Comparison of the Monthly Values of Potential Evapotranspiration Estimated through Different Methods

Usha Durgam[1], Dr. A. S. R. A. S Sastri[2]

[1]Present and Corresponding Address: O/o Deputy Director, Department of Agriculture, Darapara, Bijapur, 494444, Chhattisgarh, India

[2]Indira Gandhi Agricultural University, Raipur, 492 012, Chhattisgarh, India

Abstract: ***From the period of 1981-2012 the present daily weather data of 32 yrs have been used for the analysis of PET of monthly and annual basis. Average monthly values of PET computed by different methods in Ambikapur station shows that the Thornthwaite PET values are overestimated during summer and monsoon months and underestimated during winter months. The annual PET values computed by all methods are higher at Raipur and lower at Jagdalpur. The entire PET computed by different methods is overestimated as comparison to Pan evaporation data. Modified penman values are higher at Raipur while Hergreaves method PET values are highest at Jagdalpur and Ambikapur. In seasonal PET based on monthly PET values, the total PET during Kharif and rabi seasons were examined at different stations. The total values of PET during kharif season by different methods varied from 515 mm to 877 mm at Raipur while the varied from 598 to 747 at ambikapur and the same values computed by different methods varied from 384 to 709 at jagdalpur.***

Keywords: Thornthwaite, monthly data, PET, Seasonal and annual PET

1. Introduction

Potential Evapotranspiration (PET) is the amount of water that would be evaporated and transpired from an extended area completely covered with vegetation and there is sufficient water is 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. PET is also higher on windy days because the evaporated moisture can be quickly moved from the ground or plant surface, allowing more evaporation to fill its place.

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 climate station on a reference surface, conventionally short grass. 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

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 waterings 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 Instructional Farm, Indira Gandhi Agricultural University, Raipur 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 Raipur station, the historical weather data was collected from Department of Agrometeorology, Indira Gandhi Agricultural University, Raipur.

2. Materials and Methods

2.1 Different equations used in the study:

2.2.1 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:

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

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

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

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

Where,
e_a = saturated vapour pressure
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'

2.2.2 Thornthwaite method

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

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

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

where
UPET = Unadjusted potential evapotranspiration
T = Mean monthly temperature in ˚C
I = Annual heat index
i = monthly heat index
$i=(T/5)^{1.514}$
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.

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

2.2.3 Blaney-Criddle method

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

2.2.4 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

2.2..5 Hargreaves method

PET=0.0135(t+17.78) Rs
PET= Reference crop potential consumptive use,
t=average daily temperature
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}

2.2.6 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 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= 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

2.2.7 FAO Penman Monteith equation

Monteith (1963 and 1964) introduced resistant terms into penman method:
$LE= [\{\Delta/\gamma (Rn-G)\} + \{\rho_a Cp (es-ea)/\gamma r_a\}]/ (\Delta/\gamma +1+rc/ra)$
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
Where,
Z=height
d=Zero plane displacement = 0.63 z
Zo = Roughness parameter = 0.13 z
$r_a = [\ln\{(z-d)/zo\}]^2/uk^2$, aerodynamic resistance
U=Wind speed at height, z
K=Von Karman's constant (.41)

3. Results and Discussion

The monthly values of PET computed by different methods including open pan evaporation are shown in Table: 1.1.It can be seen from the Table: 1.1.that the monthly values in general are less in winter months and high during summer months. It can be seen from the Table: 1.1. That Thornthwaite method estimated lowest values in January (23mm) and December months (25 mm).On the contrary the PET values were over estimated during summer month. This is true in case of all the methods. In fact all the methods over estimated PET values as compared to open pan evaporation in summer months. In general the PET values varied from 132 to 184 mm in different months.

Table 1.1: Average monthly values of PET computed by different equations at Ambikapur (mm)

Month	Modified Penman	Hargreaves	Turc	Thornthwaite	Blaney Criddle	Christiansen	Open Pan PET	FAO Penman method
Jan	86	96	90	23	97	65	62	73
Feb	107	111	101	43	113	88	80	92
Mar	163	164	137	96	167	132	118	140
Apr	207	198	156	195	218	172	149	179
May	237	215	168	279	242	218	180	207
Jun	184	173	132	237	163	182	148	161
Jul	125	130	108	151	95	112	95	110
Aug	114	124	105	139	86	99	87	102
Sep	114	122	109	129	92	99	87	103
Oct	117	127	114	91	114	106	95	102
Nov	93	107	96	49	106	90	84	78
Dec	80	95	85	25	95	77	75	66
Total	**1627**	**1662**	**1401**	**1457**	**1588**	**1440**	**1260**	**1413**

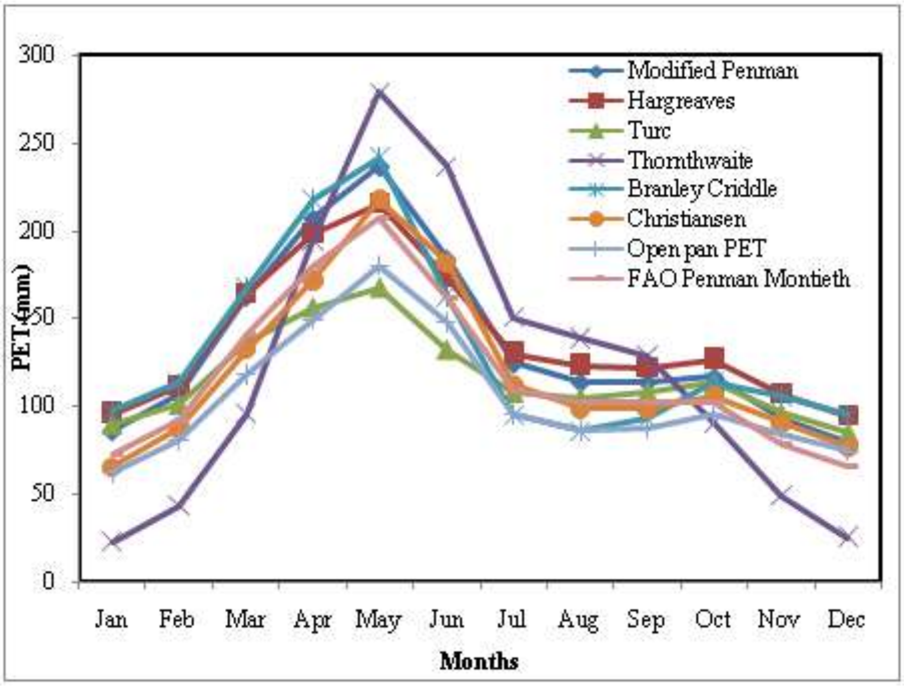

Figure 1.2: Average monthly values of PET computed by different methods at Ambikapur Station

The marches of the monthly values of PET during different months computed by different methods are shown in fig: 1.2. It is clear from the figure that Thornthwaite PET values are over estimates during summer and monsoon months and under estimated during winter months. Among the other methods, the Turc method of estimation of PET value during crop season that is July to October match with the Open Pan values. Blaney Criddle method, which is based on crop coefficient values are also, underestimated the PET values during crop season. i.e. July to October.

3.1 Raipur

The PET values in all the months by different methods are higher at Raipur as compared to Ambikapur. The highest value occurred in the month of May in all the months. The PET values in all methods are higher than the open pan evaporation value. However in the month of May Hargreaves methods of estimation of PET values are nearer to open pan evaporation values.

Table 2.2: Average monthly values of PET computed by different equations(mm) at Raipur

Month	Modified Penman	Hargreaves	Turc	Thornthwaite	Blaney Criddle	Christiansen	Open pan PET	FAO Penman Method
Jan	98	113	99	42	112	75	69	85
Feb	120	128	111	68	131	98	87	105
Mar	182	186	146	133	191	159	136	160
Apr	235	216	161	244	237	220	180	210
May	274	235	166	351	264	279	220	246
Jun	213	185	122	278	169	230	170	189
Jul	136	139	101	173	101	120	94	116
Aug	121	122	100	154	88	99	80	104
Sep	128	122	115	154	101	102	85	113
Oct	132	130	127	118	129	102	86	117
Nov	105	117	106	67	121	80	71	91
Dec	92	110	95	41	112	70	65	78
Total	1836	1803	1449	1823	1756	1634	1343	1614

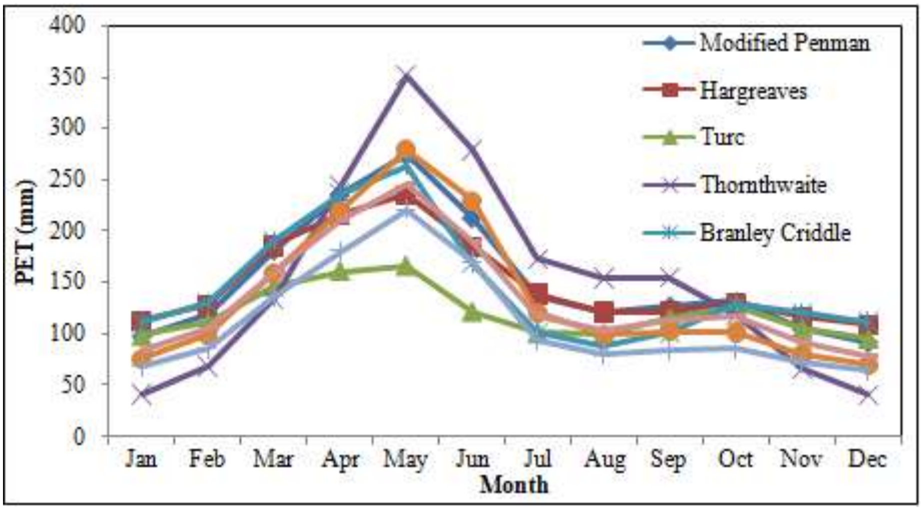

Figure 2.3: Average monthly values of PET computed by different methods at Raipur Station

The monthly march of PET values computed by different methods at Raipur are shown in Table 2.2.As was observed at Ambikapur the estimates of Thornthwaites PET at Raipur are also over estimated during summer and monsoon periods and under estimated during the winter months. It can also be seen from the Table 2.2 that Turc method of PET values were the lowest in the months of April to July which is the highest period at Raipur. In Turc method PET estimates are based on at temperature and solar radiation. Inspite of this the PET estimates were found to be lowest during summer months. However it matched with open pan evaporation during Kharif (June- October) and Rabi seasons (November –March).

3.2 Jagdalpur

The monthly values of PET computed by different methods for Jagdalpur station are shown in Table 2.4.Unlike at Ambikapur and Raipur the PET values are higher during winter months but in summer months, especially in the month of May, the PET values are lower than at Ambikapur and Raipur. This is because of the fact during the month of May thunderstorm activities are more at Jagdalpur and because of which the temperature becomes lower and humidity becomes higher and hence the PET values are lower at Jagdalpur. At Jagdalpur it can be seen from the Table 2.4 that the Christiansen PET values are closer to open pan values.

Table 2.4: Average monthly values of PET computed by different equations (mm) at Jagdalpur

Month	Modified Penman	Hargreaves	Turc	Thornthwaite	Blaney Criddle	Christiansen	Open pan PET	FAO Penman Method
Jan	103	125	95	61	102	76	69	91
Feb	116	133	99	86	110	85	75	103
Mar	154	176	122	127	140	113	98	136
Apr	169	183	128	165	152	125	105	149
May	178	192	132	189	158	141	118	157
Jun	135	152	104	136	106	88	74	118
Jul	125	142	102	119	95	70	60	109
Aug	123	140	104	115	94	69	61	108
Sep	123	139	107	117	97	77	67	108
Oct	117	136	105	94	101	80	71	103

Nov	101	120	92	67	93	72	65	88
Dec	94	116	88	53	92	69	63	82
Total	1538	1754	1278	1329	1340	1065	926	1352

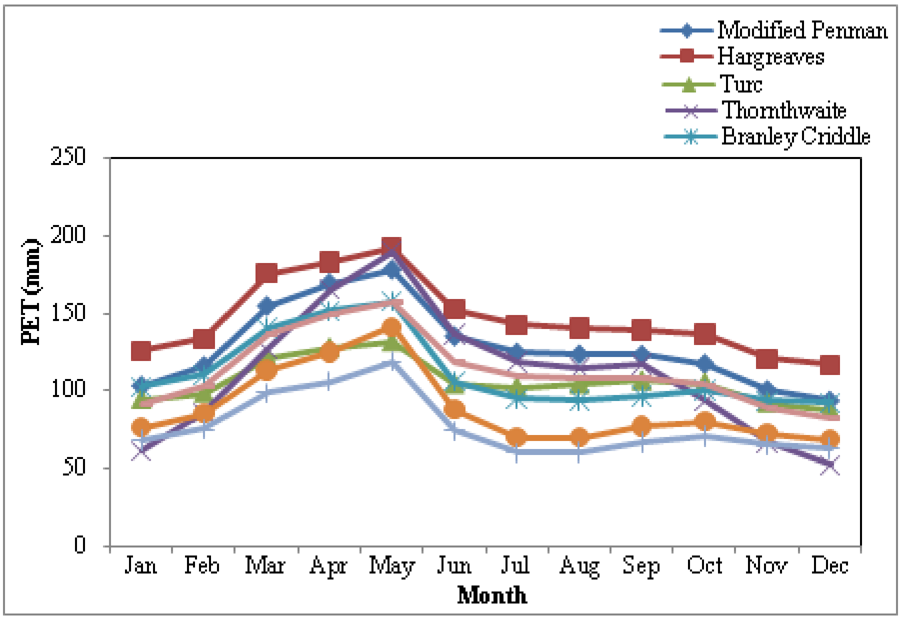

Figure 2.5: Average monthly values of PET computed by different methods at Jagdalpur Station

The march of the monthly values of PET at Jagdalpur during different months is shown in fig 2.5.It can be clearly seen from the figure that the PET values computed by different methods are not matching with each other in all the 12 months. At Raipur and Ambikapur the PET values matched with each other during winter and monsoon months. At Jagdalpur Hargreaves method of PET values are always higher than any of the methods followed by Thornthwaite. During summer months interestingly the Modified Penman method of PET values are also higher and were higher than the Open pan values in all the month except thornthwaite method in December and January. Thus, the evapotranspiration pattern at Jagdalpur is different as it is thickly forested area and hence is different as compared to other stations.

4. Annual PET

The annual PET values computed by different methods for the three stations are shown in Table 3.1.It can be seen from the Table: 3.1. That the annual PET computed by all the methods is higher at Raipur and lower at Jagdalpur except in Hargreaves method. All the values of PET computed by different methods are overestimated as compared to Pan Evaporation data. It seems from the Table 3.1 that Turc method closely follows open pan evaporation values at Raipur. Though they are higher at Ambikapur and Jagdalpur. Turc method closely follows the open pan evaporimeter. Of all the 7 methods Modified Penman values are highest at Raipur while Hargreaves method PET values are highest at Jagdalpur and Ambikapur. Because of these higher estimates the crop coefficient was more than 1 by all the methods of PET.

Table 3.1: Annual PET values at different stations using different methods

Station	Modified penman	Hargreaves	Turc	Thornthwaite	Blaney Criddle	Christiansen	Open pan	FAO
Ambikapur	1627	1662	1401	1457	1588	1440	1260	1413
Raipur	1836	1803	1449	1823	1756	1634	1343	1614
jagdalpur	1538	1754	1278	1329	1340	1065	926	1352

3.2 Seasonal PET

Based on the monthly PET values shown in Table 3.2. the total PET during for Kharif and Rabi seasons were examined at different stations. The total values of PET during Kharif season varied from 515 mm to 877 mm at Raipur while they varied from 598 to 747 at Ambikapur and the same values computed by different method varied from 384 to 709 at Jagdalpur. However the open pan values are lower during Kharif season at all the three stations as compared to different methods and hence the crop coefficient PET/E_o are greater than 1 during Kharif season.

In the same way the PET values computed by different methods shows that the Thornthwaite PET values are lowest at all the three stations and they matched with open pan evaporation value. While Blaney Criddle PET estimates are higher in Rabi season at Ambikapur and Raipur while Hargreaves value of PET during Rabi season are highest at Jagdalpur.

Thus there is no trend of PET estimate by different methods in all the 3 stations and it suggests that local variability of meteorological conditions is important for estimation of PET at different locations. But from the analysis for different seasons it was found that Thornthwaite value are lower than any other method but at Jagdalpur Thornthwaite PET value for Rabi season are more close to open pan values at Jagdalpur as compared to other stations.

Table 3.2: Seasonal PET values at different stations using different methods

Stations	Modified penman	Hargreaves	Turc	Thornthwaite	Blaney Criddle	Christiansen	Open pan	FAO penman
Kharif (june-Oct)								
Raipur	730	698	565	877	588	653	515	639
Ambikapur	654	676	568	747	550	598	512	578
Jagdalpur	623	709	522	581	493	384	333	546
Rabi (Nov-March)								
Raipur	597	654	557	351	667	482	428	519
Ambikapur	529	573	509	236	578	452	419	449
Jagdalpur	568	670	496	394	537	415	370	500

Average monthly values of PET computed by different methods at Ambikapur station showed that Thornthwaite PET values are overestimated during summer and monsoon months and under-estimated during winter months. Among the other methods the Turc method of estimation of PET value during crop season, that is, July to October, matches with open pan values. At Ambikapur the Hargreaves and Modified Penman methods are almost equal during summer months while Turc method estimated lowest values of PET during all the weeks.

During the winter months the PET values computed through 7 equations are more at Raipur as compared to Ambikapur. The average monthly values of PET computed by different methods at Raipur station, Thornthwaite estimation of PET are overestimated during summer and monsoon periods and underestimated during winter months.

In annual PET values by different methods they are higher at Raipur and lower at Jagdalpur except in Hargreaves method. All the methods of PET computed by different methods are overestimated as compared to pan evaporation data. Turc method closely followed open pan evaporation values at Raipur. Modified Penman values are higher at Raipur while Hargreaves method PET values are highest at Jagdalpur and Ambikapur.

In seasonal PET, the total PET values during during *kharif* and *rabi* seasons were examined at different stations. The total values of PET during *kharif* season varied from 515 mm to 877 mm at Raipur while they varied from 598 to 747 at Ambikapur and the same values computed by different methods varied from 384 to 709 at Jagdalpur. In the same way the Thornthwaite PET values are lowest at all the three stations and they matched with open pan evaporation values. While Blaney Criddle PET estimates are higher in *Rabi* season at Ambikapur and Raipur while Hargreaves values of PET during *rabi* season were highest at Jagdalpur.

After the analysis and computation of long term data of monthly values of PET from 1981-2012 it was found that the weekly PET for Ambikapur and Jagdalpur station Modified penman method is almost equal during summer months and Turc method estimated lowest value. Highest values of PET at Ambikapur station seen in Blaney Criddle method. In case of Raipur lowest value seen in Turc method and highest value seen in Christiansen method followed by other methods this is because of changes in weather pattern in 3 different agroclimatic zones. In monthly values of PET at Ambikapur and Raipur stations Thornthwaite PET values are over estimated during summer months and under estimated during winter months while in case of Jagdalpur Hargreaves method of PET is higher than Thornthwaite method. During summer months the Modified Penman method of PET values are also higher than open pan values in all the months except Thornthwaite method in December and January. Thus, the evapotranspiration pattern at Jagdalpur is different as it is thickly forested area.

References

[1] **Ghulam Rasul and Arif Mahmood** (1992) in Pakistan made comparative studies on Pan evaporation with four widely used methods in the world under various climatic conditions of Pakistan. They found that FAO Penman –Monteith equation worked well in all the major climatic zones of Pakistan and it was adapted to crop water requirements, water balance studies and various operational agricultural practices.

[2] **Ding and Zhang**, (1994) studied the evapotranspiration model based on Penman's formula and incorporating crop water requirement and soil moisture supply coefficients were used to calculate water requirements of winter wheat, rice, maize and cotton throughout their growing periods. In addition a supplementary method of calculating actual field evapotranspiration using evaporation gauge 20 cm in diameter and a statistical model for standard evapotranspiration.

[3] **Bhandari and Shaha** (1995) using 10 years' potential evapotranspiration and evaporation data, linear regression analysis was carried out. Three stations namely, Bangalore, Pune and Hissar in different latitude belts were selected for the study. It was observed that partitioning of the annual period in to dry and wet periods gives better results. Analysis of 10 years data for dry as well as wet periods showed that correlation coefficient is more than 0.95 and variance of residual is very small for each data set.

[4] **Das *et al.*** (1995), based on the data for the period from 1977 to 1992 during the *Kharif* season, mean weekly evapotranspiration (ET) and its contribution for different phases to total evaporative loss have been worked out for *Kharif* rice at Canning (West Bengal). The evapotranspiration, evaporation ratio (ET/EP) and crop-coefficient (Kc) were found to attain peak value during the flowering stage. A relationship between ET/EP and number of days from transplanting has been

developed and stated that this relationship helps in determining ET from knowledge of EP and date of transplanting.

[5] **Sahoo *et al.*** (1996) studied the reference crop evapotranspiration and crop coefficient values (Kc) for rice, groundnut, mustard, sesamum, green gram, black gram, potato, tomato, cauliflower, cabbage, radish, onion, cucumber, pumpkin, and beans grown in a command area of Kacharamal minor (Orissa) and their crop water requirement were determined. Monthly ET was highest (175. 91mm) for aus and aman rice in June and lowest (26.42 mm) for green gram and groundnut in December. Seasonal ET values were highest (598.32 mm) for aman rice and lowest (140.37 mm) for radish.

[6] **Shen *et al.*** (1996) estimated field evapotranspiration from rice field from the 1st and 2nd crop of rice and reported as 320 – 440 mm and 500 – 580 mm, respectively. These values were useful to local irrigation associations when making irrigation plans. Soil droughtness during the dry season was also evaluated in conjunction with available soil water and effective rainfall in the region. Results showed that if there were no irrigation facilities, the probability of drought was highest in Chia-Nan Plain, followed by the Yunlin Plain and Taichung Basin.

[7] **Howell *et al.*** (1997) measured evapotranspiration (ET) of winter wheat, sorghum and corn with weighting Lysimeters at Bushland, Texas in 1989-90, 1991-92 and 1992-93. The average seasonal ET of wheat, sorghum and corn was 877, 578 and 771 mm. Maximum daily ET rates exceeded 10mm/day on several days particularly by the wheat crop.

[8] According **to Rambabu *et al*(**1999) the irrigation scheduling needs precise information on crop water requirements. Crop coefficient values aid in the estimation of regional crop water requirements. Three empirical methods namely Blaney-Criddle, Pan Evaporation and modified Penman were used in estimating potential evapotranspiration. Evapotranspiration values estimated by these relations using kc values of Doorenbos and Pruitt (1979) were compared with those measured from pigeonpea crop. Of the three, Pan Evaporation method showed least deviation.

[9] **Rambabu and Bapuji Rao** (1999) stated that the potential evapotranspiration data being used for estimation of crop water requirement. Modified Penman method requires extensive data and use of complex formulae and therefore they felt that there is need to find a simple relation requiring limited data. They compared the PET values estimated by four empirical relations namely Thornthwaite, Hargreaves, Turc and Baier with that estimated by Penman method. Of the four, Hargreaves estimates were closer to Penman's values. On an average Hargreaves relation resulted in 21 percent error. Data when separated season wise have indicated that relations differed in their accuracy during the three seasons.

[10] **Khandelwal** *et al.* (1999) used daily weather data recorded at agrometeorological observatory, Gujarat Agricultural University (GAU), Anand, to compute weekly and monthly potential evaporation by the Christiansen (1968), FAO Blaney-Criddle (1977), Hargreaves (1985) and Penman-Monteith (1990) methods.The computed values were compared with average observed values of pan evaporation. For computation of PET on weekly basis, the Hargreaves method was found to be the best (r=0.94) with highest model ratio. This was used for assessment of rainwater harvesting potential by USDA, SCS, and CN method.