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Evaluation of different methods to estimate monthly reference evapotranspiration at Raichur region, India

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ABSTRACT

The potential evapotranspiration (PET) is an important parameter to address water needs for growing crops. Estimation of potential evapotranspiration (PET) requires knowledge of the values of many climatic variables, some of which require special equipment and careful observations. Although potential evapotranspiration is an important component of water balance, the data required for its accurate estimation are commonly available only at widely spaced measurement stations. Numerous potential evapotranspiration models have been developed and are being used, depending upon the availability of weather data. For the proposed study, the daily data of all weather parameters *viz.*, maximum and minimum air temperature, maximum and minimum relative humidity, wind speed, actual sunshine hours and rainfall for estimating potential evapotranspiration for the duration of 31 years (1991-2021) were collected from the weather station at Main Agricultural Research Station (MARS), Raichur. A number of empirical formulae or approaches have been used for the determination of potential evapotranspiration (PET) from meteorological data. Availability of climatic data and accurately converting them in terms of water requirement are of great constraints. Judging the accuracy of different PET estimation models is a difficult task. The FAO 56-Penman Monteith model was considered as a standard reference for PET estimation in this investigation over the study location. The objective was to compare various PET models with standard reference model (FAO 56 Penman-Monteith model) and choose the best suitable model for estimating PET for the study area.

Key words*: Reference evapotranspiration, Penman–Monteith method and empirical equations*

Introduction

Direct measurement of potentional evapotranspiration across locations is cost prohibitive for a country like India and an indirect models using meteorological data are potential alternative. Though, number of empirical models are available, availability of climatic data limits their application across all the loca-

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tions. As per FAO 56 (Food and Agriculture Organization), Penman Monteith model is considered as standard model for determining the potential evapotranspiration (PET) and results of it shows better performance when compared with other models. In the present study, various empirical models (Open pan, Turc, Christiansen, Blaney Criddle, Hargreaves, Modified Penman models and Penman Monteith models) were evaluated. For this investigation, the data for duration of 31 years (1991-2021) was collected on various climatologically parameters and used in the present study.

One of the most important factors for water resources planning and irrigation scheduling is crop evapotranspiration (ET) or crop water use. The water requirement of a crop varies from crop to crop, location to location and season to season according to climate change. An optimum water management issue will play a significant role in minimizing water loss by optimizing water use. Therefore, it is necessary to know the actual crop water requirement. The crop coefficient values are required for estimating the actual crop water requirement (Kingra *et al.*, 2020). It is always cumbersome and expensive to determine the water requirements of a particular variety of crops in different places by setting experiments every time rather, it is much easier to estimate crop evapotranspiration to a large degree of accuracy.

The hydrologic balance study for an area comprises both evaporation and transpiration losses, termed together as evapotranspiration. Potential evapotranspiration is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The soil and vegetation have considerable influence over potential evapotranspiration (Rajasekhar *et al.*, 2015). The potential evapotranspiration provides a good representation of the maximum possible water loss to the atmosphere (Xystrakis and Matzarakis, 2011).

Evapotranspiration is the major component of the hydrologic cycle, by which, most precipitation that falls on the land surface returns to the atmosphere in the form of evaporation from the soil surface and the plant tissue as a result of transpiration (Allen *et al*., 1998). About 60% of the yearly precipitation falling over the land surface is globally used by evapotranspiration (Irmak and Kamble, 2009). Evapotranspiration is expressed in two forms: actual evapotranspiration and potential evapotranspiration. Potential evapotranspiration (PET) is defined as "the maximum water lost from a short green crop under climatic conditions, when unlimited water is available". The term reference evapotranspiration (ET_o), which is the rate of evapotranspiration from a well-defined reference environment, is commonly used as the standard. Reference evapotranspiration (ET_o) is defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m^{-1} and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered and completely shading the ground" (Allen *et al*., 1998).

There exist a multitude of models for the estimation of potential evapotranspiration (PET) and free water evaporation, which can be grouped into five categories: (i) water budget, (ii) mass-transfer, (iii) combination, (iv) radiation-based and (v) temperature-based. The availability of many equations for determining evapotranspiration, the wide range of data types needed and the wide range of expertise needed to use the various equations correctly to select the most appropriate evapotranspiration model for a given study area (Xu and Singh, 2002).

The literature reveals that, during the past half-century, a large number of models for the calculation of reference evapotranspiration (ET_o) from climatic data have been developed. These models vary from simple empirical relationships to complex models based on physical processes. However, the choice of the model for estimating evapotranspiration is essentially based on the location, climate, intended estimation period and input data availability for the stations. The Penman-Monteith model which includes revised evapotranspiration denition has been strongly advocated as the most accurate model for daily evapotranspiration estimates for global use and supported as the calibration-base model for other models (Azhar *et al.*, 2013).

Materials and Methods

FAO 24 Blaney Criddle (1977) Model

The Blaney Criddle is a popular model developed in 1950, is widely known for its simplicity till the development of Penman-Monteith model. The temperature changes at a site are the feed for the model.

The equation is given as:

$$PET=a+bf \quad .. (3.1)$$

$$f=p(0.46Tm+8.13) \quad .. (3.2)$$

$$a=0.0043RH_{min}\text{-}n/N\text{-}1.41 \quad .. (3.3)$$

$$b=a_0+a_1Ra_3Ud+a_4RH_{min}n/N+a_5RH_{min}\,Ud \quad .. (3.4)$$

Where,

p = Mean daily per cent of annual day time hour (monthly *p* (d mo^{-1})$^{-1}$)

T_m = Mean air temperature (°C)

n/N = Ratio of possible to actual sunshine hour

RH_{min} = Minimum daily relative humidity (%)

U_d = Daytime wind at 2m height (m s^{-1})

a_0 = 0.81917

a_1 = 0.0040922

a_2 = 1.0705

a_3 = 0.065649

a_4 = 0.0059684

a_5 = 0.0005967

Hargreaves-Samani Model

The Hargreaves-Samani model developed in 1985 is an empirical relation which entails daily air temperature in addition to global radiation (R_a). This model is a regression analysis of relative humidity factor and temperature reduction co-efficient and is used when the data is meagre. It is given as

$$PET = 0.0023RA\ \sqrt{T_D}\ (T_m+17.8) \quad .. (3.5)$$

Where,

R_A = Extra-terrestrial radiation (mm d^{-1})

T_D = Difference between maximum and minimum temperature (°C)

T_m = Mean temperature (°C)

Christiansen (1968) Pan Evaporation Model

Christiansen developed the following equation using multiple correlation method to estimate Potential evapotranspiration. This equation uses coefficients for temperature, humidity, wind speed, and sunshine data

$$PET = 0.755E_OC_{T2}C_{W2}C_{H2}C_{S2} \quad .. (3.6)$$

Where,

E_O= Open pan evaporation (mm)

$$C_{T2} = 0.862+0.179(T_m/20)-0.041(T_m/20)^2 \quad .. (3.7)$$

Where,

T_m = Mean temperature (°C)

$$C_{W2} = 1.189 - 0.240(W/6.7)+0.051(W/6.7)^2 \quad .. (3.8)$$

Where,

W = Mean wind speed 2 m above ground level (km h^{-1})

$$C_{H2}=0.499 + 0.620(H_m/0.60) - 0.119(H_m/0.60)^2 \quad ..(3.9)$$

Where,

H_m = Mean relative humidity, expressed decimally.

$$C_{S2} = 0.904 + 0.0080(S/0.8) + 0.088(S/0.8)^2 \quad .. (3.10)$$

Where,

S = Percentage of possible sunshine, expressed decimally.

Turc model

Turc developed a model in 1961, an equation for potential ET under general climatic conditions of Western Europe.

$$PET = 0.013\,\frac{T_m}{T_m+15}\,(R_s+50) \quad .. (3.11)$$

Where,

T_m = Mean air temperature (°C)

R_s = Solar radiation (KJ m^{-2})

FAO 24 Modified Penman (1977) Model

$$PET = [WR_n + (1-w)f(u)(e_a - e_d)]c \quad .. (3.12)$$

Where,

PET = Potential evapotranspiration (mm d^{-1})

W = Temperature related weighing factor

R_n = Net radiation (mm d^{-1})

f(u) = Wind related function

(e_a-e_d) = Difference between saturated vapour pressure at mean air temperature and mean actual vapour pressure of air (mb)

c = Correction factor

FAO 24 Open Pan (1977) model

Evaporation from the pan provides a measurement of the combined effect of temperature, humidity, wind speed and sunshine hours on the reference crop evapotranspiration. This method is also known as FAO 24 Pan Evaporation (24-PAN) method. The data from the 'USWB-class A' pan was used for analysis.

$$PET = K_P \times E_P \quad .. (3.13)$$

Where,

PET = Potential evapotranspiration (mm d^{-1})

K_p = Pan coefficient (0.7)

E_p = Measured open pan evaporation (mm)

FAO 56 Penman Monteith model

The FAO 56 Penman-Monteith model is recommended as the sole of standard model. It is a model with a strong likelihood of correctly predicting evapotranspiration in a wide range of locations and climates. It can be calculated by using the following formula:

$$PET = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T+273}U_2(e_a - e_d)}{\Delta + \gamma(1+0.34U_2)} \quad .. (3.14)$$

Where,

PET = Potential evapotranspiration (mm d^{-1})

R_n = Net radiation at crop surface (MJ m^{-2} d^{-1})

G = Soil heat flux (MJ m^{-2} d^{-1})

T = Average temperature at 2 m height (°C)

U_2 = Wind speed measured at 2 m height (m s^{-1})

$(e_a - e_d)$ = Vapour pressure deficit for measurement at 2 m height (kPa)

D = Slope vapour pressure curve (kPa $°C^{-1}$)

γ = Psychrometric constant (kPa $°C^{-1}$)

Results and Discussion

Month-wise average daily potential evapotranspiration (mm day^{-1}) estimation by various models

The month-wise average daily potential evapotranspiration (PET) were calculated by using seven different models and data are presented in Table 1. The study revealed that, the mean month-wise average daily potential evapotranspiration ranged from 3.9, 4.2, 4.3, 4.5, 4.6, 5.3 and 5.5 mm d^{-1} by FAO-Penman Monteith model, Open pan, Turc, Christiansen, Blaney Criddle, Hargreaves and Modified Penman models, respectively for the study period (1991-2021). In comparison to FAO-Penman Monteith method (standard method), Open Pan model showed closer mean month-wise average daily potential evapotranspiration values fallowed by Turc model (Ahmad *et al*., 2017).

During the study period (1991-2021), the minimum and maximum month-wise average daily potential evapotranspiration (PET) values ranged from 3.9 to 5.3 mm d^{-1}, 4.1 to 7.0 mm d^{-1}, 3.3 to 7.0 mm d^{-1}, 3.7 to 5.2 mm d^{-1}, 3.9 to 7.3 mm d^{-1}, 2.8 to 7.0 mm d^{-1} and 2.4 to 6.4 mm d^{-1} by Blaney Criddle, Hargreaves, Christiansen, Turc, Modified Penman, Open Pan and FAO-Penman Monteith models, respectively and for better visualization depicted in Fig. 1 (Mobilia and Longobardi, 2021).

The PET was observed to be > 6 mm d^{-1} during April month in reference Penman Monteith model. Similarly, other models *viz.*, during 3 months (March, April and May) by Hargreaves model; during May month by Christiansen model; during 2 months (April and May) by Open Pan model and during 4 months (March, April, May and June) by Modified Penman model were observed (Khavse *et al*., 2017).

The PET with < 4 mm d^{-1} during 7 months (January, February and August to December) in standard Penman Monteith model. In comparison to this model, the other models *viz.*, during 4 months (July to August and November to December) by Turc model; during December month by Blaney Criddle; during 6 months (January and August to December)

Table 1. Month-wise average daily potential evapotranspiration (mm day^{-1}) estimation by various models

Month	Mean monthly PET (mm d^{-1})						
	Blaney Criddle	Hargreaves	Christiansen	Turc	Modified Penman	Open Pan	FAO-Penman Monteith
January	4.1	4.3	3.6	4.0	4.3	3.2	2.9
February	4.6	5.2	4.6	4.6	5.3	4.3	3.8
March	4.7	6.3	5.6	4.9	6.1	5.6	4.5
April	5.3	6.9	5.9	5.2	7.3	6.3	6.4
May	5.3	7.0	7.0	5.0	7.3	7.0	5.9
June	5.0	6.0	5.4	4.3	6.3	5.1	5.0
July	4.6	5.3	4.3	3.8	5.5	3.9	4.0
August	4.5	5.1	3.9	3.8	5.3	3.4	3.5
September	4.6	4.8	3.8	4.0	5.2	3.2	3.1
October	4.6	4.5	3.6	4.0	4.9	2.9	2.7
November	4.3	4.2	3.6	3.8	4.3	3.0	2.5
December	3.9	4.1	3.3	3.7	3.9	2.8	2.4
Mean	4.6	5.3	4.5	4.3	5.5	4.2	3.9
Min	3.9	4.1	3.3	3.7	3.9	2.8	2.4
Max	5.3	7.0	7.0	5.2	7.3	7.0	6.4

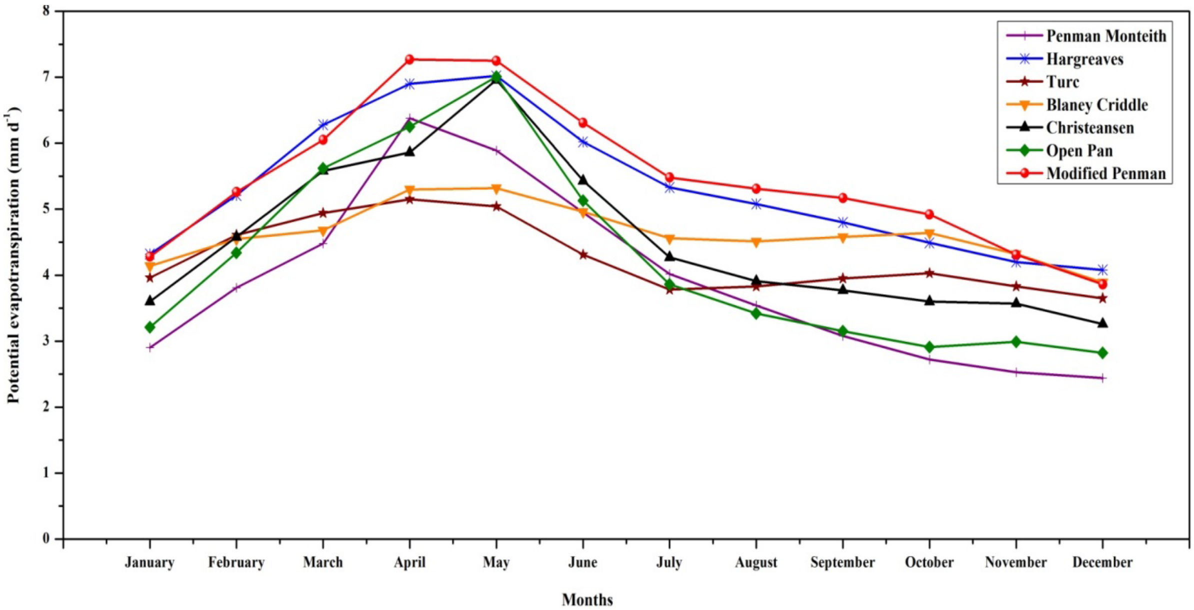

Fig. 1. Comparison of month-wise average daily potential evapotranspiration by various models at Raichur

by Christiansen model; during 7 months (January and July to December) by Open Pan model and during December month by Modified Penman model were observed. The overall analysis revealed that, maximum evapotranspiration occurs during the months of June-July and minimum evapotranspiration occurs during the months of December-January. Out of these 31 years, maximum value of ET_o for any month was of 4.95 mm d^{-1} in June 2011 and minimum was 0.63 mm d^{-1} in January 2006 and in January 2014 (Sharafi and Mohammadi, 2021).

The month-wise average daily potential evapotranspiration estimates will be very much helpful for crop planning in deciding water requirements during *kharif, rabi* and summer seasons in both dry land and command areas looking to the precipitation pattern and water availability.

Table 2. Comparison of statistical parameters of monthly potential evapotranspiration by various models at Raichur (1991-2021)

Empirical models	CC	MAE	RMSE
PM v/s BC	0.91	1.00	1.16
PM v/s Hrg	0.98	1.42	1.46
PM v/s Crstn	0.94	0.72	0.77
PM v/s Turc	0.85	0.86	0.93
PM v/s MP	0.97	4.04	1.60
PM v/s OP	0.95	0.40	0.53

Statistical analysis for comparing monthly potential evapotranspiration by various models with standard FAO-Penman Monteith model

The monthly values of statistical parameters of various models were compared with standard FAO-Penman Monteith model for study area of Raichur as listed in the Table 2. It was observed that, the correlation coefficient (CC) between PM v/s Hrg was found to be 0.98 as highest when compared to the other models, followed by PM v/s MP, PM v/s OP, PM v/s Crstn and PM v/s BC models having 0.97, 0.95, 0.94 and 0.91, respectively and lowest value was found in PM v/s Turc models of about 0.85. Further, in case of statistical errors of mean absolute error (MAE) it was observed as 0.40 per cent (low error) in case of PM v/s OP models, followed by PM v/s Crstn , PM v/s Turc and PM v/s BC which were found to be 0.72, 0.86 and 1.00, respectively and higher error was found in case of PM v/s Hrg and PM v/s MP models of about 1.42 and 4.04 per cent, respectively (Wable *et al*., 2019). Similarly, we observed lower error of root mean square error (RMSE) in case of PM v/s OP and PM v/s Crstn models which was about 0.53 and 0.77 per cent, respectively, followed by PM v/s Turc and PM v/s BC models which were found to be 0.93 and 1.16 per cent, respectively and the higher error was observed in case of PM v/s Hrg and PM v/s MP having 1.46 and 1.60 per cent, respectively (Awal *et al*., 2022).

Selected empirical models were compared with the standard FAO-Penman Monteith model. Most of the time the results showed that some models came up with fairly good results, while other models showed some fluctuations in their results. Considering all the three evaluating parameters (CC, MAE and RMSE), the Open Pan model showed close relation to standard FAO-Penman Monteith model followed by Christiansen, Turc and Blaney Criddle models. The Hargreaves and Modified Penman models showed higher MAE and RMSE values indicated that, the values obtained by Hargreaves and Modified Penman models have more variation in comparison to standard FAO-Penman Monteith model.

Conclusion

The month-wise average daily potential evapotranspiration values ranged from 3.9, 4.2, 4.3, 4.5, 4.6, 5.3 and 5.5 mm d^{-1} by Penman Monteith model, Open pan, Turc, Christiansen, Blaney Criddle, Hargreaves and Modified Penman models respectively for the study period (1991-2021). In comparison to Penman Monteith model (standard method), Open Pan model showed closer month-wise average daily potential evapotranspiration values followed by Turc model.

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