International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2016 Vol. 6 (3) July-September, pp.70-76/Jangre et al.

Research Article

INTER-COMPARISON OF DIFFERENT METHODS FOR ESTIMATION OF REFERENCE EVAPOTRANSPIRATION IN RAIPUR REGION

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ABSTRACT
Evapotranspiration is a fundamental parameter in water balance fluctuation. Evapotranspiration is one of the major components of the hydrologic cycle and its accurate estimation is of paramount importance for many studies such as hydrologic water balance, design and management of irrigation system, and water resources planning and management. Therefore, its accurate estimation is of vital importance for hydrologic studies. Three empirical methods for calculating ET, namely, Hargreaves, Blaney-Criddle (Temperature based) and Turc (Radiation Based) were evaluated using meteorological data from Raipur region. Blaney- Criddle methods were found to be the closest to the Penman-Monteith FAO-56 methods as a reference values.

Keywords: *Reference ET_0, Crop ET, Crop Coefficient, Climatic Data*

INTRODUCTION

The combination of two separate processes whereby water is lost from the soil surface by evaporation and from the crop by transpiration is referred to as evapotranspiration (ET). Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves.

The evapotranspiration rate is normally expressed in millimeters (mm) per unit time. The rate expresses the amount of water lost from a cropped surface in units of water depth. The time unit can be an hour, day, decade, month or even an entire growing period or year. Evapotranspiration (ET) is one of the major components of the hydrologic cycle and its accurate estimation is of paramount importance for many studies, such as hydrologic water balance, irrigation system design and management, crop yield simulation, and water resources planning and management. Evapotranspiration can be directly measured using Lysimeter or estimated with meteorological data.

Evapotranspiration (ET) is important to irrigation management because crop yield relates directly to ET. Evapotranspiration can be estimated directly using water balance approach or lysimeter. However, these techniques required more cost, skilled man power for observation, monitoring and more maintains. Therefore, we cannot install it everywhere. Hence, research has been going on since last fifty year to estimate ET indirectly by mathematical and statistical methods based on variable climatic parameters.

These methods include empirical equations or Methods based on physical processes of complex. One of the methods that are widely used to estimate evapotranspiration is the Penman-Monteith (Kumar *et al.*, 2002). According to research done, the Penman - Monteith is accurate methods of estimating evaporation and it can use for estimate transpiration and watering in different regimes. Empirical models are usually used to estimate ET at local and regional scales. No estimation technique is universal, but a standard method is the Penman-Monteith equation as specified by the UN Food and Agriculture Organization (FAO) in paper number 56. The FAO-56 Penman-Monteith method estimates ET rates for a well-watered reference surface based on physical atmospheric observations of solar radiation, temperature, wind speed, and relative humidity. This estimate is commonly referred to as reference ET. The reference surface is a theoretical grass reference crop with a height of 0.12 m, an albedo of 0.23, and a constant surface resistance of 70 s/m.

While dependent on time of year and location, the equation is developed for the hypothetical grass reference crop and is thus independent of specific crop characteristics and soil factors.
ET_0 was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. The only factors affecting ET_0 are climatic parameters. Crop ET for a given crop can be estimated using grass reference crop evapotranspation (ET_0) and crop coefficient, whereas ET_0 can be estimated using different methods depending on the availability of climatic data. These different methods ET_0 estimation can be Blaney –Criddle, Hargreaves, Turc. This research compares the ET_0 estimated by different methods with FAO-56 Penman-monteith due to the non-availability of lysimeter ET to identify which method fits well to the Penman-Monteith estimates.

MATERIALS AND METHODS

Study Area & Collection of Data

The meteorological observatory located in Raipur at 21º 14' 9" N latitude and 81º 42' 10" E longitude and 302 m altitude above MSL, is at a distance of about 1.7 km from Indira Gandhi Krishi Viswavidyalaya Raipur towards east on right side of National Highway-6. Data on maximum temperature (T_{max}), minimum temperature (T_{min}), relative humidity (RH), and wind speed (WS), sunshine hour (SSH) of past 6 years (1 January 2000 to 31 December 2005) were collected from Department of Agro-meteorology, IGKV, Raipur (C.G.).

Description of Methods

The ET estimation methods are generally grouped into temperature and radiation method.

Temperature Methods

Blaney and Criddle (1950) observed that the consumptive use of crops during the growing season was closely correlated with mean monthly temperature and daylight hours. They developed a simplified formula for estimating consumptive use for the arid western regions of the United States. Doorenbos and Pruitt (1977) presented the most fundamental revision of the Blaney- Criddle method. Hargreaves and Samani (1985) proposed a method for estimating reference ET that requires only maximum and minimum air temperatures.

Blaney-Criddle Method

The Blaney-Criddle method is one of the simplest techniques used to calculate ET. It was widely used before the introduction of Penman-Monteith equation. This method only considers temperature changes at a particular region for measuring reference ET. The Blaney-Criddle formula for estimating ET is as follows:

$$ET_0 = p\,(0.46\,T_{mean} + 8) \qquad \text{------------------ (1)}$$

Where,
p is the mean daily percentage of annual daytime hours due to the latitude of region.
T_{mean} is mean temperature (°C).

Hargreaves Method

The Hargreaves and Samani (1985) proposed an equation for estimating grass-related reference ET. Since solar radiation data are not frequently available, this method estimates ET_0 from extraterrestrial radiation and mean monthly maximum and minimum temperature.
The equation is expressed below:

$$ET_0 = 0.0023(T_{max} - T_{min})\ 0.5(Tm + 17.8)R_a \qquad \text{-------(2)}$$

Where,
T_m is the mean temperatures (°C).
T_{max} is maximum temperatures (°C)
T_{min} refer to minimum temperatures (°C)
R_a is the extraterrestrial radiation of the crop surface ($MJm^{-2}\ day^{-1}$).

Radiation Method

Radiation method is an adaptation of the relationship developed by Makkink (1957). It is recommended for area where the weather data are not sufficient to use the penman formula. The essential climatic data include air temperature and sunshine or cloudiness or radiation. Only general levels of wind and humidity, which could be estimated from local weather station are adequate.

Turc Method

Turc (1961) proposed a simple equation for computing ET by using only mean temperature, solar radiation and relative humidity. Jensen *et al.*, (1990) reported that the Turc method is reliable under humid conditions similar to present study area. The Turc equation is as follows:

$$ETo = 0.013\frac{Tmean}{(Tmean + 15)}(Rs + 50)\frac{1}{\lambda} \qquad \text{-------------(3)}$$

{For RHmean > 50%}

$$ETo = 0.013\frac{Tmean}{(Tmean + 15)}(Rs + 50)\frac{1}{\lambda}\left(1 + \frac{(50 - RH\ mean)}{70}\right) \qquad \text{---------- (4)}$$

{For RHmean ≤ 50%}

Where,

R'_s is the solar radiation [cal cm^{-2} d^{-1}] and can be calculated as R / 0.041869 s, R_s is solar radiation [MJ m^{-2} d^{-1}], RHmean is the average relative humidity [%] and λ is the latent heat of vaporization [$MJkg^{-1}$].

Calculation of Reference Evapotranspiration ET_0

The FAO Penman–Monteith Equation

The FAO-PM equation recommended for daily ET_0 (mm day^{-1}) estimation (Allen *et al.*, 1998) may be written as.

$$ET_0 = \frac{0.408\,\Delta\,(Rn - G) + 900\,\gamma u2\,(es - ea)/\,(T + 273)}{\Delta + \gamma\,(1 + 0.34\,u2)} \qquad \text{---------------------- (5)}$$

Where:

ET_0 - Reference evapotranspiration [mm day-1],
Rn - Net radiation [MJ m-2 day-1],
G - Soil heat flux density [MJ m-2 day-1],
T - Mean daily air temperature at 2 m height [°C],
u2 - Wind speed at 2 m height [m s-1],
es - Saturation vapour pressure [kPa],
ea - Actual vapour pressure [kPa],
es-ea - Saturation vapour pressure deficit [kPa],
Δ - Slope of the vapour pressure curve [kPa °C-1],
γ - Psychrometric constant [kPa °C-1].

Equation (1) determines the ET_0 from an assumed grass reference surface and serves as a standard to which evapotranspiration in different periods of the year. Based on the recommendations of the expert consultation of FAO methodologies for Crop Water Requirements (UNFAO, 1998) and the results of other studies, the United Nations Food and Agriculture Organization (Allen *et al.*, UNFAO, 1998) brought out a comprehensive treatise in FAO Irrigation and Drainage Paper 56, entitled Crop Evapotranspiration, Guidelines for computing Crop Water Requirement.

Performance Evaluation

The statistical model evaluation criteria considered in this study are as follows:

Mean Absolute Deviation (MAD)

It is a measure of mean absolute deviation of the observed values from the estimated values. It has a unit and is not a normalized criterion. It is expressed as,

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$$MAD = \frac{\sum_{j=1}^{n} \left| O_j - S_j \right|}{n} \qquad \text{---- (6)}$$

Where, O_j = Observed ET_O (mm/day), S_j = Simulated ET_O (mm/day), n = Total number of observations.

Root Mean Square Error (RMSE)

It is an alternative to the criterion of residual error (Yu, 1994) and is expressed as the measure of mean of the residual variance summed over the period, that is,

$$RMSE = \sqrt{\frac{\text{residual variance}}{n}} = \left(\frac{\sum_{j=1}^{n} (O_j - S_j)^2}{n} \right)^{1/2} \qquad \text{------ (7)}$$

Correlation Coefficient (CC)

The correlation between the observed and simulated values is described by the correlation statistic, called the correlation coefficient. It is estimated by the equation:

$$CC = \frac{\sum_{j=1}^{n} \left\{ \left(O_j - \bar{O}\right)\left(S_j - \bar{S}\right) \right\}}{\left\{ \sum_{j=1}^{n} \left(O_j - \bar{O}\right)^2 \sum_{j=1}^{n} \left(S_j - \bar{S}\right)^2 \right\}^{\frac{1}{2}}} x100 \qquad \text{------- (8)}$$

Where, $\bar{O}$ and $\bar{S}$ are mean of observed and simulated ET_O values.

Coefficient of Efficiency (CE)

Nash and Sutcliffe (1970) proposed the criterion on the basis of standardization of the residual variance with initial variance and named it as the coefficient of efficiency.

$$CE = \left\{ 1 - \frac{residual\ variance}{initial\ variance} \right\} x\ 100 = \left\{ 1 - \frac{\sum_{j=1}^{n} (O_j - S_j)^2}{\sum_{j=1}^{n} (O_j - \bar{O})^2} \right\} x\ 100 \qquad \text{------ (9)}$$

RESULTS AND DISCUSSION

ET_0 values were estimated by all the above methods and were used for inter comparison of different methods. The ET_0 values obtained by different method were compared with the FAO-56 Penman-Monteith ET_0 estimate due to the non-availability of reliable lysimeter data.

The monthly ET_0 was estimated using three methods (Blaney-criddle, Hargreaves and Turc method) and compared with the FAO-56 Penman-Monteith estimates. Out of three methods, the Blaney – Criddle method yielded the highest R^2 (0.804), while the Turc methods estimated the lowest R^2 (0.692). Correlation-Coefficient was found highest for Blaney-Criddle method CC (92.96) and lowest for Turc method CC (87.96). The comparison of ET_0 was done by dividing the data into following three periods i.e., Nov-Feb, March-June, and July-Oct representing the winter, summer and rainy season. For the period Nov-Feb all the three method overestimated the FAO-56 PM method while for March- June Blaney Criddle and Hargreaves method overestimated ET_0 whereas Turc method underestimated for the year 2000, 2001, 2003 and 2005. For the year 2002 and 2004 performance of Blaney Criddle was close to FAO-56 PM, whereas Hargreaves and Turc method underestimated. For the period July to Oct Hargreaves method performed better than FAO-56 PM whereas Blaney Criddle and Turc method underestimated.

Table 1: Performance Evaluation of Different Methods of ET_0

Statistical Parameters	Blaney-Criddle	Turc	Hargreaves
R^2	0.804	0.692	0.775
MAD(mm/day)	0.89	0.78	0.87
RMSE (mm/day)	1.07	1.20	1.05
CE %	80.4	69.2	77.5
CC %	92.96	87.96	91.63

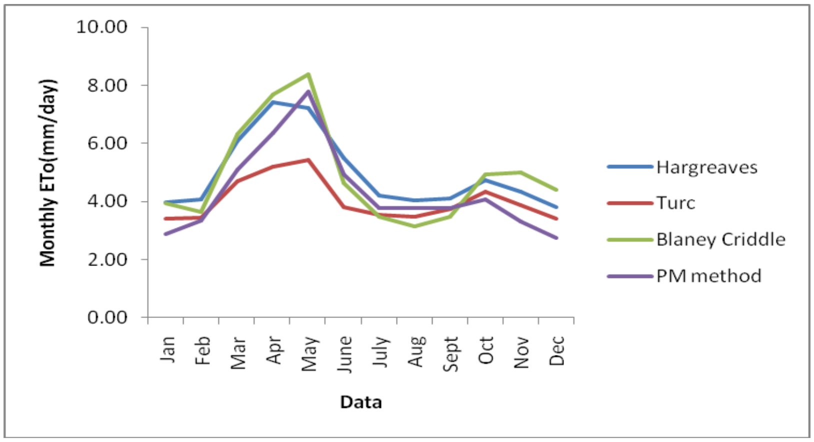

Figure 1: Comparison of ET_0 Estimates for Raipur Region for the Year 2000

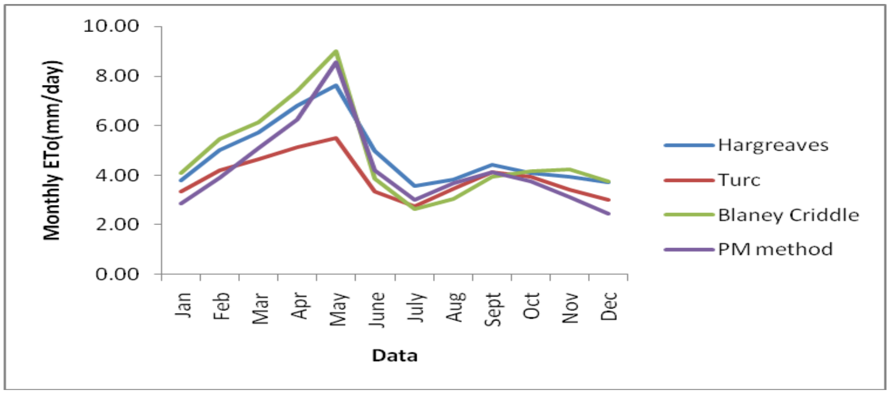

Figure 2: Comparison of ET_0 Estimates for Raipur Region for the Year 2001

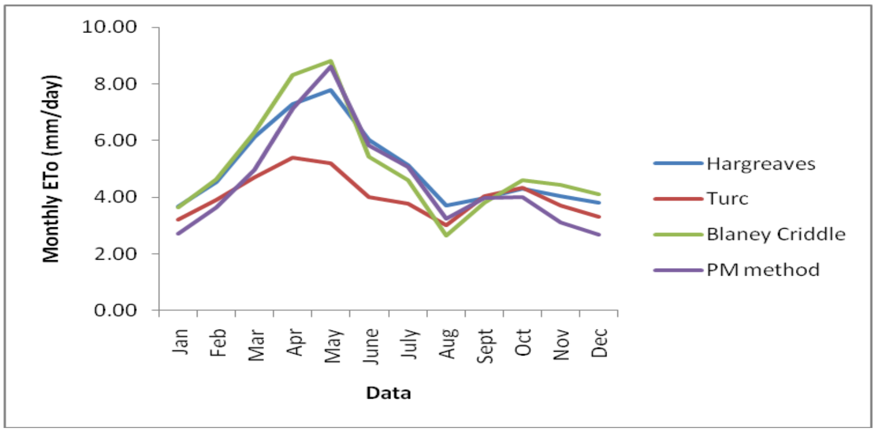

Figure 3: Comparison of ET_0 Estimates for Raipur Region for the Year 2002

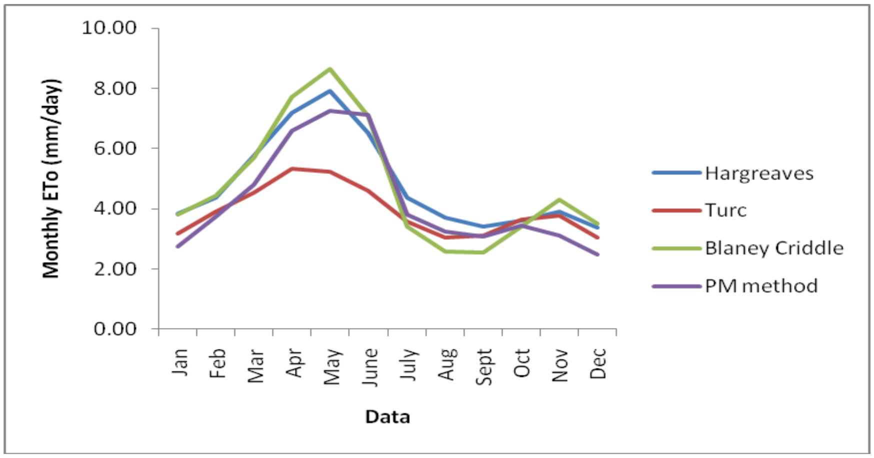

Figure 4: Comparison of ET_0 Estimates for Raipur Region for the Year 2003

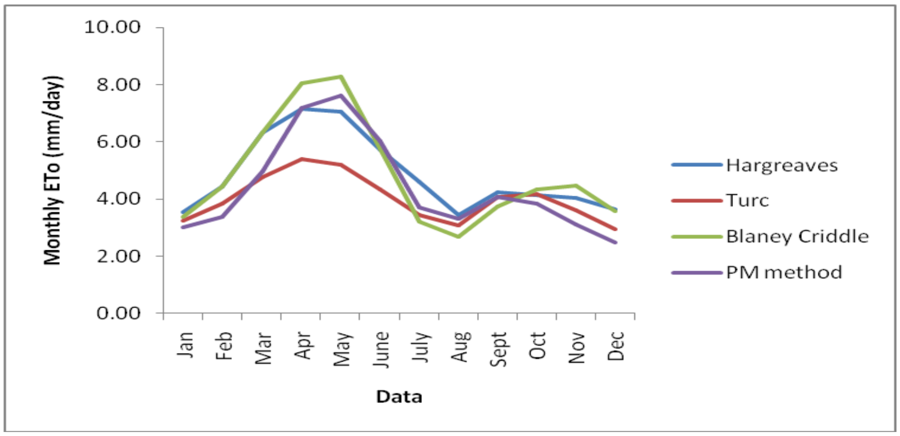

Figure 5: Comparison of ET_0 Estimates for Raipur Region for the Year 2004

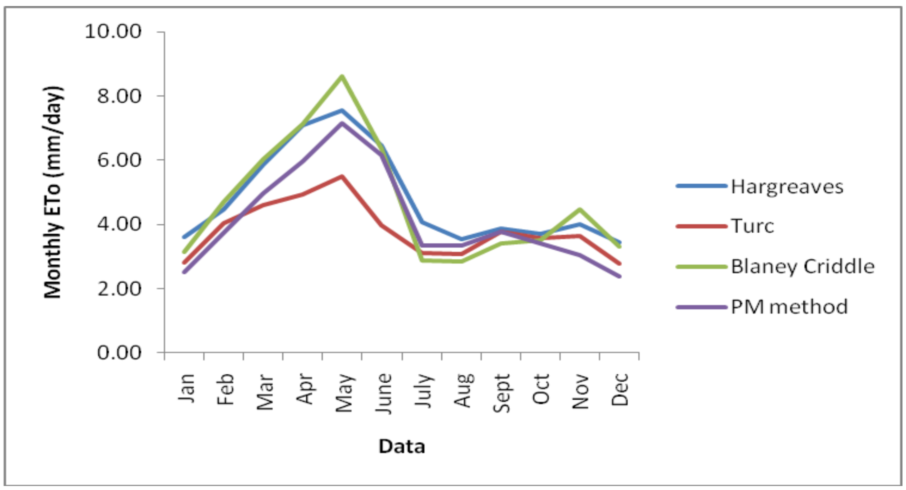

Figure 6: Comparison of ET_0 Estimates for Raipur Region for the Year 2005

Summary & Conclusion

Three empirical methods for calculating ET namely Blaney-criddle, Hargreaves and Turc method were evaluated using meteorological data from Raipur region. Due to unavailability of measured lysimeter data, the FAO-56 Penman-Monteith method as recommended by FAO was taken as the standard for evaluating the performance of those three methods. The performance of the Blaney- Criddle method was found to be in close agreement with the FAO-56 Penman-Monteith method.

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