

Comparison of Reference Evapotranspiration Determining Methods Using Climatic Data of Pusa

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ABSTRACT

A study was carried out for comparison of reference evapotranspiration by different methods under agro climatic condition of Pusa (North Bihar). Reference evapotranspiration (ET_o) values were computed by thirteen different methods using DSS-ET model and the estimates were compared with ET_o values of FAO-56 Penman Monteith method by developing relationships between mean daily ET_o of each method with FAO-56 Penman Monteith method. Besides, regression analysis and an indicator namely standard error of estimate (SEE) were evaluated. The method resulting lesser values of standard error of estimate (SEE) was considered as the better method after FAO 56- Penman Monteith method for this region. Mean monthly daily ET_o computed by different methods ranged from 4.0 mm day^{-1} (FAO 56-PM) to 5.0 mm day^{-1} (1972 KP). The results revealed that mean monthly daily ET_o values of all the methods, overestimated the ET_o values obtained from FAO 56- Penman Monteith ET_o except Hargreaves and Turc method. Amongst them, ET_o values obtained from Penman Monteith ($SEE= 0.06 \text{ mm day}^{-1}$) and Penman 1963 VPD#1 ($SEE= 0.07 \text{ mm day}^{-1}$) were strongly correlated to the standard method and thus assigned 2nd and 3rd ranks, respectively whereas Hargreaves method yielded highest value of SEE (0.60 mm day^{-1}) with poorest rank (11th) for this region. Using the developed relationships ET_o values of any applicable method can be converted into standard method estimates for this region that will help in irrigation scheduling, crop water modeling and management of water resources.

Keywords

ET_o methods, Humid, Reference evapotranspiration, Standard error of estimate.

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Introduction

Estimation of water need of crops is essential for good planning and management of water resources for irrigated agriculture. Efficient irrigation water management requires a good quantification of evapotranspiration. Irrigation futures aim to identify an appropriate model for the calculation of reference crop evapotranspiration. Water consumption of crop must be adjusted according to climatic conditions.

The evaporative power of the atmosphere is expressed by the reference evapotranspiration which is one of the methods to quantify the estimates of water demand. Reference evapotranspiration is the water removed by the reference crop/surface in the process of evaporation and plant transpiration. For efficient agricultural water management, it is essential to estimate reference crop evapotranspiration.

Several empirical relationships have been developed by many researchers worldwide to estimate reference crop evapotranspiration using climatic data (Itenfisu *et al.*, 2003; Singandhupe and Sethi, 2004; Berengena and Gavilan, 2005; Lakshaman and Kovoov, 2005; Thakur and Spehia, 2006). Hussein and Junmin (2013) and Patel *et al.*, (2017) estimated reference crop evapotranspiration (ET_o) using software. George *et al.*, (2002) used DSS model to compare the estimates of different methods with the Penman- Monteith method. The DSS_ET model determines reference evapotranspiration and includes decision-making capabilities for selecting the best ET_o estimation method among all applicable methods for a given location and data availability condition. Meteorological data requirement differs for different ET_o methods which decides applicability of method for ET_o estimation for available data set. Thus the model take into consideration both climatic condition and data availability in ranking ET_o estimation methods. Accordingly daily or monthly ET_o estimates of applicable methods can be converted into standard method estimate.

In this study an attempt has been made to calculate reference crop evapotranspiration (ET_o) by different methods using DSS_ET model and compared with that of FAO 56-Penman Monteith method (Smith *et al.*, 1991, Rohitashw *et al.*, 2011) under humid conditions of Pusa.

Materials and Methods

Study area and meteorological data collection

In order to estimate daily reference evapotranspiration (ET_o), the daily meteorological data available for the period of 5 years were collected from meteorological observatory located in Rajendra Agricultural

University, Pusa (Bihar). These meteorological data include daily minimum and maximum temperature, minimum and maximum relative humidity, wind speed, sunshine hour and rainfall which were further converted into mean daily values and used in computations. The mean weekly values of meteorological parameters have been presented in figure 1 which indicated that weekly minimum temperatures during the study period varied from 8.5⁰ C (1st standard week) to 27.5⁰ C (29th to 33rd weeks) and maximum temperature ranged from 19.7⁰ C (52nd and 1st weeks) to 36.0⁰ C (16th, 20th and 22nd weeks). Weekly minimum and maximum relative humidity ranged from 35.9 % (13th week) to 75.5% (34th week) and 74.1 % (17th week) to 91.1% (51st week), respectively whereas wind speed varied from a minimum of 0.6 ms⁻¹ (45th and 50th weeks) to a maximum of 2.2 ms⁻¹ (24th week). Total daily sunshine hour was found minimum as 3.2 hours (28th week) and maximum as 8.9 hours (15th and 16th weeks) whereas day length ranged from 10.2 to 13.75 hours.

The area concern is situated on the bank of river Burhi Gandak at 25.98⁰ N latitude, 85.67⁰ E longitude and at an elevation of 52.0 m from mean sea level. Soil of the study area is sandy clay loam (sand 61.5%, silt 25.5%, caly13%) with infiltration rate 2.5 cmhr⁻¹, field capacity 22%, wilting point 7.2% and average available moisture content of 14.8 cmm⁻¹. Water table fluctuates between 1.0 to 6.0 m depending upon rainfall pattern and pumping rate. The climate of the area is humid sub-tropical with an average annual rainfall of 1270 mm out of that 80.75% occurs during monsoon months.

Computation and comparison of reference evapotranspiration (ET_o)

Present study was carried out for estimation of daily reference crop evapotranspiration

(ET_o) for Pusa (Bihar) using DSS_ET model. The model supports twenty two ET_o methods recommended by ASCE out of which thirteen methods were applicable for the available meteorological data/ information for Pusa farm. The methods used were grouped according to their classification as (1) Combination methods such as FAO 56-Penman Monteith, Penman-Monteith, 1982 Kimberley Penman, FAO PPP-17 Penman, Penman VPD#1, Penman VPD#3, 1972 Kimberley Penman, FAO 24-Penman (C = 1), Businger-van-Bavel and CIMIS Penman (2) Radiation methods such as Turc and Priestly-Taylor and (3) Temperature method such as Hargreaves.

The FAO 56-Penman Monteith (Allen *et al.*, 1998) has been used as an index method. This method is a grass reference equation derived from the ASCE equations by fixing grass height = 0.12 m for clipped grass using latent heat of vaporization (λ) = 2.45 MJ kg⁻¹; bulk surface resistance of 70 sm⁻¹ and albedo of 0.23 and the equation to compute daily ET_o (mm day⁻¹).

Daily reference evapotranspiration (ET_o) values obtained from each method were converted into mean daily ET_o (mm day⁻¹) values. ET_o values of all the twelve methods (except FAO-56 Penman monteith) were compared with the ET_o values of FAO 56-Penman Monteith method and regression analysis was done with an attempt to develop relationships between ET_o estimates of each method versus FAO 56- Penman Monteith method. Various statistical parameters such as long term average ratio of ET_o (any method)/ET_o (FAO 56-PM), coefficient of determination (R²), standard deviation (S_d), coefficient of variation (C_v) and standard error of estimate (SEE) were evaluated to know the closeness of ET_o estimates of all the methods with respect to the FAO 56-Penman-Monteith method.

Performance evaluation of ET_o methods

Performance of all the methods (except FAO 56-PM) has also been evaluated by assigning ranks on the basis of standard error of estimate (SEE). Standard error of estimate (SEE) of mean daily ET_o values between the FAO-56 Penman-Monteith method and all the other methods were computed as:

$$SEE = \sqrt{\frac{1}{n(n-2)} \left[n \sum y^2 - (\sum y)^2 - \frac{\{n \sum xy - (\sum x \sum y)\}^2}{n \sum x^2 - (\sum x)^2} \right]}$$

Where, x = ET_o estimated by FAO 56-Penman Monteith method (mm day⁻¹), y = ET_o estimate of other methods (mm day⁻¹) and n = data sample size, 365

Standard error of estimates (SEE) was used as a mathematical tool to assign rank to ET_o methods. The ET_o method resulting lesser values of SEE was considered as the better method after FAO 56-Penman Monteith for this region whereas the ET_o methods having similar values of SEE were assigned the same rank.

Results and Discussion

Mean monthly daily ET_o estimates of different methods and their trends of variation

Daily ET_o was computed by thirteen different methods and mean monthly daily ET_o (mm day⁻¹) values of each method have been presented in Table 1. Mean monthly daily ET_o computed by different methods ranged from 4.0 mm day⁻¹ (FAO 56-PM) to 5.0 mm day⁻¹ (1972 KP). The results revealed that mean monthly daily ET_o values of all the methods, overestimated the ET_o values obtained from FAO 56-Penman Monteith ET_o except Hargreaves and Turc method and followed the same trend of variation in different

months. Jensen *et al.*, (1990) in Irmak *et al.*, (2003) also reported an overestimation of combination methods ETo with ET values measured from lysimeter. However, in this study, overestimation of mean monthly daily ETo values ranged from 0.8 % (Turc) to 40.5 % (Hargreaves) whereas under estimation ranged from 2.1 % (Turc) to 6.8% (Hargreaves). Over estimation of ETo values of all the methods were found greater during the winter months (November to February) followed by summer (March to May) and monsoon months (June to October) except in case of 1982 Kimberly Panman and Businger-van-Bavel method which have shown reverse results as compared to the other methods.

ETo values of Penman-Monteith and Penman 1963 VPD#1 were observed to be very close to FAO 56-Penman Monteith method as compared to other methods. An increase of 0.1 mm day⁻¹ was observed in Penman Monteith ETo that might be due to use of variable value of daily latent heat of vaporization (λ), bulk surface resistance and aerodynamic resistance. Penman 1963 VPD#1 produced significantly improved estimates of daily ETo than 1963 Penman VPD#3 due to use of vapour pressure deficit based on daily minimum and maximum temperature rather than using mean temperature. The 1963 Penman VPD#3 method also resulted in remarkably good estimates of mean monthly daily ETo and paralleled FAO-56 Penman-Monteith ETo fairly well throughout the year. Itenfisu *et al.*, (2000) in Irmak *et al.*, (2003) reported the same findings when compared with FAO 56-PM method and followed similar ETo trends in their study.

Relationship between ETo computed by any method with FAO 56- Penman Monteith method and performance of ETo Methods

Regression analysis was done to develop relationship between mean daily ETo

estimates (mm day⁻¹) computed by 12 different methods (except FAO 56-PM) and FAO 56-Penman-Monteith method that have been represented graphically in figures 2 to 7 along with linear equations and coefficient of determination (R^2). Various statistical parameters such as long term average ratio of ETo (any method) / ETo (FAO 56-PM), standard deviation (S_d), coefficient of variation (C_v) and standard error of estimates (SEE) were computed to know the closeness of ETo estimates of all the methods with respect to the FAO 56-Penman-Monteith method and the values have been given in Table 2. It is evident from Table 2 that coefficient of variation of ETo methods shows high value which was due to significant influence of total sunshine hours, wind speed and humidity. Figure 2 revealed that, ETo estimates of Penman Monteith ($R^2 = 0.99$) and Penman 1963 VPD#1 ($R^2 = 0.99$) shows strong correlation with FAO 56-Penman Monteith method and due to lower values of SEE (0.06 mm day⁻¹ and 0.07 mm day⁻¹, respectively) they were assigned 2nd and 3rd rank for this region. Again, it is obvious from figure 3 that FAO 24 Penman ($C=1$) with $R^2 = 0.98$ and FAO PPP-17 Penman method with $R^2 = 0.98$ performed well because the FAO 24 Penman ($C=1$) uses a more sensitive wind function than other Penman equations whereas FAO PPP-17 Penman uses wind functions depending upon temperature difference.

Both the methods had same SEE value of 0.13 mm day⁻¹ thus ranked fourth (Table 2). Coefficient of determination of 1963 Penman VPD#3 method and CIMIS Penman were 0.97 and 0.96, respectively (Fig. 4) with SEE values of 0.14 mm day⁻¹, 0.17 mm day⁻¹ thus ranked fifth and sixth (Table 2) as the method CIMIS Penman used a fixed value of wind function coefficient as $a_w = 0.29$ and $b_w = 0.53$ for $R_n > 0$ and $a_w = 1.14$ and $b_w = 0.40$ for $R_n \# 0$ and assuming soil heat flux as zero ($G=0$).

Fig.1 Variation of mean weekly meteorological parameters

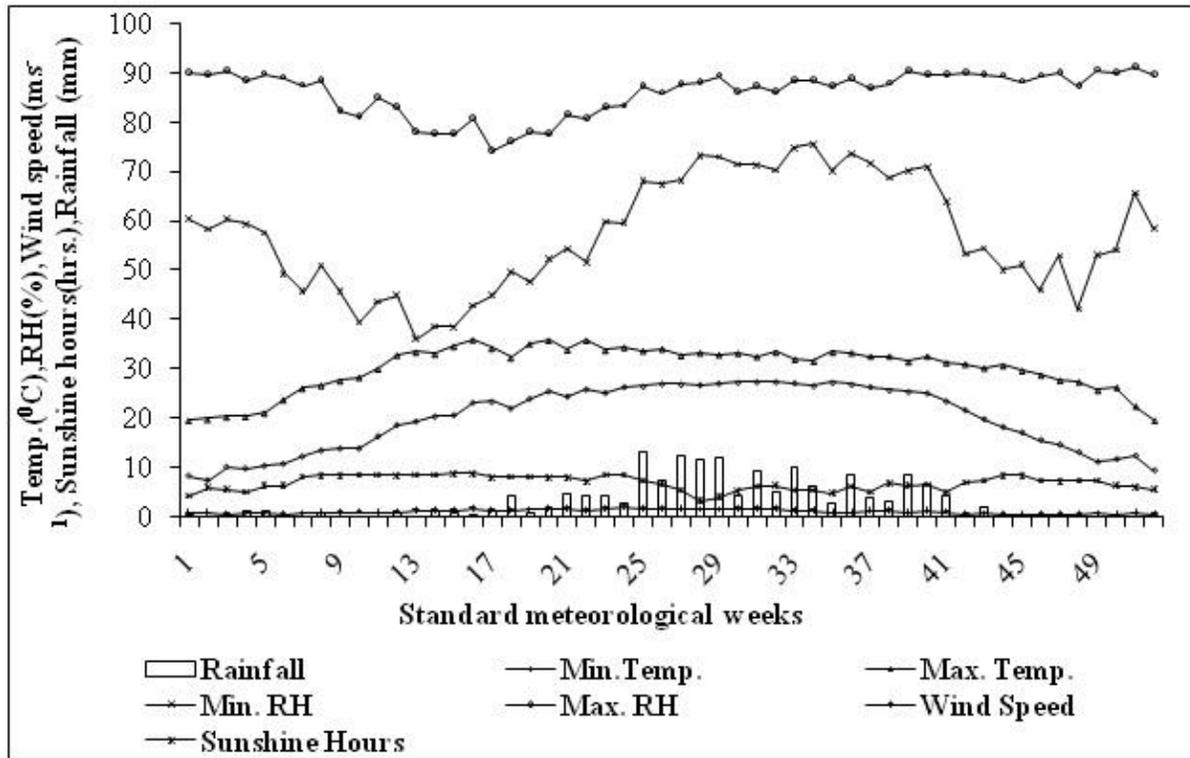


Fig.2 Relationships between mean daily ET_o values of Penman-Monteith and Penman 1963 VPD # 1 methods against FAO-56 Penman-Monteith method.

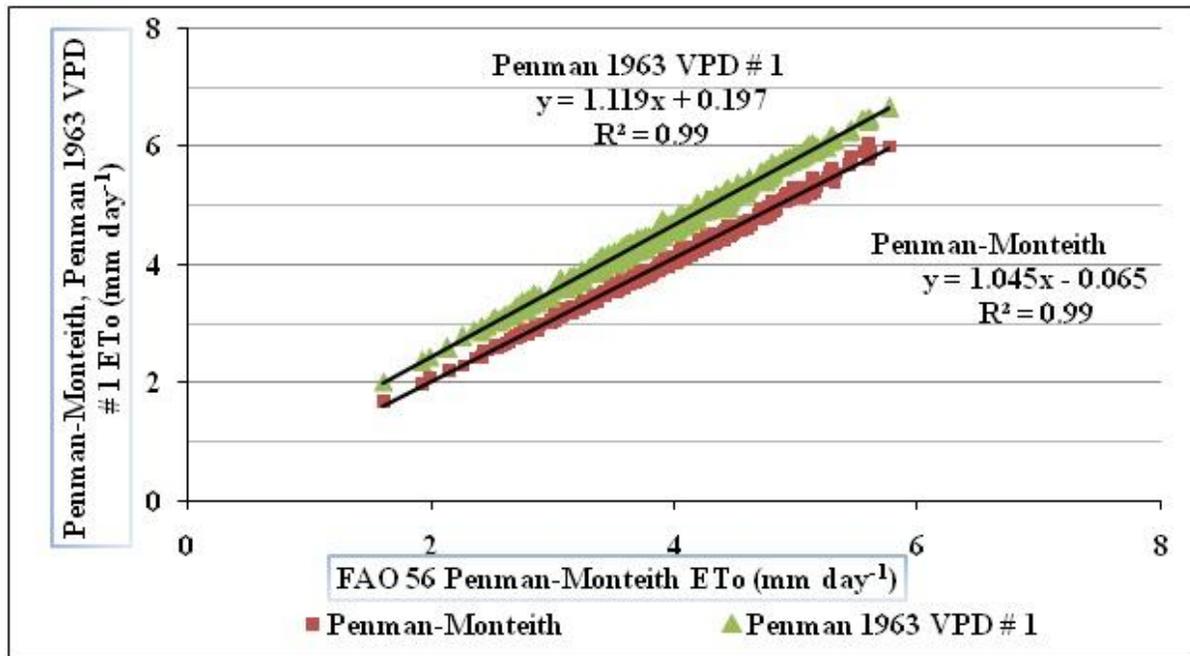


Fig.3 Relationships between mean daily ET_o values of FAO PPP-17 Penman and FAO 24 Penman C =1 methods against FAO-56 Penman-Monteith method

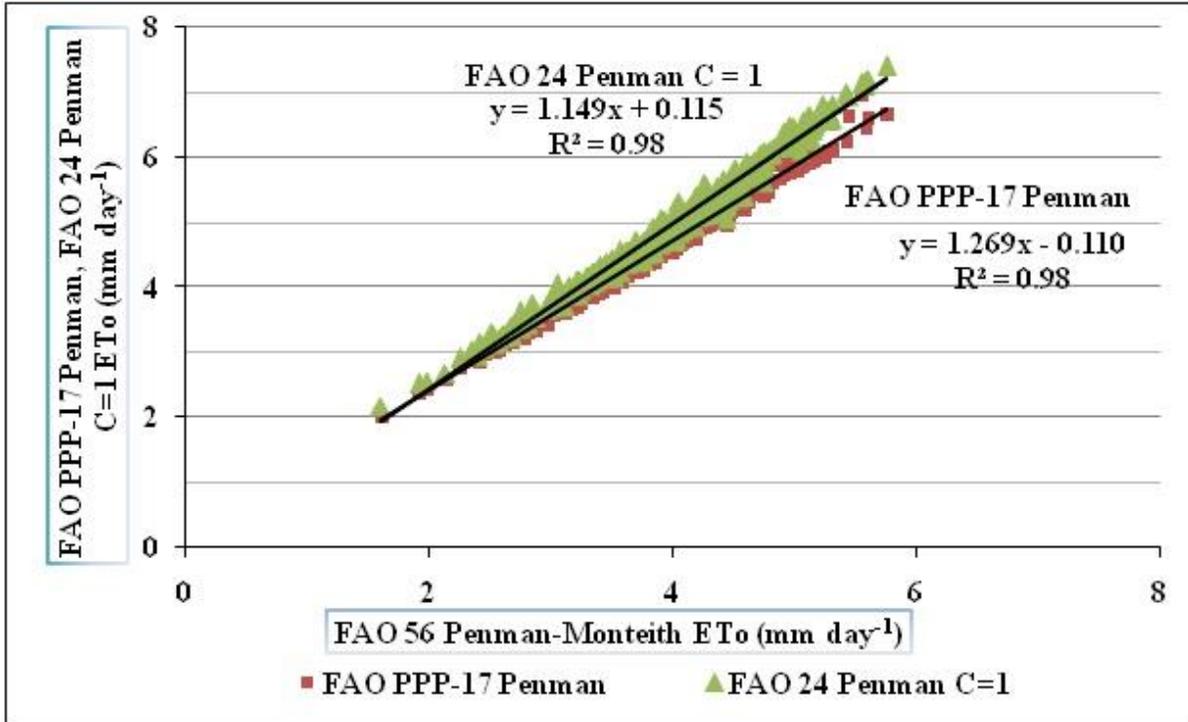


Fig.4 Relationships between mean daily ET_o values of Penman 1963 VPD # 3 and CIMIS Penman methods against FAO-56 Penman-Monteith method

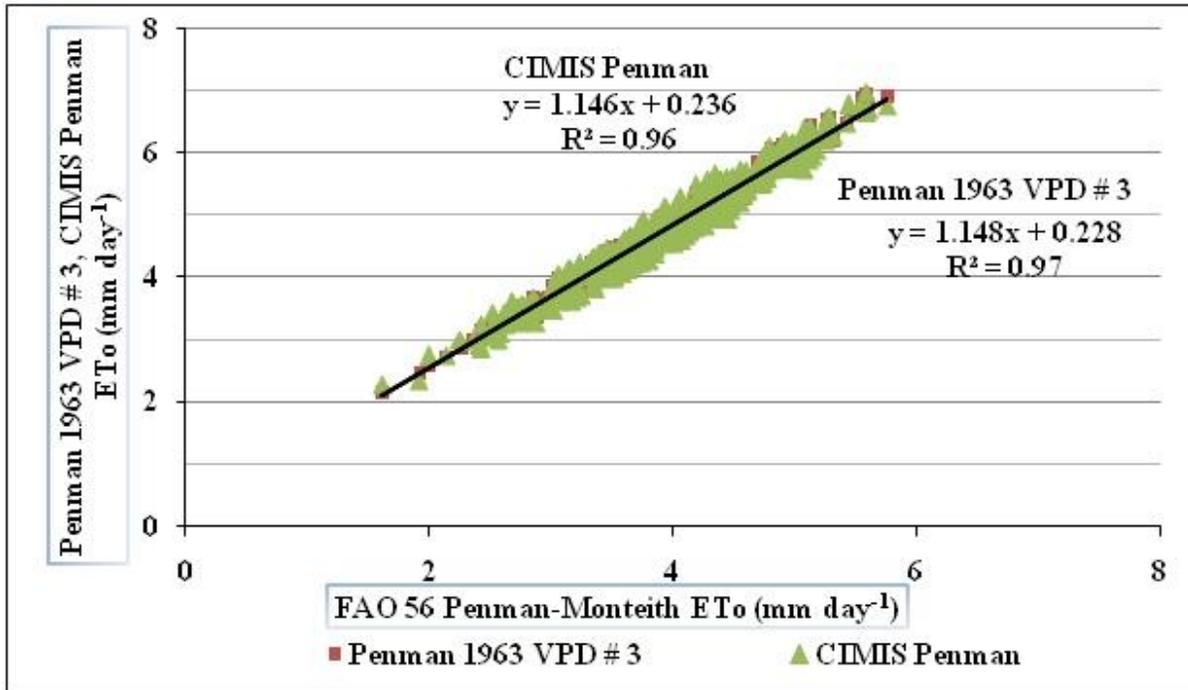


Fig.5 Relationships between mean daily ET_0 values of Businger-van-Bavel, 1972 Kimberly Penman and 1982 Kimberly Penman methods against FAO-56 Penman-Monteith method

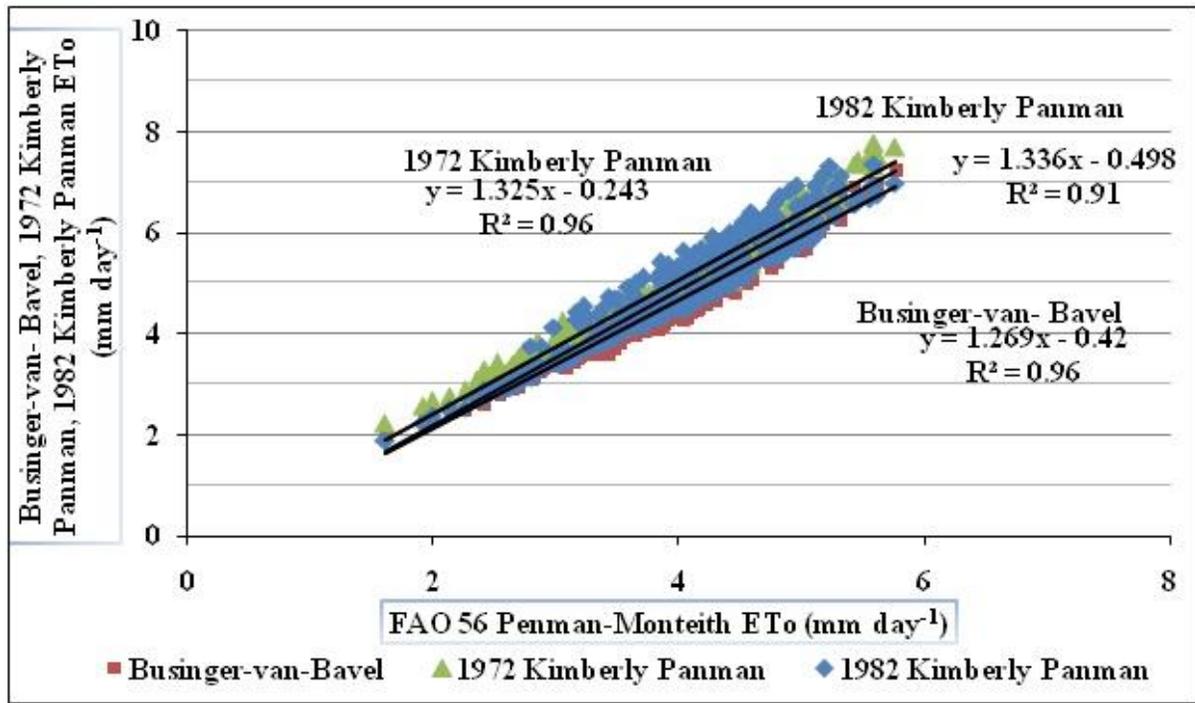


Fig.6 Relationships between mean daily ET_0 values of Turc and Priestly-Taylor methods against FAO-56 Penman-Monteith method

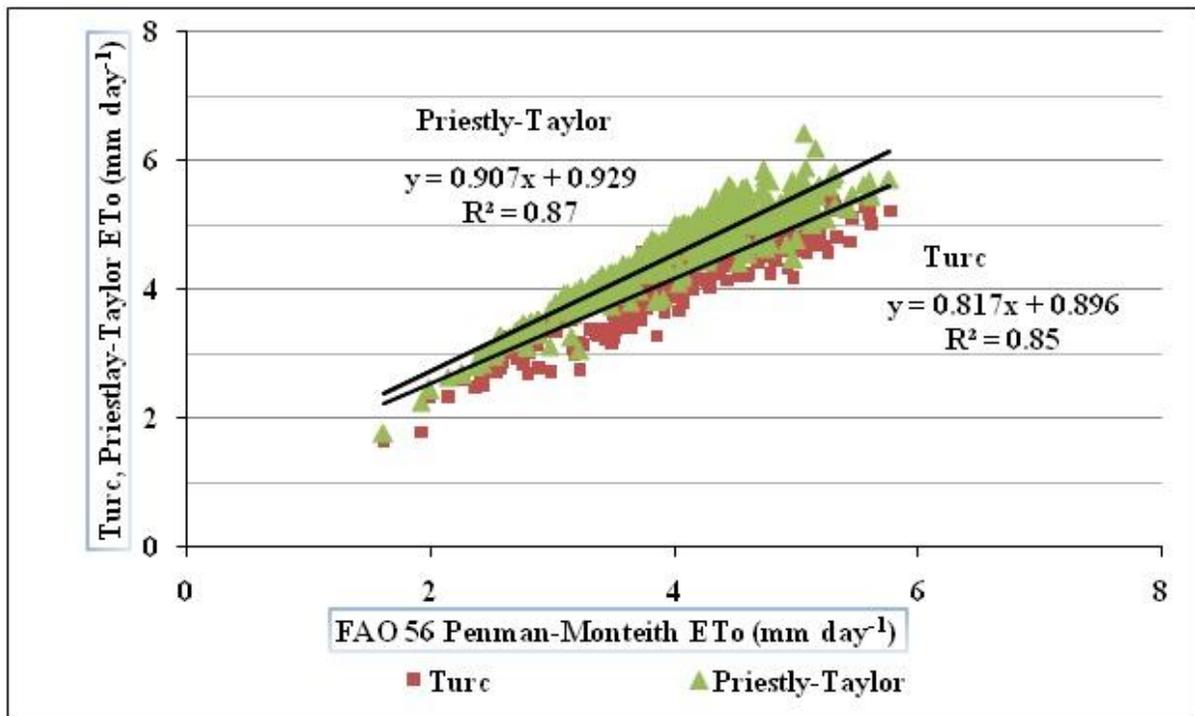


Fig.7 Relationships between mean daily ET_0 values of Hargreaves method against FAO-56 Penman-Monteith method.

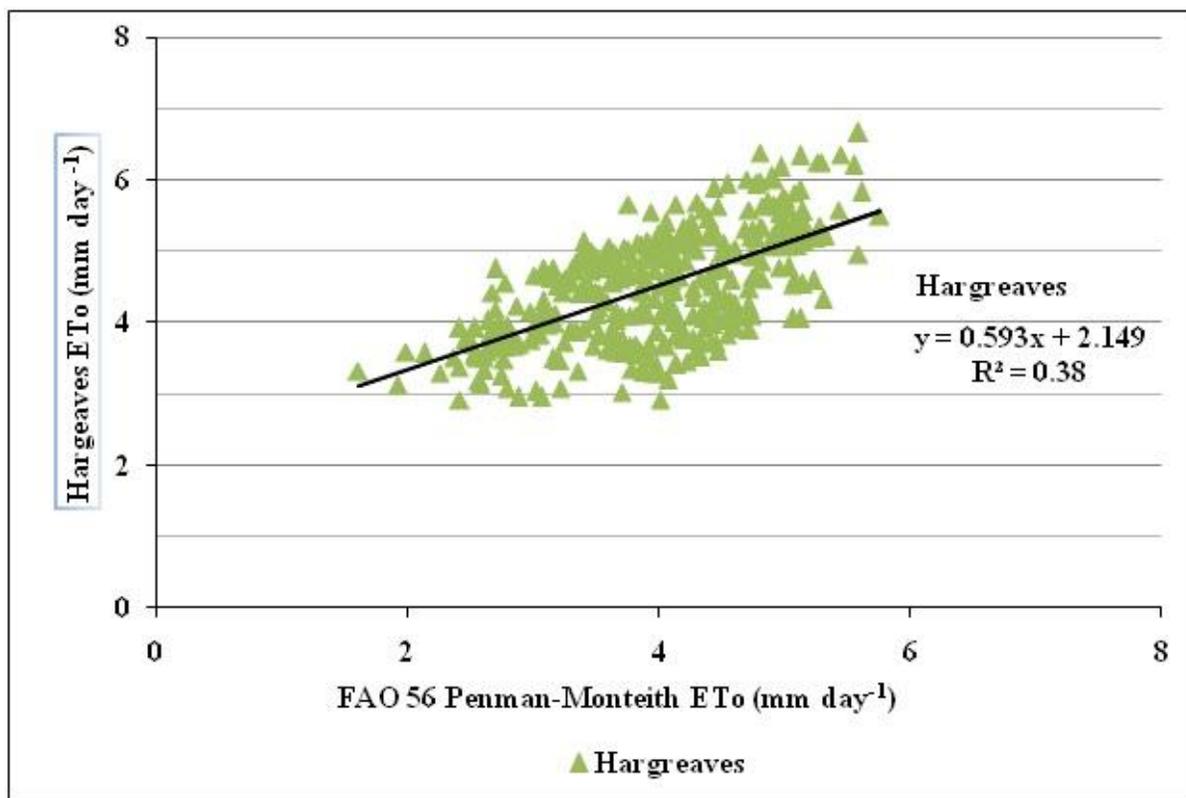


Table.1 Mean daily evapotranspiration ($mm\ day^{-1}$) under different methods in various months

Month	FAO 56 PM	P-M	1982 K P	FAO PPP-17 P	Penma n 1963 VPD#1	Penma n 1963 VPD#3	1972 KP	FAO 24 P (C=1)	B-v-B	CIM IS P	Turc	P-T	Hargreaves
January	2.6	2.7	3.0	3.1	3.1	3.2	3.3	3.3	3.0	3.3	2.9	3.1	3.6
February	3.5	3.6	4.0	4.2	4.2	4.4	4.5	4.4	4.0	4.4	4.0	4.2	4.6
March	4.5	4.7	5.1	5.5	5.3	5.6	5.9	5.7	5.2	5.6	4.7	4.9	5.5
April	5.1	5.3	6.1	6.1	5.9	6.2	6.7	6.4	6.1	6.2	5.0	5.3	5.6
May	4.8	4.9	6.2	5.6	5.5	5.7	6.2	6.0	5.7	5.7	4.6	5.0	4.9
June	4.6	4.7	6.2	5.3	5.3	5.4	5.9	5.8	5.6	5.4	4.5	5.0	4.3
July	3.6	3.7	4.8	4.2	4.2	4.3	4.5	4.5	4.3	4.3	3.6	4.1	3.7
August	4.0	4.0	5.0	4.6	4.6	4.7	4.9	4.9	4.7	4.7	4.0	4.7	3.7
September	4.1	4.2	4.8	4.7	4.7	4.8	4.9	4.9	4.7	4.8	4.3	5.0	4.2
October	4.1	4.2	4.7	4.7	4.7	4.9	5.0	4.9	4.6	4.8	4.4	4.9	4.7
November	3.8	3.9	4.3	4.5	4.5	4.6	4.7	4.6	4.1	4.6	4.3	4.5	4.9
December	3.0	3.1	3.4	3.6	3.6	3.7	3.8	3.7	3.4	3.7	3.4	3.6	4.1
Mean daily	4.0	4.1	4.8	4.7	4.6	4.8	5.0	4.9	4.6	4.8	4.1	4.5	4.5
Annual	1448	1490	1753	1707	1692	1747	1830	1798	1684	1747	1511	1652	1644

Table.2 Various statistical parameters and rank of different methods over FAO-56 Penman-Monteith Method

ET _o Methods	Average ratio of daily ET _o (method)/ET _o (FAO56-PM)	Standard deviation (S _d)	Coefficient of variation, C _v (%)	Standard error of estimate, SEE (mmday ⁻¹)	Daily estimate Rank
FAO 56- PM	-	0.79	19.88	-	1
Penman-Monteith	1.03	0.83	20.25	0.06	2
1982 Kimberly Panman	1.21	1.10	22.96	0.33	10
FAO PPP-17 Penman	1.18	0.92	19.57	0.13	4
Penman 1963 VPD#1	1.17	0.89	19.09	0.07	3
Penman 1963 VPD#3	1.21	0.92	19.15	0.14	5
1972 Kimberly Panman	1.26	1.06	21.21	0.20	8
FAO 24 Penman C = 1	1.24	1.01	20.49	0.13	4
Businger-van-Bavel	1.16	1.02	22.07	0.19	7
CIMIS Penman	1.21	0.92	19.22	0.17	6
Turc	1.04	0.70	16.91	0.27	9
Priestly-Taylor	1.14	0.76	16.89	0.27	9
Hargreaves	1.14	0.76	16.89	0.60	11

In general, ET_o computed from combination methods correlated quite well with FAO 56-Penman Monteith method (George *et al.*, 2002) than other methods in the study. Figure 5 indicated the trends of variations of mean daily ETo estimates of methods Businger-van-Bavel method (R²= 0.96), 1972 Kimberly Penman (R²= 0.96) and 1982 Kimberly Penman (R²= 0.91) and these methods were placed at 7th, 8th and 10th places, respectively as they yielded high daily values of SEEs as 0.19, 0.20 and 0.33 mm day⁻¹ (Table 2) which were due to use of variable wind functions. Businger-van-Bavel method uses a fixed value of roughness length (0.01m), atmospheric pressure, air density and not uses a canopy resistance term, r_s so ranked in lower side among combination methods.

The deviation in ETo estimates of the two Kimberly type equations might be due to using revised wind function with fixed value of coefficients as a_w = 0.75 and b_w = 0.993 by 1972 Kimberly Penman whereas 1982 Kimberly Penman uses wind function coefficient using fifth order polynomial with calendar day.

Radiation methods evaluated reasonable ET_o estimates after combination methods. Among the radiation methods, Priestly-Taylor and Turc both were assigned ninth rank (Table 2) due to similar value of SEE as 0.27 mm day⁻¹ but from figure 6, it is obvious that Turc method (R²= 0.85) shows more scattered points than that of Priestly-Taylor (R²=0.87). Priestly-Taylor overestimated FAO-56 PM ET_o throughout the year but Turc underestimate during the summer months (April to June).

Hargreaves method being single temperature method in the study showed more scattered ETo values than other methods (Fig. 7) with lowest R² value as 0.38 and assigned poorest rank (11th) due to highest value of SEE (0.60 mm day⁻¹) as mentioned in Table 2 which occurred due to use of solar radiation estimated from extraterrestrial radiation and use of temperature difference term. It does not account for R_n (net solar radiation), relative humidity, vapour pressure deficit, wind parameter and sunshine percentage which play an important role in calculating ET_o, especially in humid regions.

Reference evapotranspiration (ET_o) values were computed by thirteen different methods using DSS-ET model and estimates of these methods were compared with the mean daily ET_o values obtained from FAO 56-Penman monteith method considered as standard method. In order to compare ET_o values and develop relationships between ET_o estimates of different methods and FAO 56-Penman Monteith method, regression analysis and an indicator namely standard error of estimate (SEE) were evaluated. Mean monthly daily ET_o computed by different methods ranged from 4.0 mm day^{-1} (FAO 56-PM) to 5.0 mm day^{-1} (1972 KP). Mean daily ET_o values overestimated FAO 56-Penman Monteith method which ranged from 0.8 % (Turc) to 40.5 % (Hargreaves) whereas in some cases its value underestimated in the range of 2.1 % (Turc) to 6.8 (Hargreaves). Amongst the methods, ET_o values of Penman Montieth (SEE= 0.06 mm day^{-1}) and Penman 1963 VPD#1 (SEE= 0.07 mm day^{-1}) were strongly correlated to the standard method and thus assigned 2nd and 3rd rank, respectively for this region and Hargreaves method with highest value of SEE (0.60 mm day^{-1}) shown poorest rank (11th). The ET_o values obtained by any method applicable for available data set can be converted into ET_o estimates of FAO 56-Penman Monteith method using developed relationships for this region.

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