Identifying a Suitable Estimation Method for Evapotranspiration in Wasit Province

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Abstract. Water is one of the important natural resources due to its applicability to a broad range of contexts, the most important of which are economic and agricultural; indeed, the largest amount of water used by humans is consumed for agricultural purposes. Water resource management is thus very important to managing crises. Referential evapotranspiration constitutes a high percentage of the water consumed in agriculture, making the accurate estimation of ETo values important to determining the quantities of water required for irrigation projects. It also contributes to the planning of water investment and improving management based on predictions about the upcoming hydrological situation. The study area for the current work suffers in particular from a lack of climatic data in the Dujaila region. The focus of this study was thus on possibility of using hydrological methods that require less climatic data as compared to the Penman-Monteith equation to estimate evapotranspiration accurately. The reference evapotranspiration was estimated using the Penman-Monteith (PM-FAO-56), Jensen-Haise, Blaney Criddle, Kharrufa and Hargreaves equations, utilising climate data from the Al Kut Meteorological Station and the Agricultural Meteorological Network for the period 2013 and 2018. The other results then were compared with the reference Penman-Monteith equation in terms of the determination coefficient and mean absolute; overall, the Hargreaves equation was found to be most accurate for predicting the value of ETo, with the values of R² and MAPE being 0.995 and 6.2%, respectively.

Keywords: Reference Evapotranspiration, Penman-Monteith-FAO-56, Water Consumption

1. Introduction

A great deal of research has focused on studying and estimating evapotranspiration due to its importance in managing water resources [1]; the term evapotranspiration (ETo) is used for both evaporation from bare lands and transpiration from plants in irrigated agricultural fields due to the difficulty of separating these from each other [2] and the importance of ETo in estimating water needs for crop growth due to it representing 99% of the water required to irrigate crops, which means that just 1% is used in tissue building and other vital processes [3]. Methods for calculating evapotranspiration are based on climatic parameters that differ from one method to another [4]. The Penman-Monteith-FAO 56 method is used for verifying other methods of estimating evapotranspiration [5], but as it requires multiple climatic parameters such as air temperature, solar radiation, relative humidity, and wind speed [6], obtaining the requisite data is very difficult, with such detail being simply not available in many developing countries [7]. Researchers have thus made great efforts to identify new, simplified formulas that rely on fewer climate parameters [8]. ETo was estimated in arid and semi-arid regions of China using the Priestley-Taylor and Hargreaves methods which were compared with Penman-Monteith with results that showed the possibility of using the Hargreaves and Priestley-Taylor methods as alternatives to the Penman-Monteith equation in the absence of sufficient data [9]. Similarly, Salih and Sendil 1984 five methods to estimate the values of ETo in Saudi Arabia; however, these gave large differences in values, and the best value obtained was from the Jensen Haise equation, which was thus recommended for that region to predict ETo [10].
1964, evapotranspiration was estimated in central Iraq, with the Blaney-Criddle and Grassi equations applied with results were compared with the evapotranspiration data for wheat and cotton; based on that comparison, the methods used gave reasonable values for all months of the year [11].

Hydrological forecasting is a topic of great importance at the present time, especially in irrigation projects; by forecasting hydrological variables, decision-makers can manage water resources and formulate economic policies most effectively. This research thus aimed to calculate the values of reference evapotranspiration in the Dujaila region in Wasit Governorate using the Hargreaves, Blaney-Criddle, Kharrufa and Jensen-Haise methods, comparing the results of these with those from the Penman-Monteith method to determine the most suitable for use as an alternative to the Penman-Monteith equation where less data is available.

2. Study Area

Sufficient climatic data were collected from the Agricultural Meteorological Station, run by the Iraqi Ministry of Agriculture, and the Al Kut Meteorological Station, run by the Iraqi Ministry of Transport ([12], [13]) to estimate the reference evapotranspiration for the Dujaila irrigation project, which is located at 32°10'-32°30' N and 45°50'-46°20' E, 19 m above sea level, and which is characterised by its semi-arid climate, as shown in Figure 1. Table 1 shows climatic parameters (air temperature, wind speed at an altitude of 2 metres above the ground, relative humidity, and sunshine durations) for the study area for the period 2013 to 2018.

![Figure 1: The Dujaila irrigation project location.](image)

3. Methodology

3.1 Penman-Monteith-FAO 56 Equation

The standard Penman-Monteith equation was used to estimate the reference evapotranspiration, as this is suitable for application in most regions [14]. In 1990, Allen presented the formula for PM-FAO 56 as follows [15]:

$$ET = \frac{0.4085 (R_n - G) + 0.23 \frac{900}{\delta_0} (\delta - \delta_0)}{\delta + (1 + 0.34) \delta_0}$$  \hspace{1cm} (1)

3.2 Hargreaves Equation

The Hargreaves equation is based on air temperature, with observations of this developed into the following equation [16]:

$$ET = 0.0135 \frac{R_n}{(T+17.8)}$$  \hspace{1cm} (2)

3.3 Jensen Haise Equation

Here, evapotranspiration is estimated in arid and semi-arid regions by the following equation [17]:

$$ET_P = Rs (0.02527 + 0.078)$$  \hspace{1cm} (3)

3.4 Blaney Criddle Equation

This method is influenced by the relative weather, the percentage sunshine hours, and the air temperature [18].
where

\[ ETp = C(P(0.46Tc + 8.13)) \]  

(4)

3.5 Najib Kharrufa Equation
Kharrufa's equation is used for arid and semi-arid regions, being based on a modified Blaney Criddle equation [4].

\[ ETp = \frac{1}{2} P T^{1.3} \]  

(6)

For all the equations above, ETo is the reference evapotranspiration [mm day⁻¹], Rn is the net radiation at the crop surface [MJ m⁻² day⁻¹], G is the soil heat flux density [MJ m⁻² day⁻¹], T is the air temperature [°C], U₂ is the wind speed at 2 m above the ground [m s⁻¹], es-ea is the saturation vapour pressure deficit [kPa], \( \Delta \) is the slope vapour pressure curve [kPa °C⁻¹], γ is the psychrometric constant [kPa °C⁻¹], λ is the latent heat of vaporization, Rs is the solar radiation, and P is the percentage of hours of solar brightness in relation to their number in a year.

The parameters of the equations were calculated as shown in Table 1 using the following values [15]:

Actual vapour pressure:
Equation 7 was used to estimate the daily actual vapour pressure

\[ e_a = \frac{e^o(T_{Max}) + e^o(T_{Min})}{2} \]  

(7)

where \( e_a \) is the actual vapour pressure [kPa], \( e^o(T_{Min}) \) is the saturation vapour pressure at daily minimum temperature [kPa], \( e^o(T_{Max}) \) is the saturation vapour pressure at daily maximum temperature [kPa], RHmax is the maximum relative humidity [%], and RHmin is the minimum relative humidity [%].

Saturation vapour pressure as a function of air temperature (\( e^o(T) \)):

\[ e^o(T) = 0.6108 \exp\left[\frac{17.277}{T + 237.3}\right] \]  

(8)

where \( e^o(T) \) is the saturation vapour pressure at air temperature T [kPa], T is the air temperature [°C], and \( \exp\left[...\right] \) is 2.7183 (base of natural logarithm) raised to the power [...].

Mean saturation vapour pressure for a given period (\( e_s \)):
The mean daily, 10-day, or monthly saturation vapour pressure is calculated as the mean between the average daily maximum saturation vapour pressure and the minimum air temperature for the selected period:

\[ e_s = \frac{e^o(T_{Max}) + e^o(T_{Min})}{2} \]  

(9)

where \( e_s \) is saturation is the vapour pressure [kPa], \( e^o(T_{Max}) \) is the saturation vapour pressure at the mean daily maximum air temperature [kPa], and \( e^o(T_{Min}) \) is the saturation vapour pressure at the mean daily minimum air temperature [kPa].

Psychometric Constant (\( \gamma \)):
This is given by

\[ \gamma = \frac{C_pP}{\varepsilon \lambda} = 0.665 \times 10^{-3} \]  

(10)

where \( \gamma \) is the psychrometric constant [kPa °C⁻¹]; P is the atmospheric pressure [kPa]; \( \lambda \) is the latent heat of vaporization, taken here as 2.45 MJ kg⁻¹; \( C_p \) is the specific heat at constant pressure, given here as 1.013 \( \times 10^{-3} \) MJ kg⁻¹ °C⁻¹; and \( \varepsilon \) is the molecular weight ratio of water vapour/dry air, which is 0.622 in this case.

Atmospheric pressure (P):
This is the pressure exerted by the weight of the earth's atmosphere:

\[ P = 101.3 \left(10^{-0.00625z\text{m}}\right)^{1.26} \]  

(11)

where P is atmospheric pressure [kPa], and z is elevation above sea level [m].

Latent heat of vaporization (\( \lambda \)).
This expresses the energy required to change a unit mass of water from liquid to vapour under a constant pressure and constant temperature. The value of the latent heat thus varies as a function of temperature [19].

**Slope of saturation vapour pressure curve (Δ):**

The slope of the relationship between saturation vapour pressure and temperature is given by

\[
\Delta = \frac{\ln \left( \frac{e}{e_0} \right)}{T - T_0}
\]

where \( \Delta \) is the slope of saturation vapour pressure curve at air temperature \( T \) [kPa °C⁻¹], and \( T \) is the air temperature [°C].

**Slope of saturation vapour pressure curve (∆):**

Where \( \Delta \) is the slope of the relationship between saturation vapour pressure and temperature given by

\[
\Delta = \frac{T_{mean}}{2}
\]

where \( T_{mean} \) is the mean air temperature [°C], \( T_{min} \) is the minimum air temperature [°C], and \( T_{max} \) is the maximum air temperature [°C].

**Net radiation (Rₙ):**

This is the difference between the incoming net shortwave radiation (Rₙₛ) and the outgoing net longwave radiation (Rₙₙₙ) such that

\[
Rₙ = Rₙₛ - Rₙₙₙ
\]

where

- \( Rₙₙₙ \) is the net shortwave radiation in [MJ m⁻² day⁻¹], resulting from the balance between incoming and reflected solar radiation as given by

\[
Rₙₛ = (1 - \alpha) Rₛ
\]

where \( \alpha \) is the albedo or canopy reflection coefficient, which is 0.23 for the hypothetical grass reference crop [dimensionless]; and \( Rₛ \) the incoming solar radiation [MJ m⁻² day⁻¹].

Rs is not measured, though it can be computed using the Angstrom formula, which relates solar radiation to extra-terrestrial radiation and relative sunshine duration such that

\[
Rₛ = \left( a_1 + b_2 \right) Ra
\]

where \( n \) is the actual duration of sunshine [hours], ad \( Ra \) is the extra-terrestrial radiation [MJ m⁻² day⁻¹], given as a regression constant that expresses the fraction of extra-terrestrial radiation reaching the earth on overcast days \( (n = 0) \); generally, the values as \( a = 0.25 \) and \( b = 0.50 \) are recommended.

**Ra:**

The extra-terrestrial radiation, \( Ra \), for each day of the year and for different latitudes can be estimated from the solar constant, the solar declination and the time of the year:

\[
Ra = \frac{Gₛ c}{\sin(\delta)} \left( \frac{\frac{2π}{365}}{\sin(\phi)} \right)
\]

where \( Gₛ \) is the solar constant = 0.0820 MJ m⁻² min⁻¹,

\( \omega_s \) (sunset hour angle (rad)) = \( \arccos \left( \frac{r}{d_r} \right) \)

\( \delta \) (solar declination in rad) = \( 0.409 \sin \left( \frac{2\pi}{365} \right) \)

\( \phi \) (latitude [rad]) = Radians = \( \frac{2π}{360} \) [°]

**Daylight hours (N):**

The maximum possible duration of sunshine is thus given by

\[
N = \frac{2π}{\sin(\phi)}
\]

**Rₙₙₙ:**

This is the net long wave radiation in MJ m⁻² day⁻¹, which can be calculated using equation 23:

\[
Rₙₙₙ = \frac{0.34 - 0.14 \sqrt{Rₙₙₙ}}{0.35 (Rₙₙₚ - 0.35)}
\]

where \( \sigma \) is the Stefan-Boltzmann constant [4.903 \( 10^9 \) MJ K⁻⁴ m⁻² day⁻¹], \( T_{max,K} \) is the maximum absolute temperature during the 24-hour period \( [K = °C + 273.16] \), \( T_{min,K} \) is the minimum absolute temperature during the 24-hour period \( [K = °C + 273.16] \), \( eₕ \) is the actual vapour pressure [kPa], and \( Rs/Rₙₚ \) is the relative shortwave radiation \( (≤ 1.0) \).
Rso:
to calculate clear-sky radiation \([\text{MJ} \, \text{m}^{-2} \, \text{day}^{-1}]\), equation 24 is used:
\[
\text{Rso} = (0.75 + 2 \times 10^{-5} \times z) \, \text{R}_u
\]
(24)
where \(z\) is the station elevation above sea level \([\text{m}]\).

Soil heat flux \((G)\):
To calculate \(G\) \([\text{MJ} \, \text{m}^{-2} \, \text{day}^{-1}]\) for monthly periods, equation 25 is used:
\[
G_{\text{month},i} = 0.07(\text{T}_{\text{month},i} + 1 - \text{T}_{\text{month},i-1})
\]
(25)
and if \(T_{\text{month},i+1}\) is unknown,
\[
G_{\text{month},i} = 0.14(\text{T}_{\text{month},i} - \text{T}_{\text{month},i-1})
\]
(26)

To facilitate a comparison of the methods of estimating the reference evapotranspiration \((\text{ETo})\), the values resulting from using the various methods were compared with the values obtained from the standard Penman-Monteith equation \((\text{PM})\) using the mean absolute percentage error \((\text{MAPE})\) \([20]\) and the coefficient of determination \((R^2)\) \([21]\).

\[
\text{MAPE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{d_i - o_i}{o_i} \right|
\]
(27)
\[
R^2 = \frac{\sum_{i=1}^{n} (o_i - \bar{y}) (d_i - \bar{d})^2}{\sum_{i=1}^{n} (d_i - \bar{d})^2}
\]
(28)
where \(d\) is the predicted value, \(o\) is the actual value, \(\bar{y}\) is the mean of actual value, and \(n\) is the number of data points.

**Table 1.** Mean monthly climatic parameters.

| Month | Rain (mm) | Air Temperature (°C) | Relative Humidity (%) | Sun shine (hr/day) | Wind Speed Ws at 2 m height (m/s) | \(\lambda\) (KJ/Kg) | \(\Delta\) (KPa/°C) | es (KPa) | ea (KPa) | Rn (MJ/m²/day) | G (MJ/m²/day) |
|-------|-----------|-------------------|----------------------|-------------------|-------------------------------|----------------|----------------|-----------|---------|---------------|--------------|
| Jan.  | 10.42     | 17.5              | 60.1                 | 84.05             | 40.3                          | 6.4             | 1.47          | 2456      | 0.09    | 1.47          | 0.80         | 5.03         | 0.16      |
|Feb.   | 10.2      | 21.2              | 81.4                 | 78.62             | 29.2                          | 7.2             | 1.58          | 2455.4    | 0.11    | 1.80          | 0.79         | 7.38         | 0.57      |
|Mar.   | 15.03     | 26.98             | 12.7                 | 72.03             | 21.7                          | 8               | 1.72          | 2454      | 0.14    | 2.51          | 0.79         | 10.05        | 0.67      |
|Apr.   | 11        | 31.8              | 16.6                 | 63.20             | 15.96                         | 8.5             | 1.55          | 2443      | 0.18    | 3.30          | 0.97         | 11.88        | 0.74      |
|May    | 9.05      | 38.1              | 22.62                | 48.68             | 13.23                         | 9.8             | 1.59          | 2430      | 0.25    | 4.70          | 1.11         | 13.30        | 0.75      |
|Jun.   | 0         | 42.7              | 27.06                | 31.35             | 8.09                          | 11.9            | 2.2           | 2420      | 0.31    | 6.04          | 0.90         | 13.62        | 0.52      |
|Jul.   | 0         | 45.72             | 29.9                 | 26.72             | 7.2                           | 11.8            | 2.3           | 2411      | 0.36    | 7.08          | 0.92         | 12.80        | 0.17      |
|Aug.   | 0         | 45.74             | 28.9                 | 31.09             | 7.74                          | 11.5            | 1.87          | 2415      | 0.35    | 6.97          | 1.00         | 11.26        | -0.29     |
|Sept.  | 0         | 42.4              | 24.86                | 35.9              | 8.65                          | 10.6            | 1.53          | 2421      | 0.29    | 5.76          | 0.93         | 8.13         | -0.74     |
|Oct.   | 9.134     | 34.9              | 18.51                | 53.44             | 15.8                          | 8.9             | 1.3           | 2444      | 0.21    | 3.86          | 1.01         | 5.54         | -1.10     |
|Nov.   | 29.17     | 24.5              | 11.3                 | 78.61             | 34.1                          | 7.3             | 1.2           | 2459      | 0.13    | 2.21          | 1.05         | 4.11         | -1.00     |
|Dec.   | 9.6       | 18.1              | 6.7                  | 82.9              | 40.03                         | 6.4             | 1.3           | 2450      | 0.09    | 1.53          | 0.82         | 3.63         | -0.43     |

4. Result and Discussion

\(\text{ETo}\) was assessed for the study area for 2013 to 2018. Table 2 presents the \(\text{ETo}\) values computed using the Penman-Monteith, Jensen-Haise, Blaney Criddle, Kharrufa, and Hargreaves equations, all of
which were compared with the results of PM-FAO-56, chosen as a standard for comparison of other methods as it is considered to offer the upper limit of acceptable values [5]. Reference evapotranspiration increases in the summer months, as water consumption increases in the dry months [22] and the ETo value of crops grown in dry season is greater compared to that of those grown in rainy seasons [23]. This applied to the ETo values shown in Table 2 calculated using the equations under consideration: the values of the coefficient of determination (R²) of the equations used in the estimation of ETo indicated a very strong direct correlation despite the presence of large differences in values of ETo. The reason for this is because R² is an insensitive measure of the proportional differences between expected and the real data; as it is limited to looking at differences, it is highly biased towards outliers [21].

Examining the values of MAPE showed that the Hargreaves equation was more accurate and reliable than the other equations examined; the value of MAPE for that equation was 6.2%, indicating a very accurate prediction [24]. Haise’s equation offered a reasonable MAPE of 14%, but when compared with the PM equation, the ETo values were generally higher, overestimating ETo in most months at an unacceptable level [5]. Although the values of R² for the Blaney-Criddle and Kharrufa equations were 0.92 and 0.977, respectively, the respective values of MAPE were 67 and 52% respectively, indicating that the prediction of ETo values in the Dujaila region using these equations is weak and imprecise [25]. Figure 2 shows the ETo values estimated using the five methods of interest.

| Month | PM  | Blaney Criddle | Hargreaves | Kharrufa | Jensen-Haise |
|-------|-----|----------------|------------|----------|-------------|
| Jan.  | 2.04| 0.59           | 2.02       | 0.77     | 1.90        |
| Feb.  | 3.00| 0.81           | 2.87       | 1.11     | 2.94        |
| Mar.  | 4.47| 1.27           | 4.07       | 1.83     | 4.61        |
| Apr.  | 5.49| 1.00           | 5.15       | 2.56     | 6.19        |
| May   | 6.85| 2.53           | 6.62       | 3.66     | 8.47        |
| Jun.  | 9.08| 3.14           | 8.07       | 4.47     | 10.67       |
| Jul.  | 9.66| 3.42           | 8.49       | 4.80     | 11.38       |
| Aug.  | 8.34| 3.13           | 7.82       | 4.41     | 10.50       |
| Sept. | 6.39| 2.47           | 5.95       | 3.53     | 7.80        |
| Oct.  | 4.31| 1.63           | 3.85       | 2.37     | 4.81        |
| Nov.  | 2.49| 0.91           | 2.41       | 1.30     | 2.65        |
| Dec.  | 1.83| 0.60           | 1.81       | 0.78     | 1.73        |
| MAPE  | 67% | 6.20%          | 52%        | 14%      |             |
| R²    | 0.92| 0.995          | 0.977      | 0.993    |             |

Figure 2. Comparison of ETo values estimated using PM, Jensen-Haise, Hargreaves, Kharrufa and Blaney Criddle equations.
5. Conclusion:
Although the PM-FAO-56 method is considered the most accurate method of estimating ETo, as it relies on access to a wide range of climate parameters, it is less suitable in developing countries where there are no climate stations with sufficient data to calculate ETo in this manner. Other equations based on fewer climate parameters were thus investigated; these were the Jensen-Haise, Hargreaves, Blaney-Criddle and Kharrufa. ETo values were calculated using these, and the results were compared to the results produced by the Penman-Monteith equation. All the equations gave the highest value of ET in July and the lowest values in December and January; however, the results showed that the Hargreaves equation gave the best values, with moderate ETo estimates depending on the air temperature, and a deviation ratio of only 6.2%. Accordingly, the Hargreaves equation can be adopted to estimate ETo in semi-arid areas, especially in the absence of sufficient data for the Penman-Monteith equation.

Acknowledgements:
The authors would like to thank the ministry of Agriculture in Iraq for its support for this study.

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