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PERFORMANCE EVALUATION OF DIFFERENT REFERENCE EVAPOTRANSPIRATION MODELS

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KEYWORDS

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ABSTRACT

Accurate estimation of reference evapotranspiration (ET_o) is necessary step in water resources management. The ASCE had recommended Penman-Monteith model (FAO-56) as the sole standard method for determining ET_o over the wide variety of climatic situations over the world and it requires all types of data. At many locations, there is either lack of meteorological data or availability of meteorological parameters is limited and is of questionable quality. The present study deals with selection of alternative ET_o method for Penman-Monteith on the basis of minimum data requirement. Therefore eight ET_o methods such as SCS Blaney-Criddle, Thornthwaite, Hargreaves-Samani, Pan evaporation, Jensen-Haise, Priestly-Taylor, Turc, Radiation showing average weekly ET_o as 6.21, 5.36, 13.10, 4.90, 15.41, 3.94, 1.79, 5.70 mm/day respectively were compared with Penman-Monteith (6.20 mm/day) method for testing their suitability at Dhule station/districts. The performance of all these methods were evaluated by different statistical indicators such as RMSE, MBE, t-test, index of agreement and R² values. The results revealed that as per the RMSE values THOR (1.77) performed well followed by Epan (2.17), SCS-BC (2.68) as compared to other models. The SCS-BC method (0.01) showed very close or near equal biasness MBE value as compared to other methods followed by radiation (-0.50) and Thornthwait (-0.84) method. About the t-test values, the SCS-BC model (0.04) performed very well followed by radiation (1.22) and THOR (3.82) as compared to other models. An index of agreement was maximum for THOR (0.93) followed by Epan (0.89) model. The higher coefficient of determination (R²) was recorded for Epan model (0.93) followed by J-H (0.88), THOR(0.87) and H-S (0.87). Based on results it was recommended that Thornthwaite method resulting with low RMSE (1.77) value and high Index of agreement (0.93) and SCS Blaney-Criddle method which showing low MBE (0.01) and t test (0.04) values are alternatives to Penman-Monteith method for estimation of ET_o when only temperature data is available; when only pan evaporation data was available, the Epan model resulting with high R² values (0.93) is recommended for prediction of ET_o for Dhule station/districts.

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INTRODUCTION

Evapotranspiration is one of the key processes in the hydrological cycle and it is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surface and transpiration from plants (Allen *et al.*, 1998). It is an important climatic factor, but its accurate estimation is very difficult. Evapotranspiration varies regionally and seasonally according to weather and wind conditions. Due to this variability, water managers who are responsible for planning the distribution of water resources need to have a thorough understanding of the evapotranspiration process and knowledge about the spatial and temporal rates of evapotranspiration (Mali and Singh, 2015). The evapotranspiration rate is a function of factors such as temperature, solar radiation, humidity, wind and characteristics of the specific vegetation that is transpiring, which may vary significantly between vegetation types (Allen *et al.* 1998). Reference evapotranspiration (ET_o) is defined as "the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec m⁻¹ and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground" (Allen *et al.* 1998). It is of great importance for the management of present and future water resources, and also for solving many theoretical problems in the field of hydrology Reference evapotranspiration (ET_o) provides a standard crop (a short, clipped grass) with an unlimited water supply so that a user can calculate maximum evaporative demand from that surface for a given day. This value, adjusted for a particular crop, is the consumptive use (or demand), and deficit represents that component of the consumptive use that goes unfulfilled, either by precipitation or by soil-moisture use, during the given time period. This deficit value is the amount of water that must be supplied through irrigation to meet the water demand of the crop (Allen *et al.*, 1998). The field based direct measurement of ET_o by using Lysimetric method, though very much accurate, cannot be used everywhere because of high cost involved in installation and maintenance of lysimeter (Meena and Rao, 2015). Therefore computation of reference evapotranspiration with available meteorological data is one of the important tasks for irrigation planners, researchers to design storage reservoir, which can give the maximum benefit.

In search of the best ET_o model for wide application, many researchers (Khandelwal and Pandey, 2008; Kumar and Pandey, 2008; Itenfisuel, 2000; and Rao, 1988) have compared different evapotranspiration models. The ASCE had recommended Penman-Monteith model (FAO-56) as the sole method for determining reference evapotranspiration. This method predicts reference evapotranspiration over the wide variety of climatic situations over the world and it requires all types of data such as maximum temperature, minimum temperature, maximum humidity, minimum humidity, wind speed and bright sun shine hours.

The adoption of different approaches and models depends upon the need, accuracy and accessibility of data. The selection of proper reference evapotranspiration method mainly depends upon the location, accessibility of data, duration of data

and allocation over the period. At many locations, there is either lack of meteorological data or availability of meteorological parameters is limited and is of questionable quality. Under such conditions the use of proper methods with limited data sources is necessary. It is essential to standardize the proper method with recommended method for maintaining the accuracy in prediction of evapotranspiration within the given data set. The comparison between the different models with standard recommended model minimize the disagreements in the computation of evapotranspiration and increase the estimation accuracy between the different models with recommended model.

Therefore in the present study, different empirical models based on the minimum data requirement will be compared with Penman-Monteith (PM-56) method and tested their performance in terms of statistical indicators, so as to derive a simple model which requires less data with more accuracy and precision as that of the standard model.

MATERIALS AND METHODS

Study area and Data

The study was carried out on meteorological data collected from 1980 to 2014 by weather station located at Dhule (Mahaashtra, India). Its geographical location is 20°54'N and 74°46'E with elevation above mean sea level is about 263 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 from IMD, Pune and SAU, Rahuri.

Methods

In present the study reference evapotranspiration models were selected on the basis of minimum data requirement. The reference evapotranspiration (ET_o) was estimated for by selected methods and compare their performance with the sole standard FAO 56 Penman-Monteith method for standardization or calibration.

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, 1962) excluding humidity term. The original relationship was developed and intended for seasonal estimates. The basic assumption was that ET varies directly with the sum of the products of mean monthly air temperature and monthly percentage of annual daytime hours for an actively growing crop with adequate soil moisture. Two forms of this method are available to estimate evapotranspiration for seasonal or growing period. 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.

$$cu = KF = \sum k f$$

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:

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

Thorntwaite (THOR)

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

$$PET = 1.6 \left[10 \frac{T_{mean}}{1} \right]^a$$

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

$$I = \sum (i)$$

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

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:

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

Where,

ET_o = Reference evapotranspiration (mm/day),

T_{max} = Maximum air temperature (°C),

T_{min} = Minimum air temperature (°C),

T_{mean} = Mean air temperature (°C),

R_a = Extraterrestrial radiation (MJ/m²/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

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

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 E_{tr} :

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

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:

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

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

$$C_1 = 35 + \frac{2 \cdot Elev}{305}$$

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

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, $\alpha = 1.26$. The final equation can be expressed as:

$$E_p = \frac{1}{\alpha} (R_n - G)$$

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 $RH_{mean} > 50\%$

$$E_{to} = 0.013 \frac{T_{Mean}}{(T_{Mean} - 15)} (R_s - 50) \frac{1}{70}$$

When $RH_{mean} \leq 50\%$

$$E_{to} = 0.013 \frac{T_{Mean}}{(T_{Mean} - 15)} (R_s - 50) \frac{1}{70}$$

where, R_s is solar radiation in cal/cm²/day. If R_s (MJ/m²/day) is known, it can be obtained as

$$R_s = R_s / 0.041869.$$

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 and Pruitt, 1977 as.

$$ET_o = \frac{R_s}{\lambda + \Delta}$$

Where,

ET_o = Reference evapotranspiration (mm/day),

λ = Latent heat of vaporization (MJ/Kg),

Δ = Slope of saturation vapour pressure temperature curve (kPa/°C),

γ = Psychrometric constant (kPa/°C),

R_s = Solar radiation (MJ/m²/day).

Penman-Monteith model (FAO-56)

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

$$ET_o = \frac{0.408 (R_n - G) + \frac{900}{T + 273} U_2 (e_s - e_a)}{(1 + 0.34 U_2)}$$

Where,

ET = Reference evapotranspiration (mm/day),

Δ = Slope of saturation vapour pressure temperature curve (kPa/°C),

γ = Psychrometric constant (kPa/°C),

T = Mean air temperature (°C),

e_s = Saturated vapour pressure (kPa),

e_a = Actual vapour pressure (kPa),

R_n = Net radiation (MJ/m²/day),

G = Soil heat flux density (MJ/m²/day),

U_2 = Wind speed at 2m height (m/s),

$(e_s - e_a)$ = Saturated vapour pressure deficit (kPa).

Evaluation 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 d” RMSE (Vazquez & Feyan, 2003). The RMSE is represented by equation as

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2}$$

Where,

P_i = Reference evapotranspiration for i^{th} observation by different models (predicted)

O_i = Reference evapotranspiration for i^{th} 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 (DehghaniSanij et al. 2004). The optimal value for MBE is zero and the biasness lies between $-\infty$ to $+\infty$ ($-\infty < bias \leq +\infty$) (Vazquez and Feyan, 2003). The MBE is given as

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

Where,

P_i = Reference evapotranspiration for i^{th} observation by different models (predicted)

O_i = Reference evapotranspiration for i^{th} 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

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

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 (R²)

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 $0 \leq R^2 \leq 1$, and denotes the strength of the linear association between x and y . 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

$$R^2 = \frac{\sum_{i=1}^n (O_i - \bar{O})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^n (O_i - \bar{O})^2} \sqrt{\sum_{i=1}^n (P_i - \bar{P})^2}}$$

Where,

O = Dependent variables (measured or PM-56 model),

P = Independent variables (predicted by different models),

n = Number of observation.

Index of agreement (I.A)

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

$$d = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i| + |O_i|)^2} \dots(3.86)$$

Where,

N = Number of observations,

$$P_i = P_i - \bar{O}$$

$$O_i = O_i - \bar{O}$$

Where,

P_i = Reference ET for i^{th} observation by different models (predicted),

O_i = Reference ET for i^{th} observation by PM-56 model (measured),

\bar{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 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 6.21, 5.36, 13.10, 4.90, 15.41, 3.94, 1.79, 5.70 and 6.20 mm/day for SCS Blaney-Criddle, Thornthwaite, Hargreaves-Samani, Pan evaporation, Jensen-Haise, Priestly-Taylor, Turc, Radiation and Penman-Monteith method respectively. In fig 1 it was observed that the values obtained by the Jensen-Haise and Hargreaves-Samanimethod were overestimated, however SCS Blaney-Criddle, Thornthwaite, Pan evaporation and radiation method shows values close to Penman Monteith method., Turc and Priestly-Taylor produced underestimated ETo values as compared to the Penman Monteith method. 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 Fig. 1.

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 (R2) were evaluated for each models (Table 3). The criteria for best model was the RMSE and MBE values zero and I.A and R2 values 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 1.77 to 9.32. Based on the RMSE value THOR (1.77) performed well followed by Epan (2.17) , SCS-BC (2.68) as compared to other models. 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 (9.21) and H-S (6.90) overestimated the weekly reference ET values while Turc(-4.41)and Priestly-Taylor (-2.26)underestimates the values. The SCS-BC method (0.01) showed very close or near equal biasness as compared to other methods followed by radiation (-0.50) and Thornthwait (-0.84) method. The t-test values for selected models were evaluated and indicated that it ranged from 0.04 to 46.73. Based upon t-test values, the SCS-BC model (0.04) performed very well followed by radiation(1.22) and THOR (3.82) as compared to other models.

An index of agreement was maximum for THOR (0.93) and Epan (0.89) models. Index of agreement evaluated that the value predict by THOR and Epan models had close agreement with PM-56 model. The higher coefficient of determination (R2)was recorded for Epan model (0.93) followed by J-H (0.88),THOR (0.87) and H-S (0.87). The lower coefficient of determination estimated by TURC method was 0.71.

As overall results it indicates that Thornthwait method performed better in terms of low RMSE (1.77) values and high Index of agreement (0.93) followed by Epan method with high R2 values (0.93) and SCS-BC method with low MBE (0.01) and

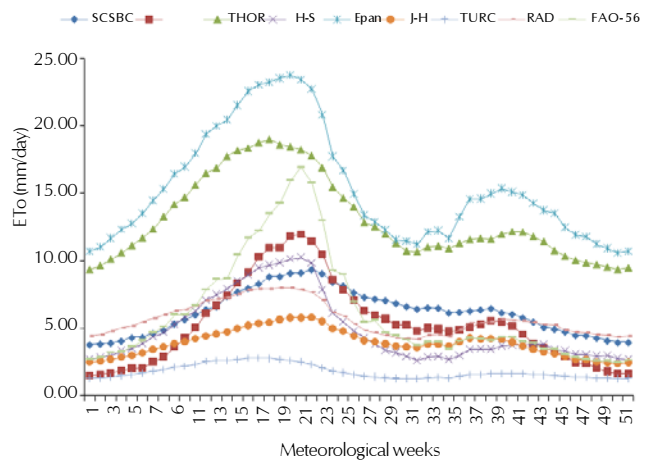


Figure 1: Average weekly reference evapotranspiration for different methods at Dhule station/districts (1980-2014)

Table 1: Reference evapotranspiration models based on minimum data requirement

Sr. No.	Models	Meteorological parameters
1.	SCS Blaney-Criddle (SCS BC)	Air temperature
2.	Thornthwaite (THOR)	Air temperature
3.	Hargreaves-Samani (H-S)	Air temperature
4.	Pan evaporation (Epan)	Pan evaporation
5.	Jensen-Haise (J-H)	Air temperature and Solar radiation
6.	Priestly-Taylor (P-T)	Air temperature and Net radiation
7.	Turc (TURC)	Air temperature, Solar radiation and Humidity
8.	Radiation (RAD)	Air temperature and Solar radiation,
9.	Penman-Monteith(FAO-56)	Air temperature, Solar radiation, Humidity, Wind speed and Sunshine hours

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

Meteorological Week	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD	FAO-56
1	3.80	1.53	9.38	2.71	10.71	2.49	1.30	4.45	2.72
2	3.85	1.59	9.67	2.87	11.04	2.59	1.33	4.57	2.86
3	3.93	1.70	10.14	2.99	11.69	2.72	1.40	4.81	3.20
4	4.06	1.89	10.63	3.33	12.36	2.87	1.49	5.04	3.30
5	4.33	2.04	11.16	3.49	12.78	3.01	1.56	5.18	3.66
6	4.35	2.07	11.72	3.90	13.53	3.18	1.71	5.48	4.11
7	4.65	2.54	12.38	4.38	14.51	3.43	1.82	5.76	4.72
8	4.87	2.92	13.30	4.72	15.38	3.62	1.97	6.03	5.14
9	5.34	3.62	14.20	5.32	16.49	3.88	2.14	6.33	6.04
10	5.66	4.28	14.74	5.85	17.01	4.02	2.20	6.42	6.01
11	6.00	5.07	15.63	6.31	18.01	4.25	2.31	6.68	6.71
12	6.41	6.12	16.51	7.11	19.44	4.44	2.57	7.07	7.88
13	6.62	6.71	16.91	7.51	20.04	4.60	2.63	7.22	8.66
14	7.37	7.43	17.75	7.92	20.51	4.75	2.65	7.30	8.71
15	7.69	8.36	18.20	8.52	21.58	5.00	2.72	7.58	10.47
16	7.96	9.18	18.37	8.99	22.65	5.24	2.81	7.87	11.72
17	8.30	10.30	18.78	9.49	23.12	5.38	2.83	7.93	12.26
18	8.82	10.97	19.01	9.68	23.30	5.44	2.81	7.93	13.52
19	8.83	11.01	18.62	9.87	23.57	5.68	2.69	8.02	14.33
20	9.07	11.85	18.47	10.17	23.79	5.79	2.63	8.02	16.00
21	9.11	11.97	18.26	10.27	23.48	5.79	2.54	7.91	16.98
22	9.34	11.47	17.79	9.85	22.80	5.82	2.35	7.72	15.80
23	9.04	10.49	16.94	7.87	20.84	5.55	2.06	7.13	13.01
24	8.42	8.63	15.48	6.13	17.76	5.01	1.81	6.22	9.33
25	8.15	7.88	14.67	5.46	16.73	4.81	1.73	5.92	9.01
26	7.63	7.12	14.02	4.82	14.98	4.44	1.58	5.36	6.98
27	7.30	6.30	12.86	4.30	13.39	4.11	1.45	4.86	5.48
28	7.18	5.99	12.57	3.80	12.93	3.99	1.41	4.72	5.60
29	7.06	5.72	12.01	3.37	12.33	3.86	1.36	4.52	4.71
30	6.85	5.25	11.33	3.20	11.58	3.68	1.29	4.28	4.47
31	6.63	5.24	10.76	2.91	11.46	3.65	1.28	4.24	4.14
32	6.44	4.82	10.69	2.63	11.21	3.59	1.27	4.18	3.75
33	6.54	5.04	11.03	2.89	12.15	3.81	1.35	4.51	3.99
34	6.50	4.97	11.14	2.92	12.27	3.82	1.37	4.56	4.00
35	6.15	4.78	10.94	2.71	11.66	3.72	1.31	4.35	3.50
36	6.20	4.89	11.33	2.97	13.28	4.03	1.47	4.94	4.08
37	6.29	5.11	11.59	3.41	14.62	4.30	1.59	5.42	4.30
38	6.38	5.32	11.68	3.47	14.63	4.24	1.59	5.40	4.25
39	6.48	5.55	11.61	3.45	15.01	4.25	1.62	5.52	4.09
40	6.16	5.48	11.98	3.71	15.39	4.20	1.66	5.66	4.38
41	6.05	5.20	12.18	3.74	15.13	3.98	1.64	5.60	4.37
42	5.78	4.57	12.15	3.75	14.90	3.72	1.63	5.59	4.06
43	5.47	3.90	11.82	3.84	14.30	3.44	1.59	5.45	3.92
44	5.09	3.59	11.45	3.81	13.76	3.25	1.55	5.29	3.49
45	4.96	3.32	10.79	3.44	13.54	3.15	1.53	5.24	3.51
46	4.76	2.95	10.36	3.34	12.52	2.95	1.44	4.90	3.10
47	4.49	2.47	10.06	3.09	11.94	2.71	1.40	4.76	2.88
48	4.47	2.40	9.86	3.07	11.80	2.71	1.39	4.71	2.76
49	4.29	2.11	9.74	2.95	11.27	2.50	1.34	4.55	2.63
50	4.08	1.81	9.55	2.97	10.96	2.43	1.32	4.49	2.63
51	3.96	1.64	9.38	2.77	10.61	2.39	1.29	4.38	2.48
52	3.96	1.65	9.51	2.71	10.72	2.48	1.30	4.42	2.65
Average	6.21	5.36	13.10	4.90	15.41	3.94	1.79	5.70	6.20

Table 3: Statistical indicators for evaluation of performance of models with FAO-56 P-Mmethod for weekly ETo at Dhule

Statistical Indicators	ETo methods							
	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD
RMSE	2.68	1.77	7.07	2.17	9.32	3.82	5.65	2.94
MBE	0.01	-0.84	6.90	-1.30	9.21	-2.26	-4.41	-0.50
t-test	0.04	3.82	31.82	5.36	46.73	5.25	8.93	1.22
R ²	0.74	0.87	0.87	0.93	0.88	0.83	0.71	0.81
d(IA)	0.76	0.93	0.60	0.89	0.54	0.56	0.49	0.67

Table 4: Ranking of evaluated models as per statistical indicators for weekly EToat Dhule

Statistical Indicators	ETo methods							
	SCS BC	THOR	H-S	Epan	J-H	P-T	TURC	RAD
RMSE	3.00	1.00	7.00	2.00	8.00	5.00	6.00	4.00
MBE	1.00	3.00	7.00	4.00	8.00	5.00	6.00	2.00
t-test	1.00	3.00	7.00	5.00	8.00	4.00	6.00	2.00
R ²	7.00	3.00	4.00	1.00	2.00	5.00	8.00	6.00
d (IA)	3.00	1.00	5.00	2.00	7.00	6.00	8.00	4.00
Total	15.00	11.00	30.00	14.00	33.00	25.00	34.00	18.00
Avg. Rank	3.00	1.00	6.00	2.00	7.00	5.00	8.00	4.00

t test (0.04) value. 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 R² values 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 11 to 34. Based upon average ranks acquired, THOR model found suitable for prediction of the weekly ETo for Dhule station/districts followed by Epan and SCS-BC method. Based on results it is recommended that THOR and SCS-BC methods are an alternatives to PM-56 for estimation of ETo when only temperature data is available. When only pan evaporation data was available and other meteorological data was not available, the Epan model is recommended for prediction of reference ET for Dhule station/districts.

As overall results it can be concluded that Thornthwait method performed better in terms of low RMSE (1.77) values and high Index of agreement (0.93) followed by Epan method with high R² values (0.93) and SCS-BC method with low MBE (0.01) and t test (0.04) value. Based on results it was recommended that THOR and SCS-BC methods are an alternatives to PM-56 for estimation of ETo when only temperature data is available; when only pan evaporation data was available and other meteorological data was not available, the Epan model is recommended for prediction of reference ET for Dhule station/district of Western Maharashtra.

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