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Differentiation of computed sum of hourly and daily reference evapotranspiration in a semi-arid climate

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ABSTRACT

Electronic weather stations have increased the availability of weather data for computing hourly and daily reference evapotranspiration (ET_o). There is a rational question applied for different climate conditions whether the sum of hourly ET_o computation may differ from direct computed daily ET_o. In this study for the Kerman area, daily and hourly reference crop water consumption were estimated by the Penman-Monteith equation, using meteorological data collected in one hour intervals by an automatic weather station at Iranian Academic Center for Education, Culture and Research (ACECR), Kerman city, Iran. The direct computed daily evapotranspiration values were compared with the sum of hourly computed evapotranspiration values. Results indicated that there is a distinctive difference between the values as calculated for this experimental station. Based on two tail 95% level t-test, the direct computed daily ET_o was greater than the sum of hourly computed ET_o. Finally, the relationship of daily and sum of hourly ET_o for the study area were presented which can be utilized to compare and convert the computed values.

1. Introduction

Crop water consumption is an amount of water vapor released to atmosphere from plant by transpiration and soil surface by evaporation (Doorenbos and Pruitt 1977). This process is expressed as evapotranspiration, ETcrop. Direct measurement of ETcrop is a costly and time consuming process. ETcrop is affected by many recognized factors including weather parameters such as solar radiation, air temperature, humidity and wind speed, and some crop factors such as crop type, variety, density, and growth stage. Managerial and environmental conditions such as soil conditions, salinity, fertility, crop disease, and pests are also governing the ETcrop process (Fadaei-Kermani et al. 2014 and Allen et al. 1998). That is why, initially reference crop water consumption values are calculated using meteorological data, and then crop water consumption is estimated by multiplying these values with a plant coefficient, kc, (ETcrop = ETo × kc) in which ETo is the reference evapotranspiration (Allen et al., 1998). Crop coefficients (kc) depend on several factors including the crop type, crop growth stage, canopy cover and density and soil moisture (Snyder et al. 1992). The standard method to quantify consumptive water use by crops utilizes the concept of reference crop, defined as an ''extensive surface of green grass of uniform height 8 to 15 cm tall—actively growing, completely shading the ground and not short of water'' (Doorenbos and Pruitt 1977) and as ''a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23'' (Allen et al., 1998). Also ET_o has been defined as "the rate at which water, if readily available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop" (Jensen et al. 1990). Reference crop water consumption (ET_o) is a measured which may be determined by a set of meteorological data for a selected reference crop. Different methods may be used to compute ET_o for different regions according to suitability to local conditions (Allen et al. 1989; Katul et al. 1992; Amatya et al. 1995; Smith et al. 1996; Ventura et al. 1999; Berengena and Gavila´n 2005). Some methods of estimation derive from sound physical principles governing the process, but most of them are empirical and usually rely on statistical correlations between ET_o and one or more climatic variables (Sharma 1985). The most preferred methods are Blaney Criddle, Penman, Penman Monteith (PM), Hargreaves-Samani and pan evaporation methods (Jacobs 2001). The Penman type equations are based on assumptions that: a surface with zero resistance and an aerodynamic term subject to local wind function calibration. The Penman Monteith equation is somewhat more physically based and attempts to incorporate the physiological and aerodynamic characteristics of the reference surface. The application of the PM equation requires measurements of solar radiation (R_s), temperature (T) and relative humidity (RH) of the air and wind speed (U). Besides, it requires measurements or estimations of net radiation (R_n), soil heat flux (G) and vapor pressure deficit (VPD). Procedures to estimate these parameters have been described in various studies (Doorenbos and Pruitt 1977; Jensen et al., 1990; Allen et al., 1998; Ortega-Farias et al., 2000; Irmak et al., 2003). The FAO standardized PM (FAO56-PM) method has been recommended to compute reference ET of a grass surface (Allen et al. 1998). In empirical type equations, the temperature-based methods namely Hargreaves and Samani have provided suitable results for different regions (Jensen et al. 1990, Allen et al. 1998). Intenfisu et al. (2003) computed reference evapotranspiration values by using hourly and daily weather data from 49 diverse geographical sites of the United States. He also compared the results of reference evapotranspiration computed by various methods and the ASCE Penman Monteith (ASCE- PM) equation by using daily time step. Besides, he also computed reference sum of hourly evapotranspiration by using hourly data and compared it with daily one as well as the ASCE- PM method estimation. Temesgen et al. (2005) compared the California Irrigation Management Information System (CIMIS) Penman equation, the Penman–Monteith equation standardized by the FAO, the

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Penman–Monteith equation standardized by the ASCE, and the Hargreaves equation. Comparisons include hourly and daily reference evapotranspiration. ET_o values estimated by the CIMIS Penman equation correlated very well with the corresponding values estimated by the standardized Penman–Monteith equations on both hourly and daily time steps. The Hargreaves equation agreed well with the FAO Penman–Monteith method. Lo´pez-Urrea et al. (2006) compared The FAO-56 and ASCE equations (hourly time step) with measured lysimeter ET_o values at Albacete (Spain) for 13 days. Results showed that the FAO-56 Penman–Monteith equation for calculating hourly ET_o values was more accurate than the ASCE Penman–Monteith method in Albacete. Villa Nova et al. (2007) proposed a method for estimating ET_o based on the local energy balance from limited meteorological data monitored in an automated weather station throughout daylight periods. To validate the presented method, climatic data and lysimetric measurements were utilized. Regression analyses revealed that a modified Bowen method provided results similar to the Penman-Monteith method and similar to measurements made by weighing lysimeters with load cells. Gavila´n et al. (2007) used the standardized ASCE Penman–Monteith and FAO-56 equations to estimate reference evapotranspiration (ET_o) using estimated and measured net radiation (R_n) and soil heat flux (G), based on hourly and daily meteorological data. The estimates were evaluated by lysimeter measurements. The results indicated that using measured or estimated values of R_n and G can have significant effect on the accuracy of the ET_o estimations, especially when calculations were made on an hourly basis.

In recent years, the Penman-Monteith method is given considerable attention because of availability of computer to handle complicated calculations. In this study, this method is selected because of better and more realistic estimation of evapotranspiration (Allen et al. 1998; Jacobs 2001) in ACECR (Iranian Academic Center for Education, Culture and Research) station conditions. The method has been applied for the Kerman city climate status in Iran. Reference crop water consumption values calculated by the Penman Monteith method using hourly meteorological data gave more reliable results compared with other available methods (Jacobs 2001). The Kerman climate according to different classification methods evaluated as: based on De Martonne classification (Liverman et al. 1984), it is classified as arid and semi-arid conditions; based on the aridity index (Barry and Chorley 2003) especially middle parts of the region has a significant annual water deficit; according to the Koppen classification (Barry and Chorley 2003) considering very arid and hot climatical conditions effective in the region, the climate was evaluated about desertification. Because of regional water shortage and demand for high water application efficiency, a proper short period irrigation scheduling is essential. Depends on continuous climatical data for shorter periods, it is possible to present a reliable scheduling. In this study, hourly and daily reference crop water consumptions were calculated by the Penman Monteith equations, using meteorological data measured in 10 minute intervals from May 1 to September 30, 2002 in ACECR- Kerman branch agrometeorology station. Daily ET_o values calculated by adding hourly crop water consumption values and compared with directly computed daily ET_o values.

2. Materials and methods

2.1. Site description and dates of measurements

The Kerman city located at latitude 30° 15´, longitude 56° 58´, with elevation 1749.5 m above sea level. In order to measure reference evapotranspiration in this area an automatic weather station was used at ACECR's Station. The climate in the experimental site is arid. Mean annual precipitation is about 154.1 mm based on 53 years of record at a synoptic weather station near the study site. The mean annual maximum and minimum daily air temperatures are 26.4 and 6.2 degree centigrade, respectively and the annual average wind speed at 2 m height is 2.3 ms^{-1}. Mean annual relative humidity is 32%. In this study, the measured data for the period between May 1 and September 30, 2002 were used to compute the hourly and daily reference crop water consumption on a grass plot of about 26 m × 26 m, which was used as a reference surface for ET_o estimation.

2.2. Meteorological measurements

An automatic weather station controlled by a programmable SIEMENS, WINCC data logger was located below the grass field. The station consisted of sensors to measure air temperature and relative humidity, soil surface temperature and wind speed and direction. Air temperature–humidity probe and wind sensors were placed 2.0 m above the surface. These parameters were measured with hourly intervals and recorded on PC hard disk.

2.3. References ET equations

Daily and hourly reference crop water consumptions are computed by the Penman Monteith methods presented in equations 1 and 2. the Penman Monteith reference crop water consumption equation for daily values is given as:

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

where ET_o is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T_{hr} is mean daily air temperature at 2 m height (^{0}C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), e_s-e_a is saturation vapor pressure deficit (kPa), Δ is slope vapor pressure curve (kPa C^{-1}), γ is psychrometric constant (kPa C^{-1}).

The Penman Monteith reference crop water consumption equation for hourly values is given as:

$$ET_o = \frac{0.408\times\Delta(R_n - G) + \gamma\dfrac{37}{T_{hr}+273}u_2\left(e_{(T_{hr})} - e_a\right)}{\Delta + \gamma(1+0.3u_2)} \tag{2}$$

where ET_o is reference evapotranspiration (mm h^{-1}), R_n is net radiation at the grass surface (MJ m^{-2} h^{-1}), G is soil heat flux density (MJ m^{-2} h^{-1}), T_{hr} is mean hourly air temperature (^{0}C), Δ is saturation slope vapor pressure curve at T_{hr} (kPa C^{-1}), γ is psychrometric constant (kPa C^{-1}), e (T_{hr}) is saturation vapor pressure at air temperature T_{hr} (kPa), e_a is average hourly actual vapor pressure (kPa), u_2 is average hourly wind speed (m s^{-1}).

Microsoft Excel software is used to perform the calculations in equations for reference crop water consumption. Daily reference crop water consumption was calculated by adding the hourly reference crop water consumption and expressed by ET_o-H. Then directly daily reference crop water consumptions have been calculated by equation 1 and expressed with ET_o-D. Paired t-test was performed to evaluate the differences between ET_o-H and ET_o-D values and regression analysis were carried out for statistical evaluation of the results (Neter et al. 1996).

3. Results and discussion

As it is shown by Figure 1, night time reference evapotranspirations (ET_o) are close to zero. In morning day time (7:00 to 12:00 am) crop water consumptions increase with very high gradient up to about 0.8 mm per hour. Then the gradient slows down and can change to zero and negative value up to 2:00 pm. After that the gradient is a negative value and the evapotranspiration decrease close to zero in early night time.

Computed direct daily, ET_o-D and indirect daily (sum of hourly), ET_o-H are presented in Figure 2. As shown there is a distinctive difference between two values for this particular area. More over there is along the July month (Figure 2-c) sum of hourly evapotranspiration (ET_o-H) vary between 6-6.5 mm day^{-1} and direct daily evapotranspiration (ET_o-D) vary between 6-8 mm day^{-1} which seems to be a significant difference. Statistical analyses have been performed for ET_o-H and ET_o-D values obtained for the period between May 1 to September 30. The Paired t-test has been applied to the distribution of the above mentioned data for 2002 year, monthly and daily periods and the results obtained were given in Tables 1 and 2.

Depending on the Paired t-test based on the difference between ET_o-H and ET_o-D values, it can be seen from the table 2 that this value for May 2002 period was calculated as 0.001 and it started to increase and reached up to pick of 0.005 in June and gradually decreased during the following months and reached to 0.001 in September. Based on two tail 95% level t-test, ET_o-D values are greater than ET_o-H values that means the difference between ET_o-D and ET_o-H values is not coincidental in this particular area. According to t-test, in July there is difference between ET_o-H and ET_o-D and their Coefficient of determination was computed 85.4%, which is relatively high value (Table 2).

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It means they are well related together and also show significant difference which they are not same. Graphical representation of the above mentioned two parameters for the regression analysis results performed for five months were shown in Figure 3. It can be seen from the figures that the relationship between the values was linear and determination Coefficient for peak month July was 85.4%. Based on the results of this study, daily water consumptions calculated by adding the hourly estimates are statistically different from directly estimated daily water consumption values. Howell et al. (2000) explained that reference crop water consumption values obtained with Penman Monteith method by using hourly climatically data provided healthier results than the values obtained with the same method by using daily data. In this case, with availability of automatic weather station, the sum of hourly evapotranspiration may be more reliable to estimate water consumption values.

Table 1. Statistical descriptions of direct and indirect daily (sum of hourly) computed evapotranspiration (mm day^{-1}).

Statistic Parameters	May		June		July		August		September	
	Sum-of-hour ET_o	Daily ET_o	Sum-of-hour ET_o	Daily ET_o	Sum-of-hour ET_o	Daily ET_o	Sum-of-hour ET_o	Daily ET_o	Sum-of-hour ET_o	Daily ET_o
Mean	5.77	6.21	6.14	6.60	6.24	6.89	5.79	6.58	4.74	6.24
Standard Error	0.02	0.15	0.02	0.18	0.02	0.10	0.02	0.10	0.10	0.14
Median	5.79	6.45	6.14	6.89	6.26	6.92	5.80	6.50	4.76	6.38
Mode	5.81	-	6.10	-	6.27	6.20	5.70	5.90	5.10	-
Standard Dev.	0.10	0.82	0.12	0.98	0.12	0.56	0.13	0.56	0.55	0.79
Sample Var.	0.01	0.68	0.01	0.96	0.01	0.32	0.02	0.32	0.30	0.63
Kurtosis	-0.57	0.49	0.13	0.09	-0.06	-0.91	-0.92	-1.10	-1.07	0.41
Skewness	-0.38	-0.93	-0.06	-0.89	-0.57	0.35	-0.05	-0.18	0.19	-0.84
Range	0.35	3.38	0.52	3.82	0.46	1.98	0.49	2.03	1.93	3.33
Minimum	5.55	4.15	5.86	4.21	5.98	6.10	5.52	5.55	3.87	4.12
Maximum	5.90	7.53	6.39	8.03	6.44	8.08	6.01	7.59	5.80	7.45
Sum	178.7	192.5	184.3	197.9	187.2	206.9	179.5	203.8	142.1	187.2
Confidence interval (95%)	0.04	0.30	0.04	0.37	0.04	0.21	0.05	0.21	0.20	0.30
Means Difference [(ET_o-D)-(ET_o-H)]	0.44		0.46		0.65		0.79		1.50	

Table 2. Statistical analysis results for ET_o-H and ET_o-D values in year 2002.

Period	Paired t-Test results	Determination coefficient (%)	Regression equation
Monthly results			
May	0.0011	89.6	ET_o-H=0.1046ET_o-D+5.1163
June	0.0049	76.5	ET_o-H=0.0909ET_o-D+5.6397
July	0. 006	85.4	ET_o-H=0.1759ET_o-D+5.0262
August	0. 002	95.2	ET_o-H=0.2251ET_o-D+4.3104
September	0.001	84.2	ET_o-H=0.582ET_o-D+1.1049
Decade results			
May 1	0.14	82.3	ET_o-H=0.0725ET_o-D+5.2774
May 2	0.17	94.8	ET_o-H=0.1131ET_o-D+5.0694
May 3	0.16	92.3	ET_o-H=0.945ET_o-D+5.2063
June 1	0.13	65.7	ET_o-H= 0.1485ET_o-D+5.2131
June 2	0.13	97.2	ET_o-H= 0.1751ET_o-D+5.0393
June 3	0.14	74.1	ET_o-H= 0.0377ET_o-D+5.9506
July 1	0.18	91.5	ET_o-H= 0.0964ET_o-D+5.5883
July 2	0.17	97.2	ET_o-H= 0.1751ET_o-D+5.0393
July 3	0.18	72.9	ET_o-H= 0.1695ET_o-D+5.0577
August 1	0. 001	96.1	ET_o-H= 0.2732ET_o-D+3.9869
August 2	0.004	93.9	ET_o-H= 0.2082ET_o-D+4.4282
August 3	0.003	95.8	ET_o-H= 0.2061ET_o-D+4.4186
September 1	0.001	85.9	ET_o-H= 0.5397ET_o-D+1.5833
September 2	0.004	81.9	ET_o-H= 0.6228ET_o-D+0.7584
September 3	0.003	71.2	ET_o-H= 0.5411ET_o-D+3.3883

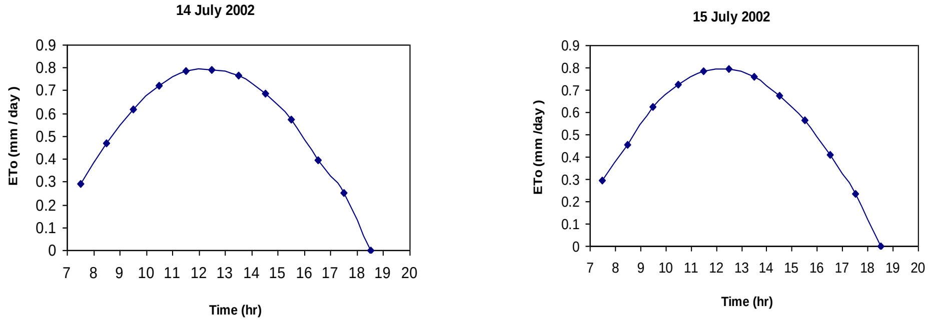

Fig. 1. Distribution of hourly reference crop water consumption 14-15 July, 2002.

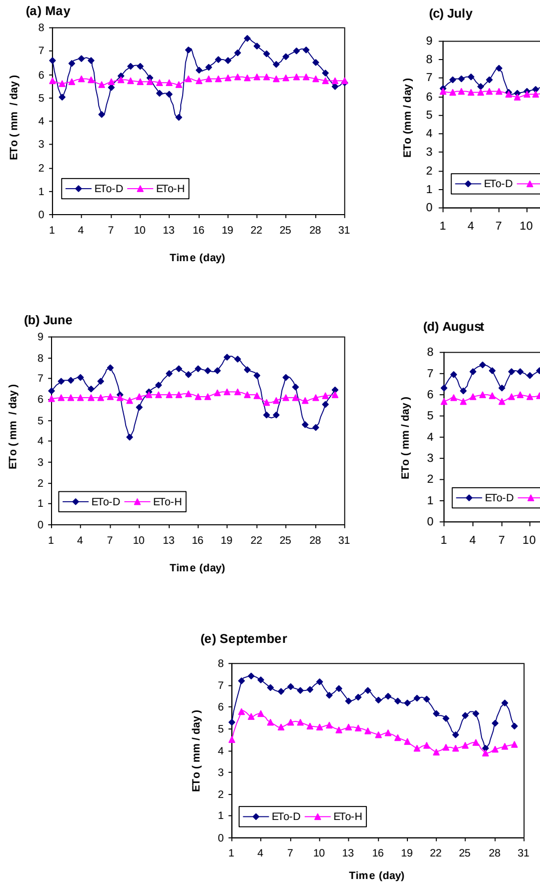

Fig. 2. Distribution of ET_o-H and ET_o-D values for the five months of year 2002.

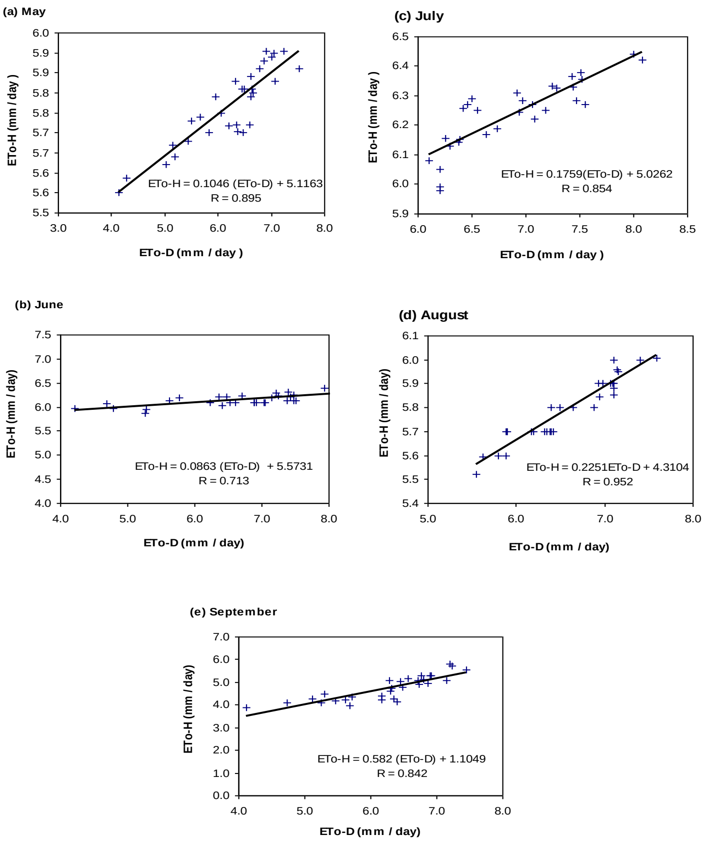

Fig. 3. Relationship between ET_o-H and ET_o-D values for the five months of year 2002.

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4. Conclusions

Estimation of reliable daily crop water consumptions can be an essential tool for irrigation scheduling. In this study it has been tried to estimate daily reference crop water consumptions by two methods (1- directly calculation by daily weather data, 2- indirectly calculation by hourly weather data). Where hourly weather data are available, the Penman-Monteith equation should give the best estimate of reference evapotranspiration. The method has been shown to be reliable in a wide range of environments (Allen et al., 1994), provided that the weather data themselves are reliable. Where there is significant local variability, e.g. in arid and semi-arid areas, an on-farm automatic weather station may be more appropriate. For Kerman, hourly weather data in an experimental station were collected for five months' period starting May 1 through September 30, 2002. When sum of hourly ET_o (neglecting night-time values) were plotted against direct daily computed ET_o, the significant differences were shown. By plotting the data for each day during a one month, it has been found that direct daily computed ET_o was consistently greater than sum of hourly ET_o during the months July, August and September, but there are decreasing in a few days in months May and June. According to paired t-test, there are significant differences between ET_o-H and ET_o-D, but their Coefficient of determinations were relatively high values. However, it is possible that accuracy problems could occur in the direct estimation of daily ET_o (ET_o-D) under high wind speed and dry atmospheric conditions. This study provides regression equations to convert ET_o-D to ET_o-H in a particular Kerman climate when hourly weather data are insufficient to apply the preferred FAO-56 Penman-Monteith method. These conclusions are based on data collected in a semiarid area under moderate to severe advection, so the writers do not pretend to make extrapolations to other areas with different climatic conditions.

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