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Computation of reference crop evapotranspiration of Nasik station of Maharashtra, India

D. T. MESHRAM, S. D. GORANTIWAR*, H. K. MITTAL** and N. V. SINGH

NRC on Pomegranate, Shelgi, Solapur, Maharashtra, India

** Mahatma Phule Krishi Vidyapeeth, Rahuri, India*

****College of Technology and Engineering, Udaipur, India***

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e mail : gomesh1970@rediffmail.com

सार – इस शोध पत्र में नासिक केन्द्र (अक्षांश 20° 53′ उ., देशांतर 75° 16′ पू. और ऊँचाई 565.0 मी. ओ. मा.स.त.) महाराष्ट्र, भारत के निर्देश फसल के वाष्पोत्सर्जन (ई.टी.$_{आर.}$) का आकलन करने के लिए सर्वोत्तम तरीके का पता लगाने के अध्ययन किया गया है। सिंचाई पद्धति का निर्धारण करने के लिए निर्देश फसल वाष्पोत्सर्जन एक आधारभूत प्रांचल है। अर्द्ध शुष्क जलवायविक स्थितियों में फसलों के दैनिक निष्पादनों का पता लगाने के लिए छः निर्देश फसल वाष्पोत्सर्जन पद्धतियों का उपयोग किया गया है। एफ.ए.ओ. द्वारा मानकीकृत किया गया पेनमैन – मॉनटीथ प्रणाली का उपयोग संशोधित पेनमैन, हरग्रीब्स–समानी, पैन वाष्पोत्सर्जन, ब्लैनी–क्रीडल एवं विकिरण प्रणाली के साथ तुलना करने के लिए किया गया है। इन प्रणालियों के कार्य निष्पादन न्यूनतम वर्ग माध्य मूल त्रुटि (आर.एम.एस.ई.) और समाश्रयण विश्लेषण (आर.ए.) के आधार पर तैयार किया गया है। आर. एम. एस. ई. का मान पैन वाष्पोत्सर्जन प्रणाली में सबसे अधिक 2.01 से 1.09 के बीच और उसके बाद क्रमशः ब्लैनी –क्रीडल, विकिरण प्रणाली, संशोधित पेनमैन एवं हरग्रीब्स – समानी प्रणाली में पाया गया है। महाराष्ट्र के नासिक केन्द्र की अद्धशुष्क जलवायविक परिस्थितियों के लिए छः प्रणालियों में से हरग्रीब्स – समानी प्रणाली को न्यूनतम वर्ग माध्य मूल त्रुटि (आर.एम.एस.ई. = 1.09 मि.मी. प्रतिदिन) तथा उच्चतम सहसंबंध गुणांक (आर.=0.99) वाला पाया गया है।

ABSTRACT. The study was conducted to know the best method for estimation of reference crop evapotranspiration (ET_r) for Nasik station (Latitude 20° 53′ N, Longitude 75° 16′ E and altitude 565.0 m amsl), Maharashtra, India. Reference crop evapotranspiration is a basic parameter in irrigation system design. Six reference crop evapotranspiration methods were used for their daily performances under semi-arid climatic condition. The Penman-Monteith method standardized by FAO was used to compare with the Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and Radiation methods. Performances of these methods were made on the basis of the least root mean square error (RMSE) and regression analysis (RA). The value of RMSE ranges from 2.01 to 1.09 with the highest in Pan Evaporation method followed by Blanney-Criddle, Radiation method, modified Penman and Hargreaves-Samani method. Out of six methods Hargreaves-Samani was found to have least root mean square error (RMSE = 1.09 mm/day) and highest correlation coefficient (r=0.99) under semi-arid climatic conditions of Nasik station of Maharashtra.

Key words – Reference crop evapotranspiration (ET_r), ET_r methods, Weather data, Semi-arid region.

1. Introduction

Reference crop evapotranspiration is one of the major components of the hydrological cycle and its accurate estimation is of the paramount importance for many studies such as hydrological water balance, irrigation system design, management of crop yield and water resource planning and management. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by the reference crop evapotranspiration. There are many methods reported by Blanney and Criddle, (1962), Doorenbos and Pruitt (1977), Subramanya (1984), Michael (1986), Mavi (1986) and NIH (1989) for estimation of reference crop evapotranspiration. In search of the best ET_r method for global application many researchers (Jensen 1974; Hargreaves and Samani 1985; Rao and Murthy 1988; Mohan 1991; Amatya *et al.,* 1995; Bhakar and Singh, 2005 and Allen *et al.,* 1998) have compared different reference crop evapotranspiration methods. Reference crop evapotranspiration (ET_r) refers to the total atmospheric loss of water from plant and soil surface during crop growth period.

A major problem faced by farmers is irrigation scheduling on low water holding capacity soils. Excess

irrigation will leach valuable plant nutrients, while limited irrigation can adversely affect growth and development of plants and finally yields and profits. Optimum irrigation scheduling, based on sound scientific principles, is becoming more important every day as water supply has become scarce. Irrigation scheduling relies on modeling or measuring evapotranspiration to update the soil water balance and to forecast future water use to predict when the allowable depletion will be reached. Methods using weather parameters to calculate reference crop evapotranspiration are used to schedule irrigations by water budgeting. The most practical approaches would be to estimate ET_r from climatic variables, such as solar radiation, air temperature, wind speed and relative humidity. The aim of this study is therefore to compare the ET_r values estimated by different methods from climatic data and to define the method which gives the most accurate results for ET_r for this region. The Penman-Monteith method was considered as standard method and other methods used were Modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and Radiation methods.

2. Data and methodology

2.1. *Location*

The study area is located at North latitude 20° 53′ and East longitude 75° 16′ in south east fringe of Maharashtra state and lies entirely between Girna and Godavari river basins with total area of 15530 km^2 which is 4.82 % of the total area of Maharashtra. The district is situated at an altitude of 565 m above mean sea level. Drainage pattern mostly dendritic and parallel drainage pattern is also developed at some places. The area has black, coarse gray and reddish soil, highly truncated with gentle sloping terrain on both the sides of river which results in quick build up of run-off into shallow precipitous tributaries that drain into Godavari river. This region is characterized by semi-arid climate with little or no water surplus. Rainfall is uncertain and scanty. The monsoon period is from second fortnight of June to end of September bringing rains from South-West monsoon.

2.2. *Climatological data*

Daily data for Nasik station (Latitude 20° 53′ N, Longitude 75° 16′ E and altitude 565.0 m amsl) with respect to 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 25 years (1986-2009) from the Indian Meteorological Department, Pune.

2.3. *Methods of estimation of ET_r*

The weekly reference crop evapotranspiration were estimated by using following methods.

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

(*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 (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 25 years.

The linear regression analysis was performed by considering the ET_r by Penman-Monteith (P-M) as the independent variable and ET_r of the remaining five methods as dependent variable to investigate the suitability for computing ET_r under limited climatic parameters *vis-a-vis* P-M method. Similarly, Root Mean Square Error (RMSE) of P-M method was taken as standard method and other methods were calculated to use this as an indicator of accuracy for other methods compared to P-M method. The RMSE provides a good measure of how closely the two independent data sets match (Ventura *et al.,* 1999).

RMSE values were calculated by using the following equation.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum\left(Yi^{p} - Yi^{o}\right)^{2}}$$

Where,

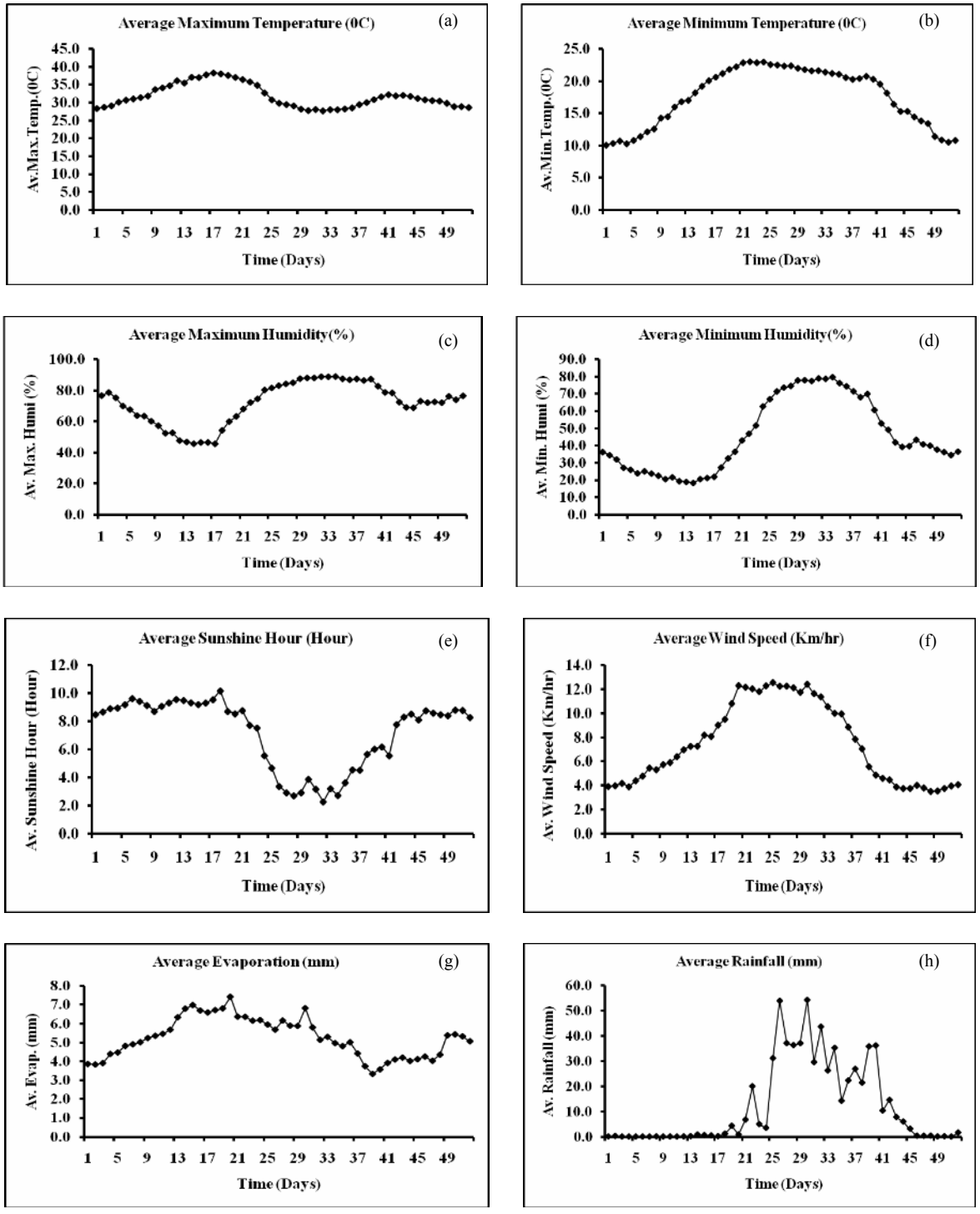
n - Number of observations

Y_i^p – ET_r estimated using P-M

Yi^o – ET_r estimated using other methods

3. Results and discussion

The climatic parameters of 25 years for the Nasik region of Western part of Maharashtra covering the period



Figs. 1(a-h). Input parameters used in the calculation of ET_r by different ET_r estimation methods (a) Average Max. Tem. (°C), (b) Average Min. Temperature (°C), (c) Average Max. Humidity (%), (d) Average Min. Humidity (%), (e) Average Sunshine Hour (Hours), (f) Average Wind Speed (km/hr), (g) Average Evaporation (mm) and (h) Average Rainfall (mm)

of January 1986 to December 2009 were analyzed for calculating the reference crop evapotranspiration (ET_r) by using different methods. Figs. 1(a-h), shows the average temperature (°C), humidity (°C), wind speed (km/hr), sunshine hour (hr), evaporation (mm) and precipitation (mm).

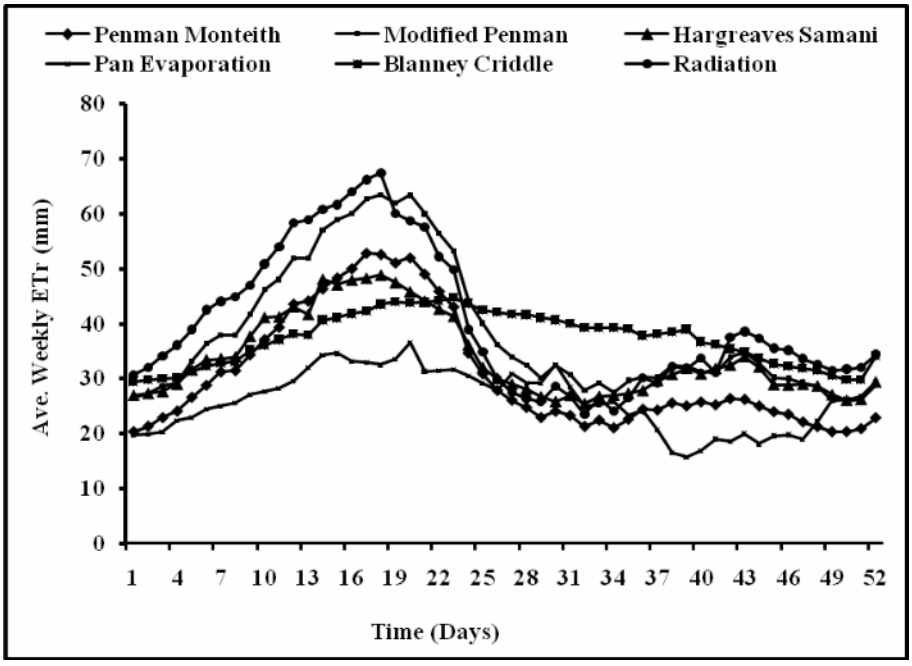
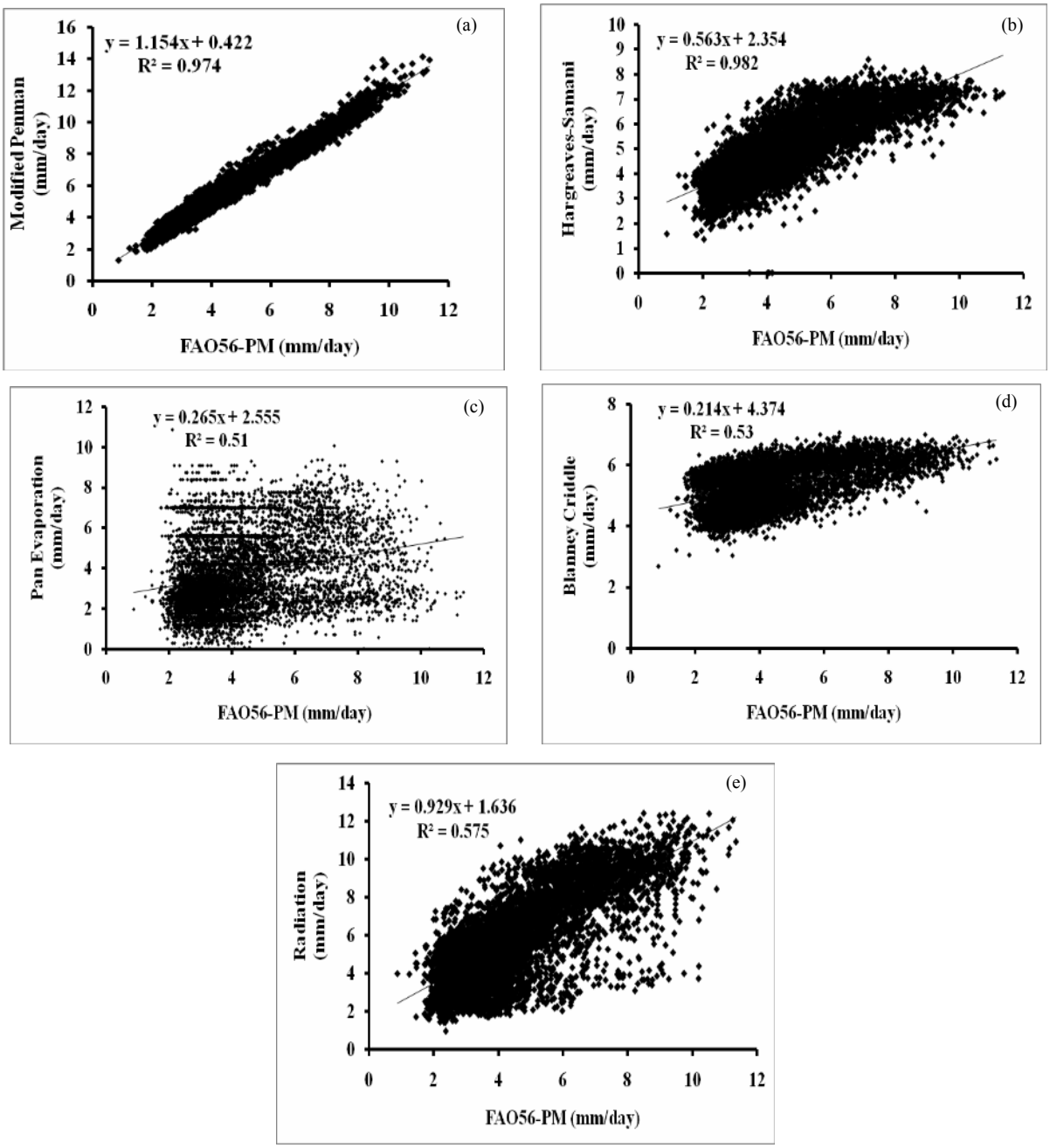


Fig. 2. Weekly reference crop evapotranspiration (mm) for Nasik station

TABLE 1

Daily root mean square error over P-M method (1986-2009) for Nasik region

	Root mean Square error (mm day^{-1})				
Years	MP	HAR	EPan	BLC	RAD
1986	1.29	1.28	3.51	1.78	1.23
1987	1.29	1.18	3.25	1.69	1.35
1988	1.14	1.08	1.80	1.30	1.16
1989	1.23	1.08	3.11	1.68	1.48
1990	1.24	1.14	2.43	1.79	1.30
1991	1.16	1.03	2.96	1.72	1.15
1992	1.50	1.10	2.38	1.78	1.66
1993	1.72	1.34	3.74	2.03	2.00
1994	1.08	1.00	2.54	1.73	1.35
1995	1.18	1.10	2.22	1.68	1.53
1996	0.95	1.07	1.06	1.88	1.55
1997	1.17	0.94	3.29	1.63	1.53
1998	0.97	1.03	2.23	1.64	1.36
1999	0.91	1.36	0.85	2.01	1.78
2000	1.04	1.27	2.49	1.88	1.66
2001	1.09	1.24	1.75	1.91	1.72
2002	1.39	1.29	1.73	1.93	2.56
2003	1.35	1.13	2.57	2.02	2.48
2004	0.92	1.16	1.08	2.02	1.82
2005	1.18	1.00	1.84	1.69	2.19
2006	1.00	1.21	1.05	2.09	1.89
2007	0.94	1.22	0.71	1.47	1.61
2008	0.99	1.11	0.89	0.99	1.12
2009	1.00	0.89	0.99	1.33	1.22
Total	27.74	27.25	50.48	41.68	38.71
Average	1.10	1.09	2.01	1.66	1.54



Figs. 3(a-e). Daily basis regression analysis of ET_r estimates of (a) Modified Penman (b) Hargreaves-Samani (c) Pan Evaporation, (d) Blanney- Criddle (e) Radiation methods for daily ET_r values at Nasik station (mm/day)

Comparison of weekly ET_r values for various methods is presented in Fig. 2. It is revealed that, the trend of the estimated ET_r values were in closeness among the applied methods, it was surprising that none of the method shows the same results. Seasonal variation in the ET_r estimation reflects the difference in the variable applied in each method. The daily basis regression analysis between P-M and other methods are shown in Figs. 3(a-e). The daily regression analysis values of coefficient of regression (r^2) between P-M method and Modified Penman, Hargreaves-Samani, Pan Evaporation, Blaney-Criddle and Radiation methods were 0.974, 0.982, 0.512, 0.534 and 0.575, respectively. These values (daily) of r^2 show that Hargreaves-Samani, Modified Penman, Pan Evaporation, Blaney-Criddle and Radiation methods are closely related to P-M method as r^2 of ET_r by P-M method

and other methods were more than 0.50. When considering the availability of input data, use of these methods are suggested as practical methods for estimating ET_r. P-M equation for ET_r deals with many parameters like radiation, aerodynamic, crop height, surface resistance, albedo, etc. It is considered as one of the soundest methods under well established weather station. But many of the climatic data are lacking due to several constraints, when micro-level study was taken up. Henceforth, P-M method cannot be used due to the complexity of its input parameters. When considering the availability of input data, use of these methods are suggested as practical method for estimating ET_r, if the P-M equation cannot be used due to the complexity of its input parameters.

The performance of the method compared to P-M was analyzed by computing the RMSE of the daily ET_r values between P-M and other methods. The lower value of RMSE implies the better performance of the applied method. Table 1 shows the average RMSE on daily and yearly basis for all the methods for all the years under consideration. These values were 1.10, 1.09, 2.01, 1.66 and 1.54 mm day^{-1} for modified Penman, Hargreaves-Samani, Pan Evaporation, Blanney-Criddle and Radiation methods, respectively. The lowest values of RMSE were found in between ET_r of Hargreaves-Samani and ET_r of P-M methods, when as the highest values was observed for ET_r by Pan Evaporation method.

The high correlation of ET_r by the Modified Penman method with P-M method clearly reflects the importance of the incident radiation as they are calculated by using the temperature and solar radiation. This fact also supported by many studies which reveal that, the Modified Penman methods are nearly as accurate as the P-M method in estimating ET_r. Therefore, the use of Modified Penman method is recommended in the case of other reliable data is lacking. The comparison made for all the methods signifies that all these methods can be successfully used to estimates the ET_r specifically in area having the same climatic condition as the one presented in this study. It can be said that all the methods tested in this study could be used at Nasik station of Maharashtra. It can be concluded that the Hargreaves-Samani method calibrated for Nasik station and presented herein is recommended as the most simple and practical method for estimating ET_r.

4. Conclusions

In this paper, the six most commonly used reference evapotranspiration estimation methods (*viz*., Modified Penman, Penman-Monteith, Hargreaves-Samani, SCS Blaney – Criddle, FAO-24 Pan Evaporation and FAO-Radiation) were compared with P-M method on the basis of root mean square error and regression analysis. Out of these methods the comparisons of ETr estimates by Hargreaves-Samani method was highly correlated with least root mean square error of 1.09 mm/day. This method can be accepted with temperature data only under semi-arid climatic condition of Nasik station of Western Part of Maharashtra.

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