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A CASE STUDY

# Comparison of the values of potential evapotranspiration estimated through different methods and their relationship

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ABSTRACT : In the present study, six empirical methods, namely, Modified Penman, Blaney Criddle, Christiansen, Thornthwaite, Open pan, Turc and FAO penman method are computed using the daily weather data for the period 1981-2012 (32 years) was collected for three stations in Chhattisgarh state representing 3 agroclimatic zones. It is found that FAO Penman method is the best method for estimating potential evapotranspiration. The comparison of ETo estimates was done based on the weekly averages of PET using correlation co-efficients and regression methods through different methods. At Ambikapur the highest correlation co-efficient between FAO Penman and Modified Penman method 0.998 and lowest in between Christiansen and Blaney criddle method 0.918. At Jagdalpur and Raipur also having the highest correlation co-efficient between FAO penman and Modified penman method 0.999 and lowest correlation co-efficient in between Christiansen and Turc method 0.85 or 0.84. Regarding regression with Open pan evaporation, highest $R^2$ values are with Modified Penman and Christiansen methods at Ambikapur while at Jagdalpur and Raipur highest $R^2$ was with Christiansen method. Thus, the open pan evaporation can be estimated by Christiansen method.

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Key Words :
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A significant part of precipitation returns back to the atmosphere by evapotranspiration. Evapotranspiration can be broadly defined as cumulative sum of water that is evaporated from the surface and transpired by the plants as a part of their metabolic process. Therefore, the term evapotranspiration is used to describe the total process of water transfer into the atmosphere from vegetation and land surfaces. Evapotranspiration depends upon the availability of water, temperature and humidity of the air, wind velocity and duration of sunshine. In tropical countries like India, abundance or scarcity of moisture has a great influence on plant growth. Rainfall is the main source for moisture supply to plants. The plant growth does not depend on rainfall alone, but it should balance the evapotranspiration of crops. Therefore, evapotranspiration studies are useful tools in irrigation scheduling for effective water resources management. It is also important in nutritional management studies since the nutritional uptake is maximum when optimum soil moisture is available to the plant. Evapotranspiration plays a vital role for irrigation scheduling under scarce water resources management. Evaporation and transpiration occur simultaneously and therefore, there is no easy way of distinguishing between these two processes. When the crop is small, water is predominantly lost by evaporation from the soil surface, but once the crop is well developed and completely covers the soil, transpiration becomes the main process (Allen *et al.*, 1996).

Estimates of evapotranspiration provide an outlook of soil water balance in association with the amount of precipitation. Such estimates are of immense importance for the calculation of water demand of the field crops and irrigation scheduling (Rasul, 1992). In Chhattisgarh state there are three agroclimatic zones and 3 stations *viz.*, Ambikapur, Jagdalpur and Raipur were considered representing Northern Hills, Bastar Plateau and Chhattisgarh plains agroclimatic zones.

## EXPERIMENTAL METHODOLOGY

### Penman's method :

For computing potential evapotranspiration (PET) daily weather data from 1981-2012 was considered for the three representing stations. The PET values for the three stations were computed using PET software developed by CRIDA, Hyderabad. Seven different equations were used which are as follows :

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

where,

$\Delta$ = Slope of the saturated vapour pressure curve at temperature. T °C

$\gamma$ = Psychrometric constant (0.49)

H = Energy balance term

$$= RA (1 - \sim) (0.18 + 0.55)\, n/N) - \pm Ta^4 (0.55 - 0.092 \sqrt{ed}) (0.10 + 0.90\, n/N)$$

where,

RA = Extra terrestrial radiation (mm of water /day)

$\alpha$ = Albedo which is assumed as 0.25

n = Actual bright sunshine hours

N = Possible bright sunshine hours

$\sigma$ = Stephen Bottzman constant = $0.817 \times 10^{-10}$ ($cal/cm^2/mm/°K^4$) later converted to 20.284 $mm/day/°K^4$

Ta = Mean air temperature

ed = Actual vapour pressure.

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

Ea = Aerodynamic term

= $0.35 (e_a - e_d) (1 + 0.0098\, U_2)$

where,

$e_a$ = saturated vapour pressure

RH=Relative humidity (%)

$U_2$ = 24 hours total wind run of two meters height in miles.

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, $U_h$ = wind run at height 'h'

### Thornthwaite method :

Thornthwaite (1948) considered temperature and day length to estimate the potential evapotranspiration

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

$$UPET = 1.695 \left[\frac{10T}{1}\right]^a$$

where,

UPET = Unadjusted potential evapotranspiration

T = Mean monthly temperature in °C

I = Annual heat index

i = monthly heat index

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

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 :

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

where,

N = Possible hours of sun shine

### Blaney-criddle method :

Blaney - Criddle formula for estimating ETo *i.e.* reference crop evapotranspiration in mm/day for the month considered is :

$$PET = [0.0173\, Ta - 0.314] \frac{Kc \times Ta \times D}{4465.6 \times 25.4}\ mm/day$$

where,

Ta = mean air temperature in °F

Kc= Crop co-efficient

D= Day length.

### Turc method :

Turc gave the following formula for the estimation of daily PET :

$$PET = 0.40\,Tc\,\frac{(RI + 50)}{(Tc + 15)N}$$

where,

PET=Potential evapotranspiration

Tc=Mean air temperature, (°C)

RI=Solar radiation (ly/day)

N=Number of days in month.

### Hargreaves method :

**PET=0.0135(t+17.78) Rs.**

PET = Reference crop potential consumptive use,

t = average daily temperature (°C)

Rs. = Incident solar radiation ly/day

Rs. = 0.10 Rso (S) ½

S = Per cent of possible sunshine

Rso = Clear day solar radiation in ly $day^{-1}$.

### Christiansen method :

Christiansen equation for estimation of ETo is presented in a following way:

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

where,

ETo = Reference crop evapotranspiration (mm $day^{-1}$)

Epan=measured evaporation from class a pan (mm $day^{-1}$) Co-efficients 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= mean relative humidity and Ho=0.6

$$Cs=0.904+0.008(S/So)+0.088\ (S/So)$$

where, S= percentage of possible sunshine expressed decimally and So=0.8.

### FAO Penman monteith equation :

Monteith (1963 and 1964) introduced resistant terms into Penman method :

**LE= [{a/¥ (Rn-G)} + {°$_a$Cp (es-ea)/¥ $r_a$}]/ (a/¥ +1+rc/ra)**

where,

$\rho_a$ = density of air (1.3 kg/m³)

Cp = Specific heat of air at constant pressure (1008 j/kg/°c)

ra =Aerodynamic resistance (s/m)

rc =canopy resistance (s/m) and taken as rs+15

rs=stomatal resistance

rs = [(rad xrab)/(rad+rab)]/LAI

rab = abaxial resistance

LAI=leaf area index

rad = adaxial resistance

ea = Actual vapor pressure, mm of Hg

es=saturation vapor pressure, mm of Hg.

**$r_a$ = [ln{(z-d)/zo}]²/uk²,aerodynamic resistance**

where,

Z=height

d=Zero plane displacement = 0.63 z

Zo = Roughness parameter = 0.13 z

U=Wind speed at height, z

K=Von Karman's constant (.41).

### Open pan evaporation :

The daily value of open pan evaporation were measured by using a U.S.W.B. class A open pan evaporimeter at 0830 and 1430 hours IST in the Agrometeorological Observatory College of Agricultural, Raipur were used.

## EXPERIMENTAL FINDINGS AND DISCUSSION

The relationship between the estimates PET between different methods is worked out through correlation co-efficients which are shown in Table 1. It can be seen that the PET values computed by different methods are very highly correlated. The correlation co-efficient values varied from 0.996 to 0.918 indicating that this 7 methods are well correlated with each other. However, at Ambikapur the relationship between Christiansen method of estimation of PET and Blaney Criddle method is lower than other methods while at Jagdalpur the correlation co-efficient among different methods of estimation of PET are relatively less as compared to Ambikapur. The lowest correlation co-efficient was between the Christiansen and Hargreaves methods and also between Christiansen and Turc method.

The highest correlation co-efficient was found with Open pan and Christiansen method of estimation of PET.

Also the correlation co-efficients between Penman Monteith and Modified Penman method are very high (C=0.999).

At Raipur also there is strong relationships between the different methods of estimation of PET. The lowest correlation co-efficient was between Christiansen and Turc methods while FAO Penman Monteith method and Modified Penman methods are very high correlated with a correlation co-efficient of 0.999.

In order to find out the relationship between open pan evaporation and PET values by different methods regression analysis was carried out on weekly basis for different stations. The results are discussed below for each station separately.

*Ambikapur* :

The relationship between open pan evaporation and PET values by different methods are shown in Fig.1. It can be seen from the figure that regression co-efficients for all in the methods of PET estimation with open pan evaporation values are very high except Turc and Blaney Criddle methods. The regression equations for Ambikapur station are as follows :

Open Pan and Modified Penman method :

**$Y= 5.6+1.149X$ ($R^2$=0.99)**

Open Pan and Hargreaves method :

**$Y= 12.9 +0.833X$ ($R^2$=0.96)**

Open Pan and Turc method :

**$Y= 16.64+0.43X$ ($R^2$=0.78)**

Open Pan and Blaney Criddle method :

**$Y= 6.69+1.0568X$ ($R^2$=0.88)**

Open Pan and Christiansen method :

**$Y= 2.97 +1.331X$ ($R^2$=0.99)**

Open Pan and FAO penman method :

**Table 1 : Correlation co-efficient between PET values under different methods at Ambikapur**

| PET under different methods | Modified Penman | Hargreaves | Turc | Blaney criddle | Christiansen | Open pan PET | FAO penman method |
|---|---|---|---|---|---|---|---|
| Modified penman | 1 | | | | | | |
| Hargreaves | 0.996 | 1 | | | | | |
| Turc | 0.984 | 0.986 | 1 | | | | |
| Blaney criddle | 0.952 | 0.949 | 0.951 | 1 | | | |
| Christiansen | 0.973 | 0.966 | 0.943 | 0.918 | 1 | | |
| Open pan PET | 0.976 | 0.916 | 0.953 | 0.941 | 0.996 | 1 | |
| FAO penman method | 0.998 | 0.995 | 0.984 | 0.938 | 0.973 | 0.973 | 1 |

**Table 2 : Correlation co-efficient between PET values under different methods at Jagdalpur**

| PET under different methods | Modified penman | Hargreaves | Turc | Blaney criddle | Christiansen | Open pan PET | FAO penman method |
|---|---|---|---|---|---|---|---|
| Modified penman | 1 | | | | | | |
| Hargreaves | 0.957 | 1 | | | | | |
| Turc | 0.960 | 0.973 | 1 | | | | |
| Blaney criddle | 0.931 | 0.938 | 0.927 | 1 | | | |
| Christiansen | 0.921 | 0.850 | 0.850 | 0.941 | 1 | | |
| Open pan PET | 0.911 | 0.859 | 0.854 | 0.955 | 0.996 | 1 | |
| FAO penman method | 0.999 | 0.960 | 0.964 | 0.934 | 0.920 | 0.916 | 1 |

**Table 3 : Correlation co-efficient between PET values under different methods at Raipur**

| PET under different methods | Modified Penman | Hargreaves | Turc | Blaney criddle | Christiansen | Open pan PET | FAO penman method |
|---|---|---|---|---|---|---|---|
| Modified penman | 1 | | | | | | |
| Hargreaves | 0.986 | 1 | | | | | |
| Turc | 0.902 | 0.914 | 1 | | | | |
| Blaney criddle | 0.934 | 0.957 | 0.944 | 1 | | | |
| Christiansen | 0.991 | 0.969 | 0.848 | 0.907 | 1 | | |
| Open pan PET | 0.995 | 0.984 | 0.886 | 0.941 | 0.995 | 1 | |
| FAO penman method | 0.999 | 0.984 | 0.906 | 0.934 | 0.991 | 0.995 | 1 |

**$Y = 3.79 + 1.0471X$ ($R^2$=0.99)**

where, X=Open Pan values

It can be seen from the regression equation that the lowest $R^2$ value was in respect of Turc method (0.78) followed by Blaney Criddle method (0.88).In case of other methods the relationship with open pan evaporation is

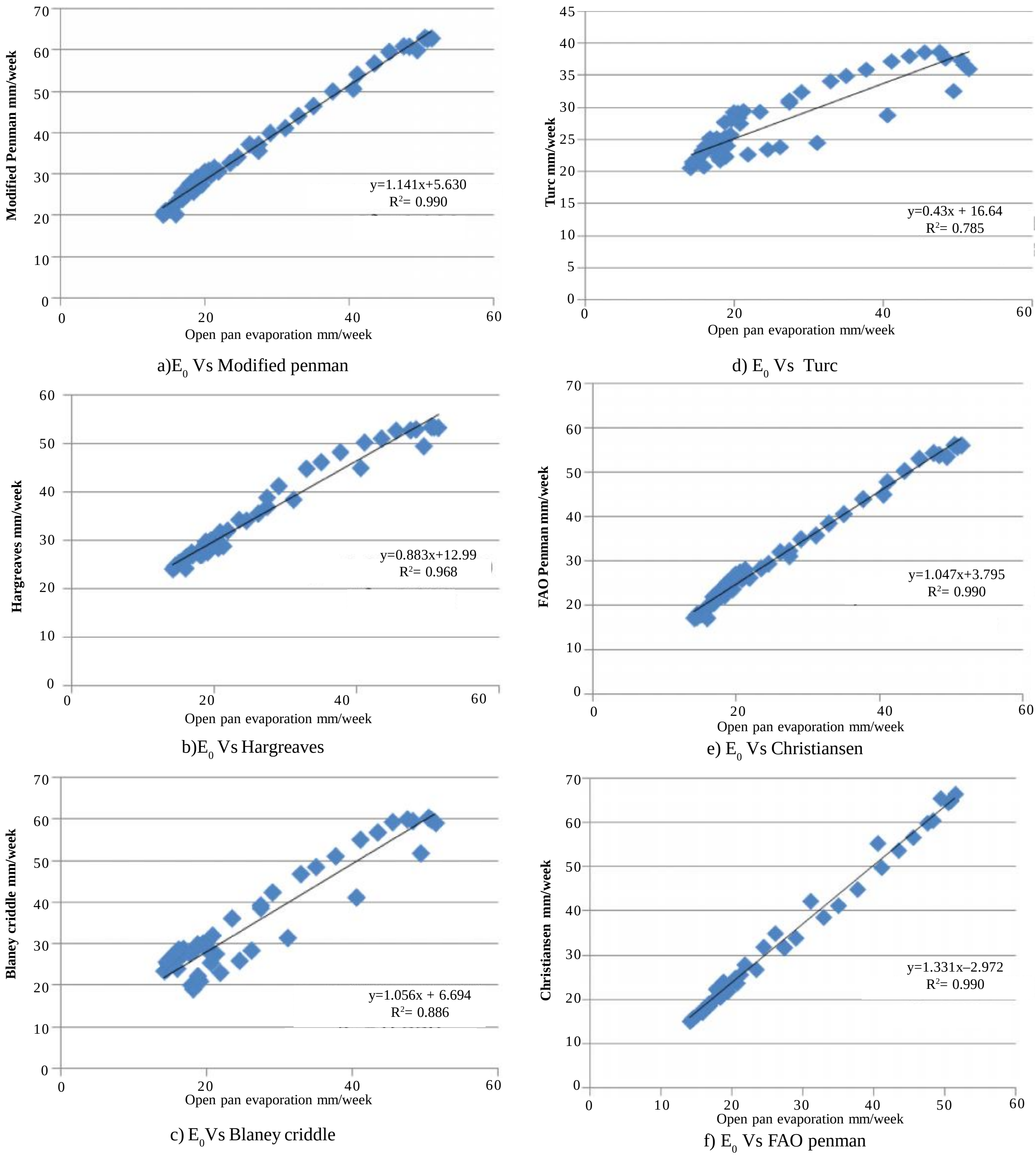



**Fig. 1 : Relation between open pan evaporation and PET values by different methods at Ambikapur station**

very high ($R^2$=0.99).

*Jagdalpur* :

The relation between open pan evaporation and PET computed by different methods are worked out and the graphic form is shown in Table 2 and Fig. 1 and 2. The regression equations for different methods of PET with open pan evaporation are shown below :

Open Pan and Modified Penman method

**Y= 8.80+1.1629X ($R^2$=0.83)**

Open Pan and Hargreaves method

**Y= 14.27 +1.0749X ($R^2$=0.73)**

Open Pan and Turc method

**Y= 14.26+0.5718X ($R^2$=0.73)**

Open Pan and Blaney Criddle method

**Y= 3.93+1.2345X ($R^2$=0.91)**

Open Pan and Christiansen method

**Y= 1.876 +1.257X ($R^2$=0.99)**

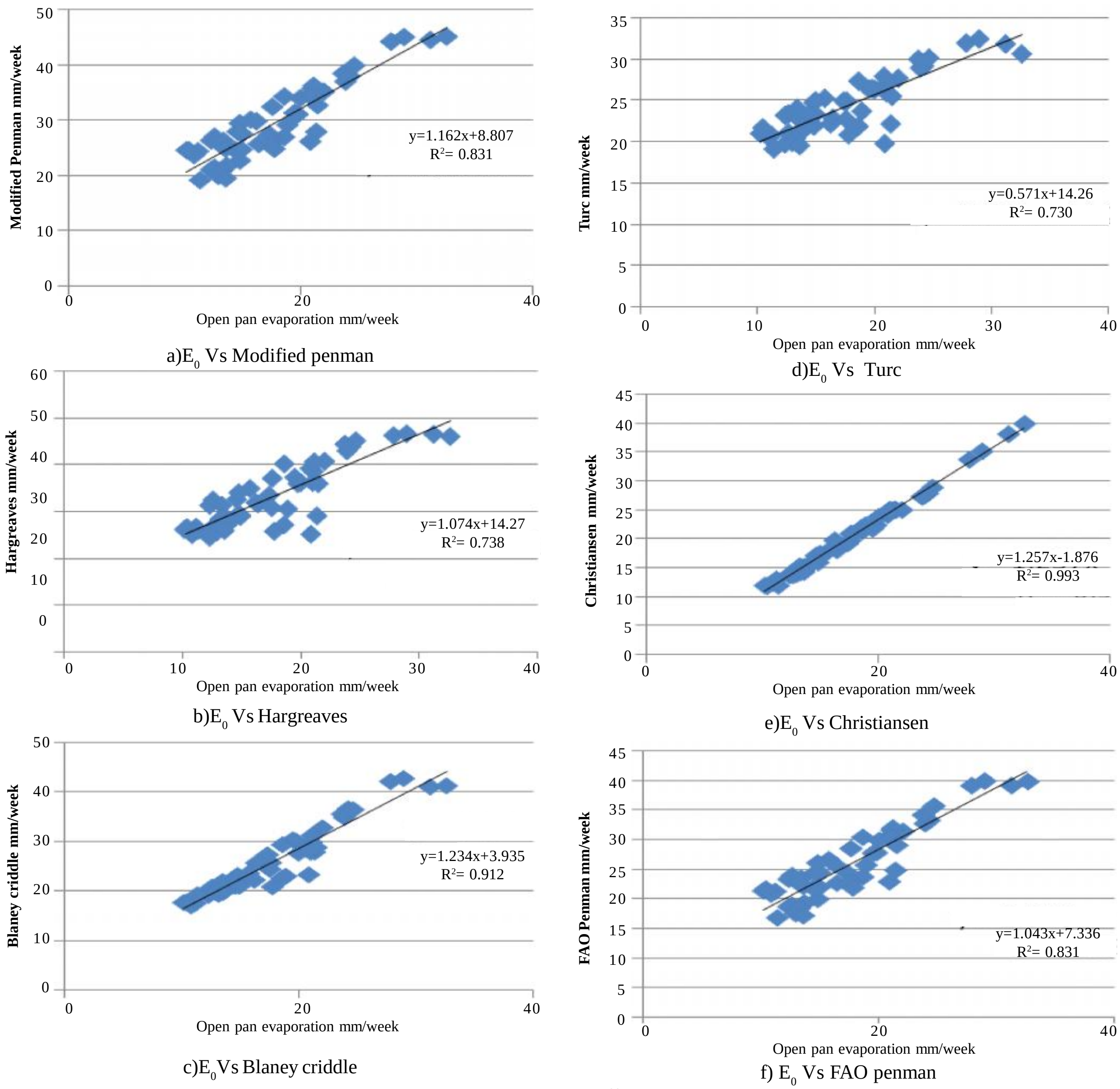



**Fig. 2 : Relation between open pan evaporation and PET values by different methods at Jagdalpur station**

Open Pan and FAO penman method

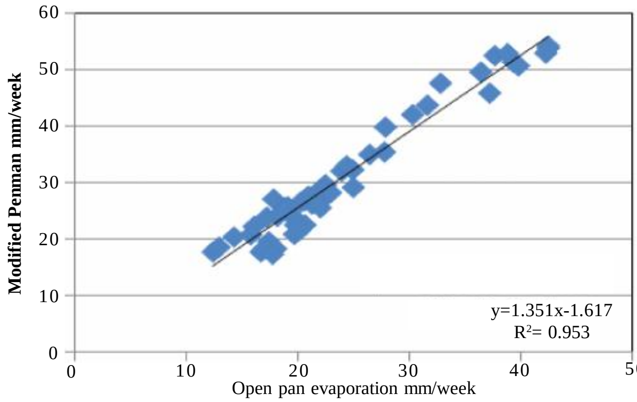
**Y= 7.33+1.043X ($R^2$=0.83)**

where, X=Open pan values

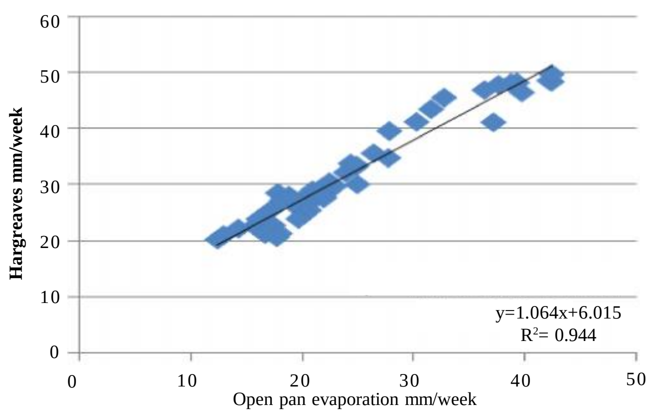
At Jagdalpur, the regression co-efficients are relatively lower in respect of all the methods. The lowest regression co-efficient was in respect of Hargreaves and Turc methods (0.73) while it is highest with Blaney Criddle method.

*Raipur* :

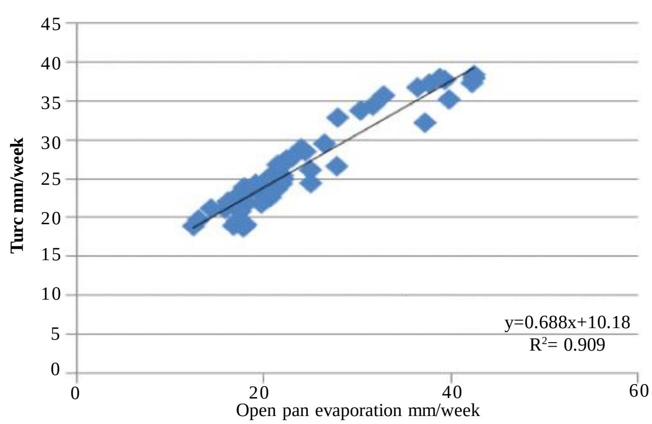
The relationship between open pan values and PET values by different methods shown in Table 3 and Fig. 3. In case of Raipur the relationship between open pan



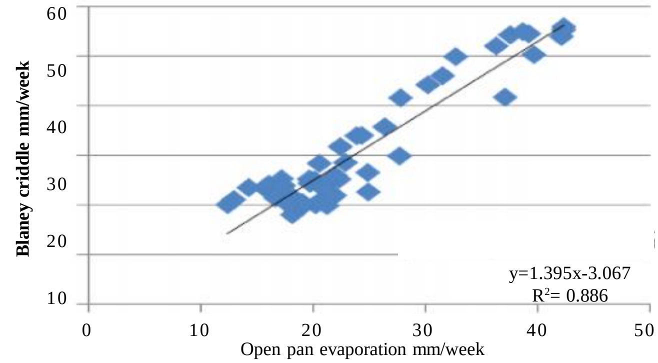

a) $E_0$ Vs Modified penman



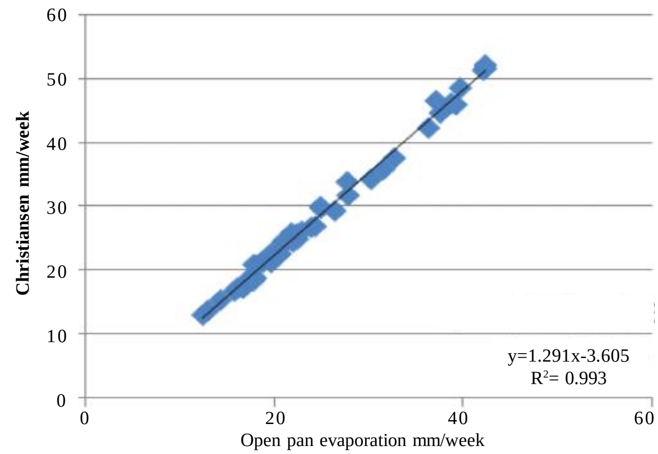

b) $E_0$ Vs Hargreaves



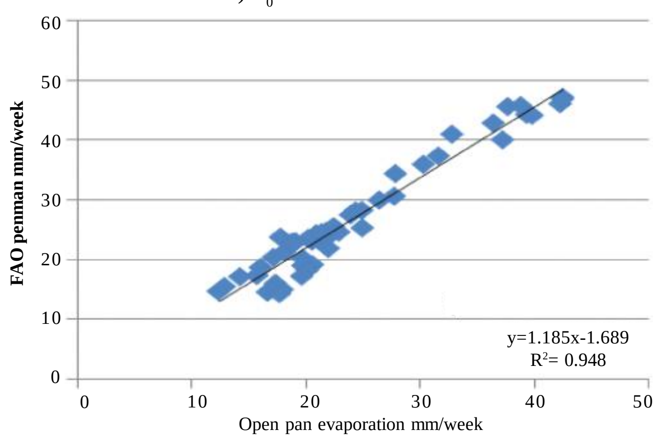

c) $E_0$Vs Turc




d) $E_0$ Vs Blaney criddle




e) $E_0$ Vs Christiansen




f) $E_0$ Vs FAO penman

**Fig. 3 : Relation between open pan evaporation and PET values by different methods at Raipur station**

evaporation and Christiansen method of estimation of PET is the highest with $R^2$ values of 0.99 followed by Modified Penman method of PET estimation. The relationship between open pan (E0) and FAO Penman and Hargreaves methods of estimation of PET are also higher with $R^2$ value of 0.94. The lowest relationship was found in respect of Turc method of estimation of PET.

Open Pan and Modified Penman method

$Y = -1.617+13516X \quad (R^2=0.95)$

Open Pan and Hargreaves method

$Y = 6.015 +1.0647X \quad (R^2=0.94)$

Open Pan and Turc method

$Y = 10.185+0.6888X \quad (R^2=0.90)$

Open Pan and Blaney Criddle method

$Y = -3.0674+1.3957X \quad (R^2=0.88)$

Open Pan and Christiansen method

$Y = 3.605 +1.2919X \quad (R^2=0.99)$

Open Pan and FAO penman method

$Y = -1.689+1.185X \quad (R^2=0.94)$

where, X=Open Pan values

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## REFERENCES

**Allen, R.G., Pruitt, W.O., Businger, J.A., Fritschen, L.J., Jensen, M.E. and Quinn, F.H. (1996).** In: Wootton et al. (Ed.), Evaporation and Transpiration. Chapter 4, ASCE Handbook of Hydrology. New York, NY. 125-252pp.

**Allen, R.G., Smith, M., Pruitt, W.O. and Pereira, L.S. (1996).** Modification to the FAO crop co-efficient approach. In: Camp, C.R., Sadler, E.J., Yoder, R.E.(Ed.), Evapotranspiration and Irrigation Scheduling. ASAE, San Antonio, TX, 124–132pp.

**De melo Giovani, L. and Andrel, T. Fernandes (2010).** Evaluation of empirical methods to estimate reference evapotranspiration in uberera, state of minas, Brazil. *J. Agric. Engg*., 875-885pp.

**Meshram, D.T., Gorantiwar, S.D., Mittal, S.D. and Purohit, R.C. (2010).** Comparison of reference crop evapotranspiration methods in western part of Maharashtra state. *J. Agrometeorology,* **12**(1):44-46.

**Rambabu, A. and Rao, B. Bapuji (1999).** Evaluation and calibration of some potential evapotranspiration estimating methods. A case study. *J. Agrometeorol.,* **1**(2):155-162.

**Rao., B. Bapuji, Sandeep, Y.M., Chawdhary, P. Shantibhushan, Pramod, V.P. and Rao, Y.U.M. (2013).** Reference crop evapotranspiration over India: A Comparison of estimates from open pan with Penman Monteith method. *J. Agrometeorol.,* **15**(2):108-114.

**Rasul, G. (1992).** Water requirement of wheat crop in Pakistan. *J. Engg. & App. Sci.,* **3**(1) : 65-79.

**Xu, C.Y. and Singh, V.P. (2002).** Cross comparison of empirical equations for Calculating potential evapotranspiration with data from Switzerland. *A Rev. Water Resources Mgmt.,* **16** (3) : 197-219.