Probability distribution functions of weekly reference crop evapotranspiration for Pune station of Maharashtra state, India

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ABSTRACT. The study was conducted to know the appropriate probability distribution for weekly ETr values at desired probability levels for Pune station (Latitude 19° 24′ N, Longitude 74° 39′ E and altitude 514.0 m amsl), Maharashtra State, India. Different ETr methods considered were Penman-Monteith, modified Penman, Hargreaves-Samani, FAO-Pan Evaporation, Blanney-Criddle and FAO-Radiation methods. The probability distribution functions that were fitted to the ETr values are Normal, Log Normal, Gamma, Gumbel and Weibull probability distribution functions. Chi-square test was performed to know the probability distribution of the best fit. The daily climatological data for 20 years (1987-2006) were used to estimate weekly ETr values by different methods. ETr values at 20%, 60% and 80% probability levels for all the methods using the probability distribution of the best fit. The weekly values at 70% probability level ETr were determined and presented.

Key words – Climatological data, Reference crop evapotranspiration, ETr methods and probability distribution functions.

1. Introduction

Evapotranspiration (ET) is the most important component of the hydrological water balance and is required for the planning, management and operation of the irrigation and water resource projects; and irrigation scheduling. ET of crop (ETc) is usually determined by estimating the reference crop evapotranspiration (ETr) and crop coefficient (kc).

As evapotranspiration depends on the climatological variables, ET varies during the year and over the years. The present practice is to take the average estimates of ETc over some years. However, simply taking the average does not result in proper estimate as the variable evapotranspiration may take on any of the values of a specified set with a certain probability. The irrigation or water resource planning should therefore be based on the probabilistic approach and for this purpose it is useful to know the ETc values at the different probability levels. Based on the probability distribution of ETc, it would be also possible to generate/forecast crop evapotranspiration with desired level of probability. The probability distribution function ETc is also required for stochastic modeling. Therefore, the study was undertaken to investigate the appropriate probability distribution functions for weekly ETc data and find out weekly ETc values at different probability levels.

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TABLE 1
The average weekly values of ET, (mm) determined by different methods

| Methods | MW | PM | MP | HAR | PAN | BLC | RAD |
|---------|----|----|----|-----|-----|-----|-----|
| 1       | 18.1 | 23.9 | 27.5 | 16.6 | 30.9 | 28.4 | 27 |
| 2       | 18.9 | 24.4 | 28.3 | 17.7 | 31.4 | 29.6 | 28 |
| 3       | 20.6 | 25.8 | 29.2 | 18.1 | 31.66 | 31.9 | 29 |
| 4       | 21.6 | 26.8 | 30.5 | 20.4 | 31.8 | 34.7 | 30 |
| 5       | 22.4 | 28.8 | 33.0 | 21.7 | 32.0 | 35.6 | 31 |
| 6       | 24.4 | 31.9 | 35.2 | 23.7 | 32.5 | 39.3 | 32 |
| 7       | 27.1 | 33.6 | 36.2 | 26.6 | 33.1 | 42.1 | 33 |
| 8       | 28.2 | 34.2 | 36.1 | 28.0 | 33.2 | 44.8 | 34 |
| 9       | 29.7 | 36.9 | 39.5 | 30.1 | 35.1 | 46.0 | 35 |
| 10      | 31.3 | 39.9 | 42.4 | 31.5 | 36.3 | 47.7 | 36 |
| 11      | 33.6 | 41.7 | 42.3 | 35.0 | 36.9 | 50.2 | 37 |
| 12      | 36.1 | 43.9 | 43.7 | 36.7 | 38.2 | 53.6 | 38 |
| 13      | 36.4 | 43.5 | 44.0 | 38.7 | 38.2 | 55.8 | 39 |
| 14      | 39.4 | 49.0 | 47.7 | 41.0 | 40.7 | 57.1 | 40 |
| 15      | 41.4 | 51.1 | 47.1 | 43.6 | 41.0 | 59.1 | 41 |
| 16      | 41.4 | 50.5 | 48.2 | 44.5 | 41.6 | 60.1 | 42 |
| 17      | 44.0 | 53.1 | 48.1 | 46.4 | 42.1 | 63.3 | 43 |
| 18      | 45.6 | 55.5 | 47.3 | 45.6 | 43.5 | 64.2 | 44 |
| 19      | 45.1 | 55.2 | 47.4 | 45.5 | 44.1 | 62.1 | 45 |
| 20      | 46.7 | 57.2 | 45.1 | 47.0 | 44.0 | 61.1 | 46 |
| 21      | 44.9 | 55.2 | 43.2 | 44.7 | 44.0 | 58.0 | 47 |
| 22      | 40.6 | 50.0 | 40.7 | 38.7 | 43.4 | 51.0 | 48 |
| 23      | 38.4 | 47.6 | 38.1 | 36.2 | 43.0 | 49.6 | 49 |
| 24      | 28.2 | 35.1 | 32.7 | 29.5 | 41.6 | 35.5 | 50 |
| 25      | 27.8 | 35.3 | 30.1 | 26.9 | 40.9 | 32.1 | 51 |
| 26      | 23.3 | 29.2 | 27.5 | 21.8 | 40.4 | 27.8 | 52 |

Note: MW- Meteorological week, PM- Penman-Monteith, MP- Modified Penman, HAR- Hargreaves-Samani, Epan- Pan Evaporation, BC – Blaney-Criddle and RAD – FAO-Radiation

Bhakar (2000) made frequency distribution of evaporation for Udaipur region using a database of 20 years. Probability curves of evaporation were developed at different levels for determination of peak crop water requirements. Kumar (2001) also developed frequency distribution of daily evapotranspiration at different probability levels. Pandey (2002) studied frequency distribution pattern of daily evapotranspiration for black gram crop. Hardofa (2003) fitted weekly and monthly pan evaporation of nineteen to twenty years data of agro-climatic stations of Ethiopia to five different frequency distributions (viz. Normal, Lognormal, Gamma, Gumbel’s and Weibull’s) and dependable weekly and monthly pan evaporation several probability levels were obtained. Jat and Singh (2005) formulated probability models for prediction of water deficit for Kota and Jaipur in Rajasthan state. From their study, the Log Pearson Type-III and Log Normal distributions were found to be the best probability models for predicting weekly water deficit for Jaipur and Kota, respectively. Wadatkar and Singh (2006)
performed the frequency analysis of maximum weekly pan evaporation data of eight stations of Maharashtra using three distributions i.e. log Pearson type–III, Gumbel and Weibull’s (maxima). The distribution that resulted in the lowest Chi-square value was selected as the best distribution for that location and maximum weekly evaporation at 20, 40, 60, 80 and 90% probability levels were computed. Patil and Gorantiwar (2007) performed the probability distribution analysis of weekly reference crop evapotranspiration values of Rahuri, Maharashtra, estimated by Penman-Monteith method. They found that, Gamma distribution function fits maximum number of weeks (37). Thus the probability distributions that were used for ET, are : (i) Normal (Ingle 1993) (ii) Log normal (Dalvi and Thakur, 1990) and Gamma distributions (Rajkumar and Kumar, 2007; Kulshrestha et al., 2007). Chi-square test (Dalvi and Thakur, 1990) and Kolmogorov – Smirnov test (Kulshrestha et al., 2007) were used to test the goodness of fit of parametric probabilistic distribution to the given set of data. In this study most commonly used methods viz., Penman-Monteith, modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and FAO-Radiation methods were used to estimate ET, values for Pune region.

2. Data & methodology

2.1. Climatological data

Daily data for Pune (Latitude 19° 24' N, Longitude 74° 39' E and altitude 514.0 m amsl) in respect of maximum temperature \( T_{\text{max}} \, ^{\circ} \text{C} \) and minimum temperature \( T_{\text{min}} \, ^{\circ} \text{C} \), maximum relative humidity (RH\text{max} %) and minimum relative humidity (RH\text{min} %), pan evaporation \( E_{\text{pan}} \, \text{mm} \), wind speed at height of 2 m \( U_2 \, \text{km/hr} \), actual sun shine hours \( S, \text{hr} \), and rainfall \( R, \text{mm} \) were collected for 20 years (1987-2006) from the India Meteorological Department, Pune.

Methods of Estimation of ET, : The weekly reference crop evapotranspiration were estimated by using following methods

(i) Penman-Monteith (Allen et al. 1998),

### TABLE 2

| Fitting of probability distribution functions for weekly ET, estimates from different methods |
|-----------------------------------------------|
| **1. Log Normal, Normal and Gamma distributions** |
| The above distributions give the best fit for Hargreaves-Samani, Blanney-Criddle, FAO-Radiation methods and Pan evaporation for all 52 weeks in the year. |
| (i) Penman-Monteith: Best fit for all three methods above and for all weeks except for one (13th) in case of normal distribution |
| (ii) Modified Penman: Best fit for all three methods above and weeks except for one and same week (16th) for both log-normal and gamma distributions |

#### 2. Gumbell distribution

| ET, Methods          | Number of weeks not fitting | Week Numbers |
|----------------------|----------------------------|--------------|
| Penman- Monteith     | 2                          | 13, 25       |
| Modified Penman      | 4                          | 12, 16, 17, 25 |
| Hargreaves-Samani    | 1                          | 15           |
| Pan Evaporation      | 1                          | 11           |
| Blanney-Criddle      | 2                          | 30, 40       |
| FAO-Radiation        | Nil                        | Nil          |

#### 3. Weibull distribution

| ET, Methods          | Number of weeks not fitting | Week Numbers |
|----------------------|----------------------------|--------------|
| Penman- Monteith     | 8                          | 5, 14, 20, 25, 28, 38, 48, 49 |
| Modified Penman      | 11                         | 17, 19, 28, 30, 38, 39, 40, 44, 47, 48, 49 |
| Hargreaves-Samani    | 17                         | 4, 9, 10, 13 to 16, 19, 20, 23, 36, 37, 41, 43, 45, 46, 50 |
| Pan Evaporation      | 6                          | 5, 7, 11, 21, 22, 28 |
| Blanney-Criddle      | 4                          | 23, 27, 48, 52 |
| FAO-Radiation        | 17                         | 1, 3, 18, 19 to 23, 25, 38, 39, 42, 45, 48, 50, 51, 52 |
TABLE 3
The best fit probability distributions for ET<sub>r</sub> values of different weeks as estimated by different methods

| MW | Methods | MW | Methods |
|----|---------|----|---------|
|    | PM  | MP  | HAR | E<sub>pan</sub> | BLC | RAD | PM  | MP  | HAR | E<sub>pan</sub> | BLC | RAD |
| 1  | N   | N   | Gu  | N   | Gu  | Gu  | 27  | LN  | N   | LN  | LN  | N   | Ga  |
| 2  | Ga  | N   | N   | LN  | N   | N   | 28  | N   | LN  | LN  | N   | W   | LN  |
| 3  | Ga  | N   | W   | LN  | N   | Gu  | 29  | LN  | N   | LN  | LN  | Gu  | N   |
| 4  | W   | N   | Ga  | LN  | Gu  | N   | 30  | LN  | N   | LN  | W   | Ga  | N   |
| 5  | Ga  | N   | Gu  | Gu  | W   | Gu  | 31  | N   | N   | N   | N   | N   | Ga  |
| 6  | Gu  | Gu  | LN  | Ga  | N   | Gu  | 32  | N   | N   | N   | LN  | Gu  | N   |
| 7  | LN  | N   | Gu  | LN  | N   | LN  | 33  | LN  | N   | N   | W   | LN  | Ga  |
| 8  | N   | N   | N   | N   | Gu  | Ga  | 34  | LN  | N   | N   | N   | W   | Gu  |
| 9  | Ga  | W   | N   | LN  | N   | N   | 35  | N   | N   | N   | N   | Ga  | LN  |
| 10 | N   | W   | Gu  | Ga  | Gu  | N   | 36  | N   | N   | N   | N   | N   | N   |
| 11 | LN  | Gu  | N   | N   | N   | N   | 37  | LN  | N   | LN  | N   | LN  | N   |
| 12 | N   | N   | N   | LN  | N   | LN  | 38  | W   | Gu  | N   | N   | N   | N   |
| 13 | W   | W   | Gu  | N   | LN  | N   | 39  | Gu  | Gu  | LN  | LN  | N   | Ga  |
| 14 | N   | W   | Gu  | LN  | Gu  | Ga  | 40  | Gu  | N   | N   | N   | N   | LN  |
| 15 | W   | Gu  | Ga  | N   | N   | N   | 41  | N   | N   | N   | Ga  | N   | Gu  |
| 16 | N   | W   | Gu  | Ga  | N   | Gu  | 42  | LN  | N   | LN  | Ga  | Gu  | Gu  |
| 17 | N   | N   | N   | LN  | N   | N   | 43  | N   | N   | Gu  | N   | N   | N   |
| 18 | N   | N   | N   | W   | W   | N   | 44  | N   | N   | Ga  | N   | N   | LN  |
| 19 | Gu  | Ga  | N   | Gu  | N   | N   | 45  | N   | N   | W   | N   | N   | N   |
| 20 | N   | Gu  | N   | W   | Gu  | W   | 46  | N   | N   | Gu  | N   | Gu  | N   |
| 21 | N   | Ga  | Ga  | Gu  | Ga  | LN  | 47  | W   | Gu  | N   | Gu  | Ga  | N   |
| 22 | N   | Gu  | LN  | LN  | Ga  | N   | 48  | Gu  | N   | N   | N   | N   | Gu  |
| 23 | N   | N   | Gu  | W   | Gu  | Ga  | 49  | Gu  | N   | W   | N   | W   | W   |
| 24 | LN  | N   | LN  | Ga  | W   | N   | 50  | Ga  | N   | N   | LN  | Gu  | Ga  |
| 25 | N   | N   | W   | N   | N   | N   | 51  | Ga  | N   | N   | N   | N   | Gu  |
| 26 | N   | Gu  | LN  | N   | N   | N   | 52  | LN  | N   | N   | W   | Gu  | N   |

Non significant at 5 % level of significance (Tabulated value of Chi-square =11.07 at D.F.5)

Note: N – Normal distribution, LN- Long-Normal distribution, Ga – Gamma distribution, Gu – Gumbel distribution and W- Weibull’s distribution)

(ii) Modified Penman (Penman, 1948),

(iii) Hargreaves-Samani (Hargreaves and Samani, 1985),

(iv) FAO Pan Evaporation (Doorenboss and Pruitt, 1977),

(v) Blanney-Criddle (Doorenboss and Pruitt, 1977) and

(vi) FAO-Radiation methods (Doorenboss and Pruitt, 1977).

The computer program in FORTRAN was developed to estimate the daily values of ET<sub>r</sub> by these methods which were then added up to obtain the weekly values for 52 standard meteorological weeks for 19 years.
Figs. 1 (a-f). Weekly ETr values at different probability levels by using best fit probability distribution functions for different methods of ETr estimation.

**Probability distribution functions:** The following five probability distribution functions were selected as stated earlier.

(i) Normal (Hann, 1977)

(ii) Log-Normal (Hann, 1977)

(iii) Gamma (Hann, 1977)

(iv) Gumbel (Hann, 1977) and

(v) Weibull (Kline and Bender, 1990)
### TABLE 4
The weekly ET, at 70 % probability level for Pune for Penman-Monteith, Pan Evaporation and Blanney-Criddle methods

| MW | Methods |        |        |        | MW | Methods |        |        |        |
|----|---------|--------|--------|--------|----|---------|--------|--------|--------|
|    | PM      | E_{pan} | BLC    |        |    | PM      | E_{pan} | BLC    |        |
| 1  | 19.3    | 17.5   | 31.8   | 27     | 26.4 | 24.0    | 40.7   |        |        |
| 2  | 20.3    | 18.8   | 32.0   | 28     | 27.2 | 24.7    | 40.7   |        |        |
| 3  | 21.6    | 18.8   | 32.4   | 29     | 23.8 | 18.8    | 39.9   |        |        |
| 4  | 22.7    | 21.2   | 32.5   | 30     | 23.6 | 21.1    | 39.5   |        |        |
| 5  | 23.5    | 23.3   | 32.5   | 31     | 24.1 | 20.2    | 38.9   |        |        |
| 6  | 25.9    | 24.1   | 33.0   | 32     | 21.7 | 18.9    | 38.4   |        |        |
| 7  | 28.3    | 27.3   | 33.7   | 33     | 21.5 | 19.6    | 38.1   |        |        |
| 8  | 29.8    | 29.1   | 33.9   | 34     | 22.8 | 20.9    | 38.0   |        |        |
| 9  | 31.5    | 31.2   | 35.8   | 35     | 23.1 | 18.8    | 38.0   |        |        |
| 10 | 33.2    | 32.9   | 36.8   | 36     | 26.2 | 19.9    | 38.3   |        |        |
| 11 | 35.9    | 36.8   | 37.6   | 37     | 26.0 | 21.6    | 38.5   |        |        |
| 12 | 38.2    | 38.8   | 38.6   | 38     | 24.5 | 21.1    | 38.8   |        |        |
| 13 | 39.9    | 40.0   | 38.9   | 39     | 25.2 | 20.1    | 39.2   |        |        |
| 14 | 42.5    | 42.9   | 41.7   | 40     | 25.1 | 21.2    | 38.3   |        |        |
| 15 | 44.3    | 46.0   | 41.5   | 41     | 24.5 | 21.4    | 38.0   |        |        |
| 16 | 44.4    | 48.0   | 42.2   | 42     | 24.3 | 21.2    | 37.2   |        |        |
| 17 | 47.4    | 48.5   | 42.7   | 43     | 24.9 | 22.0    | 36.4   |        |        |
| 18 | 48.5    | 49.4   | 44.2   | 44     | 24.2 | 21.2    | 35.3   |        |        |
| 19 | 49.5    | 48.3   | 44.6   | 45     | 23.5 | 20.6    | 34.4   |        |        |
| 20 | 49.1    | 50.8   | 44.6   | 46     | 22.0 | 19.7    | 34.1   |        |        |
| 21 | 47.8    | 47.3   | 44.5   | 47     | 21.1 | 18.3    | 33.4   |        |        |
| 22 | 44.9    | 43.4   | 44.3   | 48     | 20.5 | 18.8    | 33.5   |        |        |
| 23 | 42.5    | 41.4   | 43.6   | 49     | 19.6 | 19.8    | 31.2   |        |        |
| 24 | 42.1    | 31.5   | 42.3   | 50     | 19.4 | 19.1    | 30.5   |        |        |
| 25 | 30.8    | 30.2   | 41.5   | 51     | 19.8 | 18.2    | 30.1   |        |        |
| 26 | 27.0    | 25.1   | 41.0   | 52     | 21.8 | 20.9    | 34.8   |        |        |

**Note:** MW- Meteorological week, PM- Penman-Monteith, E_{pan}- Pan Evaporation, BC – Blanney-Criddle

**Test for goodness of fit of probability distributions:** To know the probability distribution function that fit the ET, data most, chi-square test was performed. The chi-square statistic \( \chi_{cal}^2 \) is calculated from equation.

\[
\chi_{cal}^2 = \sum_{i=1}^{k} \left( \frac{(O_i - E_i)^2}{E_i} \right)
\]

Where, \( k \) = Number of observation, \( O_i \) = Observed values, \( E_i \) = Expected values.

A probability distribution fits the weekly ET, values if the calculated values of Chi-square \( \chi_{cal}^2 \) is less than the tabulated value of chi square at 5 % level of significance \( \chi_{tab}^2 \). If in case more than one probability distribution fits the weekly ET, values then the distribution that gives the lowest value of \( \chi_{cal}^2 \) is selected as the best probability distribution for weekly ET, values. In this way the probability distribution functions for weekly ET, values
for all the 52 weeks were found out. Once the probability distribution function is obtained, the weekly ET\textsubscript{r} values were obtained at 10, 20, 30, 40, 50, 60, 70, 80, and 90% probability levels for each week.

### 3. Results and discussions

Average ET\textsubscript{r} over a period of 19 years by different methods are presented in Table 1. Table 2, summaries the weeks to which the probability distribution functions fitted to the weekly ET\textsubscript{r} values for all probability distribution functions and the methods of ET\textsubscript{r} estimation used. Table 2 shows that log normal, normal and gamma distributions can be fitted to all the weekly values with one or two exceptions. Weibull distribution does not fit weekly ET\textsubscript{r} values in several weeks and can be considered unsuitable for use in Pune conditions. Best fit weeks for ET\textsubscript{r} values for the probability distribution as estimated by different methods shown in Table 3. The best fit week’s shows that normal (25 weeks) and log normal (10 weeks) distributions are usable with Penman-Monteith method of estimation of ET\textsubscript{r}. With respect to modified Penman method, Normal distribution shows as the best fit for 34 weeks out of 52 at Pune. Similarly, in case of Hargreaves-Samani method (25 weeks), Pan Evaporation (19 weeks), Blaney-Criddle (28 weeks) and FAO-Radiation method (22 weeks) normal distribution gave the best fit followed in general, by log normal distribution.

The expected values of ET\textsubscript{r} using probability distribution functions of the best fit weeks were obtained at different probability levels for Penman-Monteith, Modified Penman, Hargreaves-Samani, Pan Evaporation, Blaney-Criddle and FAO-Radiation methods. These values are presented in Figs. 1(a-f). The expected ET\textsubscript{r} values at desired probability level and desired ET\textsubscript{r} method may readily be obtained from the graphs on the weekly basis. These values are often useful for the design, management and operation of irrigation system and development of water resources projects. In most of the irrigation and water resources projects, the values of hydrological parameters at 70 % probability level are used to minimize the risk in operation. The weekly ET\textsubscript{r} values at 70 % probability levels for Penman-Monteith, Pan Evaporation and Blaney-Criddle methods are presented in Table 4 for ready reference.

### 4. Conclusions

The studies conducted on the probabilities distribution analysis of weekly reference crop evapotranspiration for Pune Maharashtra, India using the data of 19 years (1988-2006) shows that more than one distribution (Normal, Log normal, Gamma, Gumbel’s and Weibull’s) fit to some weeks and none to few weeks. The weekly ET\textsubscript{r} values that were estimated by different methods (Penman Monteith, modified Penman, Hargreaves-Samani, FAO Pan Evaporation, Blanney Criddle and FAO Radiation) at different probability levels would be useful for irrigation and water resources planning, management and operation of Pune, Maharashtra.

### References

Allen, R. K., Pereira, L. S., Raes, D. and Smith, M., 1998, “Crop evapotranspiration. Guideline for computing crop water requirements”, *FAO Irrigation and Drainage* Paper No. 56. United Nations Food and Agricultural Organization, Rome.

Bhakar, S. R., 2000, “Modeling of Evaporation and Evapotranspiration under climatic conditions of Udaipur”, Thesis of Doctor of Philosophy submitted to faculty of Agricultural Engineering, Department of Soil and Water Engineering, CTAE, MPUAT, Udaipur, p327.

Dalvi, R. R. and Thakur, C. B., 1990, “Probability analysis of reference crop evapotranspiration”, B.Tech. Thesis submitted to M. P. K. V., Rahuri.

Doorenbos, J. and Pruitt, W. O., 1977, “Guidelines for predicting Crop Water Requirement”, *FAO Irrigation and Drainage* Paper No.24, FAO, Rome, Italy. p156.

Hargreaves, G. H. and Samani, Z. A., 1985, “Reference crop evapotranspiration from temperature”, *Applied Engineering in Agriculture*, ASAE, 1, 2, 96-99.

Hardofa, T., 2003, “Modeling of evaporation over Ethiopia” Ph.D. (Ag.) Thesis, College of Technology And Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

Hann, C. T., 1977, “Statistical methods in hydrology”, Ames, IA: Iowa State University Press.

Ingle, S. T., 1993, “Probabilistic analysis of climatological parameters for estimation of irrigation water requirement for Konkan region”, M.Tech. Thesis submitted to M.P.K.V, Rahuri.

Jat, M. L. and Singh, R. V., 2005, “Probability models for prediction of water deficit for Jaipur and Kota in Rajasthan”, *Indian Journal of Soil Conservation*. 33, 3, 264-266.

Kline, D. E. and Bender, D. A., 1990, Maximum likelihood estimation for shifted Weibull and log normal distributions”, *Transactions of the ASAE*. 33, 1,330-335.

Kumar, D., 2001, “Modeling of maize evapotranspiration under climatic conditions of Udaipur”, M.E. (Ag.) Thesis, CTAE, MPUAT, Udaipur.

Kulshrestha, M. S., George, R. K. and Shekh, A. M., 2007, “Weekly rainfall probability analysis by gamma distribution and artificial neural network”, *Journal of Agrometeorology*, 9, 2,196-202.

Patil, P. D. and Gorantiwar, S. D., 2007, “Stochastic modeling of crop evapotranspiration for Rahuri region” M.Tech. Thesis submitted to M.P.K.V., Rahuri, 70-77.
Penman, H. L., 1948, “Natural evaporation from open water, bare soil and grass”, Proc. Royal Soc. London, Ser. A. 193, 120-145.

Pandey, P. K., 2002, “Modeling of black gram evapotranspiration under climatic conditions of Udaipur”, M.E. (Ag.) Thesis, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

Rajkumar, K. M. and Kumar, D., 2007, “Time series modeling of daily rainfall during north-east monsoon season of Baptala, Andhra Pradesh”, Indian Journal of Soil Conservation, 35, 1, 21-25.

Thornthwaite, C. W. and Mather, J. R., 1955, “The Water Balance”, Publications in Climatology, Drexel Inst. of Technology, New Jersey, 8, 1, p104.

Thornthwaite, C. W. and Mather, J. R., 1957, “Instructions and Tables for Computing Potential Evapotranspiration and the Water Balance”, Publication No. 10, Laboratory of Climatology, Centerton, New Jersey.

Wadatkar, S. B. and Singh, R. V., 2006, “Frequency analysis of weekly pan evaporation of different agro-climatic zones in Maharashtra”, Indian Journal Soil Conservation. 34, 3, 204-206.