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Selection of Proper Method for Evapotranspiration under Limited Meteorological Data

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Abstract

Agricultural planning relying on evapotranspiration suffers due to inaccuracy in its estimation. The non availability of meteorological parameters required for accurate estimation of reference evapotranspiration (ETo) resulted in the development of different methods of ETo estimation. The present study compares various universally accepted methods of ETo estimation methods on the basis of minimum data requirement by considering the Penman Monteith as a standard method. The meteorological data were collected at station, Pune (Mahaashtra, India) from IMD, Pune and SAU, Rahuri for the period of 1980 to 2014. The mean weekly ETo values obtained are as 5.48, 3.83, 12.18, 3.83, 14.65, 4.14, 1.73, 5.87 and 5.85 mm/day for SCS Blaney-Criddle, Thornthwaite, Hargreaves-Samani, Pan evaporation, Jensen-Haise, Priestly-Taylor, Turc, Radiation and Penman-Monteith method respectively. The statistical indices were used for comparison as Root Mean Square Error (RMSE), Mean Bias Error (MBE), t-test, Index of Agreement (I.A) and Coefficient of determination (R^2). The RMSE values of models ranged from 2.11 to 9.05. Based on the RMSE value SCS BC (2.11) performed well followed by RAD (2.31) , THOR (2.71) as compared to other methods. Based on MBE values of J-H (8.80) and H-S (6.32) overestimated the weekly ETo values while Turc (-4.13), THOR (-2.03) and Epan (-2.02) underestimates the values. The RAD method (0.02) showed very close or near equal biasness as compared to other methods followed by SCS BC (-0.38). The t-test values for selected models were evaluated and indicated that it ranged from 0.06 to 29.91. Based upon t-test values, the RAD model (0.06) performed very well followed by SCS BC (1.29) method as compared to other models. An index of agreement was maximum for SCS BC (0.74) followed by THOR (0.70), Epan (0.69) and RAD (0.68) models. Index of agreement evaluated that the value predict by SCS Bc and THOR models had agreement with PM-56 model. The higher coefficient of determination (R^2) was recorded for THOR model (0.85) followed by SCS BC (0.81) and Epan (0.73). The lower coefficient of determination estimated by H-S (0.48) and TURC (0.52) method. As overall results it indicates that SCS BC method performed better in terms of low RMSE (2.11) values and high Index of agreement (0.94) followed by RAD method with low MBE (0.02) and t test (0.06) value and THOR with high R^2 values (0.85). Based on results it is recommended that SCS-BC methods is an alternative to PM-56 for estimation of ETo for Pune station/districts of Western Maharashtra when only temperature data is available.

Keywords: reference evapotranspiration; limited data; statistical indices.

Introduction

The knowledge of reference crop evapotranspiration (ETo) is routinely required for the estimation of crop water use in the planning, design and operation of irrigation and, soil and water conservation systems. Reference evapotranspiration (ETo) has been defined as “the rate of evapotranspiration from a hypothetical crop with an assumed crop height (0.12 m) and a fixed canopy resistance (70 s/m) and albedo (0.23) which would closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and not short of water.” (Allen et al.1998), Direct measurement of evapotranspiration is usually not feasible in many field situations because it is expensive and time-consuming. The required instrumentation may also be lacking.

The Penman–Monteith (PM) method reported by the Food and Agriculture Organization of United Nations (FAO-56; Allen 1998) has been recognized as the standard method for most reliable and precise method to estimate ET0 worldwide. (Garcia et al. 2004; Jabloun & Sahli 2008). The FAO-56 PM equation has shown to be superior over other methods when comparing the daily ET0 with lysimetric measurements for estimating ET0 (Garcia et al. 2004; Jabloun & Sahli 2008). However, the full input data for a large number of climatic variables, such as mean, maximum, and minimum air temperatures, relative humidity, solar radiation, and wind speed limit the widespread use of the FAO-56 PM method (Fooladmand et al. 2008; Xu et al. 2013). Unfortunately, the climatic data in many developing regions cannot always meet the requirements of the FAO-56 PM method for calculating ETo. Several climatic variables, especially solar radiation, used in the FAO-56 PM equation for ETo calculation are unavailable in underdeveloped and developing regions Therefore, the study for simple and reliable calculation methods with limited climate data in this region to estimate ET0 is necessary.

Several alternative methods have been proposed to substitute for FAO-56 PM method based on considering the accuracy and conciseness with the PM method and lysimetric measurements. The Turk equation, requiring solar radiation (RS), temperature (T), and relative humidity (RH) data were studied in the general climatic conditions of Western Europe (Turk 1961), which was considered equivalent to the well-watered grass reference crop in Central Serbia (Alexandris et al. 2008). Comparison with the lysimeter data from 11 stations located worldwide in different climates, the PM equation performed the best, and the Turk equation was ranked as the next best in humid condition (Jensen et al. 1990). The Priestley–Taylor and the Hargreaves–Samani equations are used widely for ETo estimation and require fewer parameters than the FAO-56 PM method. The Priestley–Taylor equation without wind speed data is simplified from the original Penman method with the aerodynamic term, replaced by an empirical coefficient (Priestley & Taylor 1972). The Hargreaves–Samani equation has been described as the simplest method to compute ETo because it requires only the mean, maximum, and minimum air temperatures (Hargreaves & Samani 1985). As previously stated, both the Priestley–Taylor and Hargreaves–Samani equations have been applied worldwide (Sentelhas et al. 2010). Liu and Lin (2005) suggested that the Priestley–Taylor equation was acceptable for the semiarid climate region in North China; however, the performance showed varied results among months. Razzaghi and Sepaskhah (2010) reported that the Hargreaves–Samani was the most appropriate method for use in a semiarid environment. According to research in Tensift basin, Er-Raki et al. (2010) also determined that the Hargreaves–Samani method was the most accurate for estimating ET0. Also, the Irmak–Allen and McCloud methods provided ETo estimates for their simplicity (Irmak et al. 2003). Relatively, new simple formulas based on Penman's simplifications using limited data were proposed by Valiantzas (2006, 2013a, 2013b). A series of Valiantzas methods was put forward as a new simplified formula. The new derived formulas by Valiantzas were adapted for calculating daily ET0 under different climatic conditions for global climatic data (Valiantzas 2013b). However, each calculation method shows inconsistent results when applied to various regions. Therefore, local calibrations are necessary for the calculation methods.

For a vast and developing country like India, direct measurement of PET across locations is cost prohibitive and an indirect method using meteorological data remains a better alternative, However very few studies examined the behaviour ETo models in Maharashtra state. Therefore the objective of this study was to examine daily ETo estimates for the Pune station/districts of Maharashtra state(India) using limited weather data

Materials and Methods

Area description and weather data

In this study, full data sets were collected at the meteorological station, Pune (Mahaashtra, India) from IMD, Pune and SAU, Rahuri. . Its geographical location is 18^0 31'N and 73^0 51'E with elevation above mean sea level is about 559 m. In order to carry out study, daily/weekly meteorological data, *viz*., maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sun shine hours, wind speed and pan evaporation were collected for the period of 1980 to 2014.

Programme in MS-Excel® for estimation of weekly average ETo

To estimate the reference evapotranspiration using climate based models for different stations, the

Microsoft Office Sub-module MS-Excel® Programme is used. The formulation and conditional statements for different reference evapotranspiration models was executed in the MS-Excel® on weekly basis. For testing of different reference evapotranspiration models and comparison among them the necessary statistical indicators are also executed in MS-Excel® programme. For graphical presentation for MS-Excel® graph programme is used.

Methods

In present the study reference evapotranspiration (ETo) models were selected as SCS Blaney-Criddle (SCS BC), Thornthwaite (THOR), Hargreaves-Samani(H-S), Pan evaporation (Epan), Jensen-Haise (J-H), Priestly-Taylor (P-T), Turc (TURC), and Radiation (RAD) method on the basis of minimum data requirement. The Data requirement for selected reference evapotranspiration models were presented in Table 1. The values of ETo were estimated for selected methods and compare their performance with the sole standard FAO 56 Penman-Monteith method for standardization or calibration.

Table 1: Data requirement for selected reference evapotranspiration (ETo) models

Sr. No	Variables	Selected ETo Methods								
		SCS BC	THOR	H-S	Epan	J-H	P-T	RAD	TURC	PM-56
1.	Maxi. Temp	-	-	Y	-	Y	-	-	-	Y
	Mini. Temp	-	-	Y	-	Y	-	-	-	Y
	Mean Temp	Y	Y	Y	-	Y	Y	Y	Y	Y
2.	Maxi. RH	-	-	-	-	-	-	-	-	Y
	Mini. RH	-	-	-	-	-	-	-	-	Y
	Mean RH	-	-	-	-	-	-	-	Y	Y
3.	Wind Speed	-	-	-	-	-	-	-	-	Y
4.	SSH	-	-	-	-	-	-	-	-	Y
	Rs	-	-	-	-	Y	-	Y	Y	Y
	Rn	-	-	-	-	-	Y	-	-	Y
5.	Pan Evapo.	-	-	-	Y	-	-	-	-	-

SCS Blaney-Criddle (SCS BC)

Blaney and Morin (1942) first developed an empirical relationship between evapotranspiration and mean air temperature, average relative humidity and mean percentage of daytime hours. Later Blaney and Criddle modified this (1945, 1950,) excluding humidity term. Jensen et al. (1990) proposed a version when monthly consumptive use coefficient, *k* is known whereas Snyder and Pruitt (1992) proposed a form when *k* values are unknown.

$$cu = KF = \sum kf$$

where *cu* is estimated evapotranspiration (consumptive use) in inches for growing period or season, *K* is an empirical consumptive use coefficient for irrigation season or growing period, *F* is the sum of monthly consumptive use factors i. e. *f* for the season or growing period, *k* is monthly consumptive use coefficient. The monthly consumptive use factor i. e. *f* can be expressed as follows:

$$f = T_{FMean}P/100$$

where T_{FMean} is mean monthly temperature (°F), *P* is mean monthly percentage of annual daytime hours (%). The following equation can be used when consumptive use coefficient, *k* is unknown:

$$E_t = \frac{25.4}{100} K_C K_T T_{FMean} P$$

where *P* is same as described above, coefficient, K_C= 1, T_{FMean} is mean air temperature in Fahrenheit (°F) and if temperature in °C is available then it can be found by:

$$T_{FMean} = 1.8\, T_{mean} + 32$$

The parameter K_T can be obtained by following relationship:

$$K_T = 0.0173\, T_{FMean} - 0.314$$

Thornthwaite (THOR)

Thornthwaite (1948) correlated mean monthly air temperature with ET determined by water balance studies in valleys of east central USA and following equation was resulted:

$$PET = 1.6\left[10\,\frac{T_{mean}}{I}\right]^{a}$$

where *PET* is unadjusted potential evapotranspiration in cm/month, *I* is annual or seasonal heat index and is the summation of 12 values of monthly heat indices, *i*

$$I = \sum (i)$$

and

$$i = \left(\frac{T_{mean}}{5}\right)^{1.514}$$

a is an empirical exponent and expressed as:

$$a = 0.000000675\, I^{3} - 0.0000771 I^{2} + 0.01792\, I + 0.49239$$

Hargreaves-Samani model (H-S)

Hargreaves method was derived from eight years of cool-season Alta fescue grass lysimeter data from Davis, California. Because solar radiation data are not available frequently, Hargreaves and Samani (1985) recommended estimating solar radiation from extraterrestrial radiation and proposed the following equation:

$$ETo = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$$

Where,

ETo= Reference evapotranspiration (mm/day),
T_{max}= Maximum air temperature (^{0}C),
T_{min} = Minimum air temperature (^{0}C),
T_{mean} = Mean air temperature (^{0}C),
Ra = Extra terrestrial radiation (MJ/m^2/day)

Pan evaporation model (E_{pan})

Evaporation from pan provides a measurement of a combined effect of temperature, humidity, sunshine hours, and wind speed on the reference crop evapotranspiration (Doorenbos and Pruitt, 1977). For class A evaporation pan, the K_p varies between 0.35 to 0.85, the average value is taken 0.7 (Brouwer and Heibloen, 1986). The USDA class A pan is used for measurement of evaporation. The reference evapotranspiration is given as

$$ETo = K_p * E_{pan}$$

Where,

ET = Reference evapotranspiration (mm/day),
E_{pan} = Pan evaporation (mm/day),
K_p = Pan coefficient.

Jensen-Haise model (J-S)

Jensen and Haise (1963) evaluated 3,000 observations of Et as determined by soil sampling procedures over a 35 year period in western USA. From this study they developed the following linear relationship for Etr:

$$E_{tr} = C_T(T - T_x)R_s$$

where C_T is temperature coefficient, T_x is intercept of the temperature axis and can be estimated by following equation:

$$T_x = -2.5 - 1.4(e_2 - e_1) - \frac{Elev}{550}$$

where *Elev*is elevation above the mean sea level in m, $e_1$and $e_2$are the saturation vapor pressure in kPa at the mean maximum and mean minimum temperatures in kPa respectively, for the warmest month of the year in an area. $C_T$can be estimated by:

$$C_T = \frac{1}{C_1 + C_2 C_H}$$

where C_2= 7.3 and expression for $C_1$and $C_H$are given below:

$$C_1 = 38 - \left[\frac{2 \times Elev}{305}\right]$$

$$C_H = \frac{5.0}{e_2 - e_1}$$

Priestly-Taylor (P-T)

Priestly and Taylor (1972) proposed an equation for surface area generally wet, which is a condition, required for potential evaporation. The aerodynamic component was deleted and energy component was multiplied by a coefficient, α= 1.26. The final equation can be expressed as:

$$E_p = \propto \frac{1}{\lambda}\frac{\Delta}{(\Delta + \gamma)}(R_n - G)$$

All the other parameters are same as others.

Turc Method

Turc (1961) developed an equation for potential ET under general climatic conditions of Western Europe. He proposed the following equations for two humidity conditions:

When *RHmean> 50%*

$$E_{to} = 0.013 \frac{TMean}{(TMean+15)} (R_s + 50) \frac{1}{\lambda}$$

When *RHmean ≤ 50%*

$$E_{to} - 0.013 \frac{TMean}{(TMean+15)} (R_s + 50) \frac{1}{\lambda} \left[1 + \frac{50-RH_{mean}}{70}\right]$$

where ,

Rs is solar radiation in cal/cm^2/ day. If *R s* (MJ/m^2/ day) is known, it can be obtained as

Rs= *Rs*/ 0.041869.

Radiation model (RAD)

The radiation model was first introduced by modification of the Makkink (1957) model (Doorenbos and Pruitt, 1977; Jensen *et al*., 1990). It was originally suggested this model be used over Penman method when measured solar air temperature and solar radiation were available but wind and humidity data were unavailable or were of questionable quality (Doorenbos and Pruitt, 1977; Jensen *et al*., 1990). The form of radiation model suggested by Doorenbos& Pruitt, 1977 as.

$$ETo = \left(\frac{\Delta}{\Delta + \gamma}\right)\left(\frac{R_s}{\lambda}\right)$$

Where,

ETo = Reference evapotranspiration (mm/day),
λ= Latent heat of vaporization (MJ/Kg),
Δ= Slope of saturation vapour pressure temperature curve (kPa/^{0}C),
γ = Psychometric constant (kPa/^{0}C),
R_s = Solar radiation (MJ/m^2/day).

Penman-Monteith model (FAO-56)

The FAO 56 Penman-Monteith method is recommended as the sole method for determining ETo. The method has been selected, because it closely approximate grass ETo at the location evaluated is physically based and explicitly incorporates both physiological aerodynamic parameters. The FAO 56 Penman-Monteith model to estimate ETo is given as

$$ETo = \frac{0.408\,\Delta\,(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)}$$

Where,

ET= Reference evapotranspiration (mm/day),
Δ= Slope of saturation vapour pressure temperature curve (kPa/^{0}C),
γ = Psychometric constant (kPa/^{0}C),
T= Mean air temperature (^{0}C),
e_s= Saturated vapour pressure (kPa),
e_a= Actual vapour pressure (kPa),
R_n= Net radiation (MJ/m^2/day),
G = Soil heat flux density (MJ/m^2 /day),
U_2= Wind speed at 2m height (m/s),
(e_s-e_a)= Saturated vapour pressure deficit (kPa).

Selection Criteria

The results of each evapotranspiration models were compared with PM-56 model. The different models were tested by means of Root Mean Square Error (RMSE), Mean bias error (MBE), Index of agreement (I.A), t-test, Coefficient of determination (R^2). The details about different statistical indicators are explained below.

Root mean square error (RMSE)

Root Mean Square Error measures of average difference. RMSE involves the square of the difference and therefore becomes sensitive to extreme values (Willmott, 1982). If the RMSE values are smaller the better is the model performance. The magnitudes of RMSE values are useful to identify model performance but not of under or overestimation by individual model (Jacovidas and Kontoyiannis, 1995). The optimum value for RMSE is zero or 0.0 ≤ RMSE (Vazquez & Feyan, 2003). The RMSE is represented by equation as

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)^2\right]^{0.5}$$

Where,
P_i = Reference evapotranspiration for ith observation by different models (predicted)
O_i = Reference evapotranspiration for ith observation by PM-56 model (measured)
N = Number of observations.

Mean bias error (MBE)

The mean bias error is good measure of model bias and is simple the average of all differences in the set. It provides general biasness but not of the average error that could be expected (Willmott, 1982). The positive MBE value indicates overestimation and negative value indicates the underestimation. The absolute value is indicator of model performance (Dehghani Sanij *et al.* 2004). The optimal value for MBE is zero and the biasness lies between - ∞ to + ∞ (- ∞ < bias ≤ + ∞) (Vazquez & Feyan, 2003). The MBE is given as

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left(P_i - O_i\right)$$

Where,

P_i = Reference evapotranspiration for ith observation by different models (predicted)
O_i = Reference evapotranspiration for ith observation by PM-56 model (measured)
N = Number of observations.

t- test

According to Jacovides and Kontoyiannis (1995), the models assess based on RMSE and MBE alone may be misleading in the absence of t-value. The t-test suggested by Jacovides and Kontoyiannis (1995) is

$$t = \left[\frac{(n-1)MBE^2}{RMSE^2 - MBE^2}\right]$$

Where,
MBE = Mean bias error,
RMSE = Root mean square error,
n = Number of observations.

The t-statistics should be used in conjunction with MBE and RMSE error to better evaluate model performance. Finally t-statistics indicator can be view as supplement of MBE and RMSE error in aiding modulus to determine whether or not model estimate are statistically significant at particular confidence level (Hess, 1998). The optimal value of t-test is zero or very small.

Coefficient of determination (R^2)

The coefficient of determination is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph. It is the ratio of the explained variation to the total variation. The coefficient of determination is such that $0 \leq R^2 \leq 1$.

The coefficient of determination represents the percent of the data that is the closest to the line of best fit. The coefficient of determination is a measure of how well the regression line represents the data. If the regression line passes exactly through every point on the scatter plot, it would be able to explain all of the variation. The further the line is away from the points, the less it is able to explain. The coefficient of determination is computed using equation

$$R^2 = \left[\frac{\sum OP - \left(\sum O * \sum \frac{P}{n}\right)}{\sqrt{\frac{\sum(O)^2 - (\sum O)^2}{n}} - \sqrt{\frac{\sum(P)^2 - (\sum P)^2}{n}}}\right]^2$$

Where,

O = Dependent variables (measured or PM-56 model),
P = Independent variables (predicted by different models),
n = Number of observation.

Index of agreement, d(I.A)

Index of agreement provides a relative measure of the error alloying cross comparison of the model (Berengena&Gavilan, 2005). The performance of model is good, when value of degree of index of agreement d ≥ 0.95. The optimal value of index of agreement is one (Willmott, 1982; Stockle*et al.*, 2004). The Willmott index of agreement, d:

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}\left(\left(\left|P_i'\right| + \left|O_i'\right|\right)^2\right)}\right]$$

…(3.86)

Where,
N = Number of observations,

$$P_i' = P_i - \overline{O}$$

$$O_i' = O_i - \overline{O}$$

Where,

P_i=Reference ET for ith observation by different models (predicted),

O_i =Reference ET for i[th] observation by PM-56 model (measured),

$\overline{O}$ =Mean value of reference ET for i[th] observation by PM-56 model (measured).

Results and Discussion

Average weekly reference ET for different methods

The weekly average climatic data for the period of 1980 to 2014 (i.e.35 years) were used to determine weekly reference crop evapotranspiration (ETo). The average weekly ETo values are presented in Table 2 and depicted in Fig.1. Figure shows that the trend of variation of average ETo values over the year for all the methods is same. However none of the methods shows the same results. The difference in values of ETo is due to different climatological variables used in each method. The mean weekly reference crop evapotranspiration (ETo) obtained are 5.48, 3.83, 12.18, 3.83, 14.65, 4.14, 1.73, 5.87 and 5.85 mm/day for SCS Blaney-Criddle, Thornthwaite, Hargreaves-Samani, Pan evaporation, Jensen-Haise, Priestly-Taylor, Turc, Radiation and Penman-Monteith method respectively. As per weekly average ETo values it was observed that the values obtained by the Jensen-Haise and Hargreaves-Samani method were overestimated, and values by Turc was underestimated, however Radiation and SCS Blaney-Criddle, showd values very close to Penman Monteith method. The Thornthwaite and Pan evaporation showed same value of weekly ETo (3.83). Similar type of results for over and underestimated values of ETo were reported (Itenfisuel,2000; Pandey 2014)

It was observed that the ETo decreases during the months of July, August and September, which comprised the peak monsoon season with high relative humidity, low wind speed and lower temperature (Kumar, 2008). Similar ETo values were observed in the month of November, December and January that comprises the winter season with low temperature causing low evaporation rates as shown in figure 1.

Table 2: Estimated weekly average ETo (mm/day) for period from 1980 to 2014

Week No	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD	FAO-56
1	3.82	1.86	9.97	2.56	11.37	2.96	1.42	4.98	2.89
2	3.87	1.92	10.39	2.62	11.63	3.05	1.45	5.07	3.03
3	3.98	2.07	10.89	2.69	12.37	3.22	1.52	5.35	3.25
4	4.01	2.10	11.35	3.04	12.92	3.36	1.58	5.57	3.31
5	4.21	2.27	11.82	3.30	13.48	3.53	1.63	5.77	3.68
6	4.21	2.26	12.46	3.61	14.13	3.69	1.71	6.05	4.00
7	4.39	2.52	12.93	3.99	14.95	3.92	1.78	6.31	4.60
8	4.51	2.69	13.69	4.09	15.75	4.12	1.86	6.60	4.66
9	4.99	3.09	14.46	4.45	16.39	4.25	1.91	6.75	5.05
10	5.23	3.47	15.11	4.69	16.73	4.36	1.98	6.79	5.54
11	5.24	3.48	15.33	4.74	17.21	4.57	2.00	6.98	5.58
12	5.84	4.51	16.52	5.62	18.55	4.72	2.29	7.28	6.90
13	5.98	4.76	16.79	5.78	18.76	4.80	2.33	7.31	7.10
14	6.47	5.22	17.05	5.98	19.60	5.03	2.39	7.54	7.80
15	6.69	5.63	17.30	6.34	20.12	5.15	2.48	7.66	8.13
16	6.85	5.95	17.45	6.45	21.18	5.41	2.57	8.00	8.95
17	7.04	6.34	17.55	6.72	21.70	5.53	2.62	8.12	9.55
18	7.44	6.63	17.33	6.69	21.90	5.71	2.50	8.14	11.18
19	7.46	6.67	16.87	6.94	22.01	5.81	2.46	8.18	12.92
20	7.52	6.79	16.23	6.98	21.93	5.93	2.34	8.13	13.66
21	7.47	6.69	15.74	6.70	21.86	6.02	2.29	8.12	14.96
22	7.53	6.43	14.96	6.19	20.12	5.74	2.13	7.51	13.07

23	7.22	5.84	13.82	5.30	17.78	5.33	1.93	6.73	10.22
24	6.74	4.99	12.03	4.09	14.85	4.70	1.67	5.75	7.95
25	6.50	4.58	11.00	3.85	13.50	4.37	1.54	5.28	8.49
26	6.31	4.37	10.56	3.68	12.63	4.16	1.46	4.98	7.21
27	6.15	4.11	10.10	3.13	12.45	4.12	1.45	4.95	6.95
28	6.16	4.12	10.02	3.00	11.91	3.97	1.39	4.73	6.91
29	6.00	3.87	9.37	2.59	10.83	3.70	1.29	4.33	5.42
30	5.88	3.70	9.12	2.40	10.53	3.63	1.26	4.24	5.43
31	5.61	3.65	9.09	2.42	10.59	3.64	1.27	4.27	5.23
32	5.58	3.61	9.09	2.57	10.58	3.63	1.27	4.28	5.03
33	5.55	3.57	9.24	2.63	11.07	3.77	1.32	4.48	4.61
34	5.59	3.63	9.52	2.71	11.64	3.91	1.38	4.70	4.57
35	5.40	3.57	9.60	2.71	11.98	3.98	1.42	4.84	4.67
36	5.46	3.66	9.94	2.64	12.24	4.01	1.44	4.94	4.69
37	5.52	3.76	10.47	2.87	13.42	4.27	1.56	5.39	4.76
38	5.61	3.91	10.68	2.80	13.43	4.24	1.56	5.37	4.51
39	5.71	4.08	10.73	2.76	13.62	4.23	1.57	5.42	4.04
40	5.57	4.22	11.09	2.78	13.88	4.20	1.59	5.49	3.95
41	5.50	4.10	11.29	2.99	14.11	4.12	1.62	5.61	3.91
42	5.29	3.74	11.57	3.10	14.52	4.09	1.68	5.84	3.88
43	5.04	3.33	11.33	3.14	14.16	3.92	1.66	5.78	3.71
44	4.68	3.05	11.16	3.32	13.38	3.62	1.59	5.52	3.63
45	4.62	2.96	10.59	3.01	12.99	3.52	1.55	5.38	3.54
46	4.50	2.76	10.28	2.77	12.28	3.30	1.48	5.13	3.39
47	4.31	2.48	10.21	2.78	12.21	3.21	1.48	5.17	3.13
48	4.19	2.35	10.04	2.73	11.88	3.09	1.46	5.06	3.02
49	4.00	2.09	9.86	2.71	11.47	2.95	1.42	4.95	2.98
50	3.89	1.95	9.77	2.56	11.33	2.92	1.41	4.93	3.01
51	3.73	1.75	9.82	2.64	11.14	2.83	1.40	4.91	2.98
52	3.82	1.85	9.72	2.48	10.82	2.83	1.36	4.74	2.76
Average	5.48	3.83	12.18	3.83	14.65	4.14	1.73	5.87	5.85

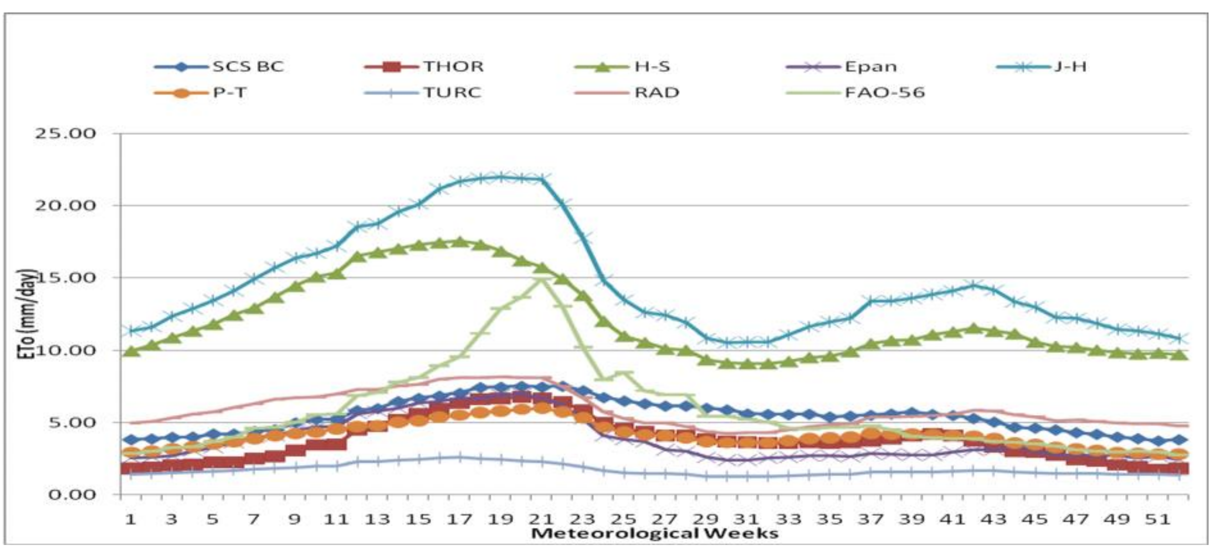

Fig. 1 Average weekly reference evepotranspiration for different methods at Pune station (1980-2014)

Comparison of ETo methods with P-M method

The different statistical indicators were worked out to test the performance of selected models with PM-56 model (Table 3) and these parameters were used for ranking purpose of models (Table 4). In present study the Root Mean Square Error (RMSE), Mean Bias Error (MBE), t-test, Index of Agreement (I.A) and Coefficient of determination (R^2) were evaluated for each models (Table 3). The criteria for best model was the RMSE and MBE values zero and I.A and R^2values equal to one or near to one. The t-test value was less, the model performance better. The ranking for MBE values were given in both positive and negative side equally.

The RMSE values of models ranged from 2.11 to 9.05. Based on the RMSE value SCS BC (2.11) performed well followed by RAD (2.31), THOR (2.71) as compared to other methods. This results were in agreement with the results obtained by (Nikam et al, 2014) The biasness which was indicated by Mean Bias Error (MBE) represents overestimation when it is positive and underestimation when it was negative. Based on MBE values of J-H (8.80) and H-S (6.32) overestimated the weekly ETo values while Turc (-4.13), THOR (-2.03) and Epan (-2.02) underestimates the values. The RAD method (0.02) showed very close or near equal biasness as compared to other methods followed by SCS BC (-0.38). The t-test values for selected models were evaluated and indicated that it ranged from 0.06 to 29.91. Based upon t-test values, the RAD model (0.06) performed very well followed by SCS BC (1.29) method as compared to other models.

An index of agreement was maximum for SCS BC (0.74) followed by THOR (0.70), Epan (0.69) and RAD (0.68) models. Index of agreement evaluated that the value predict by SCS Bc and THOR models had agreement with PM-56 model. The higher coefficient of determination (R^2) was recorded for THOR model (0.85) followed by SCS BC (0.81) and Epan (0.73). The lower coefficient of determination estimated by H-S (0.48) and TURC (0.52) method.

As overall results it indicates that SCS BC method performed better in terms of low RMSE (2.11) values and high Index of agreement (0.94) followed by RAD method with low MBE (0.02) and t test (0.06) value and THOR with high R^2 values (0.85). The similar kind of results were obtained by researchers (Nikam et al, 2014; Itenfisuel, 2000; Pandey 2014)

Ranking of selected models for weekly reference ET

The criteria for ranking to model was as the RMSE and MBE values zero , I.A and R^2values equal to one or near to one and the lower values of t-test were assign higher ranks. Based on the statistical indicators, ranks were assigned and presented in Table 4

The total ranks acquired by different models were in the range of 9 to 37. Based upon average ranks acquired, SCS BC model found suitable for prediction of the weekly ETo for Pune station/districts followed by RAD and THOR method. Based on results it is recommended that SCS-BC methods is an alternative to PM-56 for estimation of ETo for Pune station/districts when only temperature data is available.

Table 3: Statistical indicators for comparison of models with FAO-56 P-M method for weekly ETo at Pune

Statistical Indices	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD
RMSE	2.11	2.71	6.73	2.79	9.05	2.85	4.97	2.31
MBE	-0.38	-2.03	6.32	-2.02	8.80	-1.72	-4.13	0.02
t-test	1.29	8.02	19.75	7.48	29.91	5.38	10.63	0.06
R2	0.81	0.85	0.48	0.73	0.66	0.84	0.52	0.54
d(IA)	0.74	0.70	0.51	0.69	0.45	0.59	0.46	0.68

Table 4: Ranking of evaluated models as per statistical indicators for weekly ETo at Pune

Statistical Indices	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD
RMSE	1.00	3.00	7.00	4.00	8.00	5.00	6.00	2.00
MBE	2.00	5.00	7.00	4.00	8.00	3.00	6.00	1.00
t-test	2.00	5.00	7.00	4.00	8.00	3.00	6.00	1.00
R^2	3.00	1.00	8.00	4.00	5.00	2.00	7.00	6.00
d(IA)	1.00	2.00	6.00	3.00	8.00	5.00	7.00	4.00
Total	9.00	16.00	35.00	19.00	37.00	18.00	32.00	14.00
RANK	1.00	3.00	7.00	5.00	8.00	4.00	6.00	2.00

Conclusion

As overall results it indicates that SCS BC method performed better in terms of low RMSE (2.11) values and high Index of agreement (0.94) followed by RAD method with low MBE (0.02) and t test (0.06) value and THOR with high R^2 values (0.85). Based on results it is recommended that SCS-BC methods is an alternative to PM-56 for estimation of ETo for Pune station/districts of Western Maharashtra when only temperature data is available.

References

Allen, R.G., L.S. Pereira, D. Raes and M. Smith. (1998). Crop Evapotranspiration, Guideline for Computing Crop Water Requirements. FAO Irrigation and Drainage, Paper 56. FAO Rome

Alexandris S, Stricevic R, Petcovic S. 2008. Comparative analysis of reference evapotranspiration from the surface of rain fed grass in central Serbia, calculated by six empirical methods against the Penman-Monteith formula. Eur Water. 21:17–28.

Berengena, J. and P. Gavilan.(2005).Reference evapotranspiration estimation in a highly advective semiarid environment, Irrig.& Drain. Engg.,131 (2): 147 - 163.

Blaney, H. F. and Criddle, W. D. (1945).Determining water requirements in irrigated area from climatological data. (processed),: 17

Blaney, H. F. and Criddle, W. D. (1950). Determining water requirements in irrigated areas from climatological and irrigation data. S.C.S., USDA:96

Brouwer, C. and M. Heibloem. (1986). Irrigation water needs, irrigation water management FAO Training Manual, 3:11-11

Doorenbos, J. and W. O. Pruitt. (1977). Guidelines for predicting Crop Water Requirement: FAO Irrigation and Drainage Paper No.24, FAO, Rome, Italy, : 144 and 156.

Er-Raki S, Chehbouni A, Khabba S, Simonneaux V, Jarlan L, Ouldbba A, Rodriguez JC, Allen R. 2010. Assessment of reference evapotranspiration methods in semi-arid regions: can weather forecast data be used as alternate of ground meteorological parameters? J Arid Environ. 74:1587–1596.

Fooladmand HR, Zandilak H, Ravanan MH. 2008. Comparison of different types of Hargreaves equation for estimating monthly evapotranspiration in the south of Iran. Arch Agron Soil Sci. 54:321–330.

Garcia M, Raes D, Allen R, Herbas C. 2004. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano). Agric Forest Meteorol. 125:67–82.

Hargreaves, G. L. and Samani, Z. A. (1985). Reference crop evapotranspiration from temperature, Applied Engineering in Agriculture, Trans. ASAE 1(2): 96-99.

Hess, T. M. (1998).Trend in reference evapotranspiration in the North East Arid Zone of Nigeria (1961-1991). J. Arid Environments, 38: 99 - 115.

Irmak S, Allen R, Whitty EB. 2003. Daily grass and Alfalfa-reference evapotranspiration estimates and Alfalfa-to-grass evapotranspiration ratios in Florida. J Irrig Drain Eng. 129:360–370.

Itenfisuel, D., Elliott, R. L., Allen, R. G., and Walter, I. A.(2000).Comparison of reference evapotranspiration calculation across a range of climate.Proc. of the National Irrigation Symposium, ASAE, Vol. 14-16, Phoenix, pp.216-227.

Jacovides, C. P. and H. Kontoyiannis.(1995). Statistical procedures for the evaluation of evapotranspiration computing models. Agric. Water Management, 74: 87 - 97.

Jabloun M, Sahli A. 2008. Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data application to Tunisia. Agr Water Manage. 95:707–715.

Jensen, M. E. and Haise, H. R. (1963).Estimating evapotranspiration from solar radiation. J. Irrigation and Drainage Div., ASCE, 89:15-41.

Jensen, M. E. and Burman R. D. and Allen. R. G. (1990).Evapotranspiration and Irrigation Water Requirements.ASCE manual No. 70, ASCE, N.Y.

Liu XY, Lin ED. 2005. Performance of the Priestley-Taylor equation in the semiarid climate of North China. Agr Water Manage. 71:1–17.

Priestley, C. H. B. and R. J. Taylor. (1972).On the assessment of the surface heat flux and evaporation using large scale parameters. Monthly Weather Review, 100: 81 - 92.

Kumar, M., and Pandey, V. (2008) .Validation of different evapotranspiration models over semi arid region of India", Int. J. Math.Model.Simul.Appl., Vol. 1(3), pp.321-327.

Nikam B.R., Pradeep Kumar, Vaibhav Garg, Praveen K. Thakurand S. P. Aggarwal. (2014).Comparitive evaluation of different potential evapotranspiration estimation approaches.International Journal of Research in Engineering and Technology. Volume: 03 (06): 544-552.

Pandey Swati, Manoj Kumar, Soubhik Chakraborty and N.C. Mahanti. (2014).A Statistical Comparison of Reference Evapotranspiration Methods: A Case Study from Jharkhand State of India. International Journal of Innovative Research in Science, Engineering and Technology. Vol. 3 (1): 8765-8777

Razzaghi F, Sepaskhah A. 2010. Assessment of nine different equations for ET0 estimation using lysimeter data in a semi-arid environment. Arch Agron Soil Sci. 56:1–12.

Sentelhas PC, Gillespie TJ, Santo EA. 2010. Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in southern Ontario, Canada. Agr Water Manage. 97:635–644.

Snyder, R. L. and Pruitt.W.O. (1992). ETo User's Guide and ProgramDocumentation, University of California, Davis, U.S.A.

Thornthwaite, C. W. (1948). An approach towards a rational classification ofclimate. The Geographical Review, 30: 55-94.

Turc, L. (1961). Estimation of irrigation water requirements, potential evapotranspiration: A simple climatic formula evolved up to date. Ann. Agron. 12:13-14.

Valiantzas JD. 2006. Simplified versions for the Penman evaporation equation using routine weather data. J Hydrol. 331:690–702.

Valiantzas JD. 2013a. Simple forms of Penman's equation without wind and/or humidity data. I:Theoretical development. J Irrig Drain Eng. 139:1–8.

Valiantzas JD. 2013b. Simple forms of Penman's equation without wind and/or humidity data. II: Comparisons with reduced set-FAO and other methodologies. J Irrig Drain Eng. 139:9–19.

Vazquez, R. F. and J. Feyen. 2003. Effect of potential evapotranspiration estimates on effective parameters and performance of the MIKE SHE-code applied to a medium-size catchment. J. Hydro., 270: 309 – 327.

Willmott, C. J. 1982. Some comments on the evaluation of model performance. American Meteorological Soc., 63(11): 1309 - 1313.

Xu JZ, Peng SZ, Ding JL, Wei Q, Yu YM. 2013. Evaluation and calibration of simple methods for daily reference evapotranspiration estimation in humid East China. Arch Agron Soil Sci. 59:845–858.

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