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Intercomparison of evapotranspiration estimates

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Abstract Five methods of computing reference evapotranspiration from a reference crop (Penman, radiation, Blaney-Criddle, Hargreaves and pan evaporation) have been studied for their applicability under different climatic conditions. The Penman method was taken as the standard and the other four methods were compared against this method. Good correlation was obtained between the values estimated by the four methods and the Penman method although differences in magnitude were found. Regression equations were developed to correct those differences in magnitude. The method suitable for the estimation of reference evapotranspiration for each climatic condition is also suggested.

La comparaison des estimations de l'évapotranspiration

Résumé On étudie l'estimation de l'évapotranspiration de référence par les méthodes de Penman, de Blaney-Criddle et de Hargreaves et aussi par la bilan des radiations et par l'évaporation sur bacs. L'objet de l'étude est de trouver si ces méthodes sont valables sous des conditions climatiques diverses. Prenant la méthode de Penman comme base, on compare les résultats qu'elle fournit avec ceux obtenus par les autres méthodes. On trouve qu'il existe une corrélation assez satisfaisante entre les résultats quoique quelques différences se manifestent. Pour corriger ces différences on a mis au point une méthode de correction par les équations de régression. On a aussi suggéré la méthode la mieux adaptée pour l'estimation de l'évapotranspiration de référence pour chacune des conditions climatiques étudiées.

INTRODUCTION

Management practices for optimal utilization of water have been increasingly emphasized because of unevenly distributed rainfall, high evapotranspiration and excessive depletion of water resources. Thus practical methods for the accurate estimation of water losses for the conservation of water, especially in irrigation scheduling, are essential. The estimation of crop water requirements is one of the principal steps in the planning, design and operation of irrigation and water resources systems. Crop water requirements vary with crop characteristics and local conditions. Relationships between the evapotranspira-

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tion of a pre-selected crop (the reference crop), which is referred to as reference evapotranspiration, (ET_R), and other crops are established by multiplying ET_R by crop coefficients which vary with the crop and its growth stage. The term reference evapotranspiration has been used in this paper instead of the term potential evapotranspiration (PET) in accordance with the argument reported by Cuenca & Nicholson (1982). The computed values of ET_R shall be assumed using grass as the reference crop.

Models for predicting ET_R range from deterministically-based combined energy balance–vapour transfer approaches to empirical relationships based on climatological variables, or to evaporation from a standard evaporation pan. In many places, only limited meteorological information is available for estimating evapotranspiration. Expense and the effort required preclude direct measurements at most locations, including those in this study. Thus estimates are obtained from theoretical or empirical formulae, calibrated for different climatic conditions. The purpose of this study was to select a few of the most popular empirical methods and utilize them for estimating ET_R for different climatic conditions. The estimates from those methods were analysed and compared with values estimated by a standard method. The objective for such comparisons and evaluations was that the methods selected would be analysed for their suitability for different climatic conditions.

CLIMATIC CHARACTERISTICS

The region selected for this study is in Tamilnadu, India. The major feature of the rainfall pattern in this State is the northeast monsoon (October to December) which accounts for nearly 70% of the annual rainfall. The average annual rainfall of the State is 1010 mm. The normal annual maximum temperature varies between 31 and 34°C except at hill stations where it varies between 18 and 21°C. May is the month of maximum temperature except at coastal stations where June is hotter. Normal annual minimum temperature varies between 21 and 26°C, and in hilly regions from 7 to 15°C. January is the coldest month of the year, the range of temperature being 17 to 22°C.

Four stations, Meenambakkam, Madurai, Kodaikanal and Coimbatore, where meteorological data are available, were considered in this study. They are located in the climatological divisions of dry subhumid, semiarid, perhumid and humid, respectively. The locations of the stations are shown in Fig. 1. The details of the stations and the heights at which wind speed measurements are available are given in Table 1. The monthly average climatic parameters for the stations are listed in Table 2.

Daily values of maximum temperature (T_{max}), minimum temperature (T_{min}), relative humidity at 08.30 h ($RH1$) and at 17.30 hours ($RH2$), average wind speed, and actual sunshine duration (n) were collected for the period January 1982 to December 1986 from the Indian Meteorological Department for all four stations. The mean relative humidity (RH_{mean}) on any day is computed as the average of $RH1$ and $RH2$, and similarly mean temperature (T_{mean}) on any day is computed as the average of T_{max} and T_{min}. RH_{min} and RH_{max} on any day are taken as the minimum and maximum of $RH1$ and $RH2$

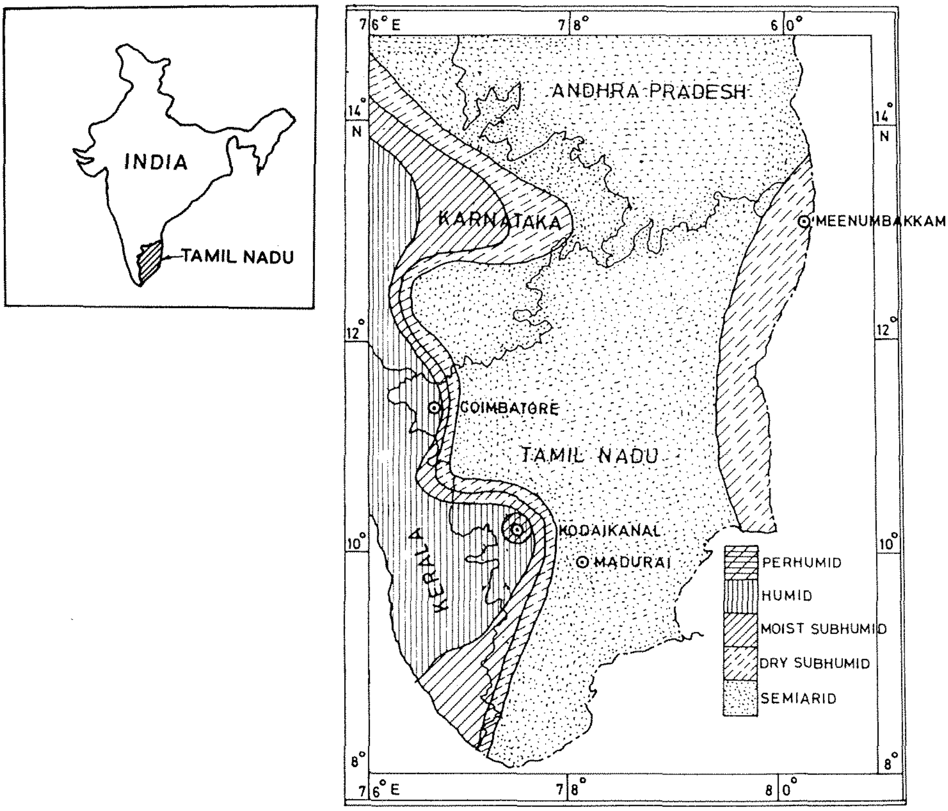

Fig. 1 Location map of the selected stations.

Table 1 Details of observation stations

Station	*Coordinates* *Latitude*	*Longitude*	*Altitude (m a.m.s.l.)*	*Wind speed measurement height (m)*	*a**	*b**
Meenambakkam	*13°00' N*	*80°11' E*	*16*	*15*	*0.20*	*0.52*
Madurai	*9°55' N*	*78°07' E*	*133*	*3.3*	*0.32*	*0.43*
Kodaikanal	*10°14' N*	*77°28' E*	*2343*	*15*	*0.31*	*0.52*
Coimbatore	*11°03' N*	*77°03' E*	*400*	*6.7*	*0.30*	*0.42*

* *Constants in the relationship* $R_s = (a + b\ n/N)R_a$.

respectively. In addition, daily pan evaporation values for the same period were available from the Indian Meteorological Department only for Meenambakkam, Madurai and Kodaikanal stations and they were also collected. The evaporation pans are located in non-irrigated areas in all three stations. Direct measurements of evapotranspiration were not available at those stations. Wind speed measured at different heights for different stations as shown in Table 1 was adjusted to a 2 m height using the 1/7th power law as

Table 2 Climatic characteristics of the stations

Station	Parameters	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Meenambakkam	T_{mean} (°C)	17.2	21.4	25.5	31.1	32.8	35.4	29.4	28.5	24.6	17.9	16.9	16.8
	RH_{mean} (%)	74.8	73.9	70.2	68.1	60.9	53.8	63.1	65.2	74.5	75.3	75.8	76.0
	Wind speed (km h^{-1})	3.8	3.4	3.3	4.5	3.5	3.2	3.4	3.3	3.4	3.4	3.2	3.2
	Radiation (MJ m^{-2} day^{-1})	18.4	22.3	24.4	24.5	22.9	20.5	19.1	19.8	20.0	17.2	15.3	15.1
	n/N	0.75	0.85	0.79	0.77	0.68	0.52	0.42	0.47	0.52	0.54	0.58	0.61
Madurai	T_{mean} (°C)	25.8	22.8	21.4	22.1	22.6	28.8	27.1	25.6	21.5	18.6	20.6	25.6
	RH_{mean} (%)	66.5	60.2	55.4	54.2	52.1	51.1	55.4	55.4	59.6	64.7	71.7	68.9
	Wind speed (km h^{-1})	3.8	3.7	3.9	3.6	3.6	3.7	3.6	3.3	3.8	3.6	3.6	3.4
	Radiation (MJ m^{-2} day^{-1})	21.1	21.3	24.5	23.9	22.6	21.5	17.2	20.0	18.7	19.2	17.1	20.3
	n/N	0.77	0.82	0.76	0.70	0.62	0.53	0.44	0.53	0.55	0.54	0.55	0.57
Kodaikanal	T_{mean} (°C)	12.5	13.3	14.6	15.7	16.6	15.4	14.3	14.3	14.5	13.9	12.9	12.5
	RH_{mean} (%)	68.0	67.1	58.6	66.7	74.1	81.7	83.7	83.0	84.0	84.4	84.1	77.4
	Wind speed (km h^{-1})	3.4	3.1	3.4	3.3	2.9	3.3	3.9	3.3	3.8	3.3	3.6	4.1
	Radiation (MJ m^{-2} day^{-1})	22.0	23.3	23.9	23.1	20.7	20.7	15.5	16.8	18.2	15.8	16.8	19.6
	n/N	0.65	0.69	0.64	0.56	0.46	0.31	0.21	0.28	0.32	0.32	0.38	0.50
Coimbatore	T_{mean} (°C)	24.5	26.2	28.4	29.0	28.6	26.5	25.5	26.0	26.4	26.2	25.2	24.3
	RH_{mean} (%)	65.5	58.9	54.8	59.9	66.1	75.3	77.9	78.7	77.2	74.4	72.8	68.6
	Wind speed (km h^{-1})	4.1	3.6	4.7	3.6	4.1	3.9	3.5	3.5	3.7	3.9	4.0	3.4
	Radiation (MJ m^{-2} day^{-1})	21.8	22.2	22.2	23.4	22.7	20.3	16.4	19.3	20.8	19.3	17.6	20.7
	n/N	0.74	0.81	0.81	0.72	0.62	0.47	0.38	0.47	0.58	0.55	0.59	0.66

suggested by Doorenbos & Pruitt (1974).

SELECTION OF ESTIMATION METHODS

The criteria adopted for choosing suitable methods for estimating ET_R from the numerous methods reported in the literature were based on the works of Doorenbos & Pruitt (1974), Svehlik (1987), Rao *et al.* (1974) and Schultz (1974). Doorenbos & Pruitt (1974) indicated that the modified version of Penman's formula (hereinafter referred to as the Penman method) gives the best estimation of ET_R, but also recommended the radiation, Blaney-Criddle and pan evaporation methods for different climatic conditions. Svehlik (1987) recommended, in the following order, the Penman, Blaney-Criddle and radiation methods. Rao *et al.* (1974) and Schultz (1974) recommended both the Penman and the Blaney-Criddle methods for reliable ET_R estimates over India. Hargreaves & Samani (1985) suggested a simple equation for estimating ET_R based on temperature and extra-terrestrial radiation.

For this study, the Penman, radiation, Blaney-Criddle, Hargreaves and pan evaporation methods were selected for daily ET_R estimation in various climatic zones in Tamilnadu. Penman's method is probably the most comprehensive approach to estimate ET_R and takes into account almost all of the factors which are known to influence ET_R, such as temperature, humidity, wind speed and solar radiation, and is also mainly used in India for ET_R estimation. Shouse *et al.* (1980) used Penman's formula as a standard when no direct evapotranspiration measurements were available. Subramanian & Rao (1985) compared the weekly evapotranspiration estimates by the Penman method for three semiarid and one dry subhumid climatic location in India for five crops (rice, wheat, maize, cotton and groundnut) with lysimeter observations for a period of two years. They reported that the estimated evapotranspiration was in close agreement for most of the crops. In a recent paper, Kizer *et al.* (1990) used the Penman equation for estimating hourly evapotranspiration of an alfalfa reference crop for both daytime and nighttime conditions. The performance of the Penman equation was compared with the field measurements of crop water use during two irrigation seasons in the years 1984 and 1985 in southwestern Oklahoma, USA, and it was found that the Penman model performed well. Kizer *et al.* (1990) reported that, even at 50% level of confidence, a *t*-test showed that the difference between the predicted and measured values was not significant. Since no direct measurements of evapotranspiration are available at the locations under study here, the Penman method was taken as the standard against which other methods would be evaluated. Brief descriptions of the Penman, radiation, Blaney-Criddle, Hargreaves and pan evaporation methods are given below.

Penman method

The climatic data required are mean temperature (T_{mean}) in °C, mean relative humidity (RH_{mean} in %), total wind speed (U in km day^{-1} at 2 m height), mean actual sunshine duration (n in h day^{-1}) or incoming shortwave radiation (R_s equivalent evaporation in mm day^{-1}), maximum possible sunshine duration (N in h day^{-1}), measured or estimated data on maximum relative humidity (RH_{max} in %) and mean daytime wind speed (U_{day} in m s^{-1} at 2 m height). ET_R, representing the mean value in mm day^{-1} over the period considered, is given by:

$$ET_{pen} = C_p\,[wR_n + (1 - w)\,.\,f(U)\,.\,(e_a - e_d)] \tag{1}$$

where: e_a = saturation vapour pressure;
e_d = actual vapour pressure in the air;

$$e_d = e_a\,.\,RH/100; \tag{2}$$

$$f(U) = 0.27(1 + U/100) \tag{3}$$

R_n = total net radiation in mm day^{-1};
w = temperature- and altitude-dependent weighting factor; and
C_p = adjustment factor for ratio U_{day}/U_{night}, RH_{max} and R_s.
A value of 1.5 is assumed for U_{day}/U_{night} as recommended by Doorenbos & Pruitt (1974) in computing the value of C_p.

Radiation method

The data required are T_{mean}, n/N or R_s, RH_{mean} and U_{day}. ET_R in mm day^{-1} is given by:

$$ET_{rad} = C_r(wR_s) \tag{4}$$

where R_s and w have the same meanings as before, and C_r depends on RH_{mean} and U_{day}.

Blaney-Criddle method

The climatic data required are RH_{min}, U_{day}, n/N, T_{mean} and percentage of daytime hours during the period considered over that of the year (p). ET_R is given by:

$$ET_{BC} = A + B\,p(0.46\,T_{mean} + 8) \tag{5}$$

where: $A = 0.0043\,RH_{min}\,n/N - 1.41$; and (6)
B = a factor depending on RH_{min}, n/N and U_{day}.

The Blaney-Criddle formula is commonly believed to underestimate ET_R at elevated sites because of the lower air temperature. An elevation correction was therefore incorporated by Doorenbos & Pruitt (1974) in the original equation to give:

$$ET_{BC} = (A + B\,p(0.46\,T_{mean} + 8)) \cdot C_e \tag{7}$$

where C_e is the elevation correction factor given by:

$$C_e = 1 + 0.1\,(\text{Elevation in m}) / 1000 \tag{8}$$

Hargreaves method

Hargreaves & Samani (1985) suggested a method involving only temperature and radiation data. Their equation is given by:

$$ET_{Har} = (0.0023\,R_a)\,(T_{mean} + 17.8)\,TD^{0.5} \tag{9}$$

in which R_a is extra-terrestrial radiation in equivalent mm of water evaporation for the time period, T_{mean} is the mean monthly temperature in °C, and TD is the difference between maximum and minimum temperatures.

Pan evaporation method

Doorenbos & Pruitt (1974) relate pan evaporation to ET_R using empirically derived coefficients (K_p) which take into account the climate, pan environment and crop type. ET_R can be obtained by:

$$ET_{pan} = K_p \cdot E_{pan} \tag{10}$$

where: E_{pan} = pan evaporation in mm day^{-1}; and
K_p = adjustment factor that depends on mean relative humidity, wind speed and ground cover.

Since the evaporation pans at the location were covered with screens, a correction factor of 1.14 as suggested by Raghunath (1985) was applied to the reported values at all three stations. The values of K_p have been taken from Doorenbos & Pruitt (1974) for the case of a pan placed in a green short-cropped area with a windward side distance of green crop of 100 m. The value of R_n in equation (1) was calculated from the relation:

$$R_n = 0.75\,R_s - R_{nl} \tag{11}$$

where R_{nl} is the net long wave radiation. Since measured values of R_s were not available, they were obtained from the equation:

$$R_s = (a + b\,n/N)\,R_a \tag{12}$$

where R_a is the extra-terrestrial radiation.

The values of a and b for each station were calculated by a regression of published mean monthly values of R against n/N (Indian Meteorological Department, 1981) and are also listed in Table 1. The a and b values differ somewhat from the values of 0.25 and 0.50 respectively assumed when no data are available. R_{nl}, e_d and n/N, as well as the values of e_a, R_a, w, C_p and C_r were taken from Doorenbos & Pruitt (1974).

ANALYSIS OF ESTIMATION METHODS

Daily ET_R values from the Penman (ET_{Pen}), radiation (ET_{rad}), Blaney-Criddle (ET_{BC}), Hargreaves (ET_{Har}) and pan evaporation (ET_{pan}) methods were computed for the period January 1982 to December 1986 from the corresponding climatic records for the Meenambakkam, Madurai and Kodaikanal stations. Only ET_{Pen}, ET_{rad}, ET_{BC} and ET_{Har} were computed for the Coimbatore station due to the non-availability of pan evaporation data for this station for the same period. From these daily values, weekly mean ET_R and weekly standard deviations were computed for all the methods at the respective stations.

Weekly mean ET_R values averaged over five years (1982–1986) from the different methods are shown in Figs 2 to 5 for Meenambakkam, Madurai, Kodaikanal and Coimbatore respectively. From Fig. 2 it can be seen that for the Meenambakkam station the Blaney-Criddle method only follows the same trend as that of Penman method even though the deviation is higher compared with other methods than the radiation, Hargreaves and pan evaporation methods. For the Madurai station (Fig. 3) ET_{rad}, ET_{BC} and ET_{pan} are less than ET_{Pen} in all the weeks except four. For this station, ET_{Har} values are somewhat closer to ET_{Pen} than the ET_R values estimated by the other methods. From Fig. 4 it is clear that for the Kodaikanal station, the Blaney-Criddle, Hargreaves and pan evaporation formulae underestimate the ET_R

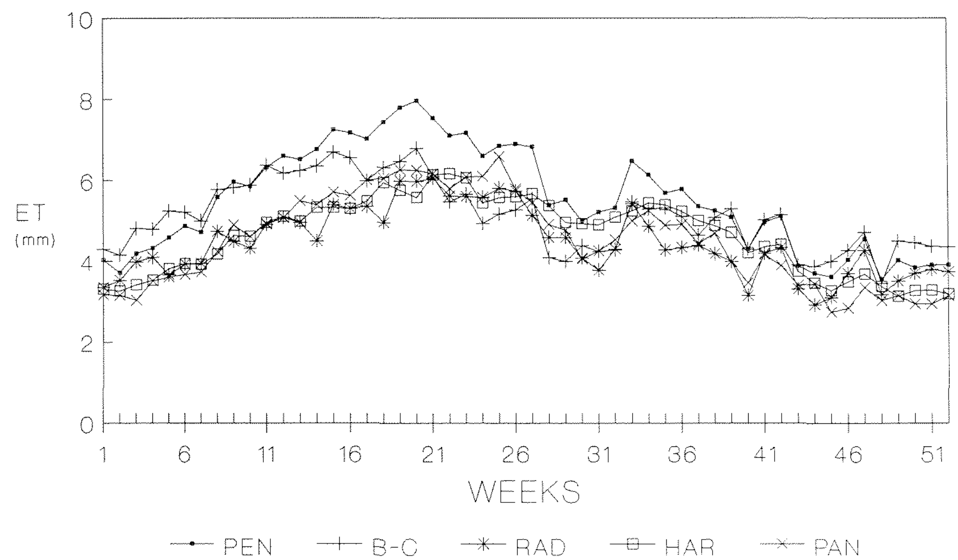

Fig. 2 Weekly mean ET_{Pen}, ET_{rad}, ET_{BC}, ET_{Har} and ET_{pan} for Meenambakkam.

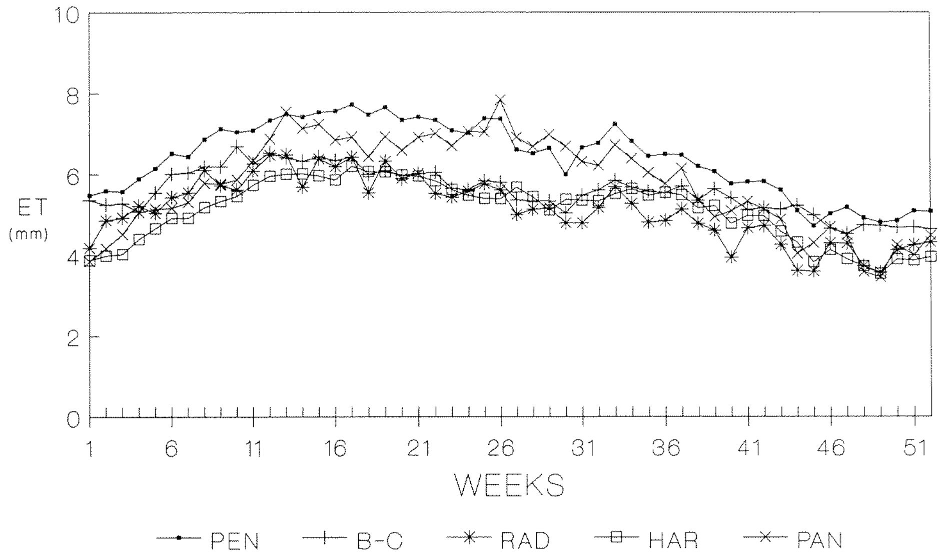

Fig. 3 *Weekly mean* ET_{Pen}, ET_{rad}, ET_{BC}, ET_{Har} *and* ET_{pan} *for Madurai.*

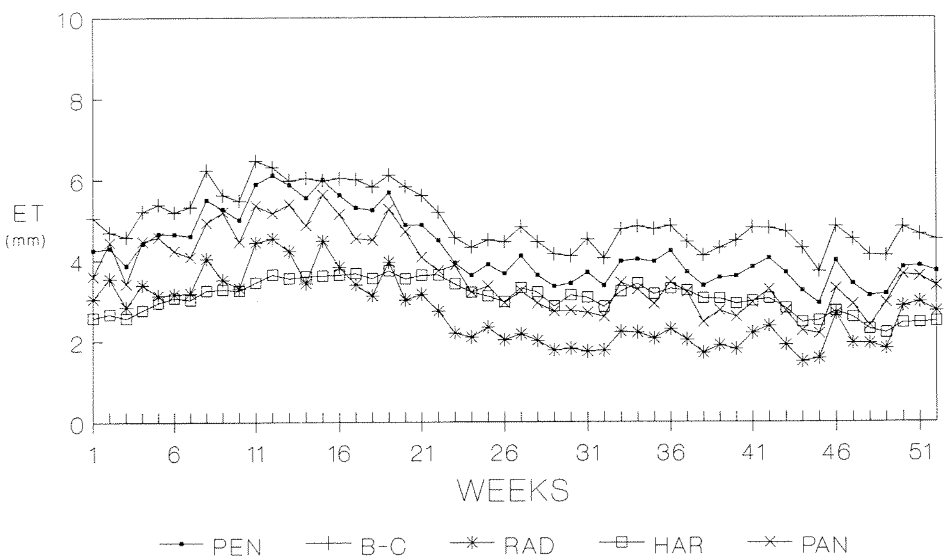

Fig. 4 *Weekly mean* ET_{Pen}, ET_{rad}, ET_{BC}, ET_{Har} *and* ET_{pan} *for Kodaikanal.*

values and the radiation formula overestimates them. For Coimbatore, the Blaney-Criddle formula underestimates ET_R values for the weeks from 14 to 42 and the other methods estimate ET_R values fairly close to those of Penman's estimates. Table 3 shows the mean annual values of ET_R at the four stations under study. It can be seen that the radiation, Blaney-Criddle and pan evaporation methods underestimate in all the stations except the hill station Kodaikanal where the radiation method has the highest estimate.

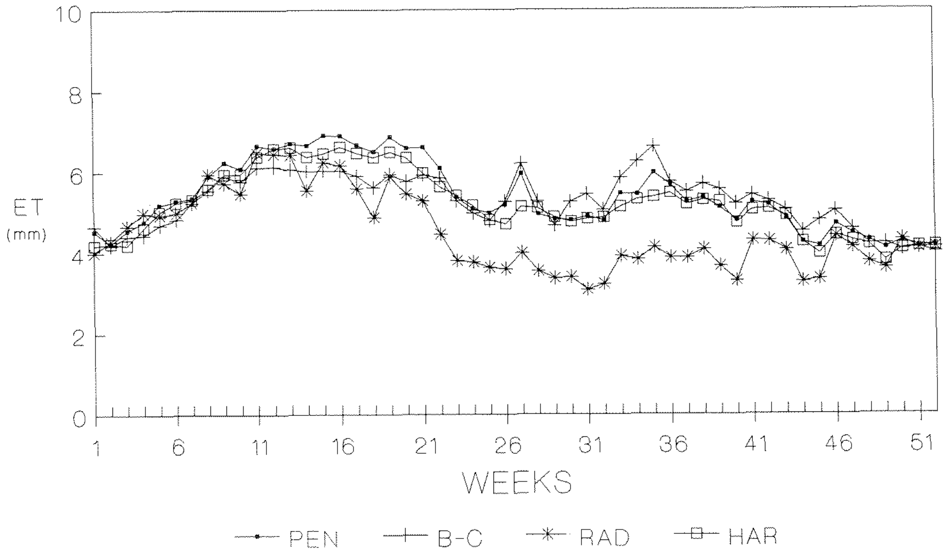

***Fig.** 5 Weekly mean ET_{Pen}, ET_{rad}, ET_{BC} and ET_{Har} for Coimbatore.*

There are three distinct seasons in a year in the region studied. Counting from the beginning of the calendar year, weeks 1 to 8 and 41 to 52 are classified as winter, 9 to 22 as summer and 23 to 40 as monsoon. Table 4 shows mean seasonal ET_R estimates by the different methods for all stations. From Table 4, it can be seen that for the Meenambakkam, Madurai and Coimbatore stations, ET_{Pen} is the highest in all seasons except for the Coimbatore station in the monsoon. For the Madurai station the pan evaporation method has the closest estimate with ET_{Pen} for the summer and the monsoon. For the perhumid Kodaikanal station, the radiation method estimate dominates and the Blaney-Criddle and pan evaporation methods greatly underestimate ET_R compared with ET_{Pen}.

***Table** 3 Mean annual ET_R (mm day^{-1}) for the stations*

Station	ET_{Pen}	ET_{rad}	ET_{BC}	ET_{Har}	ET_{pan}
Meenambakkam	*5.52*	*5.13*	*4.85*	*4.63*	*3.94*
Madurai	*6.41*	*5.59*	*5.13*	*5.10*	*5.77*
Kodaikanal	*4.27*	*4.97*	*3.18*	*3.09*	*3.08*
Coimbatore	*5.38*	*5.26*	*4.50*	*5.20*	-

CORRELATION BETWEEN METHODS

The computed weekly mean ET_R values for five years (1982–1986) from the different methods were analysed to find the components of the following

Table 4 *Mean seasonal ET_R (mm day^{-1}) for the stations*

Station	Season	ET_{Pen}	ET_{rad}	ET_{BC}	ET_{Har}	ET_{pan}
Meenambakkam	Summer	6.95	6.23	5.20	5.38	4.89
	Monsoon	5.82	5.31	4.66	5.20	4.33
	Winter	4.23	4.57	3.75	3.60	2.90
Madurai	Summer	7.39	6.27	6.03	5.90	6.72
	Monsoon	6.64	6.36	5.09	5.40	6.38
	Winter	5.53	5.15	4.54	4.28	4.52
Kodaikanal	Summer	5.40	5.88	3.65	3.55	4.07
	Monsoon	3.73	3.76	2.66	3.14	2.53
	Winter	3.96	4.78	2.64	2.69	2.08
Coimbatore	Summer	6.52	5.92	5.72	6.30	-
	Monsoon	5.22	5.45	3.68	5.08	-
	Winter	4.68	4.66	4.34	4.54	-

linear regression equation:

$$Y = mX + c \qquad (13)$$

where Y represents ET_{Pen} and X is the ET_R estimated from the radiation, Blaney-Criddle, Hargreaves and pan evaporation methods, and m and c are constants representing the slope and intercept respectively. The results of the regressions together with the cross-correlation (r^2) between the Penman and the other methods are summarized in Table 5. Table 5 also shows the standard error of the estimates (SE) which is given by:

$$SE = \left[\frac{(Y - \hat{Y})^2}{(Z - 2)}\right]^{1/2} \qquad (14)$$

where Y is ET_R estimated by Penman's method, $\hat{Y}$ is the regression estimated ET_R from the regression equation (13) and Z is the total number of values considered.

It can be noticed from Table 5 that the correlation involving the radiation method shows lower values of r^2 for the Meenambakkam, Madurai and Coimbatore stations, whereas for the Kodaikanal hill station this method shows a higher correlation than the other methods. The Blaney-Criddle estimates result in the highest correlation with that of Penman's in all stations except for the Coimbatore station in which the Hargreaves method estimates have the highest correlation. In addition, smaller values of the intercept (c) and nearly unit values of slopes (m) were observed for the relation between the radiation and Penman methods at all four stations. In contrast, higher values of intercepts and higher values of SE were observed for all the stations for the relation between pan evaporation and the Penman method. The standard error values with the Blaney-Criddle equation are the lowest among all the methods and for all stations except for the Coimbatore station in which the Hargreaves method estimates result in a lower standard error.

Table 5 *Regression coefficients and cross-correlations between ET_R estimates by Penman and other methods*

Station	*Methods of estimation Y axis*	*X axis*	*Intercept c*	*Slope m*	r^2	*SE*
Meenambakkam (dry subhumid)	ET_{Pen}	ET_{rad}	-0.05	1.09	0.67	0.84
	ET_{Pen}	ET_{BC}	-0.43	1.34	0.89	0.50
	ET_{Pen}	ET_{Har}	-0.48	1.30	0.77	0.70
	ET_{Pen}	ET_{pan}	1.04	0.99	0.82	0.62
Madurai (semiarid)	ET_{Pen}	ET_{rad}	-0.30	1.18	0.68	0.63
	ET_{Pen}	ET_{BC}	1.58	0.94	0.83	0.40
	ET_{Pen}	ET_{Har}	1.22	1.02	0.78	0.46
	ET_{Pen}	ET_{pan}	3.06	0.51	0.85	0.58
Kodaikanal (perhumid)	ET_{Pen}	ET_{rad}	-0.90	1.04	0.88	0.38
	ET_{Pen}	ET_{BC}	1.78	0.92	0.90	0.36
	ET_{Pen}	ET_{Har}	-0.84	1.66	0.65	0.63
	ET_{Pen}	ET_{pan}	1.47	0.76	0.80	0.48
Coimbatore (humid)	ET_{Pen}	ET_{rad}	0.40	0.94	0.63	0.63
	ET_{Pen}	ET_{BC}	2.14	0.72	0.68	0.59
	ET_{Pen}	ET_{Har}	-0.07	1.04	0.82	0.45

From the weekly analysis, it was observed that the magnitude of the deviations of ET_R estimates by the radiation, Blaney-Criddle, Hargreaves and pan evaporation methods from those of Penman's method changed with the season. This suggests a seasonal influence on the coefficients of the radiation, Blaney-Criddle, Hargreaves and pan evaporation formulas. To explore this, weekly ET_{Pen} values for a given season over the entire period considered were regressed on ET_{rad}, ET_{BC}, ET_{Har} or ET_{pan} values. The resulting regression equations are of the same form as shown in equation (13). These seasonal equations are listed in Table 6 along with the coefficients of correlation and standard errors of estimates. It can be observed that the Blaney-Criddle estimates are, in general, well correlated with the Penman estimates. However, the Hargreaves and radiation method do rather better for the Coimbatore station and Kodaikanal station respectively. The equations listed in Table 6 follow the same trend as that of the equations in Table 5, of course differing from season to season.

CONCLUSIONS

Five methods of calculating ET_R namely Penman, radiation, Blaney-Criddle, Hargreaves and pan evaporation, were used to estimate weekly average and seasonal values of reference evapotranspiration at four stations representing different climatic conditions in the state of Tamilnadu, India. The Penman method was taken as a standard because of its general application, and the other methods were calibrated against this standard. Seasonal and annual regression analyses were performed for the results estimated by Penman's method and the other methods in each of the four stations. Those analyses

Table 6 Seasonal regression equations between ET_R estimates by Penman and other methods

Station	Season	Methods of estimation Y axis	X axis	Intercept c	Slope m	r^2	SE
Meenambakkam (dry subhumid)	Summer	ET_{Pen}	ET_{rad}	2.368	0.736	0.52	0.71
		ET_{Pen}	ET_{BC}	1.502	1.045	0.80	0.38
		ET_{Pen}	ET_{Har}	1.535	1.005	0.62	0.63
		ET_{Pen}	ET_{pan}	2.551	0.786	0.60	0.65
	Monsoon	ET_{Pen}	ET_{rad}	0.877	1.012	0.61	0.73
		ET_{Pen}	ET_{BC}	0.615	1.119	0.93	0.31
		ET_{Pen}	ET_{Har}	-3.334	1.760	0.62	0.76
		ET_{Pen}	ET_{pan}	1.675	0.839	0.75	0.64
	Winter	ET_{Pen}	ET_{rad}	0.647	0.790	0.80	0.39
		ET_{Pen}	ET_{BC}	0.326	1.048	0.86	0.32
		ET_{Pen}	ET_{Har}	-0.904	1.433	0.78	0.41
		ET_{Pen}	ET_{pan}	1.250	0.896	0.66	0.50
Madurai (semiarid)	Summer	ET_{Pen}	ET_{rad}	3.730	0.585	0.57	0.45
		ET_{Pen}	ET_{BC}	3.886	0.582	0.73	0.25
		ET_{Pen}	ET_{Har}	2.926	0.759	0.61	0.31
		ET_{Pen}	ET_{pan}	5.632	0.262	0.52	0.41
	Monsoon	ET_{Pen}	ET_{rad}	0.093	1.181	0.62	0.63
		ET_{Pen}	ET_{BC}	2.009	0.911	0.86	0.24
		ET_{Pen}	ET_{Har}	2.120	0.839	0.64	0.56
		ET_{Pen}	ET_{pan}	4.165	0.390	0.61	0.49
	Winter	ET_{Pen}	ET_{rad}	2.121	0.660	0.61	0.65
		ET_{Pen}	ET_{BC}	2.129	0.749	0.84	0.27
		ET_{Pen}	ET_{Har}	1.814	0.867	0.68	0.41
		ET_{Pen}	ET_{pan}	3.106	0.530	0.52	0.51
Kodaikanal (perhumid)	Summer	ET_{Pen}	ET_{rad}	-0.472	0.999	0.75	0.43
		ET_{Pen}	ET_{BC}	2.329	0.843	0.92	0.25
		ET_{Pen}	ET_{Har}	-0.053	1.537	0.55	0.69
		ET_{Pen}	ET_{pan}	2.213	0.659	0.67	0.49
	Monsoon	ET_{Pen}	ET_{rad}	-0.003	0.834	0.84	0.23
		ET_{Pen}	ET_{BC}	1.425	1.146	0.89	0.20
		ET_{Pen}	ET_{Har}	-0.838	1.455	0.52	0.41
		ET_{Pen}	ET_{pan}	1.884	0.608	0.60	0.37
	Winter	ET_{Pen}	ET_{rad}	-0.674	0.968	0.86	0.38
		ET_{Pen}	ET_{BC}	1.762	0.829	0.90	0.33
		ET_{Pen}	ET_{Har}	-1.541	2.040	0.67	0.59
		ET_{Pen}	ET_{pan}	1.562	0.690	0.78	0.49
Coimbatore (humid)	Summer	ET_{Pen}	ET_{rad}	1.509	0.855	0.56	0.48
		ET_{Pen}	ET_{BC}	3.389	0.558	0.67	0.37
		ET_{Pen}	ET_{Har}	0.889	0.903	0.59	0.42
	Monsoon	ET_{Pen}	ET_{rad}	1.740	0.634	0.56	0.54
		ET_{Pen}	ET_{BC}	1.500	1.013	0.88	0.25
		ET_{Pen}	ET_{Har}	-0.573	1.139	0.54	0.55
	Winter	ET_{Pen}	ET_{rad}	1.156	0.756	0.61	0.44
		ET_{Pen}	ET_{BC}	1.804	0.664	0.78	0.33
		ET_{Pen}	ET_{Har}	0.265	0.974	0.76	0.35

demonstrated a fairly high degree of correlation between values estimated by the Penman and radiation methods for the Kodaikanal station, between the Penman and Hargreaves methods for the Coimbatore station and between the Penman and Blaney-Criddle methods for the remaining stations.

It is concluded that estimation of evapotranspiration using the radiation method for stations lying in perhumid regions, from the Hargreaves method for humid regions, and from the Blaney-Criddle method for the other semiarid and dry subhumid regions, can be recommended to yield results fairly comparable with values obtained from Penman's formula.

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