International Journal of Fauna and Biological Studies
Available online at www.faunajournal.com

IJFBS International Journal of Fauna And Biological Studies

ISSN 2347-2677
IJFBS 2018; 5(3): 186-192
Received: 25-03-2018
Accepted: 26-04-2018

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

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Abstract
Evapotranspiration is very important in water resource management especially in agriculture. Often some farmers use open pan evaporation data for irrigation management under drip and sprinkler irrigation. However, open pan evaporation values are always over estimates because of advection factor. In view of this studies are carried out to find out potential evapotranspiration or reference crop evapotranspiration using empirical formulae. The values derived with this formulae were correlated with open pan evaporation and regression equations were developed. From the analysis it was found that the Christiansen method of estimation of PET values were highly correlated with open pan evaporation in all the three stations representing three agroclimatic zones of Chhattisgarh state. Blaney Criddle equation which considers crop coefficient was not well correlated with open pan evaporation. Hence it is concluded that the Christiansen method of estimation of potential evapotranspiration is best suited for Chhattisgarh state. Using the regression equation the PET values of Christiansen method could be estimated with the help of pan evaporation data.

Keywords: Evapotranspiration, open pan evaporation, irrigation management

Introduction
Evapotranspiration is a very important component of water management in agriculture in modern irrigation practices like drip and sprinkler irrigation values of evapotranspiration are very important for day to day water management. Usually the progressive farmer collect evaporation data from near way station and manage the irrigation in their field however Open pan evaporation values are higher than the field evaporation values as advection place contributing role the Open pan evaporation values per estimating the evaporation values. Several empirical methods have been developed and in many countries the different methods are used to estimate the evaporation rate several workers like Meshram *et al*. (2010) [2], Rambabu and Bapuji Rao (1999) [3], Bapuji Rao *et al*. (2013) [4]. In India compared the empirical methods to estimate evapotranspiration methods.

Bapuji Rao *et al*. (2013) [4] compared the estimation of potential evapotranspiration with Penman Monteith method with open pan values. Xu and Sing (2002) [5] in Switzerland compared the empirical equations for calculating PET and the cross compared the data. Similarly De mello Giovani L, Fernandes Andrel (2010) [1] evaluated the empirical methods to estimate reference evapotranspiration in Brazil.

However, in each study different methods of estimation of potential evapotranspiration match differently with open pan values. This may be due to the fact that the seasonal climate and weather factors play major role in determining the suitable method for estimating potential evapotranspiration.

In view of this attempts have been made in this paper to find out the sutitable method of estimation of potential evapotranspiration which is highly correlated with open pan values. For this purpose daily weather data for the period 1981 to 2012 were collected for three stations in Chhattisgarh state (Fig1) representing the three agroclimatic zones. The potential evapotranspiration (PET) was estimates using Penman, Christiansen, Blaney Criddle, Turc and FAO Penman Monteith method. The daily values thus estimated are compared with the daily values of open pan evaporation.

The daily evaporation data for the above mentioned period for the 3 stations namely Raipur, Ambikapur and Jagdalpur (fig 1-cg map) were collected from the agrometeorological observatory situated in the three stations.

Fig 1: Agrocliamtic zones of Chhattisgarh state

Materials and Methods

1. 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,

Δ = Slope of the saturated vapour pressure curve at temperature. T °C

γ = Psychrometric constant (0.49)

H = Energy balance term

= RA (1 - α) (0.18 + 0.55) n/N) - σTa^4 (0.55-0.092 √ed) (0.10+0.90 n/N)

where,

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

α= Albedo which is assumed as 0.25

n = Actual bright sunshine hours

N = Possible bright sunshine hours

σ= Stephen Bottzman constant = 0.817 x 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

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

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'

2. 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)] Kc X Ta X D/4465.6 X25.4 mm/day

Where,

Ta = mean air temperature in° F

Kc=Crop Coefficient

D=Day Length,

3. Turc method

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

PET=0.40 Tc (RI +50)/ (Tc+15) N

Where, PET=Potential evapotranspiration

Tc=Mean air temperature,(°C)

RI=Solar radiation (ly/day)

N=NO. Of Days in month

4. 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=Percent of possible sunshine

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

5. 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})

Coefficients are dimensionless

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

Where T=mean temperature in℃ and To=20℃

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=6.7km/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

6. FAO Penman Monteith equation

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

LE= [{Δ/γ (Rn-G)} + {ρ_aCp (es-ea)/γ r_a}]/ (Δ/γ +1+rc/ra)

Where,

ρ_a=density of air (1.3 kg/m^3)

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/uk^2,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)

7. 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, Jagdalpur and Ambikapur were used.

Result and Discussion

The relationship between the estimates of PET between different methods is worked out through correlation coefficients which are shown in Table 1. It can be seen that the PET values computed by different methods are very highly correlated with each other. The correlation coefficient 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 was lower than other methods while at Jagdalpur the correlation coefficients among different methods of estimation of PET are relatively less as compared to Ambikapur. The lowest correlation coefficient was between the Christiansen and Hargreaves methods and also between Christiansen and Turc methods.

The highest correlation coefficient was found with Open pan and Christiansen method of estimation of PET. Also the correlation coefficients between Penman Monteith and Modified Penman method are very high (C=0.999).

At Raipur also there is a strong relationship between the different methods of estimation of PET. The lowest correlation coefficient was between Christiansen and Turc methods while FAO Penman Monteith method and Modified Penman methods were very highly correlated with a correlation coefficient of 0.999

Table 1: Correlation Coefficient between PET values under different methods at Ambikapur

PET under different methods	Modified Penman	Hargreaves	Turc	Blaney Criddle	christiansen	open pan	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	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 Coefficient 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	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 Coefficient 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

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

For estimation of PET using open pan evaporation data linear regression equations were worked out between open pan and different methods of estimation of PET at different stations.

The results are as follows-

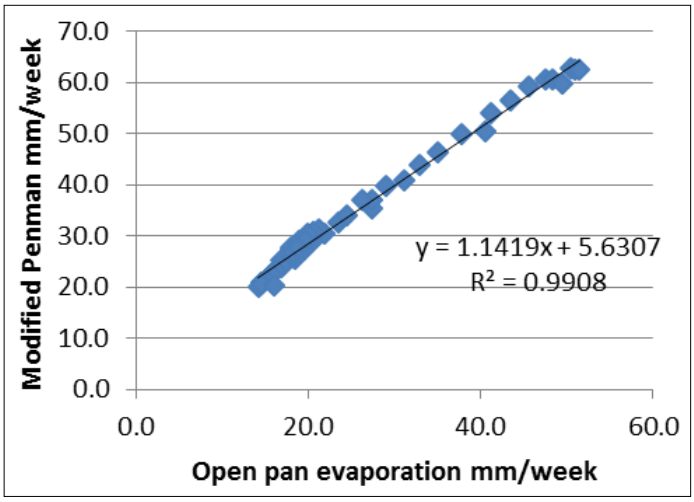
a) Ambikapur

The relationship between open pan evaporation and PET values by different methods are shown in fig.2.It can be seen from the figure that regression coefficients for all methods of PET estimation with open pan evaporation values were very high except Turc and Blaney Criddle methods. The regression equations for Ambikapur station are as follows:

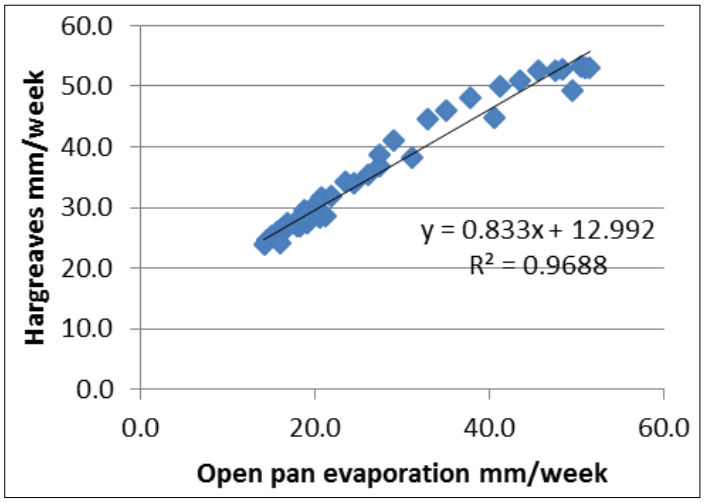
1. Open Pan and Modified Penman method
   $Y= 5.6+1.149X$ ($R^2=0.99$)
2. Open Pan and Hargreaves method
   $Y= 12.9 +0.833X$ ($R^2=0.96$)
3. Open Pan and Turc method
   $Y= 16.64+0.43X$ ($R^2=0.78$)
4. Open Pan and Blaney Criddle method
   $Y= 6.69+1.0568X$ ($R^2=0.88$)
5. Open Pan and Christiansen method
   $Y= 2.97 +1.331X$ ($R^2=0.99$)
6. Open Pan and FAO penman method
   $Y= 3.79+1.0471X$ ($R^2=0.99$)

Where X=Open Pan values

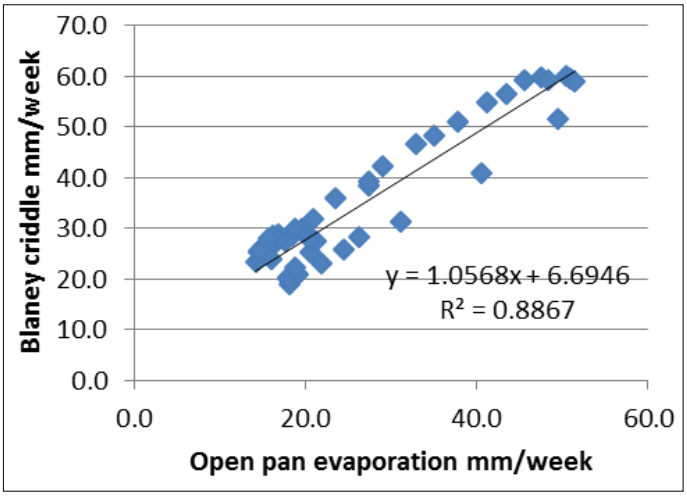
It can be seen from the regression equations that the lowest R^2 value was in respect of Turc method (0.78) followed by Blaney Criddle method (0.88).In case of other methods the relationship with open pan evaporation is very high.



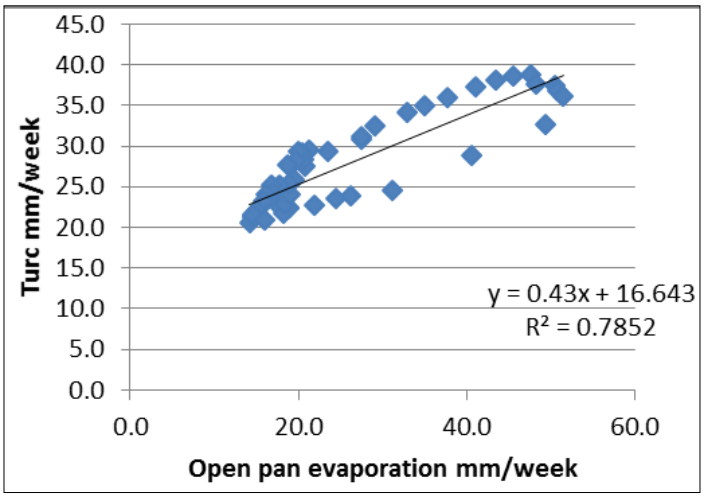
a) E_0 Vs Modified penman



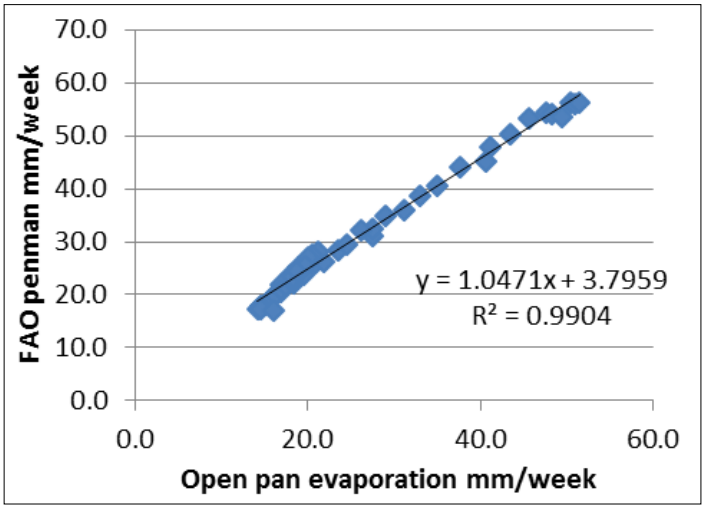
b) E_0 Vs Hargreaves



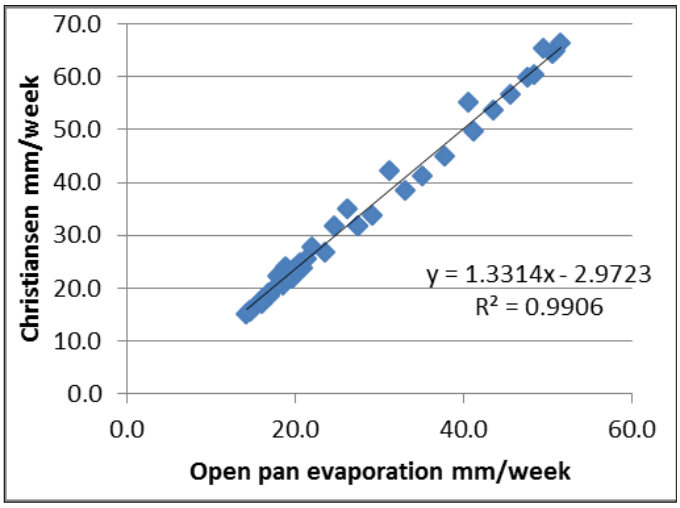
c) EoVs Blaney criddle



d) EoVs Turc



e) Eo Vs Christiansen



f) Eo Vs FAO penman

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

b) Jagdalpur

The relation between open pan evaporation and PET computed by different methods are worked out and presented in graphic form is shown in fig.3. The regression equations for different methods of PET with open pan evaporation for jagdalpur are shown below:

1. Open Pan and Modified Penman method
   Y= 8.80+1.1629X (R^2=0.83)
2. Open Pan and Hargreaves method
   Y= 14.27 +1.0749X (R^2=0.73)
3. Open Pan and Turc method
   Y= 14.26+0.5718X (R^2=0.73)
4. Open Pan and Blaney Criddle method
   Y= 3.93+1.2345X (R^2=0.91)
5. Open Pan and Christiansen method

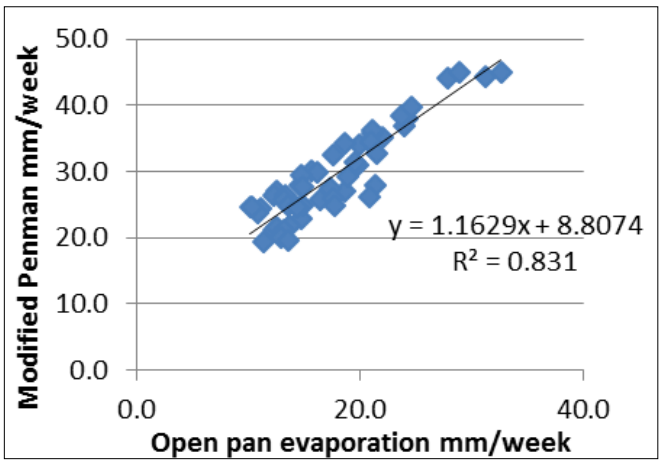
Y= 1.876 +1.257X (R^2=0.99)

6. Open Pan and FAO penman method

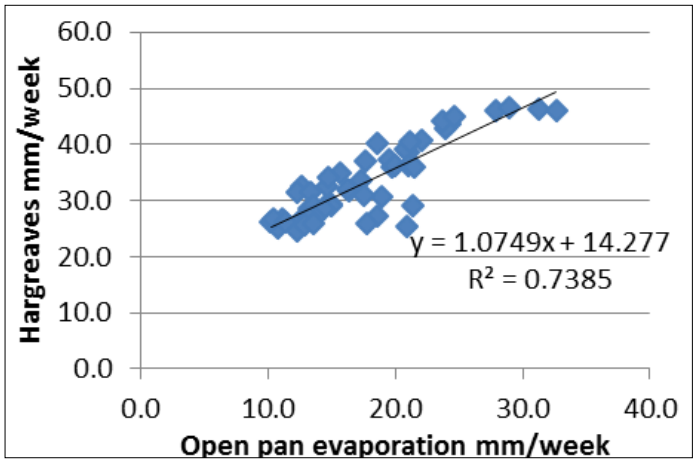
Y= 7.33+1.043X (R^2=0.83)

Where X=Open Pan values

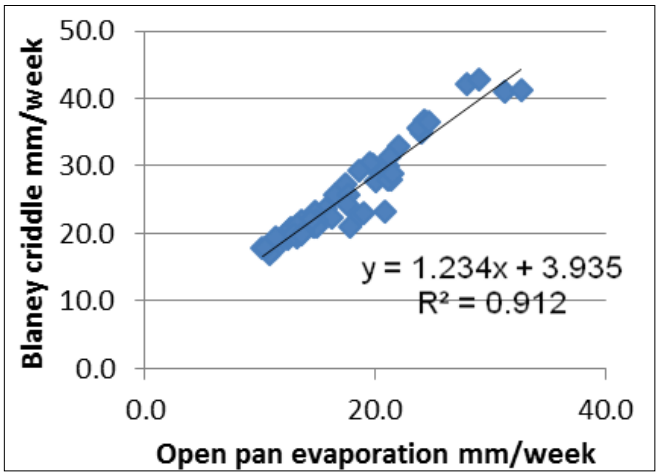
At Jagdalpur, the regression coefficients were relatively lower in respect of all the methods. The lowest regression coefficient was in respect of Hargreaves and Turc methods (0.73) while it was highest with Blaney Criddle method.



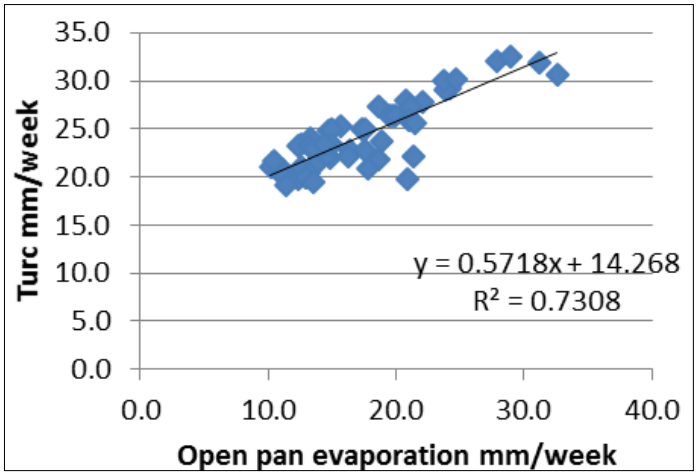
a) Eo Vs Modified penman



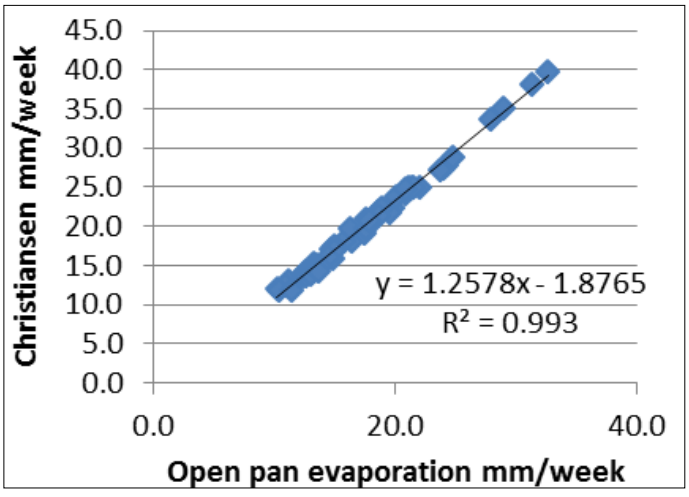
b) Eo Vs Hargreaves



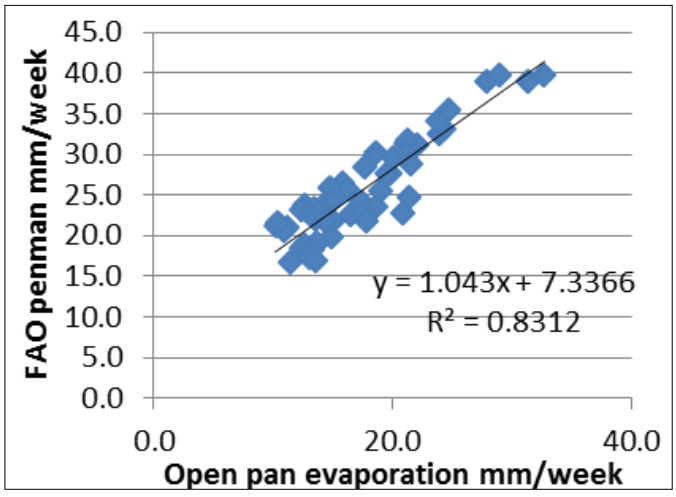
c) Eo Vs Blaney Criddle



d) Eo Vs Turc



e) Eo Vs Christiansen



f) Eo Vs FAO penman

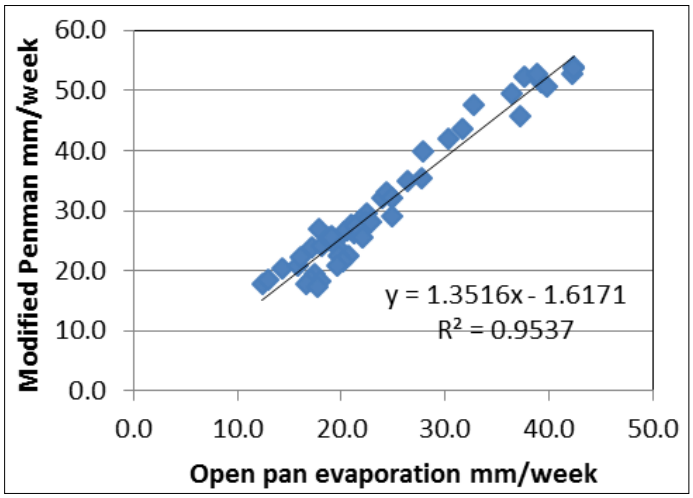
Fig 3: Relation between open pan evaporation and PET values by different methods at Jagdalpur station

c) Raipur

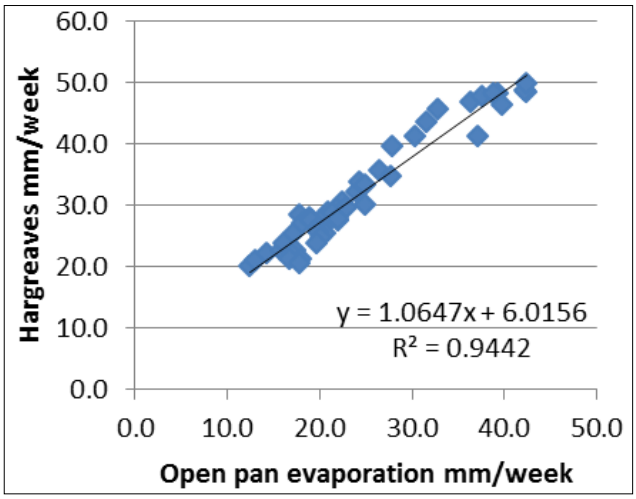
The relationship between open pan values and PET values by different methods are shown in fig 4. In case of Raipur the relationship between open pan evaporation and Christiansen method of estimation of PET was the highest with R^2 values of 0.99 followed by Modified Penman method of PET estimation. The relationship between open pan (E_0) and FAO Penman and Hargreaves methods of estimation of PET was also higher with R^2 value of 0.94.The lowest relationship was found in respect of Turc method.

1. Open Pan and Modified Penman method
   Y= -1.617+13516X (R^2=0.95)
2. Open Pan and Hargreaves method
   Y= 6.015 +1.0647X (R^2=0.94)
3. Open Pan and Turc method
   Y= 10.185+0.6888X (R^2=0.90)
4. Open Pan and Blaney Criddle method
   Y= -3.0674+1.3957X (R^2=0.88)
5. Open Pan and Christiansen method
   Y= 3.605 +1.2919X (R^2=0.99)
6. Open Pan and FAO penman method
   Y= -1.689+1.185X (R^2=0.94)

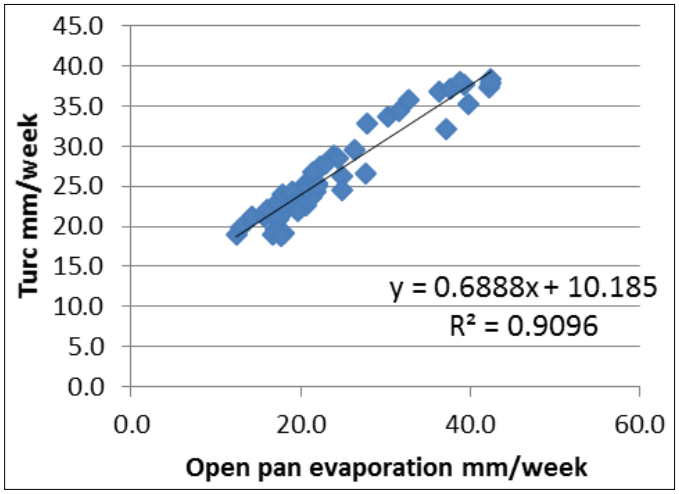
Where X=Open Pan values



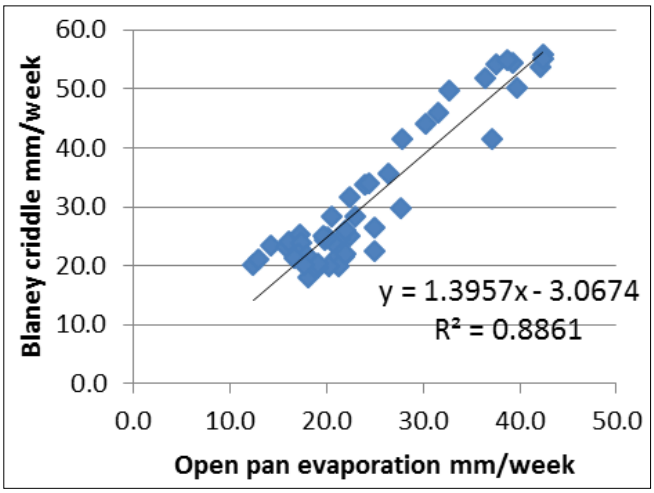
a) Eo Vs Modified Penman



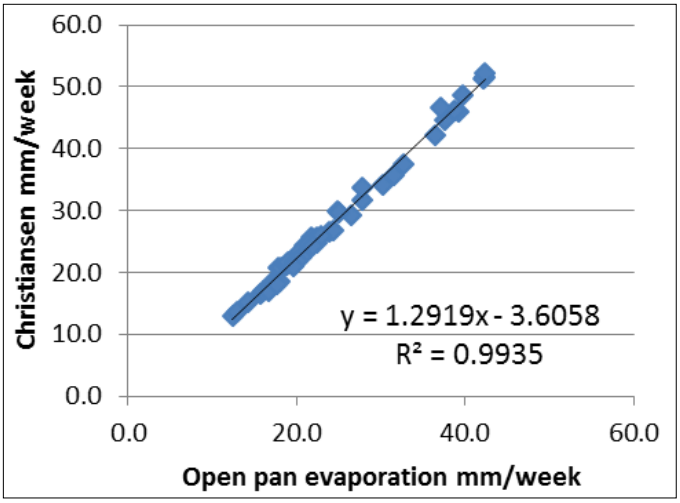
b) Eo Vs Hargreaves



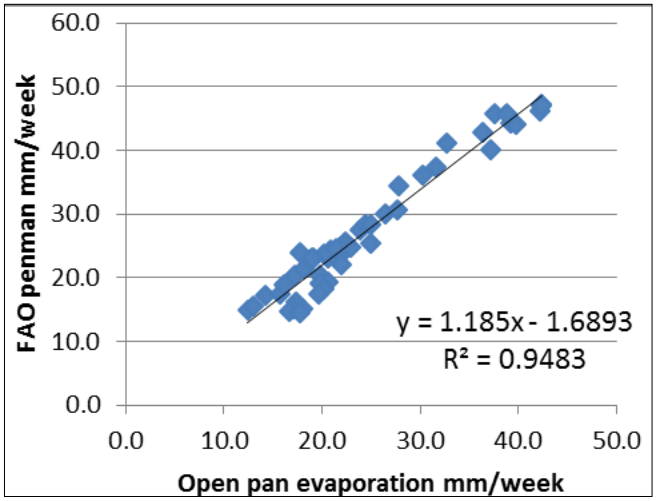
c) EoVs Turc



d) Eo Vs Blaney Criddle



d) Eo Vs Christiansene)



e) Eo Vs FAO penman

Fig 4: Relation between open pan evaporation and PET values by different methods at Raipur station

Conclusion

From the above analysis it was found that the Christiansen method is very highly correlated with open pan values at all the 3 stations (R^2=0.99).This is followed by FAO Penman Monteith method with R^2values of 0.94 at Raipur, Blaney Criddle method with R^2values of 0.99 at jagdalpur and in Modified penman method with R^2values of 0.99 at Ambikapur. Thus, it is confirmed that there are regional differences in estimation of potential evapotranspiration using different methods. The Christiansen method which considers open pan values along with temperature, wind speed, humidity and possible hours of sunshine looks a better estimate of PET in three agroclimatic regions of Chhattisgarh. However, Blaney Criddle method in which the crop coefficient is also considered was found relatively less correlated with open pan evaporation. Hence it is concluded that Christiansen method would be an appropriate method to estimate potential evapotranspiration in Chhattisgarh state.

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