MAUSAM, **72**, 3 (July 2021), 681-684

L E T T E R S

633 : 551.573

COMPARISON OF THE MONTHLY AND SEASONAL ESTIMATES OF POTENTIAL EVAPOTRANSPIRATION FOR COIMBATORE STATION OF TAMILNADU USING DIFFERENT METHODS

1. Potential Evapotranspiration (PET) is the amount of water that would be evaporated and transpired from an extended area completely covered with vegetation when there is sufficient water available. This demand incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. PET is higher in the summer, on less cloudy days and closer to the equator, because of the higher levels of solar radiation that provides the energy for evaporation. Wind also enhances PET because the evaporated moisture can be quickly moved from the ground or plant surface, allowing more evaporation to fill its place. Potential Evapotranspiration plays an important role in water cycle and energy cycle and shows a specific characteristic under certain climate and landscape conditions (Lin *et al*., 2018)

Potential evapotranspiration is usually measured indirectly, from other climatic factors, but also depends on the surface type, such as free water (for lakes and oceans), the soil type for bare soil and the vegetation. Often a value for the potential evapotranspiration is calculated at a nearby weather station on a reference surface. This value is called the reference evapotranspiration and can be converted to a potential evapotranspiration by multiplying with a surface coefficient. In agriculture, this is called crop coefficient. ETo is a complex and non-linear phenomenon since it depends on several interacting factors such as temperature, humidity, wind speed and radiation (Padh *et al*., 2020).

ET information is useful to determine how much water has evaporated from the cropped field. In most situations, daily evapotranspiration by crop equals the depletion of water from the soil that day. Therefore, the records of accumulated evapotranspiration in between two watering can be used to determine when and how much irrigation is needed to the crop. In general, the variables that affect the evapotranspiration phenomenon are wind velocity, solar radiation, humidity, temperature, cloud cover, advection, ground cover, soil, plant characteristics and the soil moisture status etc. However, the studies conducted at the Experimental Farm, Tamil Nadu Agricultural University revealed that the significance of weather parameters that influence evapotranspiration (ET) varied from year to year. Looking into this it has been hypothesized that the weather parameters influence the ET if the parameter fluctuates above and below the optimum values. In order to study the ET estimation by different methods in Coimbatore station, the historical weather data was collected from the Agro Climate Research Centre of Tamil Nadu Agricultural University, Coimbatore.

2. *Different equations used in the study - Penman's method* - The potential evapotranspiration which is the maximum amount of evaporation from soil and transpiration from vegetation that takes place over an extensive area with adequate moisture at all times, was computed by Penman's (1948) equation as given below:

$$E_0 = \frac{\Delta H + \gamma Ea}{\Delta + \gamma}$$

where, Δ is the Slope of the saturated vapour pressure curve at temperature T °C, γ is Psychrometric constant (0.49) and H is Energy balance term:

$$H = (1 - r)\ 0.95R_a\ (0.18 + 0.55)\ n/N) - \sigma\, Ta^4\ (0.55\text{-}0.092 \sqrt{ed})\ (0.10+0.90\ n/N)$$

where, R_a is the extra terrestrial radiation (mm of water /day), r is the Albedo which is assumed as 0.25, *n* is the actual bright sunshine hours, N is the Possible bright sunshine hours, σ is the Stephen Boltzman constant = 4.903×10^{-9} MJ K^{-4} m^{-2} day^{-1} later converted to 20.284 mm/day/°K^4 and Ta = Mean air temperature

ed = Actual vapour pressure;

$$ed = \frac{\text{RH mean} \times \text{ea}}{100}$$

Ea is the Aerodynamic term
= 0.35 (e_a-e_d) (1+0.0098 U_2)

where,

e_a is the saturated vapour pressure and U_2 is the 24 hours total wind run of two meters height in m/s.

The wind speed, which is measured at 10 feet height, was converted at two meter height using the logarithmic equation as:

$$U_{h1} \log h_1 = U_{h2} \log h_2$$

Therefore,

$U_{h2} = (U_{h1} \log h_1) / \log h_2$

where, U_h is the wind run at height ‘h’

2.1. *Modified Penman’s method* - The modified Penman formula can be stated as:

$$ET = C\left[W.R_n + (1-W).m.f(u).(e_q - e_d)\right]$$

where, ET is reference crop evapotranspiration in mm/day; C is adjustment factor to compensate for the day & night weather effects; W . R_n represents radiation term and (1 – W). f{u) . (e_a – e_d) represents aerodynamic term.

The meaning of various notations used in the formula is as follows:

W is temperature and elevation related weighting factor for the effect of radiation on ET and R_n is net radiation (R_{ns} – R_{nl}) in mm/day

R_{ns} is the net incoming shortwave solar radiation = R_a (1 – α) (0-25 + 0.5 n / N)

R_a is extraterrestrial radiation expressed in equivalent evaporation in mm/day, which is received at the top of the atmosphere.

R_s is solar radiation that reaches the earth after part of R_a is absorbed in the atmosphere. It is given by relation $R_s = R_a$ (0.25+ 0.5 n / N).

n is actual duration of bright sunshine; N is maximum possible duration of bright sunshine and α is reflection coefficient of surface = 0.25 for most of the crops.

R_{nl} is the net long wave radiation = f(t) . f (e_d) f(n/N)

(1 – W) is a temperature and elevation related weighting factor and the effect of wind humidity on ET.

f(u) is a wind related function and ea is saturation vapour pressure in m bar at the mean air temperature in °C.

e_d is mean actual vapour pressure of air in m bar = e_a × RH mean/100; where, RH is relative humidity.

The adjustment weather factor ‘C’ and wind related function f(u) are the important variations made in the modified Penman formula.

2.2. *Thornthwaite method* - Thornthwaite (1948) considered temperature and day length to estimate the potential evapotranspiration.

Thornthwaite’s formula for unadjusted PET (cm / month) is:

$$UPET = \left(\frac{10T^a}{1.695\,I}\right)$$

where, UPET is the Unadjusted potential evapotranspiration; T is the Mean monthly temperature in °C and I is the annual heat index.

i = monthly heat index $i = (T/5)^{1.514}$

T = mean monthly temperature (°C)

a = non linear function of heat index approximated by the expression

a = $6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239$

The unadjusted potential evapotranspiration UPET values so obtained are for an average of a 30 day month with 12 hours of day length. The values must be adjusted by multiplying by a correction factor that expresses how each particular month varies. The correction factor for each month in different years was worked out by using the formula.

$$\text{Correlation Factor} = \frac{N}{12} \times \frac{\text{No. of days in month}}{30}$$

2.3. *Blaney-Criddle method* - Blaney - Criddle formula for estimating ETo, *i.e.*, reference crop evapotranspiration in mm/day for the month considered is: PET = p (0.46 *T*mean + 8) mm/day

where, *T*mean is the mean air temperature in°C and p is the mean daily percentage of annual daytime hours.

The mean daily percentage of annual daytimehours (p) was calculated from the table values of mean daily percentage of annual daytime hours for different latitudes.

2.4. *Christiansenmethod* - Christiansen equation for estimation of ETo is presented in a following way:

ETo = 0.755 Epan. Ct. Cu. Ch. Cs

where, ETo is the Reference evapotranspiration (mm day^{-1});

Epan = measured evaporation from class a pan (mm day^{-1}) Coefficients are dimensionless

Ct = $0.862+0.179(T/To)-0.041(T/To)^2$

where, T = mean temperature in °C and To = 20 °C

Cu = 1.189-0.240 (U/Uo)+0.051 $(U/Uo)^2$

where, U is the mean wind speed at 2 m height (km/hr) and Uo = 6.7 km/hr

Ch = 0.499+0.620 (H/Ho)-0.119 $(H/Ho)^2$

where, H is mean relative humidity and Ho=0.6; Cs=0.904+0.008(S/So) +0.088 (S/So)

where, S is the percentage of Possible sunshine expressed decimally and So = 0.8

2.5. *FAO Penman Monteith equation* - Monteith (1965) introduced resistant terms into penman method:

$$LE = [\{ \Delta / \gamma \text{ (Rn-G)}\}+\{ \rho_a \text{ Cp(es-ea)}/ \gamma \, r_a\}]/ (\Delta / \gamma +1+\text{rc/ra})$$

where, ρ_a is the density of air, 1.3 kg/m³; Cpis Specific heat of air at constant pressure, 1008 j/kg/°C; ra is aerodynamic resistance, s/m; rc is the canopy resistance, s/m and taken as rs + 15.

where, rs is the stomatal resistance; rs = [(rad × rab)/(rad+rab)]/LAI

where, rab is the abaxial resistance; LAI is the leaf area index; rad is the adaxial resistance and ea is the Actual vapor pressure, mm of Hg and Es is the saturation vapor pressure, mm of Hg

where, Z is the height; d is the Zero plane displacement = 0.63 z; Zo is the Roughness parameter = 0.13 z; ra is the $[\ln\{(z-d)/zo\}]^2/uk^2$, aerodynamic resistance; U is the Wind speed at height, z and K is the Von Karman's constant (.41)

2.6. *Open Pan method* - Pans provide a measurement of the integrated effect of radiation, wind, temperature and humidity on the evaporation from an open water surface. Reflection of solar radiation from water in the shallow pan might be different from the assumed 23% for the grass reference surface. Notwithstanding the difference between pan-evaporation and the evapotranspiration of cropped surfaces, the use of pans to predict ETo for periods of 10 days or longer may be warranted. The pan evaporation isrelated to the reference evapotranspiration by an empirically derived pan coefficient:

ETo = Kp × E pan

where, ETo reference evapotranspiration [mm/day], Kp is the pan coefficient and Epan pan evaporation [mm/day].

3. *Monthly PET* : The weather data extracted from long period average of 33 years (1987-2019) were subjected to the estimation of PET. The monthly values of PET computed by different methods are shown in Table 1. It can be seen from the Table that the annual PET varied from 1141.6mm to1766.6 mm depending on various methods of estimation. Among the methods, Penman method had underestimated the PET which was followed by open pan method. In general, the PET values recorded during summer months (Mar-May) were higher irrespective of the method of estimation. The PET values were estimated to be lower during the months of Jan to Feb and Nov-Dec in most of the methods and the lowest PET of 72.1mm was recorded during Dec under Penman method and the highest monthly PET of 209.7 mm was estimated during May under Thornthwaite method. Modified Penman method recorded the highest PET of 165 mm during the month of April and the lowest PET of 108.0 mm during November. The lower PET values were observed during winter by Verma *et al.*, 2012. The FAO Penman-Monteith method ranked as the best method for all climatic conditions (Allen *et al*., 1998 and Jensen *et al*., 1990).

Seasonal PET : The season-wise and annual PET data are shown in Table 1. Among the seasons, the PET was estimated to be higher during kharif season (Jun-Sep) in all the methods tested except Penman which estimated slightly higher PET during summer (Mar-May). The highest PET of 715.6 mm was recorded during kharif season under Blaney and Criddle method which had overestimated the PET compared to other methods. The PET values were estimated to be 352.0 mm to 592.3 mm during summer and the lowest PET was estimated under Open pan method and the highest under Thornthwaite method. The PET estimated during winter season (Jan-Feb) indicated that the PET values werethe lowest among other parts of the year irrespective of the method of PET estimation. The lowest PET of 179.2 mm was recorded under Open pan method followed by Penman method. Blaney and Criddle had overestimated the PET value (305.8mm) during winter season. According to Modified Penman method, the PET values estimated were 527.4 mm during kharif, 487.4 mm in summer, 343.6mm during rabi and 252.5 mm in winter.

Annual PET - The annual PET values computed by different methods are shown in Table 1. The annual PET ranged from 1141.5 mm to 2036.1 mm and the Blaney and Criddle method had overestimated the PET while the lowest PET was estimated under Penman method. The PET value estimated under Thornthwaite method (1766.6 mm) was comparable with that of FAO Penman Monteith

TABLE 1

Average seasonal values of PET computed by different equations at Coimbatore (mm)

Month	Penman	Modified Penman	Thornthwaite	Blaney and Criddle	Christiansen	Open Pan	FAO Penman-Monteith
Jan	84.9	120.9	95.3	154.8	104.6	84.3	125.2
Feb	97.3	131.6	113.2	151.0	113.9	94.9	135.7
Winter	**182.2**	**252.5**	**208.5**	**305.8**	**218.5**	**179.2**	**260.9**
Mar	127.0	164.3	174.1	175.6	146.9	123.2	171.3
Apr	123.8	165.0	208.5	181.6	140.8	112.7	157.5
May	118.8	158.1	209.7	186.1	143.7	116.1	164.4
Summer	**369.6**	**487.4**	**592.3**	**543.4**	**431.4**	**352.0**	**493.2**
Jun	87.1	132.0	172.3	181.5	133.2	108.6	158.8
Jul	79.7	127.1	157.8	184.2	129.1	105.1	153.6
Aug	89.4	133.3	152.7	171.7	129.0	102.1	150.5
Sep	97.9	135.0	147.8	178.1	124.1	93.9	144.2
Kharif	**354.1**	**527.4**	**630.6**	**715.6**	**515.4**	**409.8**	**607.0**
Oct	88.5	127.1	135.6	163.8	106.6	93.6	121.6
Nov	75.1	108.0	107.0	153.2	88.5	73.6	117.6
Dec	72.1	108.5	92.5	154.3	125.1	112.8	108.4
Rabi	**235.7**	**343.6**	**335.2**	**471.3**	**320.2**	**280.0**	**347.6**
Annual	**1141.6**	**1610.9**	**1766.6**	**2036.1**	**1485.5**	**1221.0**	**1708.6**

(1708.7mm). The Modified Penman method estimated an annual PET of 1610.9 mm while the Open pan method estimated a lower PET value (1221 mm).

4. From the PET analysis using different methods, it was observed that the PET values varied depending on the availability of meteorological data. The monthly PET estimation indicated that the Penman and Open pan PET values were underestimated while Blaney and Criddle method overestimated the PET. The seasonal variation existed in PET which indicated that the PET values were estimated to be higher in kharif season and lower during winter season irrespective of the method adopted. The FAO Penman Monteith method recorded better results by moderating the extremities recorded under other methods. According to the FAO method, the highest PET value of 171.3 mm during March and the lowest PET value of 108.4 mm during December with an annual PET of 1708.7mm were estimated for Coimbatore station of Tamil Nadu.

5. The contents and views expressed in this research paper/article are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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