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*Full Length Research Paper*

# Evaluation of Blaney-Criddle equation for estimating evapotranspiration in south of Iran

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**The Penman-Monteith (PM) method is the standard equation for estimating reference crop potential evapotranspiration ($ET_o$) for different climates of the world. However, this equation needs full weather data, but few stations with complete weather data exist in Fars province, south of Iran. On the other hand, the Blaney-Criddle (BC) equation is a simpler alternative for estimating $ET_o$ compared with the PM equation. In this study, by using the meteorological data of seven synoptic stations inside the Fars province, the modified BC equation which included the effective temperature was evaluated based on the PM equation for every month of the year. The effective temperature can be calculated using the approach proposed by other investigators based on the minimum and maximum temperature and a calibrated coefficient (*k*). This coefficient was calibrated spatially for different months in the Fars province in another study. However, in this study the variable *k* values, and three constant *k* values (0.72, 0.69 and 0.64) that was reported by other investigators was used to evaluate the modified BC equation. The results demonstrated that using variable *k* values for considering the effective temperature in the modified BC equation was better than using mentioned constant values. Therefore, the results emphasized the superiority of using variable *k* values for considering the effective temperature.**

**Key words:** Blaney-Criddle equation, Penman-Monteith equation, Iran, evapotranspiration, effective temperature, fars province.

## INTRODUCTION

Evapotranspiration (ET) is an important parameter needed for the design, operation and management of irrigation systems. Accurate estimation of ET is essential for irrigation scheduling and water resources planning and management, especially in arid and semi-arid regions because of the lack of water resources. In most conditions, irrigation water requirement is calculated based on reference crop potential evapotranspiration ($ET_o$), and most irrigation engineers use $ET_o$ and crop coefficients to calculate different crop water requirements. Although several equations have been proposed to estimate $ET_o$, there is no universal consensus on the suitability of any given equation for a given climate, and they require rigorous local calibration (DehghaniSanij et al., 2004). However, the Penman-Monteith (PM) equation is the standard equation to compute $ET_o$ from meteorological data (Allen et al., 1998). The suitability of this equation was determined for different climates (Ventura et al., 1999; Kashyap and Panda, 2001; Irmak et al., 2003; Itenfisu et al., 2003; DehghaniSanij et al., 2004; Gavilan et al., 2006). Although the PM equation has been tested positively in different climates, the need for full meteorological data such as minimum and maximum air temperature, minimum and maximum relative humidity, solar radiation, and wind speed limits the widespread use of this equation (Pereira and Pruitt, 2004). One of the earliest equations for estimating $ET_o$ involving the use of temperature is the Blaney and Criddle (1962) that was modified by Doorenbos and Pruitt (1977). Although this equation is simple and old, it has been used in recent studies as a temperature based method for estimating $ET_o$ in different locations of the world with different climates (Chiew et al., 1995; Abu and Al-Osaimy, 1996; Barnett et al., 1998; Beyazgul et al., 2000; Trajkovic et al., 2000; George et al., 2002; Harmsen, 2003; Li et al., 2003; DehghaniSanij et al., 2004; Loukas et al., 2005; Singandhupe and Sethi, 2005; Singandhupe et al., 2005; Chauhan and Shrivastavt, 2009; Fooladmand and Ahmadi, 2009; Benli et al., 2010; Horvath et al., 2010;

Mohawesh, 2010; Razzaghi and Sepaskhah, 2010). In a trial for improving the estimation of $ET_o$, Camargo et al. (1999) proposed using effective temperature instead of average temperature in the Thornthwaite (1948) equation. The effective temperature can be calculated based on the minimum and maximum temperature and a calibrated coefficient (*k*).

The calculating approach of the effective temperature will be followed in this paper. The proposed approach was based on monthly average temperatures and their findings were satisfactorily compared with the PM equation. Pereira and Pruitt (2004) and Dinpashoh (2006) applied the effective temperature in the Thornthwaite equation and reported its reliable performance compared with the PM equation in the estimation of $ET_o$ in the USA and Iran, respectively. Fars province with arid and semi-arid climates is located in south of Iran. This area is one of the most agricultural parts of this country. Since, measured $ET_o$ data by using lysimeter is scarce in this region. On the other hand, there are few meteorological stations in Fars province that have full meteorological data for estimating the monthly $ET_o$ with the PM equation; therefore, in some studies other $ET_o$ methods have been calibrated and evaluated based on PM equation (Fooladmand and Sepaskhah, 2005; Fooladmand and Haghighat, 2007; Ahmadi and Fooladmand, 2008; Fooladmand et al., 2008; Fooladmand and Ahmadi, 2009; Fooladmand, 2011). Fooladmand and Ahmadi (2009) modified the Blaney-Criddle (BC) equation for diferent months in Fars province, and they presented the spatial distribution of the coefficients of this equation based on different values for using effective temperature in the modified BC equation. On the other hand, other investigators reported a constant value for considering effective temperature. Therefore, the objective of this research was to evalute the modified BC equation based on variable and constant values for considering the effective temperature in this equation for arid and semi-arid region of Fars province, south of Iran.

## MATERIALS AND METHODS

The study area is the geographical boundary of Fars province in south of Iran, at 50°30´ to 55°38´ E longitude and 27° 3´ to 31° 42´ N latitude, with an arable land area of 1.32 million $km^2$. The mean annual precipitation for the study area ranges from 50 to 1000 mm (Sadeghi et al., 2002). Due to lack of full meteorological data for estimating the monthly $ET_o$ with the PM equation for most meteorological stations in this region, the modified BC equation that was reported by Fooladmand and Ahmadi (2009) can be used for estimating monthly $ET_o$. The effective temperature is calculated as follows (Camargo et al., 1999):

$$T_{eff} = \frac{1}{2} k\left(3T_{max} - T_{min}\right) \quad (1)$$

Where $T_{eff}$, $T_{min}$ and $T_{max}$ are the effective, minimum and maximum monthly temperature (°C), respectively, and *k* is the calibrated coefficient.

Ahmadi and Fooladmand (2008) presented the *k* values for different months and different stations in Fars province, south of Iran. Therefore, Ahmadi and Fooladmand (2008) showed that the *k* value will be changed for different months and different locations. Fooladmand and Ahmadi (2009) considered the effective monthly temperature, and they presented the modified BC equation as follows:

$$ET_o = \left(a + 8.13b \times p\right) + \left(0.46b \times p\right)T_{eff} \quad (2)$$

Where $ET_o$ is reference crop potential evapotranspiration in mm $day^{-1}$, *p* is the mean annual percentage of daytime hours that can be obtained from Doorenbos and Pruitt (1977), and *a* and *b* are the coefficients which depend on the daily wind speed, daily minimum relative humidity and the ratio of daily actual sunshine hours to daily maximum sunshine hours. However, Fooladmand and Ahmadi (2009) presented the *a* and *b* values for different months and different stations in Fars province, south of Iran.

The values of *a* and *b* for different months and different stations in the study area were obtained based on the PM equation by using weather data up to year 2000. As mentioned, Fooladmand and Ahmadi (2009) used variable *k* values for considering the effective temperature in the modified BC equation. However, Camargo et al. (1999) suggested the constant value of 0.72 for *k*, and Dinpashoh (2006) used this value for different location of Iran. In another study, Pereira and Pruitt (2004) suggested the constant value of 0.69 for *k*. Also, Sepaskhah and Razzaghi (2009) obtained a constant value of 0.64 for *k* in a semi-arid region in Fars province, south of Iran. In this study, Equation 2 was evaluated for seven synoptic stations in Fars province by using weather data from year 2001 to 2006. The location of the stations used in this study is shown in Figure 1, and the geographic characteristics, climate and annual average values of temperature, rainfall and $ET_o$ (based on the PM equation) of each station for these years are presented in Table 1. In this study, the reported values by Fooladmand and Ahmadi (2009) for *a* and *b* were used. Also, to use the effective temperature in Equation 2, the *k* value was considered as variable (Ahmadi and Fooladmand, 2008), and constants of 0.72, 0.69 and 0.64, separately. Hereafter, these conditions will be presented by kv (that is, variable *k* values that have been reported by Ahmadi and Fooladmand (2008) for different months and different stations in Fars province), k0.72, k0.69 and k0.64.

After that, in each station four mentioned conditions were compared with PM equation for each month of year, separately. For this purpose, the root mean square error (RMSE) was computed using the following expression:

$$RMSE = \left[\frac{\sum_{i=1}^{n}\left(y_i - x_i\right)^2}{n}\right]^{0.5} \quad (3)$$

Where $y_i$ is the estimated $ET_o$ with PM equation in the considered month for the whole year, $x_i$ is the estimated $ET_o$ with Equation 2 based on four mentioned conditions for considering the *k* value, and *n* is the sample size for each month (equal to 6).

Therefore, the best equation for estimating ETo was determined for each month and each station, separately, by comparing the different values of RMSE. The best condition has minimum RMSE value. Qiu et al. (1999) and Kashyap and Panda (2001) reported RMSE values < 1 mm $d^{-1}$ for $ET_o$ studies. Finally, by using the geographical coordinates of the stations and considering the best condition for estimating $ET_o$ in each station and each month, the


**Figure 1.** Regional map of Iran, and regional map of Fars province and the selected stations in this study.

spatial distribution maps of the best condition in Fars province were prepared for each month of the year. To obtain these maps, the ArcView software one of the GIS-assisted methods were used, and the spatial maps were drawn by using the ‘assign proximity’ of the analysis menu of this software.

## RESULTS AND DISCUSSION

The RMSE values of different conditions for estimating $ET_o$ in all stations and months are presented in Table 2. According to the low values of RMSE in most station-months, the results of this study for arid and semi-arid regions in south of Iran showed a good agreement between the modified Blaney-Criddle and PM equations. More details about the obtained results in this study will be followed.

### Results for different stations

In Abadeh with arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 0.42, 0.61, 0.76 and 1.01 mm $d^{-1}$, respectively. So, the mean RMSE values of kv, k0.72 and k0.69 were lower than 1 mm $d^{-1}$ that was reported by Qiu et al. (1999) and Kashyap and Panda (2001). Also, using variable *k* values for considering the effective temperature was better than using constant values reported by many researchers (Camargo et al.,

**Table 1.** Geographic characteristics, climate and annual average values of temperature ($T_{mean}$), rainfall and $ET_o$ of each station from years 2001 to 2006.

| Station | North latitude | East longitude | Elevation (m) | Rain (mm) | $T_{mean}$ (°C) | $ET_o$ (mm $day^{-1}$) | Climate |
|---|---|---|---|---|---|---|---|
| Abadeh | 31°11' | 52° 40' | 2030 | 157.6 | 14.6 | 4.34 | Arid |
| Darab | 28° 47' | 54° 17' | 1107 | 256.1 | 22.2 | 6.47 | Arid |
| Dorodzan dam | 30° 13' | 52° 26' | 1620 | 526.5 | 18.0 | 5.39 | Semi-arid |
| Fasa | 28° 58' | 53° 41' | 1288 | 324.6 | 19.3 | 6.15 | Arid |
| Lar | 27° 41' | 54° 17' | 792 | 149.6 | 23.9 | 6.81 | Arid |
| Shiraz | $29^o$ 36' | 52° 32' | 1488 | 351.5 | 18.6 | 5.40 | Semi-arid |
| Zarghan | 29° 47' | 52° 43' | 1596 | 344.1 | 16.7 | 5.60 | Semi-arid |

1999; Pereira and Pruitt, 2004; Dinpashoh, 2006; Sepaskhah and Razzaghi, 2009). On the other hand, in Shiraz with semi-arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 0.42, 0.33, 0.48 and 0.79 mm $d^{-1}$, respectively. So, the mean RMSE values of all conditions were < 1 mm $d^{-1}$. Therefore, all conditions can be used in Shiraz region, however the best condition was using constant value of 0.72 for *k* that was reported by Camargo et al. (1999) and used by Dinpashoh (2006) for different locations of Iran. As shown, the differences between mean RMSE values of kv and k0.72 in Shiraz station was small (0.09), therefore variable *k* values for considering the effective temperature can also be used for this semi-arid region. In Dorodzan Dam with semi-arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 0.81, 1.53, 1.69 and 1.96 mm $d^{-1}$, respectively. So, the mean RMSE values of kv were lower than the suggested value of 1 mm $d^{-1}$. Therefore, the results showed that using variable *k* values for considering the effective temperature was better than using constant values reported by other researchers (Camargo et al., 1999; Pereira and Pruitt, 2004; Dinpashoh, 2006; Sepaskhah and Razzaghi, 2009). In Lar with arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 1.08, 0.85, 1.07 and 1.49 mm $d^{-1}$, respectively. Also, In Zarghan with semi-arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 1.04, 0.80, 0.98 and 1.29 mm $d^{-1}$, respectively. Therefore, the best condition for these regions were using constant value of 0.72 for *k*. As shown, the mean RMSE values of this condition were lower than the suggested value of 1 mm $d^{-1}$. However, the mean RMSE values of kv for these regions were greater than the suggested value of 1 mm $d^{-1}$. Therefore, the results showed that using variable *k* values for considering the effective temperature were not appropriate for these regions, which was in contrast to the obtained results for Abadeh, Dorodzan Dam and Shiraz regions.

In Darab with arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 1.25, 1.23, 1.45, 1.81 mm $d^{-1}$, respectively. Also, in Fasa with arid climate, the mean RMSE values of kv, k0.72, k0.69 and k0.64 were 2.25, 1.94, 2.10 and 2.36 mm $d^{-1}$, respectively. So, the mean RMSE values of all conditions were greater than the suggested value of 1 mm $d^{-1}$. However, the best condition was using constant value of 0.72 for *k*. These results were similar to the obtained results for Lar and Zarghan regions.

## Results for monthly time step

In the monthly time step, the results showed that using variable *k* values for considering the effective temperature was better for all months in Dorodzan Dam; however, for other stations using variable k values and using constant value of 0.72 for k were appropriate without any specific pattern. The results showed that in 47 station-months the best condition belonged to kv, in 36 station-months the best condition belonged to k0.72, and only in 1 station-month the best condition belonged to k0.69. So, using variable *k* values for considering the effective temperature that was reported by Ahmadi and Fooladmand (2008) and used by Fooladmand and Ahmadi (2009) was better than using constant values of 0.72, 0.69 and 0.64 that was used by other researchers (Camargo et al., 1999; Pereira and Pruitt, 2004; Dinpashoh, 2006; Sepaskhah and Razzaghi, 2009). Therefore, the results demonstrated that using constant value of 0.64 for considering the effective temperature that wasreported by Sepaskhah and Razzaghi (2009) for a semi-arid region in the study area, was not appropriate. Sepaskhah and Razzaghi (2009) obtained constant value of 0.64 for considering the effective temperature by using weighing type lysimeter data during years of 2004 and 2005; however, in this study this constant value (0.64) for considering the effective temperature was used in modified BC equation and the results compared with the PM equation.

## Monthly spatial distribution maps of the best condition for estimating $ET_o$

By using the geographical coordinates of the stations and considering the best condition for estimating $ET_o$ in each station and each month, the spatial distribution maps of the best condition in Fars province were prepared for

**Table 2.** RMSE values of different conditions for estimating $ET_o$ in all stations and months.

| Months | Abadeh | | | | Darab | | | | Dorodzan dam | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kv | k0.72 | k0.69 | k0.64 | kv | k0.72 | k0.69 | k0.64 | kv | k0.72 | k0.69 | k0.64 |
| Jan | 0.19 | 0.29 | 0.34 | 0.43 | 0.68 | 0.93 | 0.99 | 1.09 | 0.26 | 0.67 | 0.71 | 0.77 |
| Feb | 0.41 | 0.39 | 0.47 | 0.60 | 1.09 | 1.43 | 1.53 | 1.68 | 0.40 | 1.17 | 1.24 | 1.36 |
| Mar | 0.82 | 0.74 | 0.85 | 1.05 | 1.08 | 1.77 | 1.91 | 2.14 | 0.53 | 1.63 | 1.74 | 1.92 |
| Apr | 0.57 | 0.84 | 1.00 | 1.26 | 1.10 | 1.47 | 1.69 | 2.06 | 0.43 | 1.60 | 1.76 | 2.02 |
| May | 0.43 | 1.22 | 1.42 | 1.75 | 1.56 | 1.77 | 2.10 | 2.63 | 0.97 | 2.43 | 2.64 | 3.01 |
| Jun | 0.45 | 1.19 | 1.43 | 1.84 | 1.84 | 1.59 | 1.96 | 2.59 | 1.62 | 2.68 | 2.94 | 3.38 |
| Jul | 0.98 | 0.71 | 0.96 | 1.37 | 0.16 | 0.22 | 0.56 | 1.20 | 1.00 | 1.92 | 2.20 | 2.67 |
| Aug | 0.51 | 0.70 | 0.94 | 1.34 | 1.46 | 1.22 | 1.57 | 2.16 | 1.52 | 2.30 | 2.55 | 2.99 |
| Sep | 0.09 | 0.55 | 0.75 | 1.07 | 1.90 | 1.23 | 1.52 | 2.00 | 1.10 | 1.64 | 1.86 | 2.24 |
| Oct | 0.29 | 0.39 | 0.54 | 0.79 | 1.89 | 1.42 | 1.62 | 1.96 | 1.00 | 1.27 | 1.43 | 1.71 |
| Nov | 0.13 | 0.16 | 0.25 | 0.41 | 1.47 | 1.17 | 1.28 | 1.47 | 0.69 | 0.72 | 0.82 | 0.97 |
| Dec | 0.11 | 0.12 | 0.17 | 0.25 | 0.79 | 0.56 | 0.62 | 0.73 | 0.19 | 0.31 | 0.36 | 0.45 |

| Months | Fasa | | | | Lar | | | | Shiraz | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kv | k0.72 | k0.69 | k0.64 | kv | k0.72 | k0.69 | k0.64 | kv | k0.72 | k0.69 | k0.64 |
| Jan | 0.41 | 0.66 | 0.72 | 0.82 | 0.37 | 0.56 | 0.65 | 0.79 | 0.09 | 0.37 | 0.43 | 0.52 |
| Feb | 0.63 | 1.08 | 1.17 | 1.31 | 0.78 | 1.20 | 1.33 | 1.55 | 0.25 | 0.38 | 0.47 | 0.62 |
| Mar | 0.62 | 1.17 | 1.28 | 1.47 | 0.74 | 1.51 | 1.69 | 2.00 | 0.46 | 0.67 | 0.81 | 1.03 |
| Apr | 1.31 | 1.58 | 1.74 | 2.01 | 0.93 | 1.11 | 1.39 | 1.85 | 0.55 | 0.75 | 0.94 | 1.27 |
| May | 3.19 | 2.96 | 3.19 | 3.57 | 1.18 | 1.06 | 1.43 | 2.04 | 0.80 | 0.61 | 0.87 | 1.30 |
| Jun | 4.39 | 3.50 | 3.77 | 4.21 | 1.86 | 0.74 | 1.16 | 1.86 | 0.91 | 0.14 | 0.38 | 0.90 |
| Jul | 3.76 | 2.78 | 3.05 | 3.49 | 0.83 | 0.27 | 0.33 | 0.96 | 0.75 | 0.15 | 0.42 | 0.93 |
| Aug | 4.27 | 3.28 | 3.53 | 3.94 | 1.03 | 0.40 | 0.77 | 1.42 | 0.51 | 0.15 | 0.38 | 0.88 |
| Sep | 3.61 | 2.64 | 2.85 | 3.20 | 1.43 | 0.58 | 0.90 | 1.43 | 0.27 | 0.19 | 0.16 | 0.57 |
| Oct | 2.82 | 2.09 | 2.24 | 2.50 | 1.90 | 1.24 | 1.46 | 1.83 | 0.13 | 0.17 | 0.34 | 0.66 |
| Nov | 1.53 | 1.17 | 1.25 | 1.38 | 1.33 | 0.97 | 1.10 | 1.33 | 0.23 | 0.21 | 0.29 | 0.46 |
| Dec | 0.45 | 0.32 | 0.37 | 0.46 | 0.61 | 0.56 | 0.64 | 0.76 | 0.12 | 0.16 | 0.21 | 0.30 |

| Months | Zarghan | | | |
|---|---|---|---|---|
| | kv | k0.72 | k0.69 | k0.64 |
| Jan | 0.21 | 0.27 | 0.32 | 0.39 |
| Feb | 0.54 | 0.84 | 0.93 | 1.06 |
| Mar | 0.64 | 1.40 | 1.51 | 1.70 |
| Apr | 0.59 | 1.14 | 1.31 | 1.59 |
| May | 1.44 | 2.07 | 2.31 | 2.70 |
| Jun | 1.89 | 1.32 | 1.66 | 2.23 |
| Jul | 1.37 | 0.54 | 0.89 | 1.48 |
| Aug | 1.91 | 0.63 | 0.98 | 1.56 |
| Sep | 1.66 | 0.50 | 0.79 | 1.27 |
| Oct | 1.41 | 0.42 | 0.63 | 0.98 |
| Nov | 0.72 | 0.16 | 0.18 | 0.35 |
| Dec | 0.13 | 0.33 | 0.25 | 0.14 |

each month of the year. The results of all spatial distribution maps for different months, except for the months of January and April, are shown in Figure 2. In January and April, using variable *k* values for considering the effective temperature was appropriate for all stations. Also, for some months of the year the same distribution map was presented due to the similarity conditions for these months. These maps clearly show the distribution of the best condition for estimating $ET_o$ in each month of year. As shown in Figure 2, no specific pattern can be shown in Fars province. Consequently, these maps can be used to estimate $ET_o$ with a modified BC equation in


**Figure 2.** Spatial distribution maps of the best condition for different months.

different places of Fars province, south of Iran by using the appropriate condition for considering the effective temperature.

## Conclusion

Although the BC equation is a simple and old method for estimating $ET_o$, however the results of this modified equation for arid and semi-arid regions in south of Iran showed a good agreement between this method and PM equation. Therefore, modified BC equation, that is, Equation 2, with available coefficients of *a* and *b*, which have been presented by Fooladmand and Ahmadi (2009) can be used for estimating $ET_o$ in south of Iran. Moreover, the results of this study demonstrated that using variable *k* values for considering the effective temperature in modified BC equation that was reported by Ahmadi and Fooladmand (2008) was better than using constant values of 0.69 and 0.64 that was reported by Pereira and Pruitt (2004) and Sepaskhah and Razzaghi (2009), respectively. Although, the results of this study indicated that using constant value of 0.72 for considering the effective temperature in modified BC equation that was reported by Camargo et al. (1999) and used by Dinpashoh (2006) for different locations of Iran, was appropriate for some months and stations, however total obtained results for whole months and stations showed the superiority of using variable *k* values for considering the effective temperature. The monthly spatial distributions maps of *k* values were presented by Ahmadi and Fooladmand (2008) and can be used for estimating $ET_o$ for the study area in south of Iran. Similar researches should be undertaken to evaluate the superiority of using variable *k* values for considering the effective temperature in the modified or original BC equation in different places of the world with different climates.


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