statistical analyses between daily values of the sum-of-hourly ET_0 ($ET_{o,h,ASCE}$), 24 h time step ASCE ($ET_{o,d,ASCE}$, where “d” stands for daily), and sum-of-hourly FAO56-PM ET_0 ($ET_{o,h,FAO56}$) were conducted for all study years and growing seasons. Comparative and statistical analyses were performed for the peak ET_0 months. The root mean squared difference (RMSD) was used as a criterion to judge the accuracy and reliability of the methods. The standard deviation (SD) between sum-of-hourly and 24 h time step ET_0 values were also considered. The SD values were calculated to measure how widely the ET_0 values were dispersed from the average (mean ET_0) value. The RMSD between values were calculated as:

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

where n is the number of observations, x_i is the standardized sum of hourly ASCE–PM ($ET_{0,h,ASCE}$), and y_i is either the 24 h ASCE-PM or the sum-of-hourly FAO56-PM values ($ET_{0,d,ASCE}$ or $ET_{0,h,FAO}$). Because it is an indication of both bias and variance from the 1:1 line, RMSD provides an effective measure of how well datasets compare. Low RMSD values indicate better agreement.

A paired sample *t*-test (two-sample for means) was performed to identify whether $ET_{0,d}$ and $ET_{0,h,FAO}$ values were significantly different from the $ET_{0,h,ASCE}$ values at 5% significance level. The null hypothesis was that the $ET_{0,d}$ and $ET_{0,h,FAO}$ values and that hypothesized (null hypothesis) mean difference between ET_0 values was zero. The mean ratio (mean of years studied) for $ET_{0,d}$ and $ET_{0,h,FAO}$ to $ET_{0,h,ASCE}$ (% difference) was calculated and used to judge the performances. The coefficient of determination, slope, and intercept of the linear regressions between the ET_0 computation procedures were calculated. The same analyses were conducted to quantify and analyze the differences and performances for peak ET_0 months. The performance indicators were also calculated for multiple days (3-day sum) and longer periods (weekly, monthly, and annual sum) and analyzed to assess whether differences exist between daily and longer periods in comparisons of ET_0.

c. Reference evapotranspiration computation

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 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 24 h or an hourly time step by varying coefficients (Walter et al., 2001; Itenfisu et al., 2003). Computation of standardized short grass ET_0 with a 24 h 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. Equation 2 presents the form of the standardized ASCE-PM equation for all hourly and daily calculation time steps.

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{C_n}{T + 273} u_2\,(e_s - e_a)}{[\Delta + \gamma\,(1 + C_d\,u_2)]} \quad (2)$$

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 (kPa);
e_a = actual vapor pressure (kPa);
$e_s - e_a$ = vapor pressure deficit (kPa);
γ = psychrometric constant (kPa $^0C^{-1}$);
C_n = numerator constant that changes with reference surface and calculation time step (900 ^0C mm s^3 Mg^{-1} d^{-1} for 24 h time step and 37 ^0C mm s^3 Mg^{-1} d^{-1} for hourly time steps for the grass-reference surface);

C_d = denominator constant that changes with reference surface and calculation time step (0.34 s m^{-1} for 24 h time step, 0.24 s m^{-1} for hourly time steps during daytime, and 0.96 s m^{-1} for hourly nighttime for the grass-reference surface).

The 24 h form and coefficients for the FAO56-PM method are the same as for the ASCE standardized equation (eq. 2), where C_n = 900 and C_d = 0.34. The form of the FAO56-PM equation for hourly time step (Allen et al., 1998) is:

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

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

The ASCE-PM and FAO56-PM equations use essentially the same procedure for computing hourly and 24 h 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):

$$G_{h\text{-daytime}} = 01\,R_n \quad (4)$$

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

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).

Results and Discussion

The comparison and analysis of reference ET calculations were approached in two different models of Penman-Monteith method for calculating ET_0, and the option of hourly or daily time steps for these methods. In this paper, emphasis is given to ”peak” month because this is the period of most interest to agriculture, in that it is characterized by active vegetation growth pertaining to the reference ET computation.

For each side, reference ET calculations were made for daily and hourly time steps once the weather data to be used were verified. Hourly and daily grass reference ET was calculated using REF-ET for Windows, Version 1.0 Dg (Allen, 2001). Concurrently, the root-mean-square difference (RMSD) was calculated for purposes of comparing once reference ET method to another, or for comparing sum-of-hourly to daily values.

The comparison results for two of the reference ET equations evaluated are divided into the following four sections.

a. Comparison of 24 h time step ($ET_{0,d}$) and sum-of-hourly ASCE-PM ET_0 ($ET_{0,h,ASCE}$)

Comparison between $ET_{0,d}$ and $ET_{0,h,ASCE}$ for study sites is shown in figure 1. Table 1 summarizes performance indicators and statistical analyses. Results from the population statistics and *t*-test are shown in Table 2. Although the relationship between $ET_{0,d}$ and $ET_{0,h,ASCE}$ showed variation with location, the relationship was good at all locations. As example, Burreli and Korça had the lowest RMSD value (0.28 and 0.32 mm d^{-1}) among all sites, and Gjirokastra and Vlora had the highest (Table 1). The average ratio of $ET_{0,d}$ to $ET_{0,h,ASCE}$ ranged from 0.97 at Korça to 1.08 at Lushnja, indicating that the $ET_{0,d}$ estimated 3.9% lower than $ET_{0,h,ASCE}$ at Korça and estimated 7.8% higher at Lushnja for the calendar year. Vlora had similar results to Lushnja, with the $ET_{0,d}$ estimating 6.9% higher than $ET_{0,h,ASCE}$ (Table 1). The higher estimation by $ET_{0,d}$ in our study ranged from 1% at Tirana to 8% at Lushnja. Average ratios of $ET_{0,d}$ to $ET_{0,h,ASCE}$ were close to 1.0 for the Burreli and Tirana stations, ranging from 0.98 to 1.01 with lesser scatter around 1:1 line.

Table 1. Number of observations (n), root mean squared difference (RMSD), average ratio $ET_{0,d}$ to $ET_{0,h,ASCE}$ and regression coefficients between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values for the calendar year

Site	Number of observations	RMSD[(a)] (mm d^{-1})	Average ratio $ET_{0,d}/ET_{0,h,ASCE}$	a [(b)]	b [(b)]	r^2 [(b)]
Burreli	365	0.28 (1.27)	0.98	1.044	0.023	0.984
Tirana	365	0.33(1.36)	1.01	0.974	0.024	0.987
Lushnja	365	0.45(2.03)	1.08	0.919	0.02	0.991
Korça	365	0.32(1.33)	0.97	1.027	0.036	0.978
Vlora	365	0.42(2.09)	1.07	0.926	0.029	0.986
Gjirokastra	365	0.51(2.33)	1.04	0.959	0.014	0.994

[(a)] Values in parenthesis indicate standard deviation between $ET_{0,d}$ and $ET_{0,h,ASCE}$

[(b)] Regression coefficients where $ET_{0,d} = a\,ET_{0,h,ASCE} + b$

Table 2 shows that the $ET_{0,d}$ values were significantly different ($P < 0.5$) from the $ET_{0,h,ASCE}$ values. The null hypothesis was rejected for all locations.

Table 2. Statistics and results of paired sample *t*-test (two-sample for means) for the $ET_{0,d}$ versus $ET_{0,h,ASCE}$ (mm d^{-1}) values ($\alpha = 0.5$) for the calendar year

Site	Mean		Variance		$df^{(a)}$	t-test		$P_{0..05}$ [(b)]
	$ET_{0,h,ASCE}$	$ET_{0,d}$	$ET_{0,h,ASCE}$	$ET_{0,d}$		$t_{computed}$	$t_{critical}$	
Burreli	2.61	2.66	1.45	1.43	365	-3.3	1.64	*
Tirana	2.83	2.91	1.67	1.77	365	-4.8	1.64	*
Lushnja	3.67	3.71	3.39	3.01	365	16.7	1.64	*
Korça	2.72	2.64	1.71	1.94	365	18.9	1.64	*
Vlora	3.58	3.76	3.58	4.02	365	-10.4	1.64	*
Gjirokastra	3.39	3.66	3.44	4.75	365	12.7	1.64	*

[(a)] df = degrees of freedom (n – 1)
[(b)] * = significant at the 5% significance level

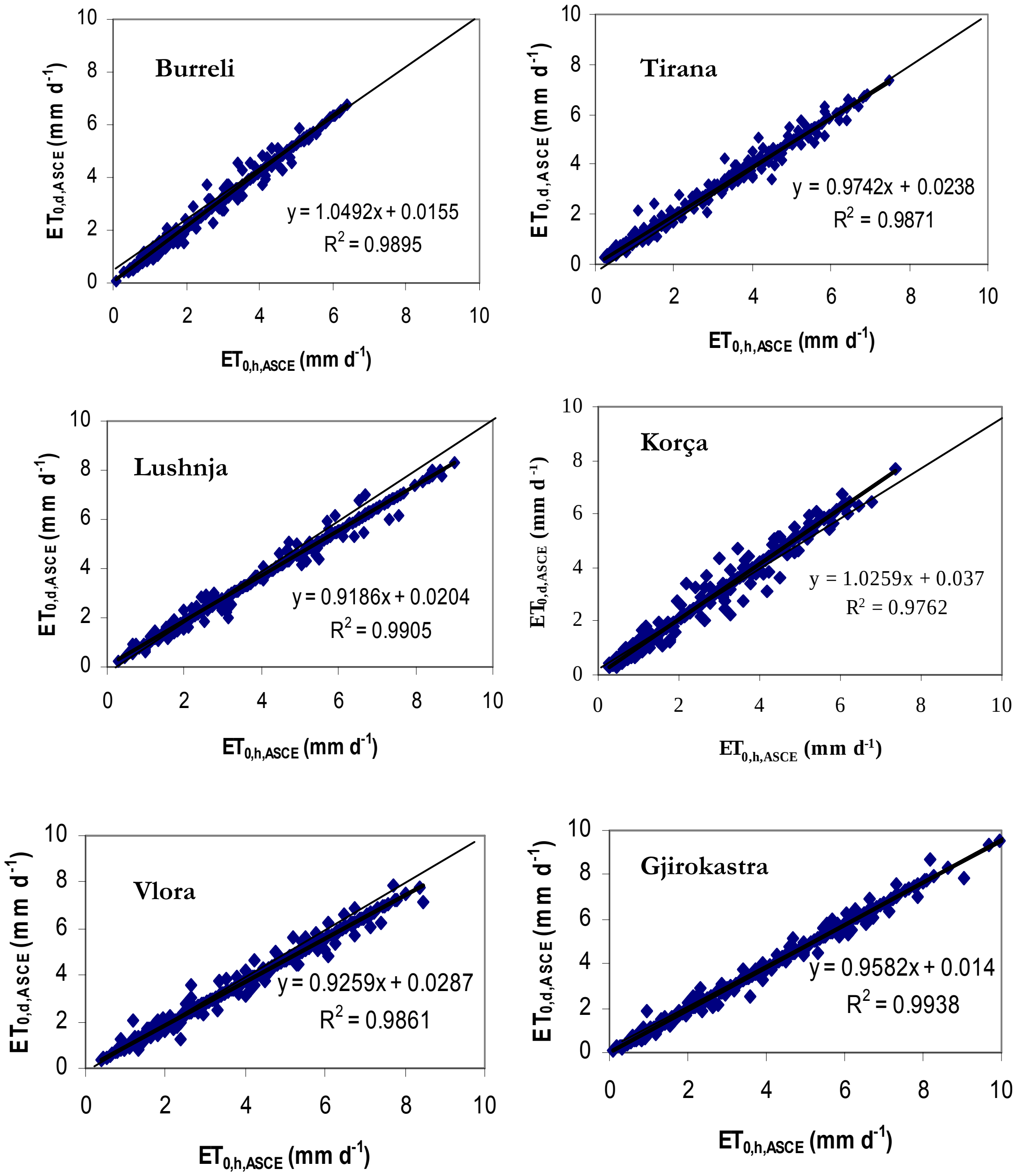

Fig. 1. Relationship between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values

b. Comparison of $ET_{0,d}$ and $ET_{0,h,ASCE}$ for peak month

In table 3 are summarized analyses for the peak ET_0. The month of peak ET_0 was selected as the month having a maximum monthly total ET_0 and not the month when the maximum daily ET_0 occurred. The agreement between $ET_{0,d}$ and $ET_{0,h,ASCE}$ for the peak month exhibited variation from one location to another, although ratios were still close to 1.0. For example, the RMSD value for Burreli, Korça and Tirana were lower (respectively 0.21, 0.23 and 0.24 mm d^{-1}) per peak ET_0 month than for entire year (respectively 0.28, 0.32, and 0.33 mm d^{-1}). In general, the $ET_{0,d}$ computation procedure estimated higher than the $ET_{0,h,ASCE}$ during the calendar year (Table 1) and estimated lower during the peak month at two of six locations, with the ratio of $ET_{0,d}$ to $ET_{0,h,ASCE}$ time step ranging from 0.95 to 1.05. On average, the $ET_{0,d}$ was 3.2% higher than $ET_{0,h,ASCE}$ at Vlora, and 5.3% higher at Lushnja during the peak month (Table 3). These findings are in agreement with Itenfisu et al. (2003).

Table 3. Peak month ET_0 statistics between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values

Study site	n	Mean value for $ET_{0,h,ASCE}$ (mm d^{-1})	RMSD[a] of daily estimate (mm d^{-1})	Average ratio $ET_{0,d}/ET_{0,h,ASCE}$	a[b]	b[b]	$r^{2(b)}$
Burreli	31	4.89	0.21(0.47)	0.95	1.044	0.08	0.879
Tirana	31	5.39	0.24(0.55)	1.02	0.963	0.09	0.966
Lushnja	31	6.25	0.33(0.73)	1.05	0.888	0.24	0.922
Korça	31	5.17	0.23(0.68)	0.96	0.995	0.21	0.996
Vlora	31	6.16	0.39(0.93)	1.03	0.895	0.25	0.921
Gjirokastra	31	6.53	0.36(0.88)	1.02	0.958	0.03	0.992

[a] Values in parenthesis indicate standard deviation between $ET_{0,d}$ and $ET_{0,h,\ ASCE}$

[b] Regression coefficients where $ET_{0,d} = a\ ET_{0,h,\ ASCE} + b$

c. Comparison of sum-of hourly ASCE-PM ($ET_{0,h,ASCE}$) and sum-of-hourly FAO56-PM ($ET_{0,h,FAO}$) methods

The standardized ASCE-PM ET_0 calculation for hourly or shorter time steps differs from the FAO56-PM method in that the former uses coefficients representing r_s = 50 s m^{-1} during daytime and r_s = 200 s m^{-1} during nighttime, whereas the latter method uses coefficients representing r_s = 70 s m^{-1} for both daytime and nighttime. The relationship between the $ET_{0,h,ASCE}$ and $ET_{0,h,FAO}$ values are shown in figure 2. In Table 4 are given the performance indicators and regression parameters, and the statistical analyses between the two methods are reported in table 5. There are a good correlation between $ET_{0,h,ASCE}$ and $ET_{0,h,FAO}$ values at all locations (Fig. 2) with $r^2 \geq 0.990$. The RMSD between $ET_{0,h,ASCE}$ and $ET_{0,h,FAO}$ values were considerably lower than those obtained by using the 24 h time step (Table 4), with Burreli and Korça having the lowest RMSD values (0.14 and 0.16 mm d^{-1}). Gjirokastra and Vlora had the highest RMSD values (0.28 and 0.26 mmd^{-1}, respectively). The $ET_{0,h,FAO}$ method estimated lower than standardized $ET_{0,h,ASCE}$ method at all locations and for all years due to the higher daytime r_s. Lower estimation is reflected in the average ratio of $ET_{0,h,FAO}$ to $ET_{0,h,ASCE}$ value in table 4. Estimations by the $ET_{0,h,FAO}$ ranged from -4.8 % at Burreli to - 7.8 % at Vlora relative to $ET_{0,h,ASCE}$. The rates of lower estimation by the $ET_{0,h,FAO}$ method are in agreement with those reported by ASCE-EWRI (2004).

Table 4. Performance indicators between $ET_{0,h,ASCE}$ and $ET_{0,h,FAO}$ for the calendar year

Site	Number of observations	RMSD[a] (mm d^{-1})	Average ratio $ET_{0,h,\ ASCE}/ET_{0,h,\ FAO}$	a[b]	b[b]	$r^{2(b)}$
Burreli	365	0.14(1.02)	0.95	1.04	0.057	0.994
Tirana	365	0.18(1.39)	0.92	1.077	-0.020	0.990
Lushnja	365	0.24(1.65)	0.94	1.056	0.045	0.997
Korça	365	0.16(1.13)	0.95	1.053	-0.007	0.999
Vlora	365	0.26(1.74)	0.92	1.087	0.002	0.999
Gjirokastra	365	0.28(1.98)	0.94	1.068	-0.001	0.996

[a] Values in parenthesis indicate standard deviation between $ET_{0,d}$ and $ET_{0,h,\ ASCE}$

[b] Regression coefficients where $ET_{0,d} = a\ ET_{0,h,\ ASCE} + b$

The $ET_{0,h,FAO}$ values were significantly different ($P < 0.5$) from the $ET_{0,h,ASCE}$ values for six locations (Table 5). The underestimation by the $ET_{0,h,FAO}$ method was due to the 70 s m^{-1} r_s used by this method during daytime, as opposed to 50 s m^{-1} r_s value used by $ET_{0,h,ASCE}$ method. All other terms in the two methods are identical. The higher value for r_s (200 s m^{-1}) used by ASCE-PM during nighttime tends to lower nighttime ET_0 and therefore counters some of the increase in daytime estimates. However, nighttime ET_0 is generally small, so complete countering is rare.

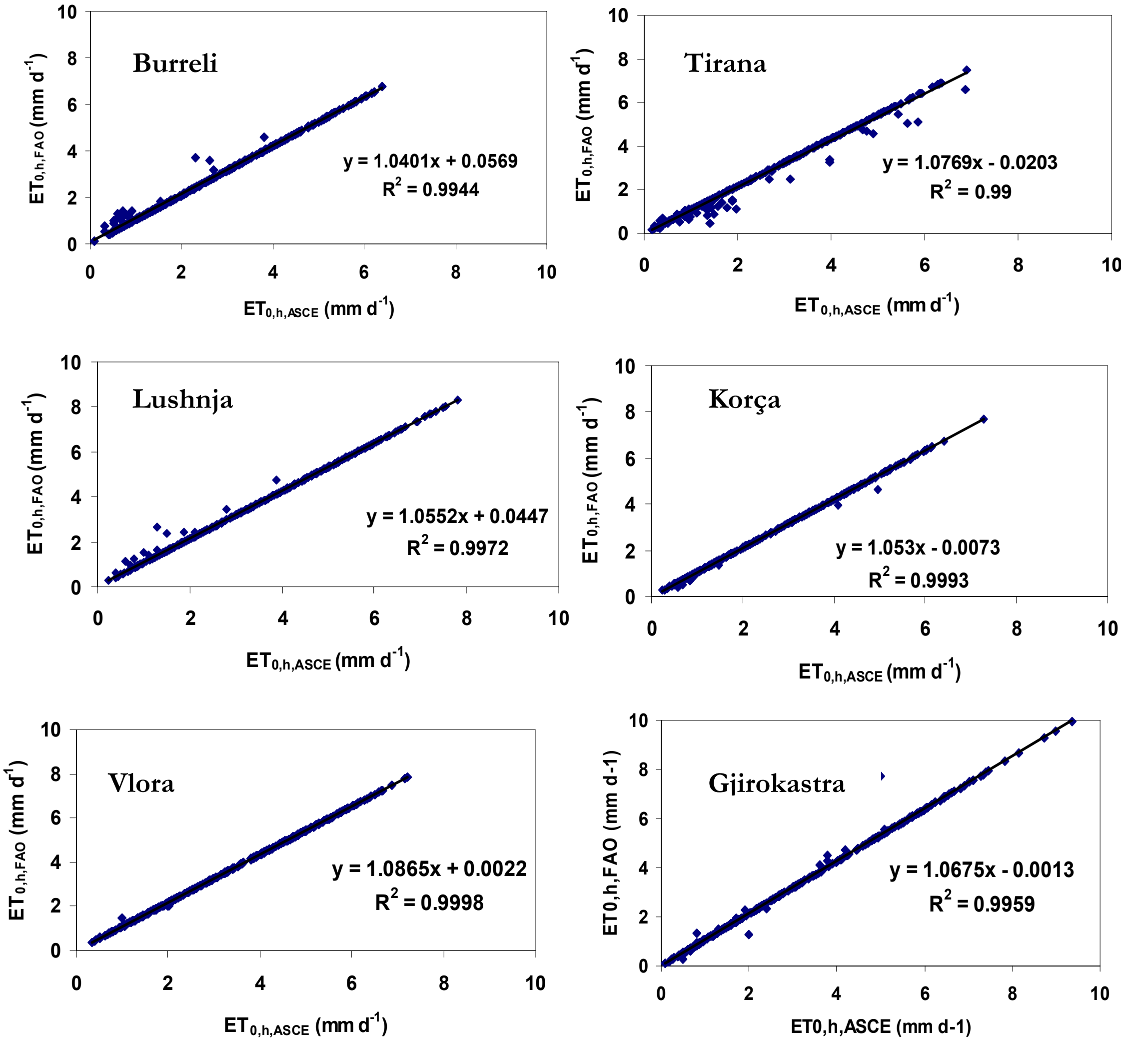

Fig. 2. Relationship between $ET_{0,h,FAO}$ dhe $ET_{0,h,ASCE}$ values

Table 5. Statistical analyses (paired sample *t*-test) between $ET_{0,h,ASCE}$ versus $ET_{0,h,FAO}$ (mm d^{-1}) values (α = 0.5) for the calendar year

Site	Mean		Variance		$df^{(a)}$	t-test		$P_{0..05}^{(b)}$
	$ET_{0,h,ASCE}$	$ET_{0,h,FAO}$	$ET_{0,h,ASCE}$	$ET_{0,h,FAO}$		$t_{computed}$	$t_{critical}$	
Burreli	2.61	2.48	1.78	1.67	365	30.7	1.64	*
Tirana	2.83	2.60	1.68	1.59	365	44.1	1.64	*
Lushnja	3.67	3.45	2.44	2.32	365	37.4	1.64	*
Korça	2.72	2.53	1.99	1.75	365	44.9	1.64	*
Vlora	3.58	3.40	3.41	3.03	365	50.7	1.64	*
Gjirokastra	3.39	3.19	5.41	4.19	365	48.1	1.64	*

(a) df = degrees of freedom (n – 1)
(b) * = significant at the 5% significance level

d. Multiple days and longer-term comparisons of $ET_{0,d}$ and $ET_{0,h,ASCE}$ for calendar year and peak ET_0 month

Field-scale irrigation system require same day to complete one irrigation cycle. The application depth for this system may be of 3 or more days of daily ET. In this case, the sum of daily ET_0 for multiple days and longer periods (i.e., weekly, monthly, and annual) becomes important. Table

6 shows the comparison statistics between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values on a weekly, and monthly sum basis. This process would help to assess whether summing daily ET_0 values over longer periods would reduce the risk of using daily ($ET_{0,d}$) values as compared with the ET_0 values computed on an sum-of-hourly basis. In general, the results in table 6 show that summing the ET_0 values over a weekly, and monthly basis somewhat reduced the differences between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values as compared with the values reported in table 1. However, the differences were not reduced with similar magnitudes at all locations. For example, at Burreli, the r^2 increased from 0.984 to 0.996 (table 1 vs. table 6), the average ratio decreased from 0.98 to 0.94 (table 1 vs. table 6) with data points scattering closer to 1:1 line when ET_0 values were summed on a weekly (7 day) period.

Similar results were obtained when ET_0 values were summed over monthly period. However, a difference at Burreli of 1.3 mm week^{-1} and 3.9 mm month^{-1} still exists between the $ET_{0,d}$ and $ET_{0,h,ASCE}$ values when daily ET_0 values were summed over a weekly, and monthly basis, respectively (table 6). The differences between the two ET_0 time steps showed significant variations from one location to another. For example, at Gjirokastra and Lushnja the differences on an monthly basis was 5.8 and 5.2 mm month^{-1}, respectively, while at Tirana, the difference on an monthly basis was 2.9 mm month^{-1}. The 5.8 and 5.2 mm month^{-1} of water will make a considerable difference in terms of designing and planning of irrigation and drainage systems and other water storage infrastructure. These differences suggest that using a 24 h time step rather than sum-of hourly time step would result in underestimations of ET_0 of as much as 5% to 8% based on the weekly, monthly, and annual average ratio given in table 6, and this may cause improper design of water management infrastructure. The Vlora and Lushnja stations resulted in the largest annual differences among all stations (table 6). The Korça station resulted in the smallest difference (11.7 mm year^{-1}) between the two ET_0 computation procedures on an annual basis.

Table 7 summarized the performance indicators to assess the differences between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values when the ET_0 values were summed over 3 day, weekly, and monthly periods in peak months. The peak ET_0 month for each location is given in table 3. When the $ET_{0,d}$ values were summed over a 3-day period for the peak ET_0 months, the differences between the two computation time steps showed considerable variations with location. In some locations, the differences between the two time steps were lower than the values reported in table 3. However, in some locations, the differences were higher than they were for the daily comparisons. For example, when the $ET_{0,d}$ values were summed for a 3-day period, the difference were lower (higher r^2 between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values) at Burreli, Tirana and Korça, whereas the differences were higher (lower r^2 values, higher deviation) at Gjirokastra, Vlora, and Lushnja (table 7). Summing the ET_0 values over a 3-day period did not change the errors associated with using the 24 h time step procedure at (Table 7). Similar results were obtained for the weekly and monthly sum comparisons (table 7). The largest 3-day, weekly and monthly differences between the $ET_{0,d}$ and $ET_{0,h,ASCE}$ values were at Gjirokastra, Vlora, and Lushnja, whereas the smallest differences were at Tirana station. These results suggest that summing the $ET_{0,d}$ values over multiple days and longer periods for the peak ET_0 months resulted in inconsistent differences with locations. In some locations (Girokastra, Lushnja and Vlora) there is a risk associated with summing the $ET_{0,d}$ values over multiple days in peak ET_0 months as compared with using the $ET_{0,h,ASCE}$ values. However, summing the $ET_{0,d}$ values over multiple days improved (lower RMSD and higher r^2, table 7) the relationship between the two ET_0 computation procedures at Tirana, Burreli, and Korça for the peak ET_0 months.

The comparison between the $ET_{0,h,ASCE}$ and $ET_{0,h,FAO}$ values were not made for multiple days or longer periods. This is because the $ET_{0,h,FAO}$ values were consistently below the $ET_{0,h,ASCE}$ values (fig.2) at all locations. Over the multiple days and longer periods, the magnitude of the difference between the two computation procedures would be steadily increasing over the 3-day, weekly, monthly, and annual sum basis, with the $ET_{0,h,FAO}$ values consistently running below the $ET_{0,h,ASCE}$ values at all locations.

Conclusions

The standardized hourly ASCE-PM model was evaluated to assess differences between using 24 h computation time step for ET_0 ($ET_{0,d}$) as compared with the sum-of-hourly ET_0 ($ET_{0,h,ASCE}$) in different climates. The sum-of-hourly FAO56-PM ET0 values ($ET_{0,h,FAO}$) were also compared against $ET_{0,h,ASCE}$ values. The agreement between the $ET_{0,h,ASCE}$ and $ET_{0,d}$ procedure was reasonable at most locations. However, our results on comparisons between the $ET_{0,d}$ versus $ET_{0,h,ASCE}$ values indicated that there are significant differences between two sets of ET_0 values. Thus, using $ET_{0,d}$ computation values to replace $ET_{0,h,ASCE}$ values would result in considerable errors. The differences between the two ET_0 computation procedures were attributed partly to uncertainties in using constant ratios of G to R_n in the hourly computation time steps and possibly to the inability of the 24 h time step computation procedure to account for the effect of abnormal diurnal changes in wind speed, air temperature, and vapor pressure deficit. Differences between the two calculation time steps ranges from – 3.9 to + 7.8% (24 h less sum-of-hourly) on an annual basis and from – 4.8 to + 5.3 % for peak ET_0 months.

In general, summing the ET_0 values over a weekly, monthly, and annual basis (for the calendar year) somewhat reduced the differences between the $ET_{0,d}$ and $ET_{0,h,ASCE}$ ET_0 values. However, the differences were not reduced with similar magnitudes at all locations. The differences suggested that using a 24 h time step rather than sum-of-hourly approach would result in underestimations of ET_0 of as much as 5% to 8% depending on the location. Summing the $ET_{0,d}$ values over multiple days and longer periods for the peak ET_0 months resulted in inconsistent differences with locations. In some locations (Gjirokastra, Lushnja and Vlora), there is a risk associated with summing the two $ET_{0,d}$ values over multiple days in peak ET_0 months as compared with the $ET_{0,h,ASCE}$ values. However, summing the $ET_{0,d}$ values over multiple days for the peak months improved (lower RMSD and higher *r*) the relationship between the two ET_0 computation procedures at Burrel, Tirana, Korça stations, and did not change the differences at Gjirokastra, Lushnja and Vlora stations.

$ET_{0,h,FAO}$ values agreed well with the $ET_{0,h,ASCE}$ values at all cases, with $r^2 \geq 0.99$ and low RMSD values (ranging from 0.14 mm d^{-1} at Burreli to 0.28 mm d^{-1} at Gjirokastra station). Although the $ET_{0,h,FAO}$ produced acceptable ET_0 estimates, it estimated lower than $ET_{0,h,ASCE}$ as – 4.8% at Burreli and – 7.8% at Vlora station.

A substantial portion of the low estimation by the $ET_{0,h,FAO}$ method was due to the use of higher surface resistance (70 s m^{-1}) during daytime periods in the hourly time step application as compared to the hourly standardized ASCE-PM, which uses 50 s m^{-1} resistance during daytime and 200 s m^{-1} during nighttime. Results suggest the benefit and potentially improved accuracy of using the standardized ASCE-PM procedure applied hourly as opposed to applying it with a 24 h time step basis. The hourly application helps to account for impacts of abrupt diurnal changes in atmospheric conditions on ET_0 estimation in advective and other environments, when hourly climate data are available.

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Table 6. Performance indicators between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values for multiple days and longer periods (n =)

	$ET_{0,d}$ versus $ET_{0,h,ASCE}$											
	Weekly Sum					Monthly Sum					Annual Sum	
Site	RMSD[(a)] (mm $week^{-1}$)	Average[(b)] Ratio	$a^{(c)}$	$b^{(c)}$	$r^{2(c)}$	RMSD (mm mo^{-1})	Average Ratio	a	b	r^2	RMSD (mm $year^{-1}$)	Average Ratio
Burreli	1.3(6.4)	0.94	1.046	0.04	0.996	3.9(23.6)	0.95	1.054	0.07	0.999	20.4(10.9)	0.96
Tirana	1.1(9.5)	1.02	0.966	0.23	0.995	2.9(20.3)	1.02	0.981	0.17	0.999	21.3(15.3)	1.01
Lushnja	1.8(12.1)	1.08	0.924	-0.03	0.999	5.2(37.6)	1.08	0.923	0.12	1	62.1(34.1)	1.07
Korça	1.4(8.9)	0.96	1.039	0.04	0.998	4.4(41.1)	0.96	1.032	0.04	0.997	11.7(6.78)	0.97
Vlora	1.5(10.3)	1.06	0.947	-0.15	0.898	4.9(50.1)	1.07	0.932	0.22	0.999	79.5(51.2)	1.05
Gjirokastra	2.1(13.7)	1.04	0.961	0.02	0.999	5.8(33.7)	1.04	0.962	0.04	1	55.9(40.4)	1.02

[(a)] Values in parenthesis indicate standard deviation between $ET_{0,d}$ and $ET_{0,h, ASCE}$
[(b)] Average ratio $ET_{0,d}/ET_{0,h, ASCE}$
[(c)] Regression coefficients where $ET_{0,d} = a\ ET_{0,h, ASCE} + b$

Table 7. Performance indicators between $ET_{0,d}$ and $ET_{0,h,ASCE}$ values for multiple days for peak ET_0 month

	$ET_{0,d}$ versus $ET_{0,h,ASCE}$											
	Three-day Sum					Weekly Sum					Monthly Sum	
Site	RMSD[(a)] (mm $3d^{-1}$)	Average[(b)] Ratio	$a^{(c)}$	$b^{(c)}$	$r^{2(c)}$	RMSD (mm $week^{-1}$)	Average Ratio	a	b	r^2	RMSD (mm mo^{-1})	Average Ratio
Burreli	0.49(1.33)	0.913	0.96	0.654	0.913	0.71(1.82)	0.96	0.994	1.231	0.904	1.34(0.97)	0.96
Tirana	0.36(1.08)	0.974	1.01	1.347	0.974	0.69(2.03)	1.00	1.037	-0.762	0.958	1.24(0.76)	1.01
Lushnja	0.77(1.52)	0.785	1.04	1.983	0.785	1.67(2.16)	1.03	0.961	3.121	0.732	5.32(3.23)	1.04
Korça	0.58(1.88)	0.976	0.97	1.099	0.976	0.91(1.45)	0.97	0.879	0.967	0.968	1.98(0.99)	0.97
Vlora	0.66(1.43)	0.893	1.03	2.456	0.893	1.27(2.31)	1.03	1.135	-1.954	0.876	4.85(2.77)	1.02
Gjirokastra	0.84(1.22)	0.937	1.02	0.987	0.937	1.84(3.01)	1.02	0.754	0.889	0.921	7.65(4.32)	1.01

[(a)] Values in parenthesis indicate standard deviation between $ET_{0,d}$ and $ET_{0,h, ASCE}$
[(b)] Average ratio $ET_{0,d}/ET_{0,h, ASCE}$
[(c)] Regression coefficients where $ET_{0,d} = a\ ET_{0,h, ASCE} + b$

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