Comparison of Evapotranspiration Models for Estimating Reference Evapotranspiration in Arid Environment

Mohammad Mehdi Heydari, Reza Nasiri Noushabadi, Mohammad Vahedi, Ali Abbasi and Morteza Heydari

1Department of Water Engineering, Sciences and Research Branch, Islamic Azad University, Khouzestan, Iran
2Department of Mechanic Engineering, Kashan Branch, Islamic Azad University, Kashan, Iran
3Young Researchers Club, Kashan Branch, Islamic Azad University, Kashan, Iran
4Department of Computer Engineering, Ashtian Branch, Islamic Azad University, Ashtian, Iran

Abstract: In this study, evapotranspiration (ET$_0$) was determined by several models for Naein city in Isfahan province (center of Iran) from 1993-2006. Outputs were obtained from IMO (Iran Meteorological Organization) weather station, located in the Naein, for all of these years. FAO Penman Monteth (FAO-56 PM) method has been accepted by many researchers and international institutes as the reference and Standard method. Accurate different methods were compared with FAO-56 PM method. Results show that Blaney-Criddle (BC) model were the best in light of mean biased error (MBE), root mean square error (RMSE) and maximum absolute error (MAXE). The mean values MBE, RMSE and MAXE computed -0.554, 0.690 and 1.429 mm.d$^{-1}$ for BC, respectively. For all the years, ET$_0$ rates were low in winter and fall and highest during the summer. Also, the maximum and minimum annual ET$_0$ estimations by Blaney-Criddle and FAO-56 PM methods was in 2001 and 1996, respectively.

Key words: Naein %Evapotranspiration %Blaney-Criddle %Turc %Fao Penman Montieth

INTRODUCTION

ET$_0$ is one of the key processes in the hydrological cycle and it is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surface and transpiration from plants [1]. Evaporation from water bodies are about 112% of precipitation. Information about ET$_0$, or consumptive water use, is significant for water resources planning, for irrigation scheduling in crops [2-5]. Estimation of ET$_0$ is one of the major hydrological components for determining the water budget and it is therefore, reliable and consistent estimate of ET$_0$ is of great importance for the management of water resources efficiently. Efficient water management requires an accurate ET$_0$ which can be derived from the meteorological variables. ET$_0$ is always the important research subjects on hydrology, soil, agriculture, meteorology; ET$_0$ also has important applications in water resources in arid areas, regional planning and management of agricultural production [6, 7]. In the semi-arid and arid zones which cover most of the Iranian plateau, evaporation can be till 96% of annual precipitation. In the average about 50% of all precipitation loose in evaporation process in the catchments. Therefore, investigation on ET$_0$ process could be very important in this country [8].

Empirical methods are used when all the data needed for Penman-type equations are not available. Direct measurement of evapotranspiration is usually not feasible in many field situations because it is expensive and time-consuming. The ET$_0$ computation methods can be classified into three types: temperature methods, radiation methods and combination methods. The Food and Agriculture Organization (FAO) recommends the use of the FAO-56 PM method for estimating reference evapotranspiration (ET$_0$) [1, 9]. This method is the most widely used in the world and has been proven to accurately estimate ET$_0$ in different climates [1, 10-14].
However, it requires several measurements of climatic variables such as air temperature, relative humidity, solar radiation and wind speed. At the planning and design stages of irrigation and water conservation schemes, historical average daily values of ET$_0$ for multi-day periods (e.g. weekly, ten-day and monthly) may be satisfactory for estimation of crop water use [15]. Naein city that covers an area of 35928 km$^2$ is located in 145 km northeast of Isfahan province, in center Iran. Due to the difference in unevenness and locating in the neighborhood of "NAMAK" desert, the north and south parts of this area are different in climate. In the north, climate is hot and dry and the south is mountainous [8]. In this region there is no permanent river but there are some dry streams which lead the floods of the neighboring mountains to the salt lake [16]. Increase of water demands associated with rapid urban development and expansion of agricultural lands has led to overexploitation of water in this city. Water withdrawal continues, water shortage crisis will happen in this area [17]. The purpose of this study was to estimate evapotranspiration of the Naein, an arid in centenal of Iran. The meteorological data necessary for the equations from 1993-2006 were obtained from synoptic station placed at Naein. In this study, 11 methodologies for estimating evapotranspiration was calculated and compared with the reference method (FAO-56 PM). The most appropriate method to estimate ET$_0$ using statistical indicators (RSME, MBE, RE and R$^2$) in Naein is selected and suggested Blaney-Criddle. Also, given the similarity of ET$_0$ and temperature distribution, the regression relationship with a regression coefficient of between temperature and FAO-56 PM method were determined and plotted.

MATERIALS AND METHODS

Naein city is located in central Iran and on the eastern outskirts of central mountains adjacent to Kavir desert (between the Karkas mountain slope and Iran Central Desert [18]) is between 32° 30' to 34°15' N latitude and 52°35' to 55°02' E longitude and Located in an altitude of 1,549 m above sea level (Fig. 1). It has a desert climate, with a maximum temperature of 41°C in summer and a minimum of -9°C in winter.

Naein city has a dry climate with very little precipitation. The region has a typical desert climate and the most important part of rainfall in winter and spring are unusable and most of rainfall may be in form of floods [19]. As a whole, Naein climate is dry and warm and the summer and winter temperature variation is too high because of the dry nature, stone, sandy and saline soil in the north and high evaporation in south. Climatology station in study area is Naein station. Based on years morphological statistic data, in this city, precipitation mean has reported 98.70 mm in a year and annual Temperature and humidity mean is +16.60° (centigrade) and 31%, respectively. Several hydrometeorological variables, including air temperature, wind speed, relative, solar radiation and net radiation among others, have been continuously recorded for the period of 1993 to 2006. The mean weather data for the period of study are given in Table 1 and Figure2.

In this study, the amount of reference evapotranspiration was calculated, using FAO-56 PM method, in 15 selected synoptic. FAO-56 PM ET$_0$ equation is given by Allen et al. [1] for predicting ET$_0$ where applied on 24-h calculation time steps has the form:

![Fig. 1: The location of area study on Iran map](image_url)
Table 1: Mean climatology at the Naein Station used in the study

<table>
<thead>
<tr>
<th>Variables</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tmin (°C)</td>
<td>-1.70</td>
<td>0.30</td>
<td>4.20</td>
<td>10.0</td>
<td>14.0</td>
<td>19.0</td>
<td>22.0</td>
<td>20.0</td>
<td>16.0</td>
<td>11.0</td>
<td>4.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Tmax (°C)</td>
<td>9.70</td>
<td>13.0</td>
<td>17.0</td>
<td>24.0</td>
<td>28.0</td>
<td>34.0</td>
<td>37.0</td>
<td>36.0</td>
<td>32.0</td>
<td>25.0</td>
<td>17.0</td>
<td>12.0</td>
</tr>
<tr>
<td>Tmean (°C)</td>
<td>4.0</td>
<td>6.6</td>
<td>10.0</td>
<td>17.0</td>
<td>21.0</td>
<td>26.0</td>
<td>29.0</td>
<td>28.0</td>
<td>24.0</td>
<td>18.0</td>
<td>11.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Wind speed (m.s⁻¹)</td>
<td>2.38</td>
<td>3.38</td>
<td>3.46</td>
<td>3.62</td>
<td>3.55</td>
<td>3.54</td>
<td>3.48</td>
<td>3.26</td>
<td>3.03</td>
<td>2.75</td>
<td>2.56</td>
<td>2.27</td>
</tr>
<tr>
<td>RHmean (%)</td>
<td>52.0</td>
<td>41.0</td>
<td>36.0</td>
<td>28.0</td>
<td>24.0</td>
<td>18.0</td>
<td>17.0</td>
<td>19.0</td>
<td>20.0</td>
<td>26.0</td>
<td>35.0</td>
<td>44.0</td>
</tr>
<tr>
<td>Ra (mm.d⁻¹)</td>
<td>19.50</td>
<td>23.60</td>
<td>29.30</td>
<td>36.30</td>
<td>41.20</td>
<td>38.00</td>
<td>32.90</td>
<td>26.60</td>
<td>20.90</td>
<td>22.50</td>
<td>17.80</td>
<td>17.80</td>
</tr>
</tbody>
</table>

Table 2: Methods for calculation of ET₀, in mm d⁻¹

<table>
<thead>
<tr>
<th>Method</th>
<th>Equation form</th>
<th>Climate parameters required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hargreaves-Samani [20]</td>
<td>(ET_0 = 0.0023 \times R_n (T_{mean} + 17.80) \times (T_{max} - T_{min})^{0.50})</td>
<td>(T_{min}, T_{max}, R_n)</td>
</tr>
<tr>
<td>Hargreaves-SamaniDroogers and Allen [21] (HS1)</td>
<td>(ET_0 = 0.0030 \times R_n (T_{mean} + 20) \times (T_{max} - T_{min})^{0.40})</td>
<td>(T_{min}, T_{max}, R_n)</td>
</tr>
<tr>
<td>Hargreaves-SamaniDroogers and Allen [21] (HS2)</td>
<td>(ET_0 = 0.0025 \times R_n (T_{mean} + 16.8) \times (T_{max} - T_{min})^{0.50})</td>
<td>(T_{min}, T_{max}, R_n)</td>
</tr>
<tr>
<td>Rn- radiation [26]</td>
<td>(ET_0 = 0.489 + 0.289 \times R_n + 0.023T_{mean})</td>
<td>(T_{mean}, R_n)</td>
</tr>
<tr>
<td>Rs- radiation [26]</td>
<td>(ET_0 = 0.611 + 0.149 \times R_n + 0.079T_{mean})</td>
<td>(T_{mean}, R_n)</td>
</tr>
<tr>
<td>TURC [25]</td>
<td>(PET = 0.013 \left( \frac{T_{mean}}{15+T_{mean}} \right) (R_s + 50)) (RH &gt; 50%)</td>
<td>(T_{mean}, R_s, RH_{mean})</td>
</tr>
<tr>
<td>Blancy-Criddle [24]</td>
<td>(ET_0 = a + b \left[ T^2 \left( 0.46T_{mean} + 8.13 \right) \right] )</td>
<td>(T_{mean}, U, RH_{mean})</td>
</tr>
<tr>
<td>Makkink [22]</td>
<td>(ET_0 = \frac{\Delta R_n}{\Delta + \gamma} )</td>
<td>(T_{min}, T_{max}, R_n)</td>
</tr>
<tr>
<td>Priestley-Taylor [23]</td>
<td>(ET = 1.26 \frac{\Delta R_n}{\Delta + \gamma} )</td>
<td>(T_{min}, T_{max}, R_n)</td>
</tr>
</tbody>
</table>

\[ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \left[ \frac{900}{T_d + 273} \right] U_2 (e_s - e_d)}{\Delta + \gamma (1.0 + 0.34U_2)} \tag{1}\]

where FAO-56 PM ET₀ = the grass reference evapotranspiration (mm.d⁻¹); Rₙ = the net radiation at the crop surface (MJ/m².d); G = the soil heat flux density (MJ/m².d); T = the mean daily air temperature at 2m height (°C); U₂ = the wind speed at 2m height (m.s⁻¹); eₛ = the saturation vapor pressure (kPa); e_d = the actual vapor pressure (kPa); eₛ - e_d = the saturation vapor pressure deficit (kPa); \(\Delta\) = the slope vapor pressure curve (kPa°C); and \(\gamma\) = the psychometric constant (kPa°C/°C).

Nine evapotranspiration models: Hargreaves-Samani original [20] (HS), Hargreaves-Samani Modified 1 (HS1) [21] and Hargreaves-Samani Modified 2 (HS 2) [21], Makkink [22] (Makk), Priestley-Taylor [23] (PT), Blaney-Criddle [24] (BC), TURC [25], (Rs) based method [26] and (Rn) based method [26] were used to estimate ET₀ (Table 2).
ET\textsubscript{o} was estimated using various empirical equations is compared with the FAO-56 PM equation. The models were compared using standard statistics and linear regression analysis (Douglas et al., 2009). Root Mean Squared Error (RMSE), mean biased error (MBE), Relative Error (RE) and coefficient of determination (Pearson type goodness of fit index, \( R^2 \)) were computed using the equations described below:

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (ET_{EQ} - ET_{FAO})^2}
\]  
\[\text{(2)}\]

\[
MBE = \frac{1}{N} \sum_{i=1}^{N} (ET_{EQ} - ET_{FAO})
\]  
\[\text{(3)}\]

\[
MAXE = \max (|ET_{EQ} - ET_{FAO}|)_{i=1}^{n}
\]  
\[\text{(4)}\]

\[
RE(\%) = \frac{ET_{EQ} - ET_{FAO}}{ET_{EQ}} \times 100
\]  
\[\text{(5)}\]

\[
R^2 = \frac{\sum_{i=1}^{N} (ET_{EQ} - \bar{ET}_{EQ})(ET_{FAO} - \bar{ET}_{FAO})}{\left(\sum_{i=1}^{N} (ET_{EQ} - \bar{ET}_{EQ})^2\right)\left(\sum_{i=1}^{N} (ET_{FAO} - \bar{ET}_{FAO})^2\right)}
\]  
\[\text{(6)}\]

In order to have a quantitative evaluation, the calibration parameters were defined using the following equation [5]:

\[
ET_{EQ} = A + B \cdot ET_{FAO}
\]  
\[\text{(7)}\]

Where \( ET_{EQ} \) and \( ET_{FAO} \) as reference the method represents the ET\textsubscript{o} values estimated using the empirical methods and FAO-56 PM. The best prediction model is the one with the smallest RMSE, MBE and RE, the highest coefficient of determination (\( R^2 \)), B value closest to zero and A value closest to unity.

**RESULTS AND DISCUSSION**

The 14 year-monthly weather data were used to validate the performance of the commonly used ET\textsubscript{o} estimation methods. Monthly ET\textsubscript{o} values computed from ten empirical methods were first compared with the FAO-56 PM values (Fig. 3). A visual comparison shows that the values Blaney-Criddle and Turc empirical equations worked quite well.

The details of statistical comparison are shown in Table 3. Table 3 shows the performance of the models by comparison between models predicted ET\textsubscript{o} and FAO-56 PM model. According to all the statistics, the best results are obtained by Blaney-Criddle, while the weakest statistics are obtained by \( R_e \) radiation [26] and Makkink.

This results reveals a very good agreement (slope=1.05 and \( R^2=0.985 \)) between the Blaney-Criddle and FAO-56 PM. This results were in agreement with the obtained results by Fooladmand and Ahmadi [28]. They found correlation coefficients up to 0.96 in the linear regression analysis between the Blaney-Criddle and the FAO-56 PM methods applied in the south of Iran. For arid conditions of Iran, Mostafazadeh-Fard et al. [29] compared nine different methodologies with lysimeter data and observed that the the Blaney-Criddle and Turc methods showed very close agreement with the lysimeter data. Also, Blaney-Criddle is best method in North of Isfahan province [8], Mazandaran province and South

![Fig. 3: Total annual ET\textsubscript{o} estimates given by the 2 methods and FAO-56 PM at Naein synoptic (1987-2007), in mm.year\textsuperscript{-1}](image-url)
Table 3: Summary of the comparison results obtained from the models, error analysis and linear regression analysis and FAO-56 PM

<table>
<thead>
<tr>
<th>Method</th>
<th>RMSE</th>
<th>MBE</th>
<th>MAXE</th>
<th>RE %</th>
<th>R²</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hargreaves Samani (HS)</td>
<td>1.774</td>
<td>-1.496</td>
<td>4.283</td>
<td>-25.80</td>
<td>0.968</td>
<td>0.695</td>
<td>0.169</td>
</tr>
<tr>
<td>Hargreaves Samani (HS1)</td>
<td>1.558</td>
<td>-1.257</td>
<td>4.012</td>
<td>-20.20</td>
<td>0.967</td>
<td>0.711</td>
<td>0.326</td>
</tr>
<tr>
<td>Hargreaves Samani (HS2)</td>
<td>1.518</td>
<td>-1.248</td>
<td>3.833</td>
<td>-21.00</td>
<td>0.968</td>
<td>0.744</td>
<td>0.134</td>
</tr>
<tr>
<td>Blaney-Criddle</td>
<td>0.690</td>
<td>-0.555</td>
<td>1.429</td>
<td>-14.83</td>
<td>0.985</td>
<td>1.050</td>
<td>-0.830</td>
</tr>
<tr>
<td>Priestley-Taylor</td>
<td>1.957</td>
<td>-1.761</td>
<td>4.318</td>
<td>-34.65</td>
<td>0.963</td>
<td>0.743</td>
<td>-0.354</td>
</tr>
<tr>
<td>Makkink</td>
<td>2.599</td>
<td>-2.112</td>
<td>5.997</td>
<td>-33.00</td>
<td>0.965</td>
<td>0.484</td>
<td>0.712</td>
</tr>
<tr>
<td>TURC</td>
<td>0.833</td>
<td>-0.679</td>
<td>2.478</td>
<td>-16.65</td>
<td>0.973</td>
<td>0.943</td>
<td>-0.368</td>
</tr>
<tr>
<td>Rs−radiation (Irmak 2003)</td>
<td>2.338</td>
<td>-1.840</td>
<td>5.648</td>
<td>-27.70</td>
<td>0.964</td>
<td>0.511</td>
<td>0.835</td>
</tr>
<tr>
<td>Rn−radiation (Irmak 2003)</td>
<td>2.775</td>
<td>-2.176</td>
<td>7.268</td>
<td>-31.97</td>
<td>0.900</td>
<td>0.422</td>
<td>0.988</td>
</tr>
</tbody>
</table>

Fig. 4: Total annual ET₀ estimates given by Blaney-Criddle and the FAO-56 PM methods, in mm.year⁻¹ and total annual precipitation (1993-2006)

Fig. 5: Regression analysis and relationship of between mean temperature and FAO-56 PM method (1993-2006)

Balochestan province. Figure 4 shows the comparisons of annual ET₀ estimations between the Blaney-Criddle and the FAO-56 PM methods and annual precipitation.

The maximum annual sum of ET₀ estimations by BC and FAO-56 PM method is 1885 and 2146 in 2001, respectively. While in this year annual sum of precipitation is the lowest values (55 mm). The high correlation of ET₀ by the BC with FAO-56 PM method clearly reflects the importance of the temperature and solar radiation. With According to the importance of temperature and its effect on evaporation in this region and the process parameters temperature and evaporation, which together have a lot of similarity with respect to time, strong relationship between these two parameters is determined. The linear regression relationship was produced between FAO-56 PM method and mean air temperature data (Fig. 5).

Linear regression of air temperature and ET₀ as FAO-56 PM method explains 90% of the variance. The advantage of this method is that only climatic parameter used in it is temperature and in all weather stations is available. Thus, ET₀ models can help to choose an appropriate deficit irrigation approach by combining ET₀ information with the crop performance and soil water content [30, 31].

CONCLUSION

In arid regions, ET₀ is a large component of the hydrologic cycle and a key component of any applied catchment model. An improved irrigation schedule, results in enhanced water use efficiency and hence irrigation water saving. The 14-year meteorological data derived from Naen station located in Isfahan Iran was applied as input parameters for comparing different methods to estimate ET₀ under existing climatic conditions arid and warm in Naen, Iran. Nine empirical methods for calculating ET₀ were evaluated using meteorological data from Naen Station in Iran. The FAO-56 PM method as recommended by FAO was taken as a standard in evaluating the nine methods. In this study, using statistical indicators, the best method to estimate ET₀ in Naen station is selected and suggested Blaney-Criddle. The Blaney-Criddle method underestimated FAO-56 PM in the all of the months. The linear regression are describes between FAO-56 PM method with mean air temperature ET₀ = 0.325xT (R²=0.93). Additionally, the comparisons made for all the methods signifies that all these methods can be successfully used to estimate the ET₀ specifically in areas having the same climatic conditions as the one presented in this study.
REFERENCES


