MAUSAM, **61**, 4 (October 2010), 517-524

551.573 : 633

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

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(*Received 22 February 2010, Modified 16 April 2010*)

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सार – इस शोध पत्र में भारत के महाराष्ट्र राज्य में पुणे स्टेशन (अक्षांश 19° 24′उ., देशांतर 74° 39′ पू. और 514.0 एम. ए. एम. एस. एल. की ऊँचाई पर) के वांछित संभाव्यता स्तरों पर साप्ताहिक ई. टी. आर. (ET_r) मानों के लिए समुचित संभाव्यता वितरण का पता लगाने के लिए अध्ययन किया गया है। इस अध्ययन में पेनमैन–मॉनटीथ, संशोधित पेनमैन, हारग्रीवस– समानी, एफ. ए. ओ.–पेन वाष्पोत्सर्जन, बलेनी–क्रीडल और एफ. ए. ओ.–विकिरण पद्धति जैसी विभिन्न प्रकार की ई. टी. आर. (ET_r) की पद्धतियों को विवेचन किया गया है। ई. टी. आर. (ET_r) मानों के लिए उपयुक्त संभाव्यता वितरण प्रकार्य हैं–सामान्य, लाग सामान्य, गामा, गुम्बेल और वीबुल संभाव्यता वितरण प्रकार्य। सबसे अधिक उपयुक्त संभाव्यता वितरण का पता लगाने के लिए चाई–स्क्वेयर जाँच किए गए। विभिन्न पद्धतियों द्वारा साप्ताहिक ई. टी. आर. (ET_r) मानों का आकलन करने के लिए 20 वर्षों (1987-2006) के दैनिक जलवायविक आँकड़ों का उपयोग किया गया है। सभी पद्धतियों के लिए 20%, 60% और 80% संभाव्यता स्तरों पर ई. टी. आर. (ET_r) मानों में सबसे अधिक उपयुक्त संभाव्यता वितरण का उपयोग किया गया है। संभाव्यता स्तर पर ई. टी. आर. (ET_r) के 70% साप्ताहिक मानों को निर्धारित किया गया है और इस शोध पत्र में प्रस्तुत किया गया है।

ABSTRACT. The study was conducted to know the appropriate probability distribution for weekly ET_r 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 ET_r 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 ET_r 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 ET_r values by different methods. ET_r 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 ET_r were determined and presented.

Key words – Climatological data, Reference crop evapotranspiration, ET_r 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 (ET_c) is usually determined by estimating the reference crop evapotranspiration (ET_r) and crop coefficient (k_c).

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 ET_r 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 ET_r values at the different probability levels. Based on the probability distribution of ET_c, it would be also possible to generate/forecast crop evapotranspiration with desired level of probability. The probability distribution function ET_r is also required for stochastic modeling. Therefore, the study was undertaken to investigate the appropriate probability distribution functions for weekly ET_r data and find out weekly ET_r values at different probability levels.

TABLE 1

The average weekly values of ET_r (mm) determined by different methods

MW	Methods						MW	Methods					
	PM	MP	HAR	PAN	BLC	RAD		PM	MP	HAR	PAN	BLC	RAD
1	18.1	23.9	27.5	16.6	30.9	28.4	27	23.6	29.9	26.4	19.8	40.2	28.0
2	18.9	24.4	28.3	17.7	31.4	29.6	28	25.6	32.9	26.3	22.5	40.1	29.1
3	20.6	25.8	29.2	18.1	31.66	31.9	29	23.0	29.31	25.7	18.2	39.6	26.2
4	21.6	26.8	30.5	20.4	31.8	34.7	30	21.8	28.0	24.1	19.9	39.2	26.1
5	22.4	28.8	33.0	21.7	32.0	35.6	31	22.2	28.5	24.6	17.6	38.5	25.4
6	24.4	31.9	35.2	23.7	32.5	39.3	32	20.5	25.9	24.1	17.2	37.8	22.1
7	27.1	33.6	36.2	26.6	33.1	42.1	33	21.8	27.6	24.8	17.9	37.7	26.2
8	28.2	34.2	36.1	28.0	33.2	44.8	34	20.4	25.9	25.0	17.8	37.8	25.1
9	29.7	36.9	39.5	30.1	35.1	46.0	35	22.0	28.0	26.1	17.1	37.7	26.4
10	31.3	39.9	42.4	31.5	36.3	47.7	36	24.8	30.3	27.3	18.8	37.9	31.5
11	33.6	41.7	42.3	35.0	36.9	50.2	37	24.5	30.3	28.7	20.1	38.1	30.8
12	36.1	43.9	43.7	36.7	38.2	53.6	38	24.6	30.7	30.0	18.9	38.3	31.5
13	36.4	43.5	44.0	38.7	38.2	55.8	39	22.6	28.8	30.3	18.3	38.8	29.2
14	39.4	49.0	47.7	41.0	40.7	57.1	40	22.9	27.4	30.3	19.4	37.8	29.5
15	41.4	51.1	47.1	43.6	41.0	59.1	41	23.8	29.4	31.6	20.6	37.6	30.6
16	41.4	50.5	48.2	44.5	41.6	60.1	42	23.9	30.6	32.2	20.5	36.8	32.9
17	44.0	53.1	48.1	46.4	42.1	63.3	43	23.7	31.4	33.8	20.9	36.0	34.4
18	45.6	55.5	47.3	45.6	43.5	64.2	44	22.9	29.1	31.1	20.4	34.8	33.6
19	45.1	55.2	47.4	45.5	44.1	62.1	45	22.1	25.8	27.6	19.9	33.8	33.1
20	46.7	57.2	45.1	47.0	44.0	61.1	46	20.1	24.1	26.5	18.2	33.6	30.7
21	44.9	55.2	43.2	44.7	44.0	58.0	47	19.8	24.5	27.0	17.6	33.3	30.5
22	40.6	50.0	40.7	38.7	43.4	51.0	48	19.2	24.3	27.6	17.6	32.7	28.6
23	38.4	47.6	38.1	36.2	43.0	49.6	49	18.4	23.5	27.3	18.5	30.7	28.7
24	28.2	35.1	32.7	29.5	41.6	35.5	50	18.1	23.2	26.8	18.1	30.1	28.9
25	27.8	35.3	30.1	26.9	40.9	32.1	51	19.1	24.4	27.5	17.2	29.6	30.1
26	23.3	29.2	27.5	21.8	40.4	27.8	52	20.9	26.7	30.8	19.0	34.2	32.2

Note : MW- Meteorological week, PM- Penman-Monteith, MP- Modified Penman, HAR- Hargreaves-Samani, E_{pan}- Pan Evaporation, BC – Blanney-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)

TABLE 2

Fitting of probability distribution functions for weekly ET_r 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 (13^{th}) in case of normal distribution	
(*ii*) Modified Penman	Best fit for all three methods above and weeks except for one and same week (16^{th}) for both log-normal and gamma distributions	
2. Gumbell distribution		
ET_r 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_r 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 to16,19, 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

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_r 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_r 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_{max} °C) and minimum temperature (T_{min} °C), maximum relative humidity (RH_{max} %) and minimum relative humidity (RH_{min} %), pan evaporation (E_{pan} mm), wind speed at height of 2 m (U_2, km/hr), actual sun shine hours (S, hr) and rainfall (R, mm) were collected for 20 years (1987-2006) from the India Meteorological Department, Pune.

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

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

TABLE 3

The best fit probability distributions for ET_r values of different weeks as estimated by different methods

MW	Methods						MW	Methods					
	PM	MP	HAR	E_{pan}	BLC	RAD		PM	MP	HAR	E_{pan}	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	N	LN	LN	LN	Gu	N
4	W	N	Ga	LN	Gu	N	30	LN	N	N	LN	W	Ga
5	Gu	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	N	W	Gu
8	N	N	N	N	Gu	Ga	34	LN	N	N	W	W	Gu
9	Gu	W	N	LN	N	N	35	N	N	N	N	Ga	LN
10	N	W	Gu	Gu	Gu	N	36	N	N	N	N	N	N
11	LN	Gu	N	N	N	N	37	LN	N	N	LN	N	LN
12	N	N	N	LN	N	LN	38	W	Gu	W	N	N	N
13	W	W	Gu	Gu	N	LN	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	Gu
25	N	N	W	N	N	N	51	Ga	N	N	N	N	Gu
26	N	Gu	N	LN	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),

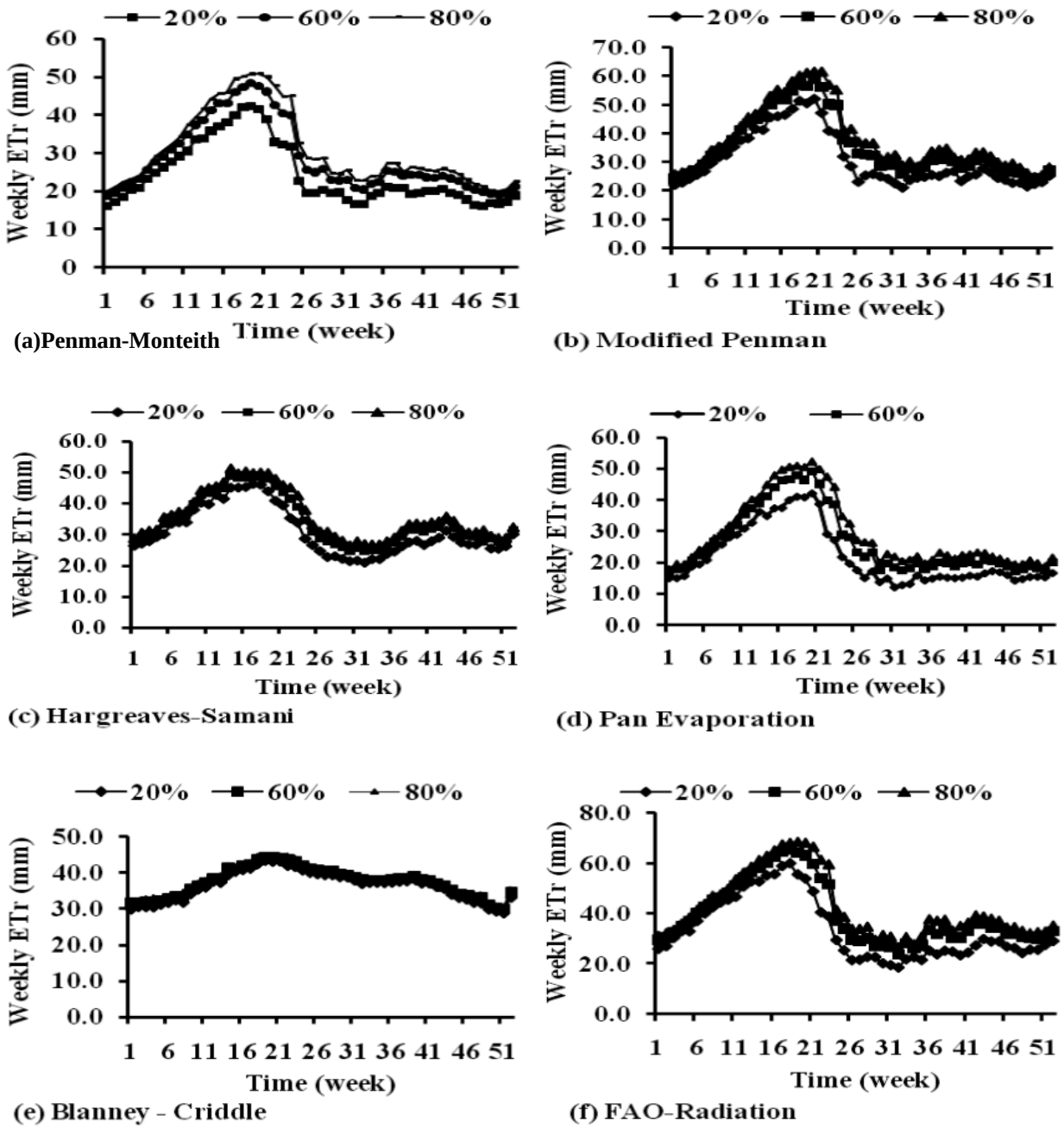
(*iii*) Hargreaves-Samani (Hargreaves and Samani, 1985),

(*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_r 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_r 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_r data most, chi-square test was performed. The chi-square statistic $\left(\chi^2_{cal}\right)$ is calculated from equation.

$$\chi^2_{cal} = \sum_{i=1}^{k} \frac{(Oi - Ei)^2}{Ei}$$

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

A probability distribution fits the weekly ET_r values if the calculated values of Chi-square χ^2_{cal} is less than the tabulated value of chi square at 5 % level of significance χ^2_{tab}. If in case more than one probability distribution fits the weekly ET_r values then the distribution that gives the lowest value of χ^2_{cal} is selected as the best probability distribution for weekly ET_r values. In this way the probability distribution functions for weekly ET_r values

for all the 52 weeks were found out. Once the probability distribution function is obtained, the weekly ET_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_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_r values for all probability distribution functions and the methods of ET_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_r values in several weeks and can be considered unsuitable for use in Pune conditions. Best fit weeks for ET_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_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), Blanney-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_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, Blanney-Criddle and FAO-Radiation methods. These values are presented in Figs. 1(a-f). The expected ET_r values at desired probability level and desired ET_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_r values at 70 % probability levels for Penman-Monteith, Pan Evaporation and Blanney-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_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.

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