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**ORIGINAL ARTICLE**

# Comparison of Different Evaporation Estimation Equations in Kashan

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**ABSTRACT**
*Estimation of Evaporation is necessary for planning, design and irrigation design and water resources management. Evaporation can be estimated on basis of pan evaporation data ($E_{pan}$), whose measurements have the advantage of low cost, simple data interpretation and application as well as suitability for locations with limited availability of meteorological data. In this paper, accurate different methods and CROPWAT model were applied and then their results were compared with $E_{pan}$ using data of Kashan synoptic meteorological station during the years 2000 to 2008 in the growing season (April to December). The results indicated that the Blaney-Criddle model was the most appropriate for this study area compared to the $E_{pan}$ . Higher temperature combined with lower humidity has resulted in higher values of $E_{pan}$ and Blaney-Criddle method.*

***Keywords:*** *pan evaporation, Kashan, Arid environment, Blaney-Criddle, Penman Montieth, CROPWAT model.*

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## INTRODUCTION

Due to droughts in recent years, suitable management of existing water resources and better solutions for their usage are essential [1].Evapotranspiration can be either estimated with lysimeter measurements or a water balance approach or estimated from climatological data [2]. Because a large volume of water can be lost through the soil surface, the estimation of evapotranspiration has played an important role in water resource management. Evaporation and evapotranspiration processes are the major components of the hydrologic cycle which play a vital role in agricultural and hydro-meteorological studies. The largest part of Iran is located in semi-arid and arid climates. In these areas, in average, about 50% of all precipitation is lost by evaporation processes. Therefore, estimation of evaporation is very important [3,4]. Estimation of evaporation from the pan evaporation data ($E_{pan}$) is commonly practiced. Since Class-A pan evaporimeters are widely available, in the estimation of reference crop evapotranspiration due to its simplicity, low cost, ease of data interpretation and suitability for areas with limited availability of meteorological data. Also, estimation of evapotranspiration directly from the pan evaporation data can easily be done. Moreover, direct measurement of evapotranspiration using a lysimeter is difficult and time consuming. Many researchers reported a high correlation between Epan and evaporation, when evaporation pans are properly maintained. Therefore, several equations have been proposed to estimate evaporation. The objective of this paper is to compare the pan evaporation data ($E_{pan}$) and the performance of seven widely used simple evaporation methods, namely Linacre [5,6], Hargreaves-Samani (H-S) [7], Blaney-Criddle (B-C) [8], Penman Fao, Penman-montith (FAO-56 PM) [9], Thorthwaite [10] and Jensen-Haise [11] and CROPWAT model in estimating evaporation at Kashan area for the period 2000–2008.

## MATERIALS AND METHODS

For evaluating evaporation in an arid region, data from Kashan region in the center of Iran were used. It is located 33° 59′ north latitude and 51° 27′ east longitude and Located in an altitude of 982.30 m above sea level. The region has a typical desert climate that is dry and warm in the north and more temperate in the south and it is near the Karkas Mountain and center of Iran and the most important part of rainfall in winter and spring are unusable and most of rainfall may be in form of floods [12]. Annual average values of temperature and rainfall of Kashan station are 19.1º and 138.40 mm, respectively. The location of the study area and stations is shown in Figure 1.

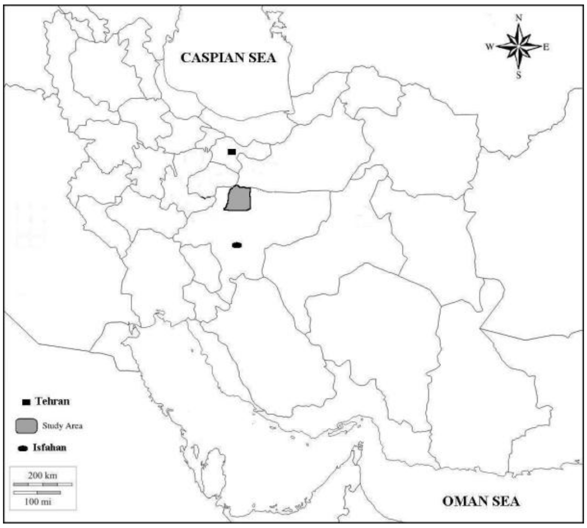



**Figure 1: The area study on Iran map**

The mean monthly values of the meteorological data for the period 2000–2008 at Kashan station are presented in Table 1. The Class-A pan evaporimeter is surrounded by dry fallow land.

**Table 1: Mean monthly values of the meteorological parameters during 2000-2008 in Kashan station**

| Variables | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| $RH_{mean}$ (%) | 61.80 | 50.00 | 40.50 | 40.20 | 33.50 | 25.00 | 23.00 | 23.00 | 27.70 | 37.20 | 53.70 | 67.30 |
| $T_{mean}$ (°C) | 6.00 | 8.60 | 14.00 | 19.70 | 24.60 | 30.10 | 32.80 | 32.10 | 27.50 | 21.10 | 12.10 | 6.90 |
| Wind speed ($m.s^{-1}$) | 0.17 | 0.48 | 0.61 | 0.92 | 0.86 | 0.56 | 0.76 | 0.59 | 0.35 | 0.33 | 0.17 | 0.14 |
| $T_d$ Dew point (°C) | -2.10 | -2.90 | -1.00 | 3.80 | 6.20 | 6.90 | 8.10 | 7.70 | 6.40 | 4.40 | 1.80 | 0.30 |
| n (hr) | 6.10 | 6.60 | 7.90 | 7.40 | 9.90 | 11.10 | 10.70 | 11.10 | 9.90 | 9.00 | 6.70 | 5.10 |
| Daily Max Sun (N) (hr) | 10.20 | 11.00 | 11.90 | 13.10 | 13.90 | 14.40 | 14.20 | 13.40 | 12.40 | 11.40 | 10.40 | 9.90 |
| n/N | 0.60 | 0.60 | 0.66 | 0.56 | 0.71 | 0.77 | 0.75 | 0.83 | 0.80 | 0.79 | 0.64 | 0.52 |
| Ra ($mm.d^{-1}$) | 7.60 | 9.70 | 12.20 | 14.60 | 16.5 | 17.10 | 16.70 | 15.50 | 13.30 | 10.70 | 8.20 | 7.00 |

Monthly evaporation was estimated using different methods by Linacre, Hargreaves-Samani (H-S), Blaney-Criddle (B-C), Penman Fao, Penman-montith (FAO-56 PM), Thornthwaite, Jensen-Haise and pan evaporation data ($E_{pan}$) and CROPWAT model. FAO-CROPWAT model built based on the recommended FAO-56, 1998 [9] method which is proven by many researches as a best available approach.

Linacre**:**

$$ET = \frac{\dfrac{700\times\left(T_{mean}+0.006\times Z\right)}{100-L}+15\times(T_{mean}-T_d)}{80-T_{mean}}$$

(1)

Hargreaves and Samani:

$$ET_0 = 0.0023\times R_a\times(T_{mean}+17.80)\times\left(T_{max}-T_{min}\right)^{0.50} \quad (2)$$

where $ET_0$ is in mm $day^{-1}$, $R_a$ is the extraterrestrial radiation (mm $day^{-1}$).

Blaney and Criddle:

$$ET_0 = a + b\left[P\left(0.46T_{mean}+8.13\right)\right] \quad (3)$$

where $ET_0$ is in mm day$^{-1}$, a and b are the parameters of the equation and P is the mean annual percentage of daytime hours.
Penman-Fao**:**

$$ET = \left[ \frac{\Delta}{\Delta+\gamma} R_n + \frac{\gamma}{\Delta+\gamma} (0.27)(1.0+0.01U_2)\,(e_s - e_d) \right]$$
(4)

FAO-56 PM:

$$ET_0 = \frac{0.408\Delta\,(R_n - G) + \gamma \left[ \frac{900}{(T_{mean}+273)} \right] U_2\,(e_s - e_d)}{\Delta + \gamma(1.0+0.34U_2)}$$
(5)
where, FAO-56 PM $ET_0$ (mm.d$^{-1}$); Δ = slope of the saturation vapor pressure function (kPa/°C); $R_n$ = net solar radiation (MJ/m$^2$.d$^{-1}$); G = soil heat flux density (MJ/m$^2$.d$^{-1}$); T = mean air temperature (°C); $U_2$ = average 24-h wind speed at 2- m height (m.s$^{-1}$); $e_s$ - $e_a$ = vapor pressure deficit (kPa); and γ = psychometric constant (kPa/°C). Usually, the weather stations do not have all of these parameters and, therefore, the application of this equation has been limited.
Thornthwaite:

$$ET_0 = 16\left(10\frac{T_{mean}}{I}\right)^{\alpha} \qquad (6)$$

$$I = \sum_{n=1}^{12}\left(\frac{T_{mean}}{5}\right)^{1.514} \qquad (7)$$

$$\alpha = \left(492390 + 17920I - 77.10I^2 + 0.675I^3\right) \times 10^{-6} \qquad (8)$$

where $ET_0$ is the reference evapotranspiration (mm month$^{-1}$)**.**
Jensen and Haise:

$$ET_0 = \frac{C_t\,(T_{mean} - T_a)\,R_s}{\lambda} \qquad (9)$$

where $ET_0$ is in mm day$^{-1}$ , λ is in cal gr$^{-1}$, Rs is in mm day$^{-1}$, $C_t$ (temperature constant) = 0.025, and $T_a$ = -3 when $T_{mean}$ is in degrees Celsius.

## RESULTS AND DISCUSSION

The monthly mean predicted values of daily evaporation by pan evaporation data ($E_{pan}$) and the different equations are given in Table 2. The lowest and highest values of evaporation for all equations are obtained in December and July, respectively.

**Table 2: Mean monthly values of evaporation (mm) for each equation and pan evaporation data ($E_{pan}$)**

| Month | Linacre | H-S | CROPWAT | B-C | Penman | Fao-56 PM | Thornthwaite | Jensen-Haise | $E_{pan}$ |
|---|---|---|---|---|---|---|---|---|---|
| April | 262.20 | 144.00 | 122.50 | 224.10 | 135.00 | 134.60 | 85.50 | 335.60 | 144.70 |
| May | 335.40 | 192.60 | 160.30 | 301.80 | 176.90 | 176.70 | 162.90 | 441.30 | 242.30 |
| June | 453.40 | 232.90 | 171.20 | 338.20 | 225.30 | 215.10 | 267.90 | 529.50 | 353.50 |
| July | 512.80 | 233.40 | 182.00 | 391.10 | 224.60 | 222.50 | 336.70 | 551.70 | 416.80 |
| August | 497.70 | 220.60 | 160.30 | 346.00 | 214.30 | 203.80 | 303.60 | 503.70 | 393.30 |
| September | 396.00 | 171.90 | 112.30 | 246.40 | 166.90 | 146.30 | 184.10 | 385.30 | 308.50 |
| October | 273.4 | 109.80 | 71.40 | 159.50 | 103.80 | 81.00 | 90.20 | 249.20 | 210.10 |
| November | 152.60 | 57.90 | 33.60 | 74.70 | 53.10 | 39.30 | 20.50 | 136.20 | 102.70 |
| December | 96.30 | 36.40 | 21.30 | 31.10 | 29.30 | 20.50 | 5.10 | 89.30 | 17.60 |
| Total | 2979.90 | 1399.50 | 1034.90 | 2112.90 | 1329.2 | 1239.80 | 1456.50 | 3221.80 | 2189.50 |

Figures 2 to 5 compare evaporation estimated by the Epan values of a Class-A pan evaporimeter and different equations.

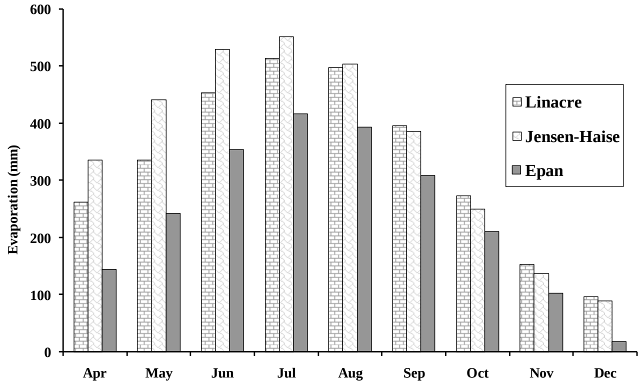



**Figure 2: Comparison between evaporation estimates obtained using $E_{pan}$ and Linacre and Jensen-Haise**

As Figure 2, the monthly evaporation estimates with the Linacre and Jensen-Haise equations were generally higher than the monthly evaporation obtains with the $E_{pan}$ in the growing season (April to December). Results indicated that the average monthly evaporation estimates with the H-S and Thornthwaite equations were lower than the monthly evaporation obtains with the $E_{pan}$ by 64% and 67%, respectively (Figure 3).

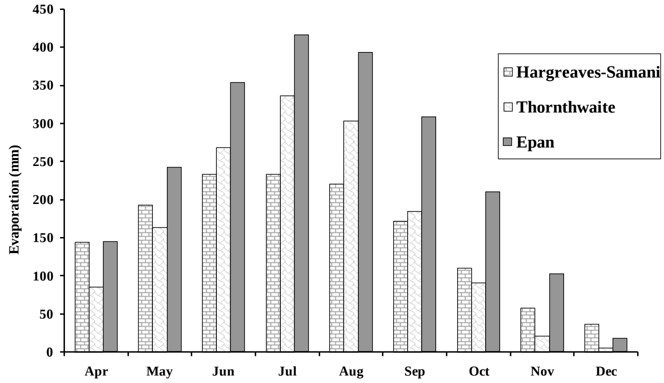



**Figure 3: Comparison of evaporation obtained by $E_{pan}$ and H-S and Thornthwaite**

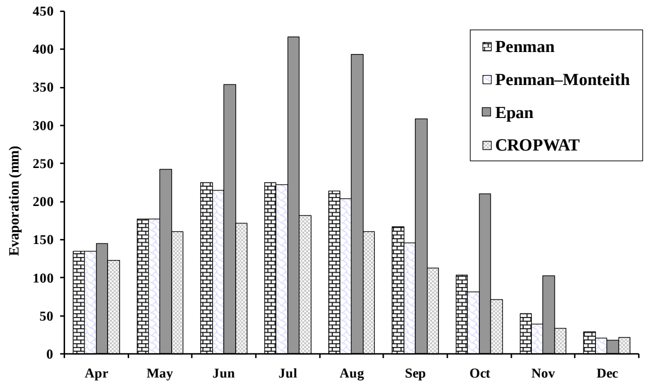



**Figure 4: Comparison of evaporation obtained by $E_{pan}$ and Penman-Fao, Penman-Montith and CROPWAT**

The result indicated that the Penman-Fao equation gave similar evaporation estimates as the FAO-56 PM method at this station for all months (Figure 4). Also, according to Figure 4 and the monthly results, the lowest evaporation values of were calculated by CROPWAT. In general, all these equations predicted evaporation values very low. The equation of Blaney-Criddle (B-C) indicated the best adaptation to the

$E_{pan}$ compared to the other equations and adequate performance for the estimation of evaporation under the climate and environmental conditions of the study area (Figure 5). The annual sum of evaporation estimations by Blaney-Criddle and $E_{pan}$ were 2112.90 mm $yr^{-1}$ and 2189.50 mm, respectively.

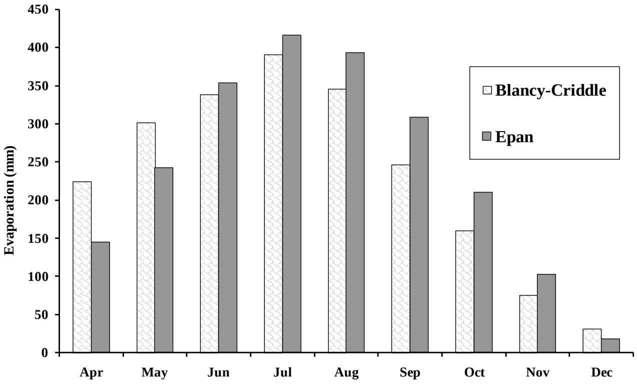
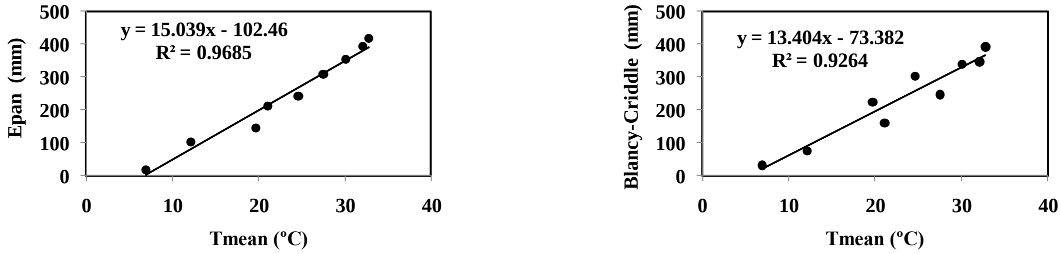


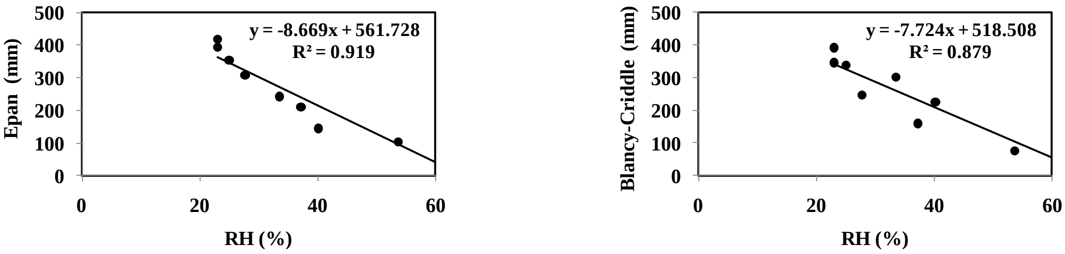

**Figure 5: Comparison of evaporation obtained by $E_{pan}$ and B-C**

Blaney-Criddle considered as temperature method and using few weather input are suitable to the study area where the complete data required for evaporation estimation is complex [13, 14] and in different locations of the world with different climates [15-19]. This fact is also supported by many studies which reveal that the Blaney-Criddle method is nearly as accurate as the $E_{pan}$ in estimating evaporation.
The values of evaporation $E_{pan}$ and Blaney-Criddle method were dependent on air temperature (T) and relative humidity (RH). Good correlations between temperature (T) or humidity (RH) and the $E_{pan}$ and Blaney-Criddle method values were found. The mean monthly values of T and RH are plotted against $E_{pan}$ and Blaney-Criddle method in Figures 6 and 7, respectively. Higher temperature combined with lower humidity has resulted in higher values of $E_{pan}$ and Blaney-Criddle method [1].




(a) (b)

**Figure 6: Relationship between mean temperature ($T_{mean}$) and (a) Epan measured and (b) evaporation calculated (Blaney-Criddle)**




(a) (b)

**Figure 7: Relationship between relative humidity (RH) and (a) Epan measured and (b) evaporation calculated (Blaney-Criddle)**

## CONCLUSIONS

Estimating of evaporation is often based on pan evaporation measurements ($E_{pan}$) due to low cost, simplicity of measuring equipment, simple data interpretation and application as well as suitability for locations with limited availability of meteorological data. In this study, seven common evaporation equations and CROPWAT model were evaluated for prediction of evaporation in the growing season (April to December) in arid region of Kashan in center of Iran using data from 2000-2008. The Blaney-Criddle approach was best suited compared to $E_{pan}$. The lowest and highest values of evaporation for all equations are obtained in December and July, respectively. The Jensen-Haise equation showed the weakest ability to predict evaporation.

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