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Performance of Different Methods for Computation of Reference Evapotranspiration under Semiarid Condition

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ABSTRACT

Performance of different methods for estimation of potential evapotranspiration (PET) was evaluated with reference to Penman-Monteith (PM) method. Five year meteorological data were used for calculation of PET and reference evapotranspiration (ET0) using different methods. PET and ET0 calculated by different methods were compared with ET0 computed by PM method. Performance of Priestley-Tailor and Makkink's method were in good agreement with PM method. Thornthwaite method was found to be under estimating PET during winter and overestimating during summer. Makkink's and Blaney-Criddle methods were comparable to PM method though these methods required less input as compared to PM method and hence may serve good for areas with less parameter measurements.

Key words: Sunshine hours, potential evapotranspiration, reference evapotranspiration, thornthwaite, blaney-criddle, makkinks, oriestley-taylor and penman-monteith.

Introduction

Evapotranspiration, which is a vital component of hydrological cycle, is considered as necessary evil too. Evapotranspiration estimates are used in scheduling irrigation particularly in arid and semiarid areas. These are used in yield prediction, soil moisture estimation, water balance study in watershed, studying drainage basin processes and also an important component of soil erosion models. Evapotranspiration estimates are required for defining the geographical limit of economic rain fed farming. For judicious application of precious water resources in arid and semi-arid areas, it is almost necessary to have estimation of Potential evapotranspiration (PET).

There are several approaches to estimate Potential evapotranspiration or Reference evapotranspiration using different inputs like temperature, radiation, wind speed, relative humidity etc. These are Thornthwaite (1948) method, Penman-Monteith (1948) approach, Priestley Taylor (1972) method, Makkink's (1957) Method & Blaney-Criddle (1957) approach. Penman (1948) defined PET as "the amount of water transpired in unit time by short green grass of uniform height, completely covering the soil and never short of water". Later, Doorenbas and Pruitt (1977) gave the concept of reference evapotranspiration and defined it as "the rate of evapotranspiration from an extensive surface of 5-15cm tall green grass cover of uniform height actively growing completely shading the ground and not short of water".

The widely acclaimed method proposed by FAO in Irrigation and Drainage Paper 56 (Allen *et. al.* 1998) recommends computation of ETO solely based on parameterizations proposed by Allen *et. al.* (1989) for the Penman-Monteith equation (Monteith, 1965). Though the method performs well in many climates, the requirement of several inputs (seldom available in developing region, particularly in remote area) limits its wider application. The alternate is empirical methods. The ETO computation using empirical methods has great advantage because of nondestructiveness and less input demand. This paper deals with the different methods for computation of PET/ETO and comparison with PM method.

Material and Methods

Five year (1999-2003) monthly average data were collected from meteorological station of Indian Agricultural Research Institute, New Delhi and were used for computation of PET and ETO. The following formulae have been used for monthly computation of PET or ETO.

Thornthwaite method

$$PET_{unad} = 1.6*(10*T/I)^a$$

Where

PET_{unad} = Unadjusted PET in cm/month

T = Mean monthly air temperature (^0C)

I = Annual heat Index = $\sum_{1}^{12} i$

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

'a' is an empirical constant computed as

a = $0.000000675 * I^3 - 0.0000771 * I^2 + 0.01792 * I + 0.49239$

The assumption that there are thirty days in each month of twelve-hour sunshine needs modification.

The adjustment factor K is computed as

$$K = \frac{\sum_{i-1}^{n} \text{Sunshine hr.}}{12 * 30}$$

n = no. of days in month

Adjusted PET (mm/month) = K * PET_{unad} * 10

Blaney-Criddle method

This method uses temperature as a main input but it requires estimate of relative humidity, wind speed and actual sun shine hour.

$$ET0 \text{ (mm/day)} = C * [P * (0.46 * T + 8)]$$

T = Mean monthly temperature in ^0C

P = Monthly mean % of total annual day light hour

C = Adjustment factor depends on minimum relative humidity, daytime wind speed and sun shine hour.

Makkink's method (1957)

$$PET \text{ (mm/day)} = 0.61 * Rs * \frac{\Delta}{\Delta + \gamma} - 0.12$$

Rs = Global radiation (mm/day)

Δ = slope of saturation vapor pressure vs. air temperature curve at air temperature (mm Hg / ^0C)

$$\Delta \text{ (KPa/}^0\text{C)} = \frac{4098 * 0.6108 * \exp\{17.27 * T/ (T + 237.3)\}}{(T + 237.3)^2}$$

γ = Psychrometric constant

Rs = Ra * (a + b * n / N)

Where, a and b for Delhi condition are 0.32 and 0.46, respectively.

Ra is the theoretical amount of radiation that should reach the earth in absence of atmosphere. Ra was calculated using solar constant, solar declination and Julian day of the year.

$$\gamma \text{ (mm Hg)} = 0.665 * 10^{-3} * P * 7.5$$

Where,

$$P \text{ (KPa)} = 101.3 * \left[\frac{293 - 0.0065 * Z}{293}\right]^{5.26}$$

Z = height above sea leven (m)

Priestley-Tailor (1972)

$$\lambda ET0 \text{ (mm/day)} = 0.408 * \alpha * \left[\frac{\Delta *(Rn - Gi)}{\Delta + \gamma}\right]$$

Here, α = 1.26

The symbols Δ and γ are already discussed above.

Rn = Net radiation ($MJ/m^2/day$)

Gi = Soil heat flux calculated on monthly basis.

Gi = $0.14 * (T_i - T_{i-1})$

Where,

T_i = monthly temperature of that month

T_{i-1} = monthly temperature of previous month

Penman- Monteith method **(Allen *et al.* 1998)**

$$\lambda ET = \frac{\Delta *(R_n - G_i) + \rho_a Cp * \{(e_a - e_d) / \gamma_a\}}{\Delta + \gamma (1 + \gamma_s / \gamma_a)}$$

For reference crop this formula is simplified to

$$ET0 \text{ (mm/day)} = \frac{\begin{array}{c} 0.408 * \Delta *(R_n - G_i) \\ \gamma * 900 * v_2 * (e_a - e_d)/(T + 273) \end{array}}{\Delta + \gamma * (1 + 0.34 * v_2)}$$

Where,

v_2 = wind speed at 2m (m/s)

e_a = Saturation vapour pressure at air temperature (Kpa)

e_d = Saturation vapour pressure at dew point (Kpa)

The PET/ETO computed by different methods were compared with ETO calculated by Penman-Monteith method for annual and seasonal periods.

Results and Discussion

As per the estimation, maximum ET0 was encountered in May-June and minimum was observed in Dec-Jan. Table 1 shows the mean monthly value of reference/potential evapotranspiration along with their standard deviation. There are two maxima in coefficient of variation; one is in Dec-Jan and other in July. The first maximum is attributed to variation in radiation and temperature as well as difference between maximum and minimum temperature. The second maximum is due to cloudy and cloud free days during monsoon season, which in turn affect radiation, temperature and relative humidity. The maximum as well as minimum PET among different methods of computation is in case of Thornthwaite method. The maximum monthly PET was 335.8 mm with standard deviation 32.2 was in May. The maximum value of ET0 estimated by Penman-Monteith method was 211.3 mm with SD of 23.4 in the month of May. Maximum ET0 estimated by Priestley-Taylor method was in June with mean value of 168.5 mm.

The annual PET by Thorthwaite was 1880 mm, value of ET0 calculated by Blaney-Criddle method was 1490 mm, by Makinks method it was 1616 mm, by Priestley-Taylor method 1405 mm and by Penman-Monteith method it was 1486 mm.

Comparison between different methods

Fig. 1 shows that Thornthwaite method based PET was lower than all other methods during November to March while it was higher from May to October. From January to April, ETO estimated by Makkink's method was higher as compared to ET0 estimated by other method. ETO estimated by Priestley-Taylor method was relatively low from February to June. For rest of the period, all methods perform at par except Thornthwaite method.

Fig. 2a shows the 1:1 comparison between ET0 estimated by Penman method and by Thornthwaite method. The ETO was found to be underestimated at lower value and overestimated at higher values. Similar pattern could be observed more clearly in Fig 3a and 4a during *kharif* (June-Oct) and *rabi* (Nov-Mar) seasons. Another evidence is the high value of mean relative deviation, which is equal to 0.54. ETO computed by Blaney-Criddle method was in good agreement with ETO computed using PM method. Most of the points were between the 10% deviation lines Fig (2b). This may be because this method uses estimates of radiation, wind speed and relative humidity along with main input as temperature. The value of mean relative deviation was 0.14, which is very low as compared to Thornthwaite method. Fig (3b) shows slight over estimation during *rabi* season towards higher value and under estimation towards lower value. Same is the case during kharif season (Fig. 4b). ETO estimated by Makkink's method was also in good agreement with PM method though there are significant overestimation during rabi season and also in lower value of kharif season (Fig. 2c, 3c and 4c). The mean relative deviation was 0.15, which indicates a good agreement between Makkink's and PM method. There was least mean relative deviation (0.11) for ETO estimated by PT method. Though

Table 1. Mean ETO (mm/month) computed by different methods and their standard deviation

Months	Thornthwaite		Blaney-Criddle		Makkink's method		Priestley-Taylor		Penman-Monteith	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Jan	12.0	2.0	37.8	9.3	55.2	7.2	49.4	2.1	51.9	6.3
Feb	21.5	3.3	68.9	12.5	85.1	2.2	62.6	1.6	68.8	3.9
Mar	73.1	3.3	131.4	1.5	150.0	15.4	105.8	3.3	121.8	17.9
Apr	194.6	16.6	181.8	11.2	202.5	4.2	140.6	2.0	168.1	18.1
May	335.8	32.2	204.6	15.2	204.6	9.0	165.0	6.6	211.3	23.4
Jun	304.2	34.8	172.8	29.7	180.0	17.1	168.5	8.1	177.3	17.6
Jul	300.4	74.3	151.9	37.5	160.3	20.9	164.4	8.6	162.9	38.5
Aug	254.0	13.8	125.2	1.5	149.4	17.9	160.3	11.7	145.4	15.2
Sep	185.2	11.2	124.2	25.0	141.6	19.2	142.7	7.4	133.0	23.3
Oct	127.7	10.1	130.8	5.3	131.4	4.2	116.5	3.8	110.8	6.7
Nov	52.1	4.3	91.8	5.2	91.8	7.2	73.9	1.7	76.4	5.9
Dec	19.1	3.6	68.8	8.2	63.6	12.4	55.4	1.7	58.0	6.2

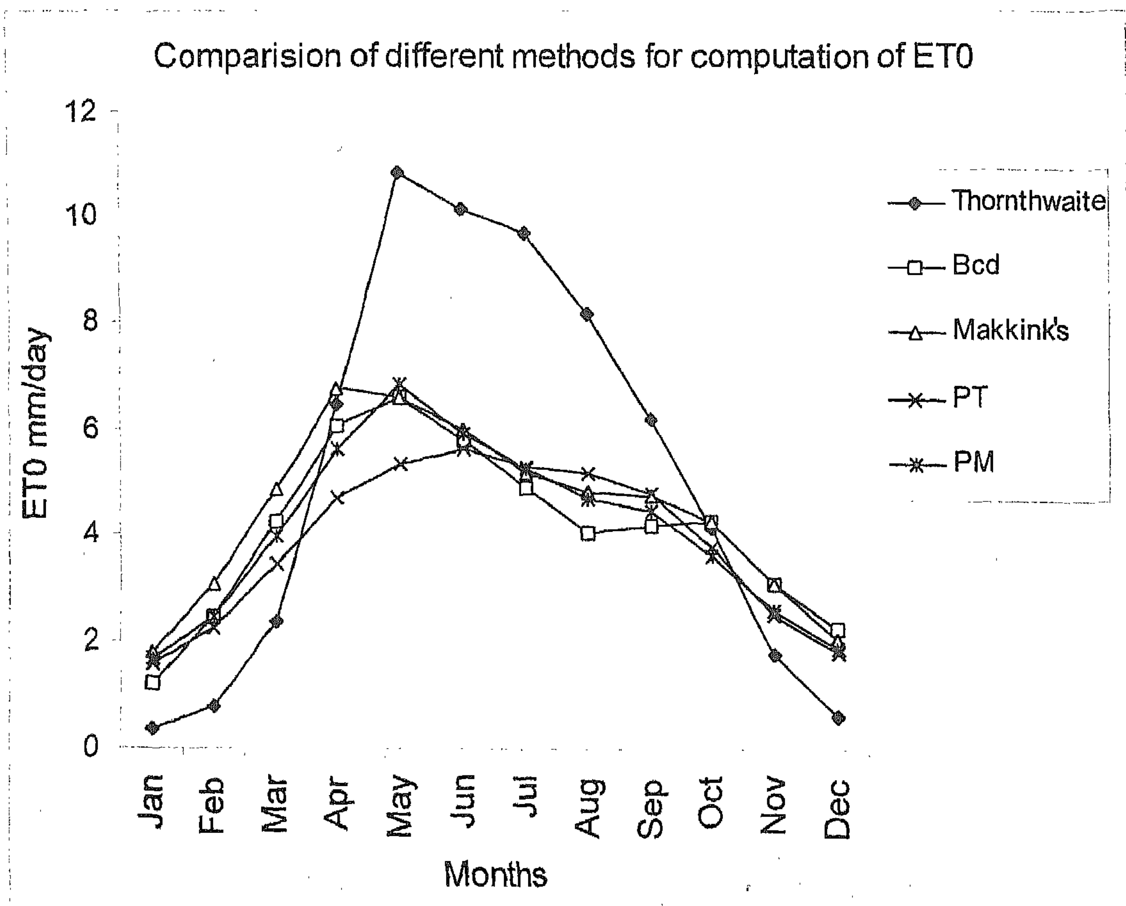

Fig. 1. Average estimated ETO by different methods (Bcd : Blaney-Criddle, PT: Priestley-Taylor, PM : Penman monteith)

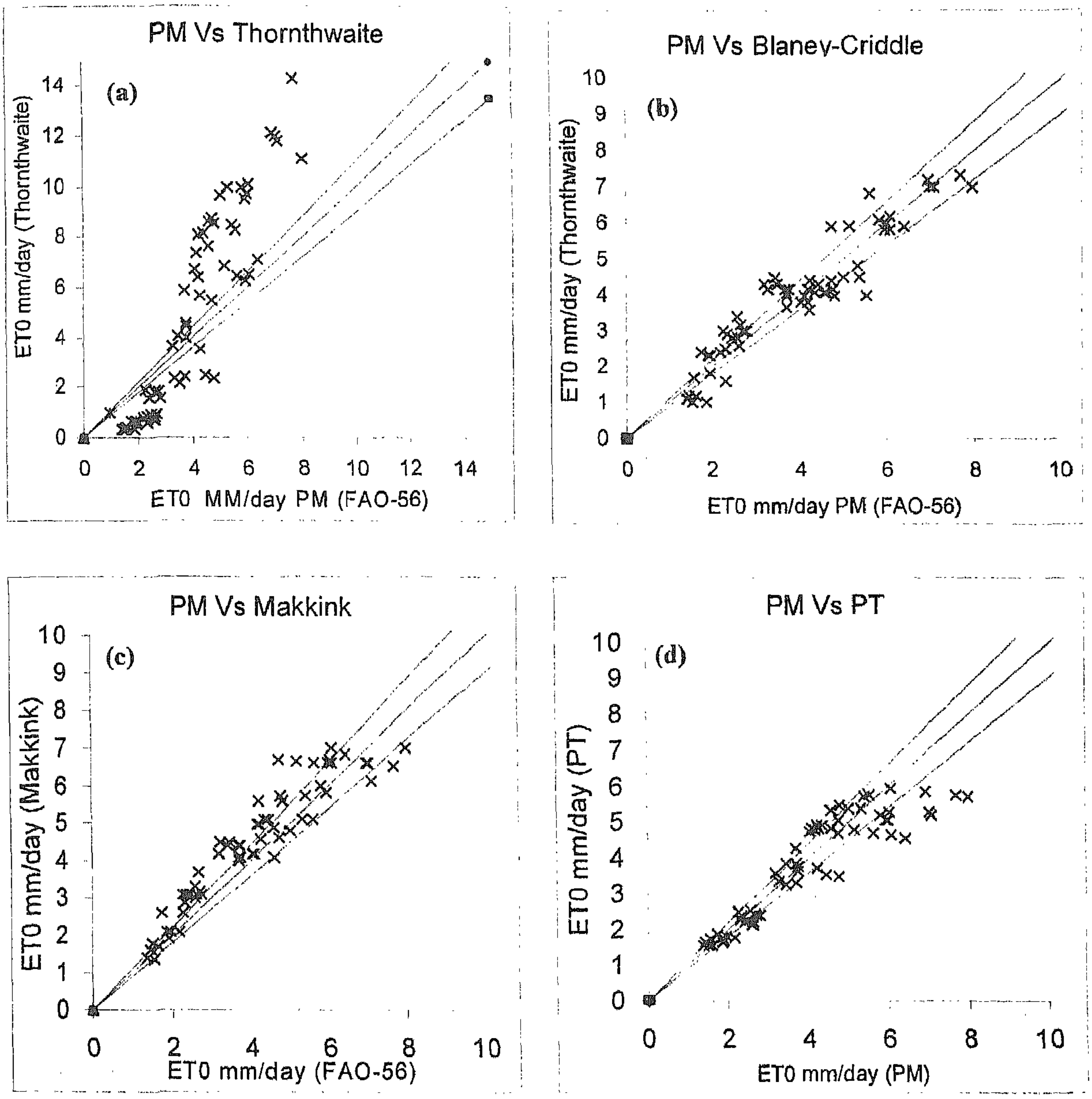

Fig. 2. Comparison between ETO estimated by Penman-Monteith Method (PM) and (a) Thornthwaite (b) Bcd, (c) Makkink's and (d) Priestley-Taylor (PT) method

most of the points were within 10 % deviation line there are evidences of over estimation and under estimation (Fig. 2d, 3d and 4d). During *rabi* season, PT method performs better than other method.

Conclusions

Though Thornthwaite method is less input demanding, it is observed to be less suitable for semiarid condition like Delhi. The other choice may be Blaney-Criddle method or Makkink's method. In addition to temperature, they require estimates of sunshine hour, wind speed and minimum relative humidity. In case of Makkink's method, there is requirement of estimates of mean relative humidity and wind speed. These two methods are relatively less input demanding as compared to PM or PT

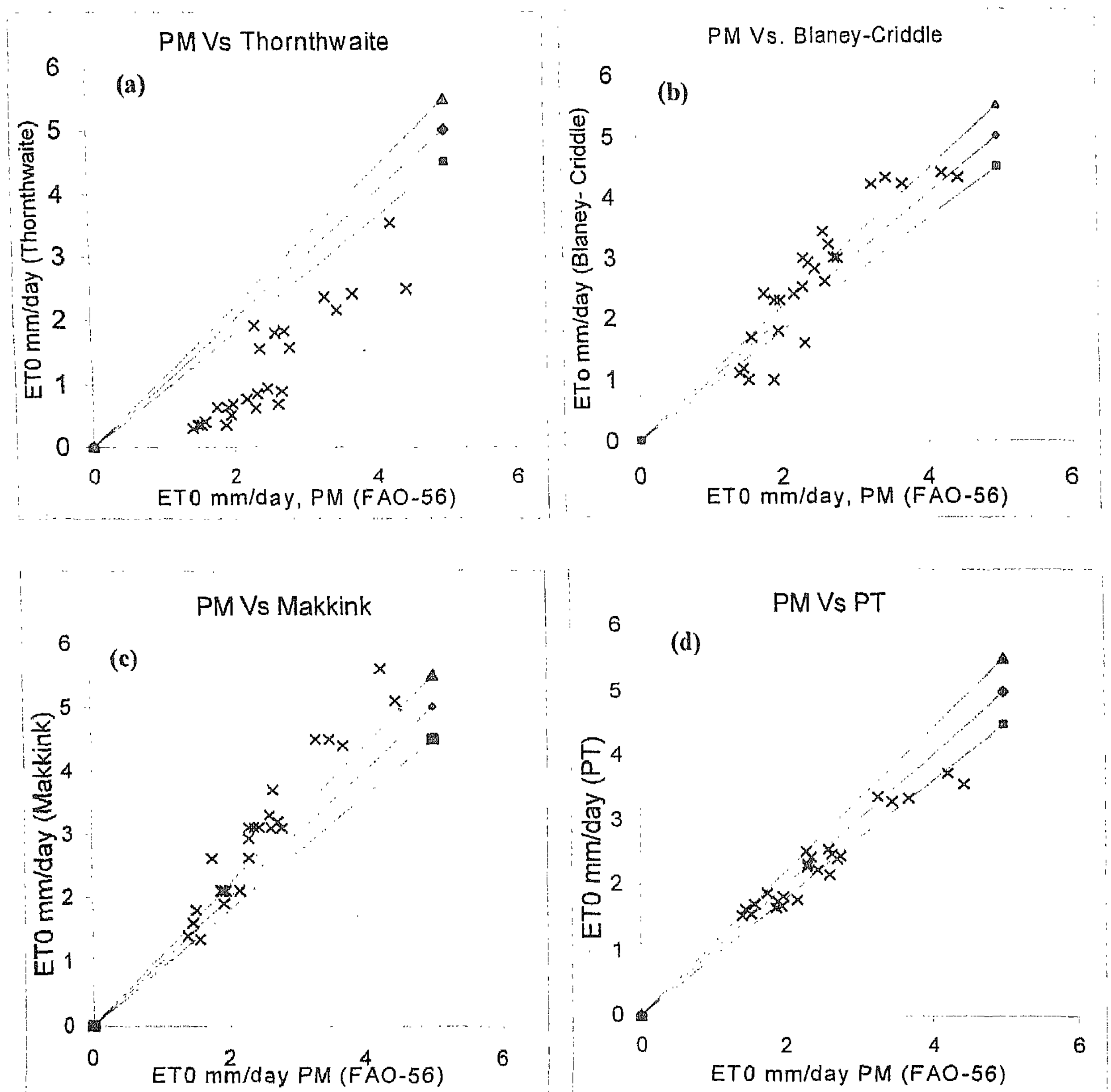

Fig. 3. Comparison between ETO estimated during *rabi* (November-March) season by Penman-Monteith method and (a) Thornthwaite (b) Bcd (Bcd), (c) Makkink's and (d) Priestley-Taylor (PT) method

method and promising for estimation of ETO over large area. PT method estimates ETO at par with PM method because of use of similar inputs like temperature, net radiation, ground heat flux and altitude. In addition, PM method requires saturated vapour pressure at different level. Hence, for semi arid condition like Delhi, the Makkink's and Blaney-Criddle methods are good option.

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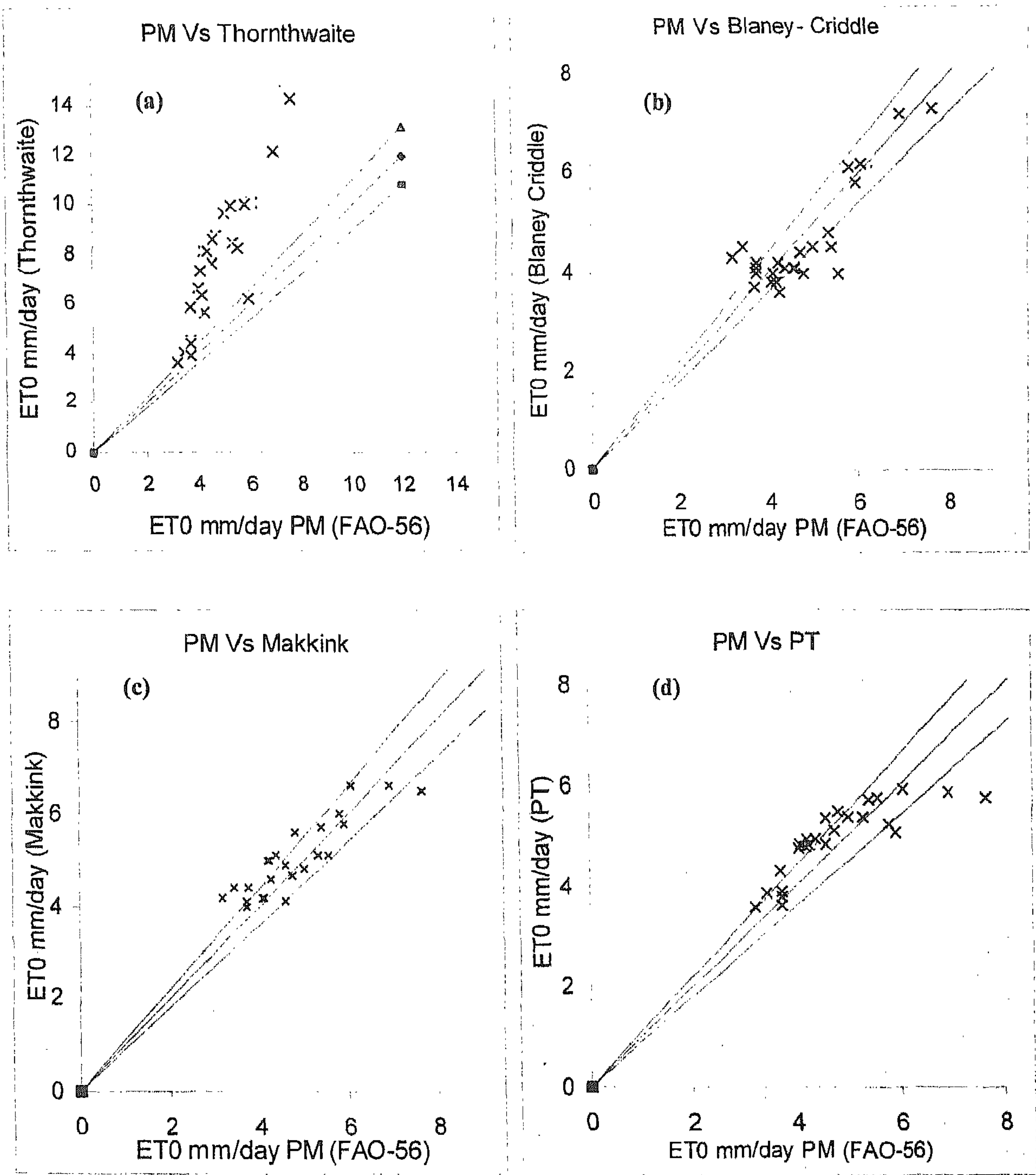

Fig. 4. Comparison between ETO estimated for *kharif* (June-October) season by Penman-Monteith method and (a) Thornthwaite (b) Bcd (c) Makkink's and (d) Priestley-Taylor (PT) method

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Table 2. Coefficient of variation (%) of ET0 estimated by different methods

	Tht	Bcd	Makkink's	PT	PM
Jan	17.0	24.5	13.0	4.2	12.2
Feb	15.4	18.1	2.6	2.5	5.7
Mar	4.6	1.2	10.3	3.1	14.7
Apr	8.5	6.1	2.1	1.4	10.7
May	9.6	7.4	4.4	4.0	11.1
Jun	11.4	17.2	9.5	4.8	9.9
Jul	24.7	24.7	13.1	5.2	23.6
Aug	5.4	1.2	12.0	7.3	10.5
Sep	6.0	20.1	13.6	5.2	17.5
Oct	7.9	4.1	3.2	3.3	6.0
Nov	8.3	5.7	7.9	2.3	7.7
Dec	19.1	11.9	19.5	3.0	10.8

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