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Research Paper :

Comparison of several reference evapotranspiration methods for hot and humid regions in Maharashtra

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ABSTRACT

The accurate estimation of reference crop evapotranspiration (ETo) in the water balance or irrigation scheduling allows us to improve the crop water management practices. The present study was planned to estimate the reference crop evapotranspiration (ETo) with four different evapotranspiration estimation methods *viz.*, Pan Evaporation, Blaney-Criddle, Hargreaves- Samani and Priestly-Taylor. These methods were then compared with FAO Penman - Monteith (FAO-56) to test capabilities to predict daily ETo under the given climatic conditions of southern hot and humid region of *Konkan* platue in Maharashtra state. Daily weather data of Shindhudurg region for 15 years was used for the analysis. The estimated ETo and statistical parameters based on coefficient of regression, root mean square error and average deviation indicated that Blaney-Criddle is the most reliable and accurate methods for estimation of ETo for Konkan region of Maharashtra. Under the unavailability of data on all weather parameters the preference for ETo estimation method for Konkan region should be Blaney-Criddle, Hargreaves-Samani, Pan evaporation and Pristley-Taylor.

Key words : Reference crop evapotranspiration,estimation methods, Weather data, water balance, Root mean square error, Correlation coefficient and average deviation

Being an agricultural based country, agriculture sector plays a dominating role in Indian economy. Major source of water for agriculture in the country is the rainfall, which receives mostly from South West monsoon during the period from June to September. However, uneven and erratic nature of rainfall necessitates the use of irrigation water more efficiently to avoid the loss of crop yields. Evapotranspiration is one of the major hydrological components for water resource assessment and budgeting. Hence reliable and consistent estimate of evapotranspiration is necessary in the context of many issues, for example, crop production, efficient management of water resources, scheduling of irrigation, evaluation of the effects of changing land use on water resources and environmental assessments. Similarly efficient irrigation management requires exact quantification of evapotranspiration

Reference crop evapotranspiration (ETo) is defined by several workers (Jensen *et al.*, 1990; Smith *et al.*, 1992) as the rate of evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water. Since, direct measurement of ETo for short grass is difficult, time consuming and costly, the most practical approach would be to estimate ETo from climatic variables, such as solar radiation, air temperature, relative humidity and wind speed. Several methods were developed to estimate reference crop evapotranspiration from climatological data involving equations ranging from the most complex energy balance methods requiring detailed climatological data (Allen *et al.*, 1989) to simpler methods requiring less data (Hargreaves and Samani, 1982; Samani, 1985). Some of these methods need several weather parameters as input while others need fewer. Among the methods of evapotranspiration estimation some techniques have been developed partly in response to the availability of data (Lee *et al.*, 2004).

FAO Penman-Monteith (F-PM) method is preferred as the standard and accurate method for daily ETo estimation (Jensen *et al.*, 1990; Allen *et al.*, 1998). However, the major constraint of this method is the requirement of extensive weather data such as air temperature, relative humidity, wind speed and solar radiation which could not be easily available at many places. In addition to the use of complicated unit conversions and lengthy calculations, the reliable quality data and difficulties in data collection present another serious limitation for this method.

In contrast, there are other methods requiring data on only one or two weather parameters and give comparatively better ETo estimates such as Thornthwaite requiring monthly average air temperature and

Hargreaves requiring only temperature and incident radiation. However, Thornthwaite method overestimates ETo in arid regions (Mintz and Walkar, 1993), underestimates (Rosenberg *et al.*,1983; Mckenny and Rosenberg, 1993) and gives remarkable inconsistence estimates in winter (Tsutsumi *et al.*, 2004). The reliable assumption that temperature is an indicator of the evaporative power of the atmosphere is the basis of these temperature-based methods. Although temperature based methods are useful when data on other meteorological parameters are unavailable, the estimates produced are generally less reliable than those, which take other climatic factors into account. Blaney-Criddle and, to a lesser extent, Hargreaves are most sensitive to temperature change (Mckenny and Rosenberg, 1993) while their relative sensitivity varies with location and time of year. Roy and Ahmed (1999) used Blaney-Criddle method to Selangor state of Malaysia for irrigation simulation of various crops just because it is a simpler method for estimation. Modified Blaney-Criddle method (Allen and Pruitt, 1986) is not merely the temperature based method since it uses temperature, minimum relative humidity, day time wind speed and day length as a function of latitude and time of the year (Maidment, 1992).

Hargreaves method (Hargreaves, 1994) also was found to give nearly accurate estimates as that of F-PM method. In a comparative study of different methods (Thornthwaite, Blaney-Criddle, Hargreaves, Samani-Hargreaves, Jensen-Haise, Priestley-Taylor, Penman and Penman- Monteith) for North American Great Plains it was observed that Thornthwaite produced the lowest annual values whereas Penman the highest (Mckenny and Rosenberg, 1993). Jensen-Haise gave relatively low estimates of ETo, followed by Blaney-Criddle, Priestley-Taylor, Hargreaves, and Hargreaves- Samani. The Penman-Monteith method gave values, which are second highest than those of the other methods.

Chhabda *et al.* (1986) reported that reference evapotranspiration by modified Penman and Hargreaves methods have been found to be highly significant in Maharashtra, India. Priestley-Taylor was also found to underestimate potential evapotranspiration, particularly under advective conditions. This equation is similar to the Penman and Penman-Monteith formulations, with the exception that mass transfer effects are represented by a constant value, rather than computed from information on wind speed, humidity, and vegetation characteristics. Gunston and Batchelor (1983) found that the estimates from Priestley-Taylor and Penman methods agree closely when monthly rainfall exceeds monthly evapotranspiration within the latitude zone of 25°N to 25°S.

The pan evaporation method for practical irrigation scheduling is well recognized which sometimes provide more satisfactory means of estimating evapotranspiration of crops under flooded conditions than any other available techniques. It is also reported that pan evaporation is a more satisfactory method of estimating reference evapotranspiration than other methods for rice (Azar *et al.*, 1992).

Although, many approaches have been developed and applied for various applications based on available input data, there is still a remarkable range of uncertainty related to which method is to be adopted for the estimation of ETo. The applicability of different methods under varying climatic conditions have given confusing results. Before recommending a method to a particular location, the estimating capability of these methods needs to be verified. Therefore, the main aim of this study was to test the various evapotranspiration methods in hot and humid region of Konkan in Maharashtra state whose meteorological properties are characterized as having high humidity and heavy precipitation. This study compares the estimated evapotranspiration by Pan Evaporation (Epan), Hargreaves-Samani (H-S.), Blaney-Criddle (B-C), Priestly Taylor (P-T) and FAO Penman - Monteith (F-PM) to find out an easy but accurate method.

METHODOLOGY

Study area and data

The Shindhudurg region of Konkan platue was selected for the study which is hot and humid monsoon region covering a gross area of 5270 sq. km. It is located at 16^0 00'N to 16^0 05' N latitude and 73^0 25'E to 73^0 30'E longitude at an altitude of 38 m above mean sea level. The topography of the region is undulating and steep valley with dense forest cover. The climate is cold and dry in typical winter season, with low intensity of north - eastern wind (November to February) and hot dry season from March to May followed by rainy season (June to September). Average annual rainfall of the region is 2275 mm which mostly occurs during rainy season (June to October). The average atmospheric temperature ranges from a minimum of 13.5^0C to a maximum of 33.1^0 in June and May, respectively. The average relative humidity varies from 69.4 per cent in April to 98 per cent in July.

Daily data on temperature (maximum and minimum), relative humidity (maximum and minimum), wind speed, solar radiation, sunshine hours, atmospheric pressure and pan evaporation for a period of 15 years from 1991-2006 was collected from Water Resources Department, Hydrology Project (Surface Water), Government of Maharashtra, Nashik (India). The data was used for the estimation of reference crop evapotranspiration by different methods.

Evaluation of ETo estimation methods:

Five different reference evapotranspiration estimation methods that are commonly used were selected for the study. Out of them Blaney-Criddle and Hargreaves-Samani were temperature based methods. Maidment (1992) reported that the Blaney-Criddle and Hargreaves-Samani equations are recommended only for the purpose of evapotranspiration estimation based on temperature. Blaney-Criddle method uses the monthly climatic values which were calculated using the daily values. Hargreaves-Samani needs information on latitude and time of the year to represent the latitudinal and seasonal variation of the incoming solar radiation. The remaining three methods *viz.*, FAO Penman-Monteith (FAO-56), Priestley- Taylor and Pan Evaporation methods are combination methods since they combine the effects of both radiation and mass transfer on reference evapotranspiration. Pristley-Taylor is a simplified combination equation which uses an empirical coefficient to account for mass transfer effects. FAO Penman-Monteith is the most soundly based on the physical principles and includes both climatic and vegetation characteristics in quantifying mass transfer effects.

The input data required for estimation of ETo by different evapotranspiration estimation methods is shown in Table 1 and the equations used to estimate ETo are described in the succeeding section.

Equation used for estimation of (ETo):

Pan evaporation model (Epan):

$$ET_0 = E_{pan} \times K_p \quad \ldots \quad (1)$$

where, ET_o=Reference evapotranspiration, mm/day; K_p = Pan coefficient, (0.7); and E_{pan} = Pan evaporation, mm/day.

Hargreaves - Samani (H-S) model:

$$ET_0 = 0.0023\,(T_{mean}+17.8)\,(T_{max} - T_{min})\,0.5\,R_a \quad \ldots(2)$$

where, ETo = Reference evapotranspiration, (mm/day); T_{mean}= Mean air temperature (°C); T_{max} = Daily maximum temperature, (°C); T_{min} = Daily minimum temperature, (°C) and R_a is extraterrestrial radiation [MJ m^{-2} day^{-1}]. The mean air temperature in the Hargreaves-Samani equation is calculated as an average of T_{max} and T_{min} and R_a is computed from information on location of the site and time of the year. Therefore air temperature is the only parameter that needs to be measured continuously in order to use Eq. (2).

Blaney - Criddle model (B-C):

$$ET = K * f \quad \ldots (3)$$
$$f = T * P / 100$$

where, K = Empirically determined crop coefficient, f = Consumptive use factor, T = Mean monthly temperature, (°F); and P = Monthly percentage of annual daytime, hours

FAO Penman Monteith (F-PM, FAO56):

The FAO Penman-Monteith method is recommended as the most accurate method for estimating reference evapotranspiration.

$$ETo = \frac{0.408\Delta(R_n - G) + ¥\,\frac{900}{T+273}(e_s - e_a)}{\Delta + ¥\,(1+0.34\mu_2)} \quad \ldots (4)$$

where, ET_o = Reference evapotranspiration, (mm/day); R_n = Net radiation at the crop surface, (MJ/m²/day); G = Soil heat flux density, (MJ/m²/day); T = Mean daily air temperature at 2 m height, (°C); u_2 = Wind speed at 2 m height, (m/s); e_s = Saturation vapor pressure, (k Pa); e_a = Actual vapour pressure, (k Pa); e_s - e_a = Saturation vapour pressure deficit, (k Pa); Δ = Slope of vapour pressure curve, (k Pa/°C); and γ=Psychometric constant,

Table 1 : Input data required for estimating ETo by each empirical formulae

Method	Meteorological data required							Temporal resolution of data
	T	Rs	RH	U	n	P	D	
Pan method			x	x			x	Daily
Blaney-criddle	x		x	x	x			Daily
Samani-hargreaves	x							Daily
Penman– monteith (FAO – 56)	x	x	x	x		x		Daily
Priestly-taylor	x	x						Daily

where, D- Pan evaporation(mm), n- Sunshine hours (Hrs), P- Atmospheric pressure (Kpa), RH- Relative humidity (%), Rs –Solar radiation (Hrs), T-Temperature (°c), U-Wind speed (m/sec).

(k Pa/ °C).

In application having 24 hour calculation time steps, G is presumed to be zero and e_s is computed as:

$$e_s = \frac{e^0 (T_{max}) + e^0 (T_{min})}{2} \quad \text{... (5)}$$

where, e^0 is the saturation vapour function and T_{max} and T_{min} are the daily maximum and minimum air temperature. The FAO Penman-Monteith equation predicts the evapotranspiration from a hypothetical grass reference surface that is 0.12 m in height having a surface resistance of 70 s m^{-1} and albedo of 0.23. The equation provides a standard to which evapotranspiration in different periods of the year or in other regions can be computed and to which the evapotranspiration from other crops can be related. The standardized equations for computing each of the parameters in equation (4) are described in Allen *et al.* (1998) and Smith *et al.* (1992).

Priestly taylor:

$$ET_0 = \alpha \frac{\Delta (Rn - G)}{\Delta + \gamma} \quad \text{... (6)}$$

where, α = 1.26 in both cases, γ = Psychometric constant, (k Pa /^{0}c), G = Soil heat flux, Rn = Net radiation flux, (MJ $m^{-2} day^{-1}$) and Δ = Slop at saturation vapor pressure at air temperature, (k Pa /^{0}c).

The daily reference crop evapotranspiration (ETo) was estimated by these five methods and the daily ETo of 15 years were used to calculate weekly and monthly average ETo. In case of Blaney-Criddle method the equation was used to calculate monthly ETo. The monthly average values required for this method were calculated from the available daily data. The ETo estimates by four methods namely; Pan Evaporation, Hargreaves-Samani, Blaney-Criddle, and Priestley-Taylor were then compared with the ETo estimates of FAO Penman Monteith (F-PM) method.

Statistical analysis:

The performance of each ETo estimation method was compared with ETo estimates of F-PM for the period for their accuracy using coefficient of correlation (R^2), average deviation (D) and root mean square error (RMSE). The correlation coefficient close to one shows better calibration, agreement and accuracy of the estimation method when compared to F-PM method. RMSE reflects the estimated sensitivity and extreme effect of samples, smaller value means more accuracy. The best method is the one with highest R^2, smallest RMSE and smallest (D).

Coefficient of correlation (R^2):

$$R^2 = \frac{[(Xi - X)(Yi - Y)]^2}{[(Xi - X)^2 (Yi - Y)]^2} \quad \text{... (7)}$$

where, Xi and Yi = i^{th} actual and estimated data, X and Y = Average of the data arrays of Xi and Yi

Root mean square error (RMSE):

$$RMSE = \sqrt{\frac{\sum (Pi - Oi)}{N}} \quad \text{... (8)}$$

where, N = Number of observations; Pi = ETo estimated by different methods and Oi = ETo of F-PM method

Average deviation:

$$\overline{D} = \frac{\sum_{i=1} |Pi - Oi|}{n} \quad \text{(9)}$$

where P_i is the estimated ETo values by four methods ; O_i is the ETo value computed by F-PM method and n is the number of observations.

RESULTS AND DISCUSSION

The average daily ETo values estimated by different methods are depicted in Fig. 1. The ETo estimated by Priestely-Taylor (PT) and Hargreaves-Samani (HS) gave significantly higher values as compared to other estimation methods thoughout the year. The remaining methods showed lower values and there was no significant difference between them (P= 0.05). The Penman method estimated lowest values throughout the year except during the MW 25 to 42. During MW 25 to 44 F-PM method estimated the lowest ETo values (Fig. 1). The annual average daily ETo values estimated by Pan (Epan), Blaney-Criddle, FAO Penman Mointeith (F-PM), Hargreaves–Samani and Priestly-Taylor methods are 2.27, 2.97, 2.78, 3,27 and 3.84 mm, respectively. The ETo estimated by standard method F-PM matches well with BC method for the initial period of the year (MW 1 to 24) where BC method underestimates ETo whereas for the later period of the year BC method overestimates ETo as compared to F-PM method. For the later period of the year during MW 23 to 52 the ETo estimated by Epan method are closer with the values of F-PM method (Fig. 1). This is in conformity with the results of Khodke and Gundekar (2009) and Rao and Rajput (1993). The HS method slightly overestimates ETo as compared to ETo of F-PM method.

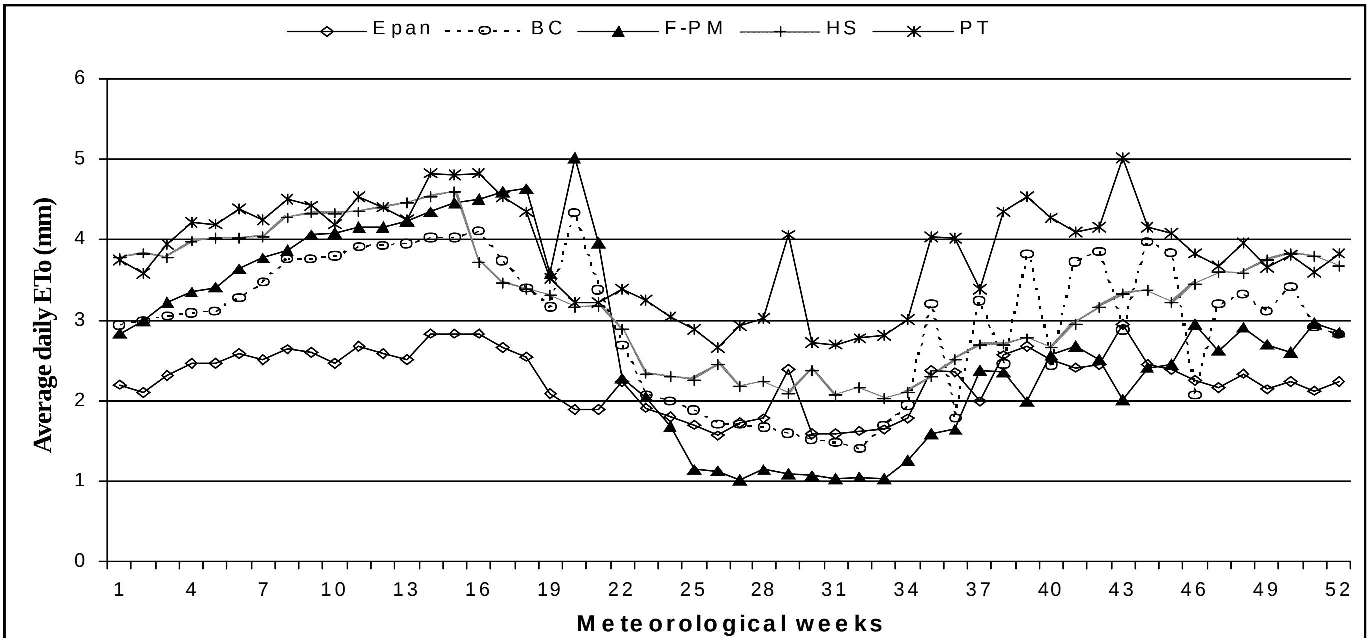

Fig. 1: Week-wise daily ETo estimated by different methods at Shindhudurg

The average daily ETo values estimated by different methods for various months also show the similar trend (Fig. 2). The ETo estimates by FAO Penman-Monteith (F-PM) during June to December months are less than the ETo of all other methods which could be due to low radiation and sunshine hours. The ETo estimated by BC method are better matching with ETo of F-PM method during the months of January to May. However during the remaining months ETo estimated by Epan method matches well with ETo of F-PM months. In both Fig. 1 and 2, PT method overestimated ETo when compared to ETo estimates of F-PM method. HS also overestimated ETo but with slight difference. The results show that Pan Evaporation and Blaney-Criddle method is equally better to FAO Penman Monteith method for the study area. ETo estimation methods in order of preference as BC, HS and Pan Evaporation requiring only one weather parameter seem to be more suitable in hot and humid region of the Maharashtra state.

The ETo estimated by different methods is compared

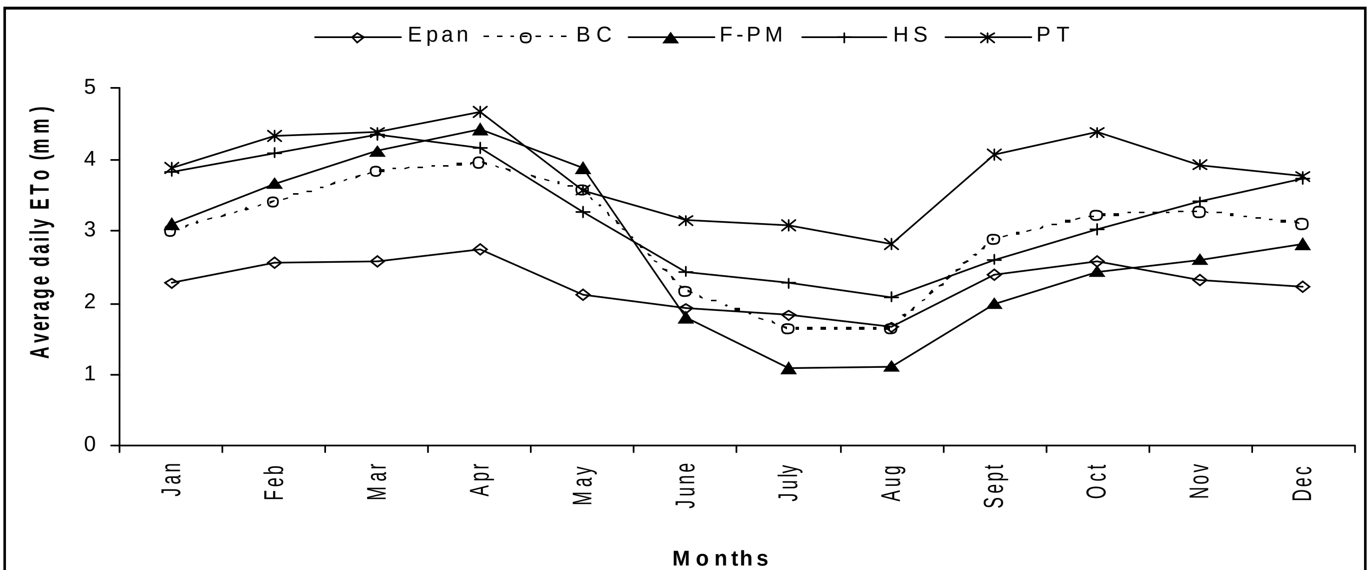

Fig. 2 : Month-wise daily ETo for the study area

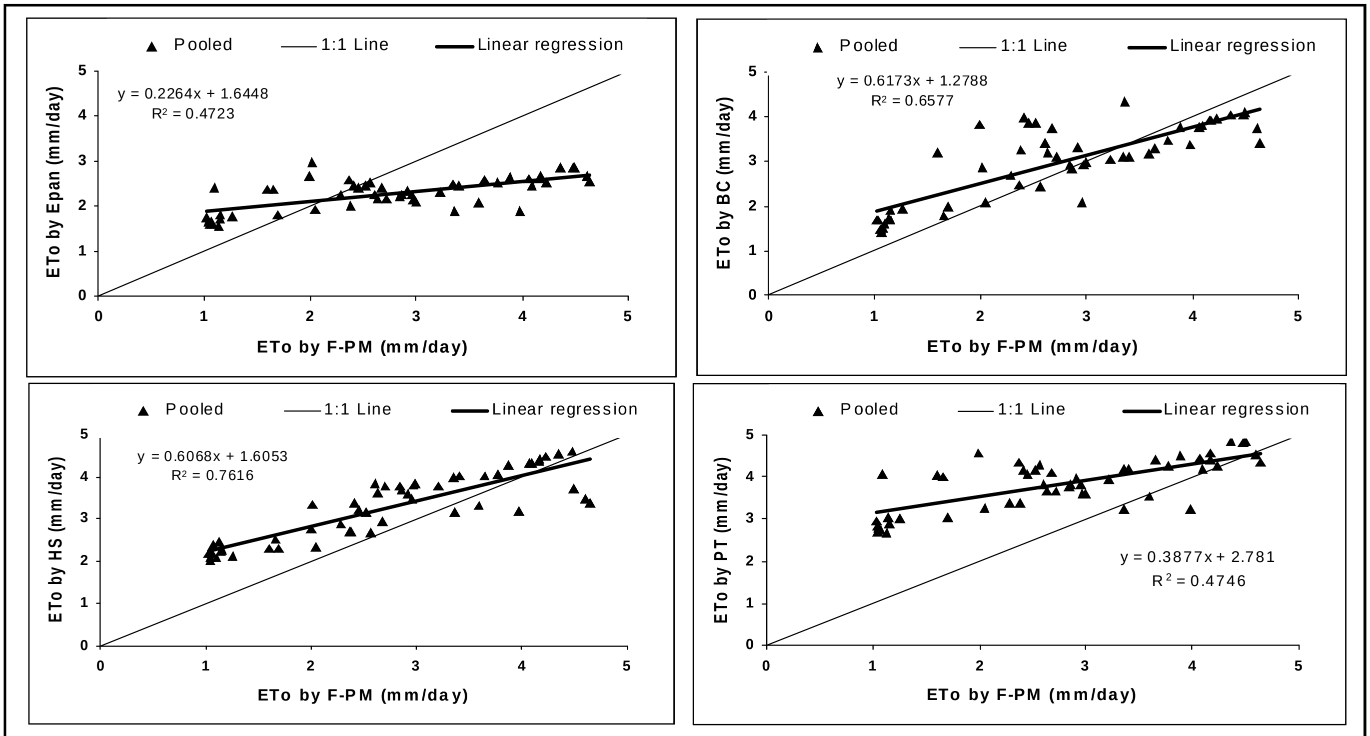

Fig. 3 : Comparison of weekly ETo estimates of different methods with F-PM method

Table 2 : Weekly statistical analyses between the F-PM method and other methods of ETo for period 1991 to 2006

Estimation method	Regression equation	R^2	RMSE (mm/day)	Average deviation (mm/day)
Epan	y = 0.2264x + 1.6448	0.47	1.03	0.86
BC	y = 0.6173x + 1.2788	0.66	0.70	0.55
HS	y = 0.6068x + 1.6053	0.76	0.79	0.70
PT	y = 0.3877x + 2.781	0.44	1.38	1.15

with ETo estimates of F-PM method and shown in Fig. 3. The ETo estimated by BC method are well distributed around 1:1 line indicating its better performance whereas PT method overestimated ETo values. Epan method overestimates ETo for the range below 2 mm and underestimates ETo beyond the value of 2mm (Fig.3).

The different ETo estimation methods were also evaluated for their capabilities to predict ETo based on the statistical parameters. The performance of each method in estimating ETo was compared with F-PM method using RMSE, average deviation and coefficient of correlation. The values of coefficient of correlation (R^2), root mean square error (RMSE) and average deviation for each method are shown in Table 2. The data shown in Table 2 indicate that BC method gives better performance on the basis of RMSE and average deveiation as compared to other methods although R^2 value is less than that in HS method. HS method overestimated ETo for greater range of ETo values. This corroborates with the earlier results of Temesgen *et al.* (2005) who indicated that high humidity conditions may result in an overestimation of ETo by HS method whereas high wind speed may result in under estimation of ETo.

Therefore, it could be recommended to use Blaney-Criddle method followed by Hargreaves- Samani method in case the data on all weather parameters is not available in hot and humid region of Maharashtra.

Conclusion:

The ETo estimates by all methods used for analysis results the same trend throughout the year. The reference evapotranspiration (ETo) estimated by five methods shows that maximum ETo values were observed in the months of March to May and the minimum ETo values were found in the months of June to September.

The BC method is the most reliable method for estimating ETo in hot and humid region of Maharashtra when compared to FAO Penman Monteith method. This method can be efficiently used in case the data on all weather parameters is not available. However, for daily ETo estimates HS method may be conveniently used as substitute to F-PM method.

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