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:

\[
\text{PET} = \frac{H + \gamma E_a}{\Delta + \gamma}
\]

where,
- \(\Delta\) = Slope of the saturated vapour pressure curve at temperature. T °C
- \(\gamma\) = Psychrometric constant (0.49)
- \(H\) = Energy balance term

\[
= RA (1 - \alpha) (0.18 + 0.55) n/N - \sigma T a^4 \text{mm/day/}^\circ \text{K}
\]

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/cm²/mm/°K⁰⁴) later converted to 20.284 mm/day/°K
- \(T a\) = Mean air temperature
- \(ed\) = Actual vapour pressure.

\[
ed = \frac{RH \text{mean} \times e_a}{100}
\]

\[
E_a = \text{Aerodynamic term}
\]

\[
= 0.35 (e_a - e_d) (1 + 0.0098 U^2)
\]

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:

\[
U_h \log h_1 = U_h \log h_2
\]

Therefore, \(U_h = (U_h \log h_1) / \log h_2\)

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:

\[
\text{UPET} = 1.695 \left(\frac{10^T}{I^a} \right)
\]

where,
- \(UPET\) = Unadjusted potential evapotranspiration
- \(T\) = Mean monthly temperature in °C
- \(I\) = Annual heat index
- \(i\) = Monthly heat index
- \(a\) = 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:

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

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:

\[
\text{PET} = \left(0.0173 Ta - 0.314\right) \frac{Kc \times Ta \times D}{4465.6 \times 25.4} \text{mm/day}
\]

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:

\[
\text{PET} = 0.40 Tc \left( \frac{RI + 50}{Tc + 15N} \right)
\]

where,
- PET = Potential evapotranspiration
- \(Tc\) = Mean air temperature, (°C)
- \(RI\) = Solar radiation (ly/day)
- \(N\) = Number of days in month.

Hargreaves method:
\[
\text{PET} = 0.0135(t + 17.78) \times \text{Rs.}
\]

- PET = Reference crop potential consumptive use,
- \(t\) = average daily temperature (°C)
- \(\text{Rs.}\) = Incident solar radiation (ly/day)
- \(\text{Rs.}=0.10 \text{Rs.}_0 (S)^{0.5}\)
- \(S\) = Per cent of possible sunshine
- \(\text{Rs.}_0\) = Clear day solar radiation in ly day\(^{-1}\).

Christiansen method:
Christiansen equation for estimation of E\(To\) is presented in a following way:

\[
\text{E}To = 0.755 \times \text{Epan} \times \text{Ct} \times \text{Cu} \times \text{Ch} \times \text{Cs}
\]

where,
- E\(To\) = Reference crop evapotranspiration (mm day\(^{-1}\))
- E\(\text{pan}\) = measured evaporation from class a pan (mm day\(^{-1}\))
- Co-efficients are dimensionless:
  - \(\text{Ct}=0.862+0.179(T/To)-0.041(T/To)^2\)
  - \(\text{Cu}=1.189-0.240(U/Uo)+0.051(U/Uo)^2\)
  - \(\text{Ch}=0.499+0.620(H/Ho)-0.119(H/Ho)^2\)
  - \(\text{Cs}=0.904+0.008(S/So)+0.088(S/So)^2\)

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

\[
LE = \left[ \Delta\gamma \left( Rn-G \right) + \left( \rho_a^2 C_p \left( es-ea \right) / \gamma r_a \right) \right] \Delta\gamma / \left( \Delta\gamma + 1 + rc/ra \right)
\]

where,
- \(\rho_a\) = density of air (1.3 kg/m\(^3\))
- \(C_p\) = 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
- \(rs = [(\text{rad} \times \text{rab})/(\text{rad} + \text{rab})]/\text{LAI}\)
- \(\text{rad}\) = adaxial resistance
- \(\text{LAI}\) = leaf area index
- \(\text{S}\) = percentage of possible sunshine expressed decimally and \(So=0.8\).

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 Observatary 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**

<table>
<thead>
<tr>
<th>PET under different methods</th>
<th>Modified Penman</th>
<th>Hargreaves</th>
<th>Turc</th>
<th>Blaney Criddle</th>
<th>Christiansen</th>
<th>Open pan PET</th>
<th>FAO penman method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified penman</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hargreaves</td>
<td>0.996</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turc</td>
<td>0.984</td>
<td>0.986</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blaney Criddle</td>
<td>0.952</td>
<td>0.949</td>
<td>0.951</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christiansen</td>
<td>0.973</td>
<td>0.966</td>
<td>0.943</td>
<td>0.918</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open pan PET</td>
<td>0.976</td>
<td>0.916</td>
<td>0.953</td>
<td>0.941</td>
<td>0.996</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FAO penman method</td>
<td>0.998</td>
<td>0.995</td>
<td>0.984</td>
<td>0.938</td>
<td>0.973</td>
<td>0.973</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>PET under different methods</th>
<th>Modified penman</th>
<th>Hargreaves</th>
<th>Turc</th>
<th>Blaney Criddle</th>
<th>Christiansen</th>
<th>Open pan PET</th>
<th>FAO penman method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified penman</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hargreaves</td>
<td>0.957</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turc</td>
<td>0.960</td>
<td>0.973</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blaney Criddle</td>
<td>0.931</td>
<td>0.938</td>
<td>0.927</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christiansen</td>
<td>0.921</td>
<td>0.850</td>
<td>0.850</td>
<td>0.941</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open pan PET</td>
<td>0.911</td>
<td>0.859</td>
<td>0.854</td>
<td>0.955</td>
<td>0.996</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FAO penman method</td>
<td>0.999</td>
<td>0.960</td>
<td>0.964</td>
<td>0.934</td>
<td>0.920</td>
<td>0.916</td>
<td>1</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>PET under different methods</th>
<th>Modified Penman</th>
<th>Hargreaves</th>
<th>Turc</th>
<th>Blaney Criddle</th>
<th>Christiansen</th>
<th>Open pan PET</th>
<th>FAO penman method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified penman</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hargreaves</td>
<td>0.986</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turc</td>
<td>0.902</td>
<td>0.914</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blaney Criddle</td>
<td>0.934</td>
<td>0.957</td>
<td>0.944</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Christiansen</td>
<td>0.991</td>
<td>0.969</td>
<td>0.848</td>
<td>0.907</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open pan PET</td>
<td>0.995</td>
<td>0.984</td>
<td>0.886</td>
<td>0.941</td>
<td>0.995</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FAO penman method</td>
<td>0.999</td>
<td>0.984</td>
<td>0.906</td>
<td>0.934</td>
<td>0.991</td>
<td>0.995</td>
<td>1</td>
</tr>
</tbody>
</table>
Y = \text{3.79} + \text{1.047}X \quad (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**
  
  \[ Y = 1.162x + 8.807 \quad (R^2=0.83) \]

- **Open Pan and Hargreaves method**
  
  \[ Y = 1.074x + 14.27 \quad (R^2=0.73) \]

- **Open Pan and Turc method**
  
  \[ Y = 0.571x + 14.26 \quad (R^2=0.73) \]

- **Open Pan and Blaney Criddle method**
  
  \[ Y = 1.234x + 3.935 \quad (R^2=0.91) \]

- **Open Pan and Christiansen method**
  
  \[ Y = 1.257x - 1.876 \quad (R^2=0.99) \]

**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 coefficients are relatively lower in respect of all the methods. The lowest regression coefficient 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

\[ a) \quad E_0 \ Vs \ Modified \ penman \]
\[ y = 1.351x - 1.617 \quad R^2 = 0.953 \]

\[ b) \quad E_0 \ Vs \ Hargreaves \]
\[ y = 1.064x + 6.015 \quad R^2 = 0.944 \]

\[ c) \quad E_0 \ Vs \ Turc \]
\[ y = 0.688x + 10.18 \quad R^2 = 0.909 \]

\[ d) \quad E_0 \ Vs \ Blaney \ criddle \]
\[ y = 1.395x - 3.067 \quad R^2 = 0.886 \]

\[ e) \quad E_0 \ Vs \ Christiansen \]
\[ y = 1.291x - 3.605 \quad R^2 = 0.993 \]

\[ f) \quad E_0 \ Vs \ FAO \ penman \]
\[ y = 1.185x - 1.689 \quad R^2 = 0.948 \]

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

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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 ($E_0$) 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

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

Open Pan and Hargreaves method

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

Open Pan and Turc method

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

Open Pan and Blaney Criddle method

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

Open Pan and Christiansen method

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

Open Pan and FAO penman method

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

where, $X$=Open Pan values

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REFERENCES


