

## DETERMINATION OF REFERENCE $ET_0$ BY USING DIFFERENT $K_p$ EQUATIONS BASED ON CLASS A PAN EVAPORATION IN SOUTHEASTERN ANATOLIA PROJECT (GAP) REGION

AYDIN, Y.

*Department of Biosystem Engineering, Faculty of Agriculture, Siirt University, Siirt, Turkey  
(e-mail: yusufaydin@siirt.edu.tr; phone: +90-484-212-1111; fax: +90-484-223-1998)*

(Received 28<sup>th</sup> Jun 2019; accepted 11<sup>th</sup> Oct 2019)

**Abstract.** An accurate estimation of ET is very important and the ET estimation method that is suited to the region should be used. Evapotranspiration (ET) is calculated by multiplying reference  $ET_0$  with the crop coefficient for the studied plant ( $K_c$ ) or its pan evaporation coefficient ( $K_p$ ). The purpose of this study was to use the  $K_p$  equations developed based on the Pan evaporation principle for estimating  $ET_0$  values and determining the best  $K_p$  equation for the GAP region by making comparisons via the standard method.  $K_{p-Pere}$  method (RMSE: 0.48, MAE: 0.30, MR: 0.64 and PE: 3.19) displayed a better performance than  $K_{p-Sny}$  (RMSE: 1.08, MAE: 0.70, MR: 0.80 and PE: 29.35) in the semi-arid climate conditions of the GAP region. It was determined according to the regression analysis results that the  $K_{p-Sny}$  equation is better than  $K_{p-Pere}$  by a margin of 2.1%. Accordingly,  $K_{p-Pere}$  equation based on Pan evaporation can be used as an alternative to the standard method for determining reference  $ET_0$  in the semi-arid conditions of the GAP region. Similarly,  $K_{p-Sny}$  equation together with  $K_{p-Pere}$  can be used as substitutes for the standard  $ET_{0-PM}$  method since it requires less climate data.

**Keywords:** *evapotranspiration, reference  $ET_0$ , methods comparisons, FAO-PM equation, pan evaporation coefficient, Snyder and Pereira equations*

### Introduction

Evapotranspiration (ET) is a synchronous process during which the water is transferred to the atmosphere by way of transpiration and evaporation from the soil-plant system. Hence, ET is a critical parameter for irrigation planning and operation as well as for climatologic and hydrologic studies. Agricultural yield per unit area should be at a maximum level in order to meet the food demand that is increasing due to rapid urbanization and population increase, industrialization as well as decrease in agricultural areas over time and global warming. This can be accomplished best by applying the amount of irrigation water required by the irrigated plants in order to obtain maximum yield from the agricultural activity while eliminating excessive water use (Ertek, 2011). There are many factors that have an impact on evapotranspiration and these factors should be calculated at different regions for each plant species since they are more closely related to the land and climate conditions. Actual evapotranspiration ( $ET_c$ ) is generally calculated by multiplying the reference evapotranspiration ( $ET_0$ ) with a coefficient specific to the plant that can be calculated based on many factors encompassing the water regime and operation. Reference evapotranspiration ( $ET_0$ ) is the amount of evapotranspiration (FAO-24) from the grass plant covering the soil surface at a height of 8-15 cm under full irrigation conditions and is calculated via mathematical methods based on the evapotranspiration  $ET_0$  of other plants (Çobaner et al., 2016). The FAO-56 Penman-Monteith (PMF-56) equation developed by Allen et al. (1998) which is also known as the combination method based on mass transfer is widely used as the standard method for determining the reference evapotranspiration. In addition to the standard method, various other techniques have also been developed for calculations based on climate data such as

temperature (Thorntwaite, 1948; Doorenbos and Pruitt, 1977), solar radiation (Doorenbos and Pruitt, 1977; Hargreaves and Samani, 1985; Djaman et al., 2015). Direct and indirect measurement methods used in  $ET_o$  estimation vary subject to the region, climate, plant species, current data and the purpose of the calculation (Kanber, 2006). Lysimeter method is generally used for the direct estimation of  $ET_o$ . However, the evapotranspiration values acquired using this method are not suited for making comparisons with values calculated from meteorological data. The use of lysimeters in  $ET_o$  measurement is not a proper method due not only to its cost and complex operation but also the facts that it is used for measurements at limited areas, does not have sufficient surface area and the acquired data are not sufficiently significant.  $ET_o$  estimation in application can be calculated from meteorological data as well as by multiplying the evaporation values obtained from the Pan evaporation cup by a transformation factor ( $K_{pan}$ ) (Tabari et al., 2013). Trajkovic and Kolakovic (2009) reported that the  $ET_o$  estimation method based on Pan evaporation principle can be used successfully as an alternative to the standard method of PMF-56 under Serbia conditions. Similarly, Tabari et al. (2013) carried out a study under the humid climate conditions of Iran comparing the PMF-56 model with a total of 31 reference evapotranspiration calculation models with 8 based on Class A Pan, 7 on temperature, 10 on mass transfer, 4 on radiation and 2 again on radiation. According to the comparisons carried out, the methods based on evaporation and temperature and the  $K_p$  equation based on evaporation developed by Snyder (1992) displayed the best performance for  $ET_o$  estimation. Castaneda and Rao (2005) used the FAO-56 PM method as standard for comparing the Thorntwaite, Blaney-Criddle, Turc and Makkink methods used for estimating reference  $ET_o$  in Southern California conditions. Djaman et al. (2015) compared the 16  $ET_o$  estimation method with the ASCE-PM equation for developing an equation that can be used for  $ET_o$  estimation under Senegal conditions with less data. Similarly, Shahidian et al. (2012) compared models based on temperature and radiation with the PMF-56 model developed by Allen et al. (1998) published in FAO Irrigation and Drainage Paper, No: 56 which can be operated based on 4 basic data such as temperature, wind speed, radiation and relative humidity. Aydınşakir et al. (2003) indicate that Class A Pan evaporation method is the best  $ET_o$  estimation method for use in estimating grass reference evapotranspiration via empirical models.

The purpose of this study was to compare the reference  $ET_o$  values estimated via different methods with the standard PMF-56 standard method and determine the performance of the  $K_p$  equations based on pan evaporation method in the GAP region with arid and semi-arid climate conditions. For this purpose, 4 year climate data for the Gaziantep province in Southeastern Anatolia Region acquired from Turkish State Meteorological Service (TSMS) records for the years 1999-2002 were used. The  $ET_o$  values calculated using the standard reference evapotranspiration method of FAO-PM and the pan coefficients ( $K_p$ ) developed by Snyder and Pereira calculated based on Class A Pan were compared. The  $ET_{o-PM}$  values calculated at a daily level under Gaziantep climate conditions by Aydın (2004) and Ünlü (2005) were used as the standard FAO-PM method. The same climate data were used for calculating the compared  $K_p$  equations.

## Materials and method

### *Description of study area and weather data*

Southeastern Anatolia Region, one of the 7 geographical regions of Turkey is known as the GAP region due to the project comprised of 13 project packages on the Firat-Dicle

basin for improving soil and water resources and covers a total of 9 provinces including Gaziantep, Kilis, Şanlıurfa, Adıyaman, Diyarbakır, Batman, Mardin, Siirt and Şırnak (Fig. 1) (Anonymous, 2019). The GAP region displays continental climate characteristics. Summers are quite hot, whereas winters are rarely cold. Annual average temperatures are  $16.4\text{ }^{\circ}\text{C}$  with July averages of  $29.8\text{ }^{\circ}\text{C}$ . Annual average rainfall in the region is 565 mm and majority of the rainfall takes place during the winter and spring due to the irregularity in the rain regime. The intensity of aridness increases during the summer months since the annual relative humidity value reaches 53.6% on average. The province of Gaziantep where the study has been carried out is located between eastern longitudes of  $36^{\circ} 28'$  and  $38^{\circ} 0'$  and between the northern latitudes of  $36^{\circ} 38'$  and  $37^{\circ} 32'$ . It has a climate structure with transition characteristics between the Mediterranean and continental climates. Summers are quite hot and arid, whereas winters are cold and rainy. Average annual temperature is  $14.9\text{ }^{\circ}\text{C}$ , with a maximum temperature of  $44\text{ }^{\circ}\text{C}$  and minimum temperature of  $-17.5\text{ }^{\circ}\text{C}$ . The hottest month is July with 27.7 and the coldest month is January with 3.4 whereas the average annual rainfall amount is 544.3 mm. Rains generally take place during the winter months and rarely during the summer months when crops need water and when evapotranspiration is high (Aydın, 2004).



*Figure 1. Locational view of study area*

### ***ET<sub>0</sub> estimation methods***

Food and Agriculture Organization (FAO), together with the International Commission on Irrigation and Drainage and the World Meteorological Organization (WMO) put forth in 1990 that the FAO-PM (Allen et al., 1998) method can be taken as reference since it yields more consistent and reliable results in comparison with other methods (Castaneda and Rao, 2005; Çobaner et al., 2016). Therefore, FAO-56-PM method was taken as reference in this study for comparing the other methods. Different methods that can be operated with less data have been developed for the difficulties experienced while using the standard method for reference  $ET_0$  estimation as well as conditions when sufficient amount of data cannot be acquired. The  $ET_0$  estimation

developed by Snyder (1992) and Pereira et al. (1995) via  $K_p$  equations is one of the widely used methods. Hence, various empirical equations used for determining reference evapotranspiration have been evaluated comparatively. However, since these methods are equations operated based on Class A Pan evaporation values and since evaporation is not measured in Turkey during the winter season,  $ET_o$  calculations were made only for the April-November period when evaporation measurement is made. In graphical representations, it is shown only as DOY in order to make the number of days between the mentioned periods high and the graphs easy to understand. The climate data used for this purpose have been obtained from the Turkish State Meteorological Service (TSMS) (Anonymous, 2018).

### ***FAO-56 Penman Monteith method***

The FAO-56 Penman Monteith method used for determining reference evapotranspiration can be used with daily meteorological data such as temperature, wind speed, evaporation, relative humidity. This equation can be expressed as below (Fisher et al., 2013).

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

where  $ET_o$ : reference evapotranspiration (mm/day);  $R_n$ : net radiation ( $\text{MJ m}^{-2}$ ),  $G$ : soil heat flux ( $\text{MJ m}^{-2}$ ),  $T_{\text{mean}}$ : average air temperature ( $^{\circ}\text{C}$ ),  $U_2$ : wind speed at 2 m height ( $\text{m.s}^{-1}$ ),  $e_s$ : saturation vapor pressure (kPa),  $e_a$ : actual vapor pressure (kPa),  $\Delta$ : slope of vapor pressure curve ( $\text{kPa } ^{\circ}\text{C}^{-1}$ ),  $\gamma$ : psychrometric constant ( $\text{kPa } ^{\circ}\text{C}^{-1}$ ).

The  $ET_o$  software developed by FAO-56 was used for determining reference evapotranspiration. All parameters used in this software are data measured daily and acquired from the meteorological station.

### ***Snyder equation***

The equation developed by Snyder (1992) was used for calculating the  $K_p$  values based on Class A Pan. This equation can be expressed as follows:

$$K_p = 0.482 + 0.0424 \times \ln(F) - 0.000376 \times W_s + 0.0045 \times RH \quad (\text{Eq.2})$$

where  $F$ : fetch distance (meter) has been assumed as 1 m.  $W_s$ : daily average wind speed ( $\text{m sec}^{-1} \text{ day}^{-1}$ ) and  $RH$ : daily relative humidity (%).

### ***Pereira equation***

The equation developed by Pereira et al. (1995) for calculating reference  $ET_o$  based on Class A Pan which is the second method used for comparisons can be expressed as follows (Tabari et al., 2013).

$$K_p = \frac{0.85 \times (\Delta + \gamma)}{[\Delta + \gamma \times (1 + 0.33 \times U_2)]} \quad (\text{Eq.3})$$

$$\Delta = \frac{4098 [0.6108 \exp(\frac{17.27T}{T+237.3})]}{(T+237.3)^2} \quad (\text{Eq.4})$$

where  $\Delta$ : slope of the saturated vapour pressure versus temperature curve (kPa °C<sup>-1</sup>) and  $\gamma$ : the psychrometric coefficient (kPa °C<sup>-1</sup>), T: mean air temperature (°C), exp (...) 2.7183 base of natural logarithm) raised to the power (...).

$$T_{mean} = \frac{T_{max} + T_{min.}}{2}; \quad \gamma = 0.665 \cdot 10^{-3} \times P; \quad P = 101.3 \left( \frac{293 - 0.0065z}{293} \right)^{5.26} \quad (\text{Eq.5})$$

Parameters such as slope ( $\Delta$ ), average temperature (T), psychrometric constant ( $\gamma$ ), elevation above sea level (z) and pressure (P) included in the above equations were calculated in accordance with FAO-56.

The K<sub>p</sub> coefficients obtained from the equations were used in reference ET<sub>o</sub> calculation, (Doorenbos et al., 1977) and the following equation suggested by Tabari et al. (2013).

$$ET_o = E_{pan} \times K_{pan} \quad (\text{Eq.6})$$

ET<sub>o</sub>: Reference evapotranspiration, mm day<sup>-1</sup>; K<sub>pan</sub>: Coefficient based on Class A Pan evaporation cup, E<sub>pan</sub>: Class A Pan evaporation value, mm day<sup>-1</sup>

The ET<sub>o</sub> values for the studied years related with the FAO-56 PM method taken as the standard method were first calculated in the study. Climate parameters such as temperature, relative humidity, wind speed, solar radiation, rain and evaporation for the years between 1999 and 2002 were acquired from meteorological records after which reference ET<sub>o</sub> values were estimated using both the standard method for ET<sub>o</sub> estimation and the compared K<sub>p</sub> equations. Since the climatic data used in the estimation of ET<sub>o</sub> for the last years could not be obtained from the meteorological records, the data of 1999-2002 were used in FAO-56 PM calculations. Fetch distance was taken as 1 m while calculating the K<sub>p-Sny</sub> equation since the meteorological station is covered with irrigated green plants. The calculations were made separately for each study year, after which 4 year averages were calculated for the ET<sub>o</sub> values of the same day thereby obtaining the long term averages for the daily ET<sub>o</sub> values. Annual average ET<sub>o</sub> values were calculated using the average daily ET<sub>o</sub> values. However, since evaporation measurements are not made during the rainy winter months at the meteorological station, ET<sub>o</sub> estimation was made by calculating the K<sub>p</sub> values with the E<sub>pan</sub> values for the months during which measurements were made (April-November).

### Statistical analysis

ET<sub>o-Sny</sub> and ET<sub>o-Pere</sub> obtained by using the standard FAO-PM ET<sub>o</sub> values calculated daily and the K<sub>p</sub> values calculated using Snyder (1992) and Pereira et al. (1995) equations were compared statistically. Paired comparisons were made between R<sup>2</sup> values and ET<sub>o</sub> values which were then subject to linear regression analysis and the R<sup>2</sup> equation was determined for the obtained curve. The equations in *Table 1* suggested by Djaman (2015) and Diouf (2016) were used for a more advanced evaluation of the compared equations.

### Result and discussion

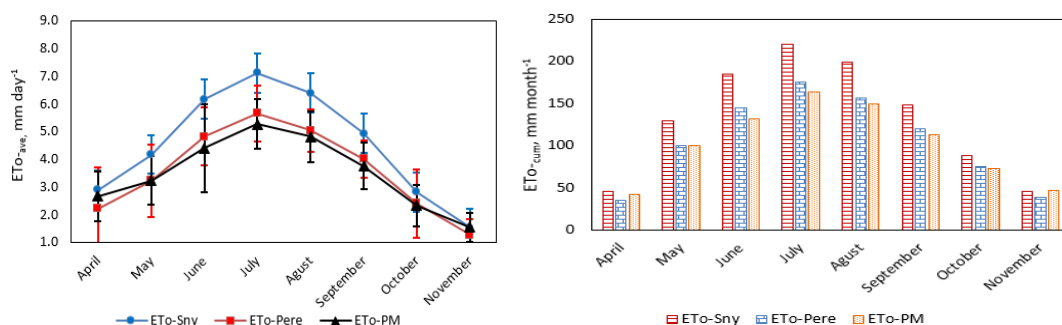
*Figure 2* shows monthly average and cumulative ET<sub>o</sub> values. The reference ET<sub>o</sub> values calculated via the pre-determined methods. While the references ET<sub>o</sub> values

calculated using  $K_p$  equations based on Pan evaporation were determined to be higher in comparison with the values obtained using the standard method for the months of May-October (overestimated),  $ET_{o-Pere}$  value for the months of April and November were calculated as below the values obtained using the standard method (underestimated).

**Table 1.** Statistical analysis equations

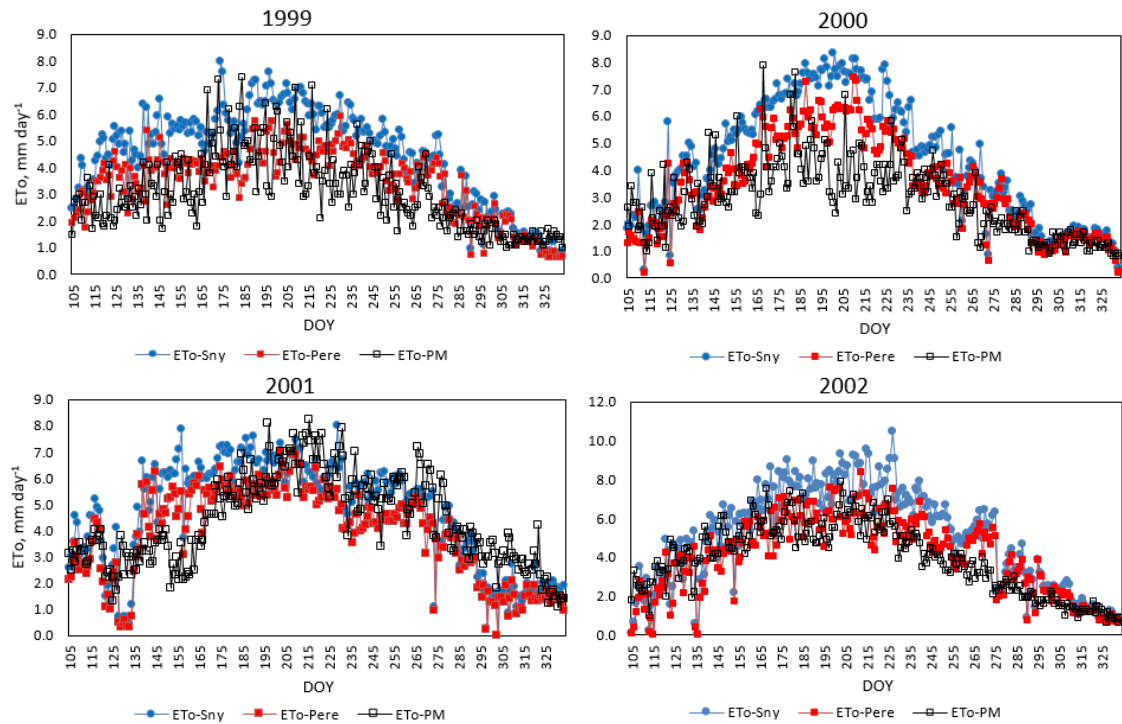
Source	Equation
Root mean square error (RMSE)	$RMSE = \sqrt{\frac{\sum_{k=0}^n (P_i - O_i)^2}{n}}$ (Eq.7)
Mean absolute error (MAE)	$MAE = n^{-1} \sum_1^n (P_i - O_i)$ (Eq.8)
Percentage error (PE)	$PE = \left  \frac{P_{ave} - O_{ave}}{O_{ave}} \right  100\%$ (Eq.9)
Mean ratio (MR)	$MR = n^{-1} \sum_1^n \frac{P_i}{O_i}$ (Eq.10)
Determination coefficient ( $R^2$ ) (Todorovic et al., 2013)	$R^2 = \left\{ \frac{\sum_{i=1}^n (O_i - \bar{O}) \cdot (P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \cdot \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}} \right\}^2$ (Eq.11)

RMSE: root mean square error; MAE: mean absolute error; MR: mean ratio; PE: percentage error of estimate; n: number of observations,  $P_i$ : estimated  $ET_o$  by other equations,  $O_i$ : PM-estimated  $ET_o$  (actual),  $P_{ave}$ : mean of the estimated  $ET_o$ ,  $O_{ave}$ : mean of the  $O_i$ . In order to determine  $R^2$  the pair wise comparisons were made by using linear regression



**Figure 2.** Temporal variation of four years monthly average and cumulative  $ET_o$  values (vertical bars show the standard errors)

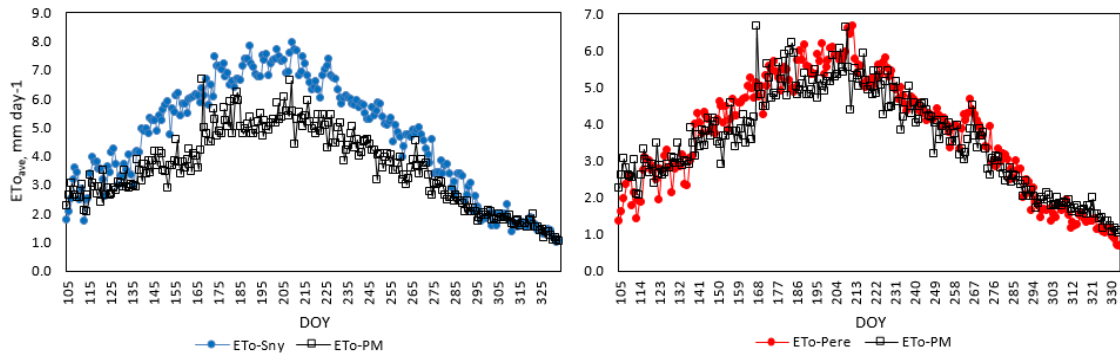
The  $ET_o$  values calculated via  $K_p$  equations were subject to comparisons between themselves as well as with the standard method. It was observed when the study years were evaluated separately (Fig. 3) that the  $ET_{o-Sny}/ET_{o-Pere}$  values calculated via  $K_p$  equations and the standard  $ET_{o-PM}$  values put forth tendencies similar to the changes in the monthly averages. The values closest to the standard  $ET_{o-PM}$  method were calculated using the  $ET_o$  values obtained by  $K_{p-Pere}$  equation which displayed a better performance than the  $ET_{o-Sny}$  values. This relationship was observed for all study years.



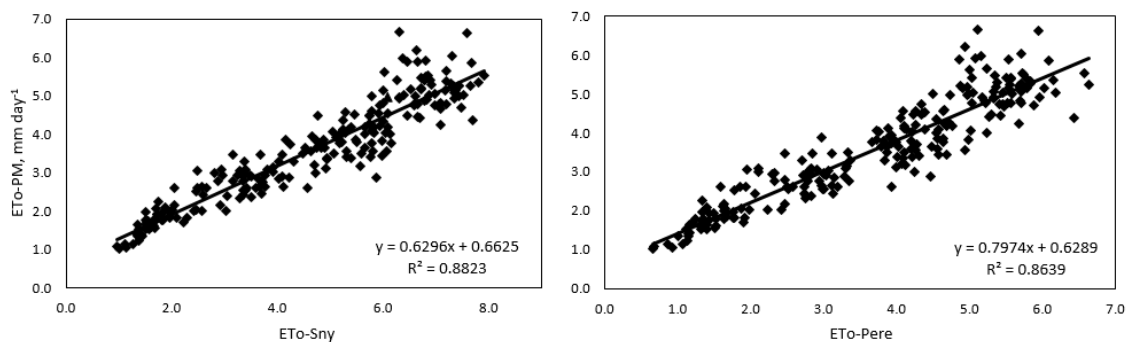
**Figure 3.** Comparison of daily average  $ET_0$  values obtained from equations and standard method during study years

Long term daily average  $ET_0$  values calculated daily during the study years via  $K_p$  equations were subject to paired comparisons separately with the standard FAO-56 PM method (Fig. 4). As can be seen from the figure, the  $ET_0$  values calculated via the  $K_{p-Pere}$  equation were determined to be closer to the values calculated with the standard method with lower rate of change and change % for the comparison. When compared with the standard method, the  $K_{p-Pere}$  equation displayed a better performance in comparison with the  $K_{p-Sny}$  equation. While both equations yielded overestimated values compared with the standard method, the performances vary with regard to the rates of change and change %. When the changes of the curves in Figure 2 and the rates of change and change percentage (%) in Table 2 are evaluated, it can be observed that the  $K_{p-Pere}$  equation put forth a better performance in comparison with  $K_{p-Sny}$  at both the monthly averages level and the hottest months and long term averages levels.

The regression analysis carried out for determining the relationship between the  $ET_0$  values obtained via the equations and the standard method along with the  $R^2$  values have been given in Figure 5 and Table 3.



**Figure 4.** Comparison of long term daily average  $ET_o$  values obtained by  $K_p$  equations with standard method

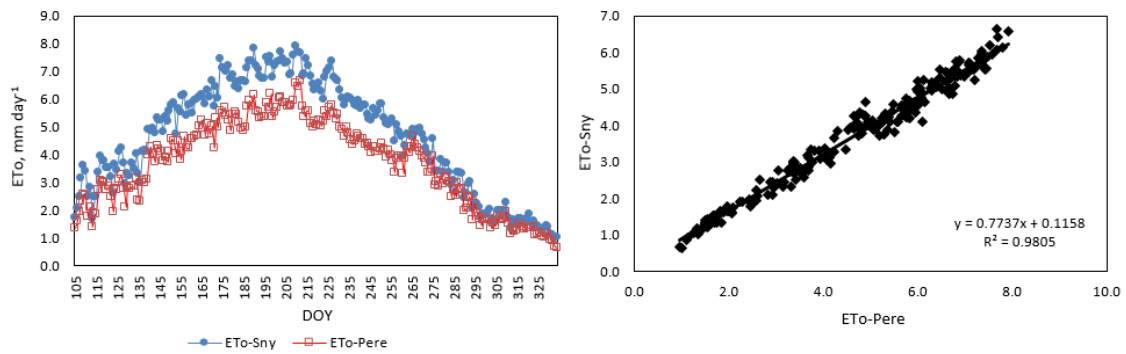


**Figure 5.** Determination of regression coefficients between long term daily average  $ET_o$ -equations values and standard  $ET_o$ -PM method

The  $ET_o$  values calculated via  $K_{p-Sny}$  and  $K_{p-Pere}$  equations used for calculating reference  $ET_o$  value were subject to comparisons among themselves for determining their performances and changes throughout the study years (*Fig. 6*). As can be seen from the figure, long term average  $ET_{o-Pere}$  values were lower than  $ET_{o-Sny}$  which can be observed more clearly during the evaporation period, especially during the hot summer months. This distinction can be seen in *Figure 4* where the  $ET_o$  values calculated via equations are compared with the standard method. It was observed as a result of the comparison made between  $ET_o$  values calculated via equations and the standard method that the  $ET_{o-Pere}$  values provided results that are closer to the standard method than  $ET_{o-Sny}$  thereby displaying a better performance and that the rate of change and change % between the  $ET_{o-Sny}$  and  $ET_{o-PM}$  values are higher in comparison with  $ET_{o-Pere}$ .

As can be seen from the comparison between the  $K_p$  equations (in *Fig. 6*; *Table 2*), the  $ET_{o-Sny}/ET_{o-Pere}$  rate of change varied between 1.30 and 1.17 throughout the calculation period with an average of 1.25 which was calculated as 1.27 for the month of August. The similarities or differences in the rates of change of the equations can also be monitored here when the change %'s are examined. The highest rate of change % was calculated for the month of April (30.3%) while the lowest rate of change was calculated for the month of October and the long term average rate of change was calculated as 24.82%.





**Figure 6.** Comparison of  $ET_o$  values obtained by  $K_p$  equations with each other and regression coefficient

Table 2 summarizes the comparisons made between the  $ET_o$  values obtained from  $K_p$  equations based on Pan evaporation principle used for reference  $ET_o$  estimation and Standard FAO-56 PM method. Long term monthly averages were calculated for the  $ET_o$  values calculated via the equations and FAO-56 PM values. Afterwards, paired comparisons were carried out for both these values with each other and with the standard method and the relations between the  $ET_o$  values and their rates of changes were calculated on a monthly basis.

**Table 2.** Monthly average  $ET_o$  values obtained from equations and comparison by standard methods

Methods	Monthly average $ET_o$ values of methods								
	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Mean
$ET_{o-Sny}$	2.9	4.2	6.2	7.1	6.4	4.9	2.8	1.5	4.5
$ET_{o-Pere}$	2.2	3.3	4.8	5.7	5.1	4.0	2.4	1.3	3.6
$ET_{o-PM}$	2.7	3.3	4.4	5.3	4.8	3.8	2.4	1.6	3.5
Comparisons of equations between them and the standard method as change percentage (%)									
$ET_{o-Sny}/ET_{o-PM}$	1.09	1.29	1.40	1.35	1.33	1.31	1.21	0.99	1.24
$ET_{o-Pere}/ET_{o-PM}$	0.83	1.00	1.09	1.07	1.05	1.07	1.03	0.83	1.00
$ET_{o-Sny}/ET_{o-Pere}$	1.30	1.29	1.28	1.26	1.27	1.23	1.17	1.19	1.25
Variation rates of $ET_o$ values obtained by equations according to standard method (%)									
$ET_{o-Sny}/ET_{o-PM}$	8.7	28.8	39.8	35.0	32.8	31.0	20.5	-1.2	24.42
$ET_{o-Pere}/ET_{o-PM}$	-16.6	0.1	9.3	7.4	4.9	6.6	2.9	-17.2	-0.33
$ET_{o-Sny}/ET_{o-Pere}$	30.3	28.7	27.9	25.8	26.6	22.9	17.2	19.3	24.82

As can be seen from the table, the change in  $ET_{o-Pere}$  values was observed to be lower (underestimated) ( $0.83 < 1.09$  and  $0.83 < 0.99$ ) in comparison with  $ET_{o-Sny}$  as a result of the comparison between the  $ET_o$  values obtained from equations and the standard method during the months when the evaporation measurement started and ended and the rate of change was calculated as -16.6 and -17.2. The same values were determined as 8.7 and -1.2 respectively for the  $ET_{o-Sny}$  equation. When the compared long term averages are examined, the rate of change for  $ET_{o-Pere}/ET_{o-PM}$  was determined as 1.00 whereas, the rate of change for  $ET_{o-Sny}/ET_{o-PM}$  was calculated as 1.24. The

underestimated values observed for  $ET_{o-Pere}$  were at about the same level throughout all the months and were lower than  $ET_{o-Sny}$  during the hottest month of July with a value of 1.07. Similarly, it was also observed as a result of the comparison between  $ET_{o-Pere}$  and  $ET_{o-Sny}$  values with the standard method of  $ET_{o-PM}$  that  $ET_{o-Pere}$  displayed a better performance with regard to the comparison between each other as well as the % rate of change. Trajkovic and Stojnic (2008) carried out a study on reference  $ET_o$  determination methods during which Christiansen and FAO-24 Pan evaporation methods were compared with the standard FAO-PM method. It was reported in the study that the Christiansen method put forth a better performance in comparison with the standard FAO-PM and the FAO-24 Pan method which is due to the fact that the Christiansen method makes use of more climate parameters than FAO-24 Pan. Moreover, it was also indicated that the Pan evaporation values can be used as a substitute for the FAO-56 PM method.

Statistical evaluations were carried out in order to define the relationships between the compared  $K_p$  equations and the standard FAO-56 PM methods accurately and to determine the levels of relationships (Table 3).

**Table 3.** Result of statistical analysis among  $ET_o$  methods

	RMSE (mm/day)	MAE (mm)	MR	PE (%)	R <sup>2</sup>
$ET_{o-Sny}-ET_{o-PM}$	1.08	0.70	0.80	29.35	0.8823
$ET_{o-Pere}-ET_{o-PM}$	0.48	0.30	0.64	3.19	0.8639
$K_{p-Sny}-K_{p-Pere}$	---	---	---	---	0.9805

As can be seen from the table, the  $ET_o$  values calculated via  $K_{p-Pere}$  equation yielded values closer to the standard method during the comparisons of the  $ET_o$  values obtained using  $K_p$  equations with the standard method. The root mean square error (RMSE) values for the  $ET_{o-Pere}-ET_{o-PM}$  comparison were observed to be lower than  $ET_{o-Sny}$  with regard to error statistics ( $0.48 < 1.08$ ). Similarly,  $ET_{o-Pere}$  put forth values lower in comparison with those of  $ET_{o-Sny}$  with regard to the other error statistics of mean absolute error, mean ratio and percentage error values thereby displaying a higher accordance with the standard method. Contrary to the aforementioned comparisons, a smaller difference is observed only between the R<sup>2</sup> values with  $ET_{o-Sny}$  having an R<sup>2</sup> value of 2.1 times higher than that of  $ET_{o-Pere}$ . The  $K_p$  equations used in the study were subject to regression analyses as a result of which the R<sup>2</sup> value was calculated as 0.9805 (Table 3; Fig. 6). This is an indication that both methods can be used together for  $ET_o$  prediction. Tabari et al.(2013) carried out a study during which a total of 31 different models used for determining reference  $ET_o$  under the humid climate conditions of northern Iran. A total of 8 methods based on Pan evaporation were evaluated and while the  $K_{p-Sny}$  method was ranked number 4 under humid region conditions (R<sup>2</sup>: 0.86, RMSE: 0.53, PE: 4.91), the  $K_{p-Pere}$  method (R<sup>2</sup>:0.88, RMSE:0.82, PE:30.16) was ranked number 6. Another study with similar results under conditions of Brazil was carried out by Conceição (2002) regarding the usability of Class A Pan evaporation based equations for determining reference  $ET_o$ . In this study, Pan evaporation based  $K_{p-Sny}$ ,  $K_{p-Pere}$  equations were compared with the standard FAO-PM methods. As a result of the study, the best estimation was obtained with the  $K_{p-Sny}$  equation. It is considered that the better performance of  $K_{p-Pere}$  equation is due to the climate conditions of the region. The consistency and reliability of the method should be re-evaluated for methods based on

Pan evaporation in case they are used for different regions and climate conditions since they yield reliable results for the environmental conditions for which they have been developed (Kaya et al., 2016). Sentelhas and Folegatti (2003) carried out a study under Brazil-Sao Paulo conditions for the determination of  $K_p$  coefficients while determining daily reference  $E_{T_0}$ . It was determined in this study during which six equations based on Class A Pan were tested that the  $K_{p-Pere}$  (Pereira et al., 1995) and Cuenca (1989) equations displayed the best performance for  $E_{T_0}$  estimation. However, the researcher suggested the calibration of the equations used for different climates and regions.

## Conclusion

Even though the standard  $E_{T_0}$  estimation method suggested in FAO-56 and developed by Allen et al. (1998) is widely used, its usage is still limited due to its complex structure and its requirement of climate data such as temperature, relative humidity, wind speed, soil heat flux and radiation. It is not always possible to obtain these data in many developing countries due to the required technological infrastructure and the high costs involved. Hence, equations that can be operated with less climate data which can easily be obtained have been developed for use in  $E_{T_0}$  estimation. The  $K_p$  equations based on Pan evaporation principle for  $E_{T_0}$  estimation developed by Snyder (1992) and Pereira (1995) have been used in the present study which were compared with the standard method.

In conclusion, it was determined that methods based on evaporation can be used as alternative or substitute methods to the standard methods for reference evapotranspiration estimation under the hot and semi-arid conditions of the GAP region and that the  $K_{p-Pere}$  equation displayed a better performance under these conditions in comparison with  $K_{p-Sny}$ . However, it is expected that changes will take place in the climate of the region over time due to the developing structure of the region, the expansion of drainage basins as well as the increase in evaporation surface areas. Hence, reference evapotranspiration studies should be evaluated in detail for the region including the standard methods as well and further studies should be carried out for determining high performance methods which can adapt to the continental climate conditions of the region. Accurate estimation of reference evapotranspirations will enable the effective use of the irrigation sources for the ongoing projects in the GAP region in addition to the execution of the correct irrigation programs, thereby paving the way for obtaining maximum yield as well as water savings with the efficient use of irrigation water.

## REFERENCES

- [1] Allen, R. G., Pereira, L. S., Raes, D., Smith, M. (1998): Crop Evapotranspiration (Guidelines for Computing Crop Water Requirements). – Irrigation and Drainage Paper No: 56. FAO, Rome.
- [2] Anonymous (2018): General Directorate of State Meteorological Affairs (DMİGM). – <https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=A&m=SIIRT> (date of access, Dec 06, 2018).
- [3] Anonymous (2019): Republic of Turkey, Ministry of Industry and Technology, Regional Development Administration of Southeast Anatolian Project (GAP). – <http://www.gap.gov.tr/gap-illeri-sayfa-13.html> (date of access: April 16, 2019).

- [4] Aydın, Y. (2004): The effect of different irrigation water and Nitrogen Levels on Yield and Alternate Bearing in Pistachio. – Çukurova Uni. Institute of Natural and Applied Science. Department of Agriculture Structure and Irrigation. Ph.D. Thesis (in Turkish).
- [5] Aydınşakir, K., Baştuğ, R., Büyüктаş, D. (2003): A research on calibration of some empirical equations for grass reference evapotranspiration under field and small lysimeter conditions in Antalya Region. – Akdeniz Uni. Journal of Agriculture Faculty 16(1): 107-119 (in Turkish).
- [6] Castañeda, L., Rao, P. (2005): Comparison of methods for estimating reference evapotranspiration in southern California. – Journal of Environmental Hydrology 13(14).
- [7] Cuenca, R. H. (1989): Irrigation System Design: An Engineering Approach. – Prentice-Hall, Englewood Cliffs, NJ.
- [8] Çobaner, M., Çitakoğlu, H., Haktanır, T., Yelkara, F. (2016): Determination of optimal Hargreaves-Samani equation for the Mediterranean region. – Dicle University, Faculty of Engineering, Journal of Engineering 7(2): 181-190 (special issue, in Turkish).
- [9] Conceição, M. A. F. (2002): Reference evapotranspiration based on class A pan evaporation. – Scientia Agricola 59(3): 417-420.
- [10] Diouf, O. C., Weihermüller, L., Ba, K., Faye, S. C., Faye, S., Vereecken, H. (2016): Estimation of Turc reference evapotranspiration with limited data against the Penman-Monteith formula in Senegal. – Journal of Agriculture and Environment for International Development - JAEID 110(1): 117-137. DOI: 10.12895/jaeid.20161.417.
- [11] Djaman, K., Balde, A. B., Sow, A., Muller, B., Irmak, S., N'Diaye, M. K., Manneh, B., Moukoubi, Y. D., Futakuchic, K., Kazuki Saito, S. (2015): Evaluation of sixteen reference evapotranspiration methods under Sahelian conditions in the Senegal River Valley. – Journal of Hydrology: Regional Studies 3: 139-159.
- [12] Doorenbos, J., Pruitt, W. O. (1977): Guidelines to Crop Water Requirements. – Irrigation and Drainage Paper No: 24 (revised). FAO, Rome.
- [13] Ertek, A. (2011). Importance of pan evaporation for irrigation scheduling and proper use of crop-pan coefficient ( $K_{cp}$ ), crop coefficient ( $K_c$ ) and pan coefficient ( $K_p$ ). Full length research paper. – African Journal of Agricultural Research 6(32): 6706-6718. DOI: 10.5897/AJAR11.1522.
- [14] Fisher, D. K., Pringle III, H. C. (2013). Evaluation of alternative methods for estimating reference evapotranspiration. – Agricultural Science 4(8A): 51-60. <http://dx.doi.org/10.4236/as.2013.48A008>.
- [15] Hargreaves, G. H., Samani, Z. A. (1985): Reference crop evapotranspiration from ambient air temperature. – American Society of Agricultural Engineers, Hyatt Regency, Chicago IL, 1985 Winter Meeting December 17-20, Paper No: 85-2517.
- [16] Kanber, R. (2006): Irrigation. – ÇU. Agriculture Faculty, General Publication Number: 174, Textbook Publication Number: A-52: 530 (in Turkish).
- [17] Kaya, S., Evren, S., Daşcı, E. (2016): Comparison of various equations for prediction of class A pan evaporation in semi-arid climatic conditions. – Uludağ Uni. Journal of Agriculture Faculty 30(2): 1-9. Bursa (in Turkish).
- [18] Pereira, A. R., Nilson, A. V. N., Pereira, A. S., Barbieri, V. (1995): A model for the class A pan coefficient. – Agricultural and Forest Meteorology 76: 75-82.
- [19] Sentelhas, P. C., Folegatti, M. V. (2003): Class A pan coefficients ( $K_p$ ) to estimate daily reference evapotranspiration ( $ET_o$ ). – Revista Brasileira de Engenharia Agrícola e Ambiental 7(1): 111-115. <http://www.agriambi.com.br>.
- [20] Shahidian, S., Serralheiro, R., Serrano, J., Teixeira, J., Haie, N., Santos, F. (2012): Hargreaves and Other Reduced-Set Methods for Calculating Evapotranspiration. – In: Irmak, A. (ed.) Evapotranspiration—Remote Sensing and Modeling. InTech, Morn Hill, pp. 59-80. DOI: 10.5772/725.
- [21] Snyder, R. L. (1992): Equation for evaporation pan to evapotranspiration conversions. – J. Irrig. Drain Eng. 118(6): 977-980.

- [22] Tabari, H., Grismer, M. E., Trajkovic, S. (2013): Comparative analysis of 31 reference evapotranspiration methods under humid conditions. – *Irrigation Science* 31: 107-117.
- [23] Thornthwaite, C. V. (1948): An approach toward a rational classification of climate. – *Geograph Rev.* 38: 55-94.
- [24] Todorovic, M., Karic, B., Pereira, L. S. (2013): Reference evapotranspiration estimate with limited weather data across a range of Mediterranean climates. – *Journal of Hydrology* 481: 166-176.
- [25] Trajkovic, S., Kolakovic, S. (2009): Evaluation of reference evapotranspiration equations under humid conditions. – *Water Resour. Manage.* 23: 3057-3067. <http://dx.doi.org/10.1007/s11269-009-9423-4>.
- [26] Trajković, S., Stojnić, V. (2008): Simple daily  $E_{T_0}$  estimation techniques. – *Facta Universitatis Series: Architecture and Civil Engineering* 6(2): 187-192. DOI: 10.2298/FUACE0802187T.
- [27] Ünlü, M., Kanber, R., Steduto, P., Aydın, Y., Diker, K. (2005): Effects of different water and nitrogen levels on the yield and periodicity of pistachio (*Pistachia vera* L) – *Turkish Journal of Agriculture and Forestry Sciences*, 29(2005) 39-49.