Use of a decision support system to establish the best model for estimating reference evapotranspiration in sub-temperate climate: Almora, Uttarakhand

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Abstract: FAO-56-Penman-Monteith (FAO56PM) is regarded as a standard method worldwide for calculation of ETo. However due to requirement of detailed meteorological data, its application is often constrained under data scarce region. Under such situation, a suitable alternative method with equivalent efficacy to that FAO56PM needs to be identified. The present study is undertaken to evaluate 13 different ETo model from DSS_ET program using monthly long-term (1985-2010) meteorological data from VPKAS, experimental farm located in mid Himalaya region of Uttarakhand state of India with respect to standard (FAO56PM) method. The result revealed that combination method, Penmen-Monteith was found most suitable (R^2=0.96, NSE= 0.98, ｜RE｜= 0.01, NRMSE= 1% day^{-1} followed by 1972 Kimberly Penman (R^2=0.94, NSE= 0.96, ｜RE｜= 0.01, NRMSE= 6% day^{-1}). Among radiation method Turc ETo model (R^2=0.97, NSE= 0.97, ｜RE｜= 0.04, NRMSE= 4% day^{-1}) was found most appropriate, while in the temperature-based method, it was not possible to select a model with satisfactory performance, the Hargreaves model, the best among them, showed indexes and errors below the selection limits (R^2 = 0.40, NSE = 0.38, 'RE ' = 0.31, NRMSE = 25% day^{-1}). In general, the combination method to estimate ETo followed by the radiation-based method were the best performing, and indicated for the study site.

Keywords: irrigation management, radiation-based methods, temperature-based methods, mid Himalayan region

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1 Introduction

The reference evapotranspiration (ETo) portant parameter for calculating irrigation requirement, which is the largest user of irrigated water globally (Wisser et al., 2008). Precise estimation of ETo is indispensable for well-planned irrigation scheduling, crop yield modelling, assessing ground water recharge, water resource management and impact of climate change on water resources (Almorox and Hontoria, 2004; Jhorar et al., 2011; Khoob, 2008; Qiu et al., 2011; Kumar et al., 2020; Singh and Pawar, 2011). Globally, about 60% of annual precipitation goes into atmosphere (Oki and Kanae, 2006; Kumar et al., 2021a). The measurement of actual evapotranspiration is done by water balance model, lysimeter, Bowen ratio and eddy covariance method, which is troublesome and tedious process (Bandyopadhyay et al., 2012; Ding et al., 2013). ETo is frequently correlated to enumerate actual ET, which was contrarily difficult to estimate by lysimeter observation and water budget technique. ETo is beneficial to

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estimate the required climatic water requirement of the environment and accordingly could be practised for several purposes inclusive of accurate irrigation scheduling, drought assessment, crop yield estimation. In addition, in recent times ETo has been extensively used in determination of actual ET utilizing various remote sensing algorithms (Allen et al., 2007; Senay et al., 2007; Wagle et al., 2017; Kumar et al., 2021b). Therefore, as a key parameter in different ET model, ETo could also be employed in tracking actual ET of a region. Allen et al. (1998) defined ETo as a hypothetical evapotranspiration from an assumed crop height of 0.12 m, a fixed surface resistance of 70 m s^{-1} an albedo of 0.23 and the reference crop surface is uniform well-watered and completely shading the ground.

FAO56PM is combination of physiological and aerodynamic, which needs observed weather parameters such as air temperature, wind speed at 2 m height (u2; m s^{-1}), relative humidity (RH; %) incident solar radiation (Rs; MJ m^{-2}) and air temperature (°C). However, detailed meteorological parameters are often difficult to obtain due to explicit network of metrological observatory, especially in mid and high altitude of Indian Himalayan Region (IHR) (Pandey et al., 2016; Singh et al., 1995; Pant, 2003). In the light of previous discussion, other method must be evaluated as an alternative to FAO56PM Model.

The present study region lies are situated mid Himalayan region of Uttarakhand state with adverse topography and complex microclimate. To our knowledge, no study has been reported to evaluate the performance of various ETo model with FAO56PM model by statistical analysis in this region. The present research is focused on performance evaluation of thirteen ETo models (simulation value) with FAO56PM Model (standard value) using DSS_ET. In addition, Nash-Sutcliffe efficiency (NSE), relative error (RE) , Normalized root mean squared error (NRMSE), Percent bias (PBIAS) and coefficient of determination (R^2) are used to identify a suitable alternative to the FAO56PM.

2 Study area and data used

The ICAR- VPKAS, Hawalbagh study site (29°36′N; 79°40′E at 1250 m above sea level) an agricultural research experimental farm, is located in mid Himalayan region of Uttarakhand state of India (Figure 1). Long-term (1985-2010) average monthly climatic parameter such as maximum temperature, minimum temperature, average relative humidity, average wind speed and monthly rainfall were used from meteorological station of research experimental farm for the present research. The whole year was divided into four seasons as suggested by Kumar et al. (2021c). Monthly climatic variable data was further used for used for preparing annual and seasonal, i.e., monsoon season (JJAS), post monsoon season (ON), cold winter season (DJF) and premonsoonal (MAM) time series data.

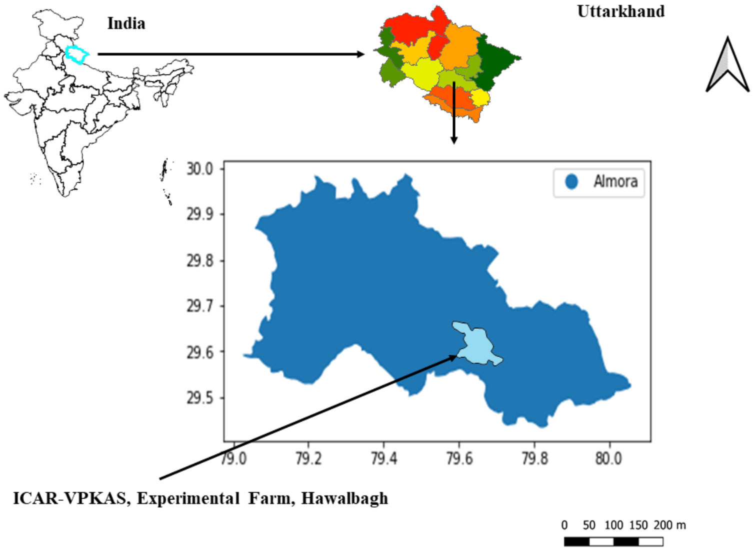


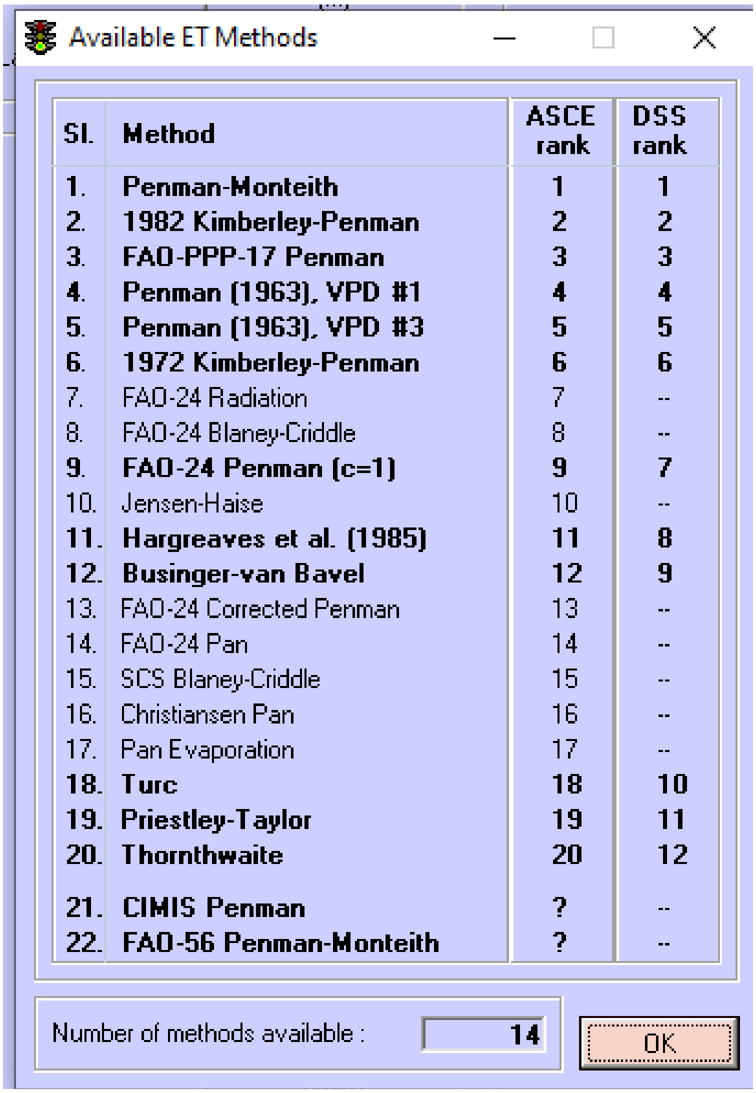
Figure 1 Location of study site

3 Materials and methods

Calculation of ETo is done using user friendly decision support system (DSS_ET) software (Bandyopadhyay et al., 2012). There are 22 well-established and widely used methods are available in the DSS_ET. Most of these methods can be used for computing ETo values at monthly and daily scales. The important feature of the DSS_ET model includes options for estimating the required input parameters, each by a number of equations available in the literature, thus by providing more accurate information on ETo calculation and enhancing the flexibility of the model. In addition to this, options for estimation of missing data, flexibility of importing data from spread sheet applications, good documentation and extensive user help makes this model a handy tool for various applications.

At the top of screen of the main window of the DSS_ET model there is a menu bar for user to access different menu. The first menu is file menu under which three submenus, viz., New Data Input File, Open Data Input File and Exit is listed. Both New Data Input File, Open Data Input File submenus open the first window of Data Input file (DIF), in which user needs to specify the station name, data frequency (daily/monthly) and available parameters along with units.

Checkboxes are checked according to the availability of different parameter for a specified station. Once this process is completed, the user can see the availability of different ETo model (Figure 2) for that station under with the particular data availability condition by clicking Available ET method button. Based on the selection parameter, available data are imported to DSS_ET from file selected by the user corresponding to a specified station.



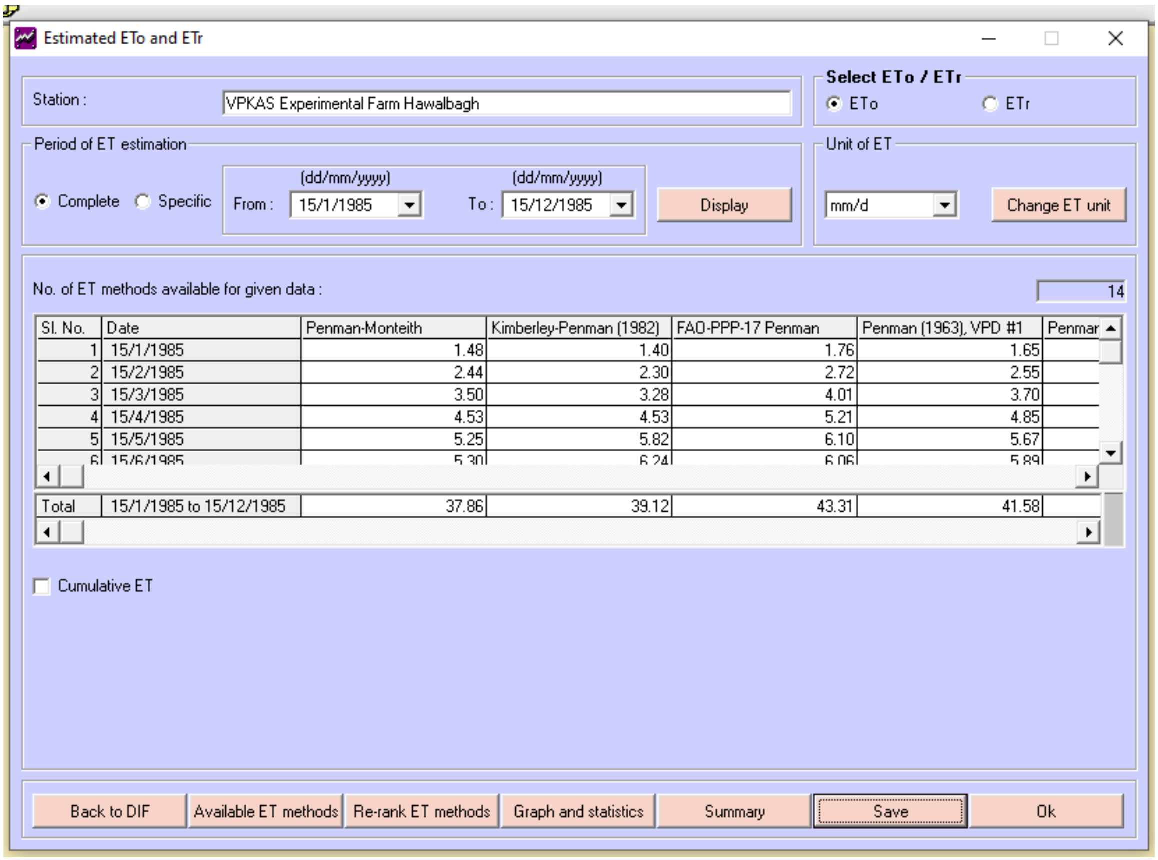
Sl.	Method	ASCE rank	DSS rank
1.	**Penman-Monteith**	**1**	**1**
2.	**1982 Kimberley-Penman**	**2**	**2**
3.	**FAO-PPP-17 Penman**	**3**	**3**
4.	**Penman (1963), VPD #1**	**4**	**4**
5.	**Penman (1963), VPD #3**	**5**	**5**
6.	**1972 Kimberley-Penman**	**6**	**6**
7.	FAO-24 Radiation	7	--
8.	FAO-24 Blaney-Criddle	8	--
9.	**FAO-24 Penman (c=1)**	**9**	**7**
10.	Jensen-Haise	10	--
11.	**Hargreaves et al. (1985)**	**11**	**8**
12.	**Businger-van Bavel**	**12**	**9**
13.	FAO-24 Corrected Penman	13	--
14.	FAO-24 Pan	14	--
15.	SCS Blaney-Criddle	15	--
16.	Christiansen Pan	16	--
17.	Pan Evaporation	17	--
18.	**Turc**	**18**	**10**
19.	**Priestley-Taylor**	**19**	**11**
20.	**Thornthwaite**	**20**	**12**
21.	**CIMIS Penman**	**?**	--
22.	**FAO-56 Penman-Monteith**	**?**	--

Number of methods available : **14**

Figure 2 Available ET model for calculation

Clicking the Next button proceeds to second window of Data Input File. The user has to fill the data either through keyboard or copy paste function from spread sheet applications.

Once all the data and options are entered, the user can save the DIF file by clicking the Save DIF button, which is used for further editing and correction if needed. By clicking the submenu Estimate ETo and ETr submenu under the Run menu a message of ETo and ETr estimated successfully display on the screen, which confirms the calculation of PET using the available method. After ET calculations are finished, the results (Figure 3) can be viewed by clicking ETo and ETr submenu under Results menu.



Station : VPKAS Experimental Farm Hawalbagh

● ETo ○ ETr

● Complete ○ Specific

From : (dd/mm/yyyy) 15/1/1985 To : (dd/mm/yyyy) 15/12/1985

mm/d

No. of ET methods available for given data : 14

Sl. No.	Date	Penman-Monteith	Kimberley-Penman (1982)	FAO-PPP-17 Penman	Penman (1963), VPD #1	Penmar
1	15/1/1985	1.48	1.40	1.76	1.65	
2	15/2/1985	2.44	2.30	2.72	2.55	
3	15/3/1985	3.50	3.28	4.01	3.70	
4	15/4/1985	4.53	4.53	5.21	4.85	
5	15/5/1985	5.25	5.82	6.10	5.67	
6	15/6/1985	5.30	6.24	6.06	5.89	
Total	15/1/1985 to 15/12/1985	37.86	39.12	43.31	41.58	

☐ Cumulative ET

Figure 3 Screen showing result of ETo calculation from available ET model

For easy access later, the estimated ETo/ETr values can be saved to a Microsoft Excel (.xlsx) by clicking the Save button (Figure 3).

4 Accuracy assessment

To evaluate the best ETo model with respect to FAO56PM for ETo four performance indicator, viz. Nash-Sutcliffe efficiency (NSE), relative error (RE), and normalized root mean squared error (NRMSE) were used. The value of performance indicators were calculated using the following equation and linear regression was calculated using Microsoft excel.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(ETo_{FAO56PM} - ETo)^2}{\sum_{i=1}^{n}(ETo_{FAO56PM} - \overline{ETo_{FAO56PM}})^2} \qquad (1)$$

$$RE = \frac{\sum_{i=1}^{n} ETo - ETo_{FAO56PM}}{\sum_{i=1}^{n} ETo_{FAO56PM}} \qquad (2)$$

$$\text{NRMSE} = \frac{\frac{\sqrt{\sum_{i=1}^{n}(ETo - ETo_{FAO56PM})^2}}{n}}{\sigma ETo_{FAO56PM}} \times 100 \qquad (3)$$

$$R^2 = \frac{\sum(ET_o - \overline{ETo_{FAO56PM}})^2}{\sum(ETo_{FAO56PM} - To - ETo_{FAO56PM})^2} \qquad (4)$$

Where n is number of ETo observation; $ETo_{FAO56PM}$ is the value of ETo calculated by FAO56PM method (mm day^{-1}); and ETo is the value estimated by another model.

We have extended the methodology (Lang et al., 2017) for selecting the best one which fulfils all the following criteria: $0<\text{NSE}<1$; $0\leq|\text{RE}|\leq 0.2$; $0\% \leq \text{NRMSE} \leq 20\%$ and $0.8 \leq R^2 \leq 1$. Percent bias (PBIAS) was computed for understanding to measure the average tendency of the simulated data to be larger or smaller than standard estimated data, which is calculated using the following equation.

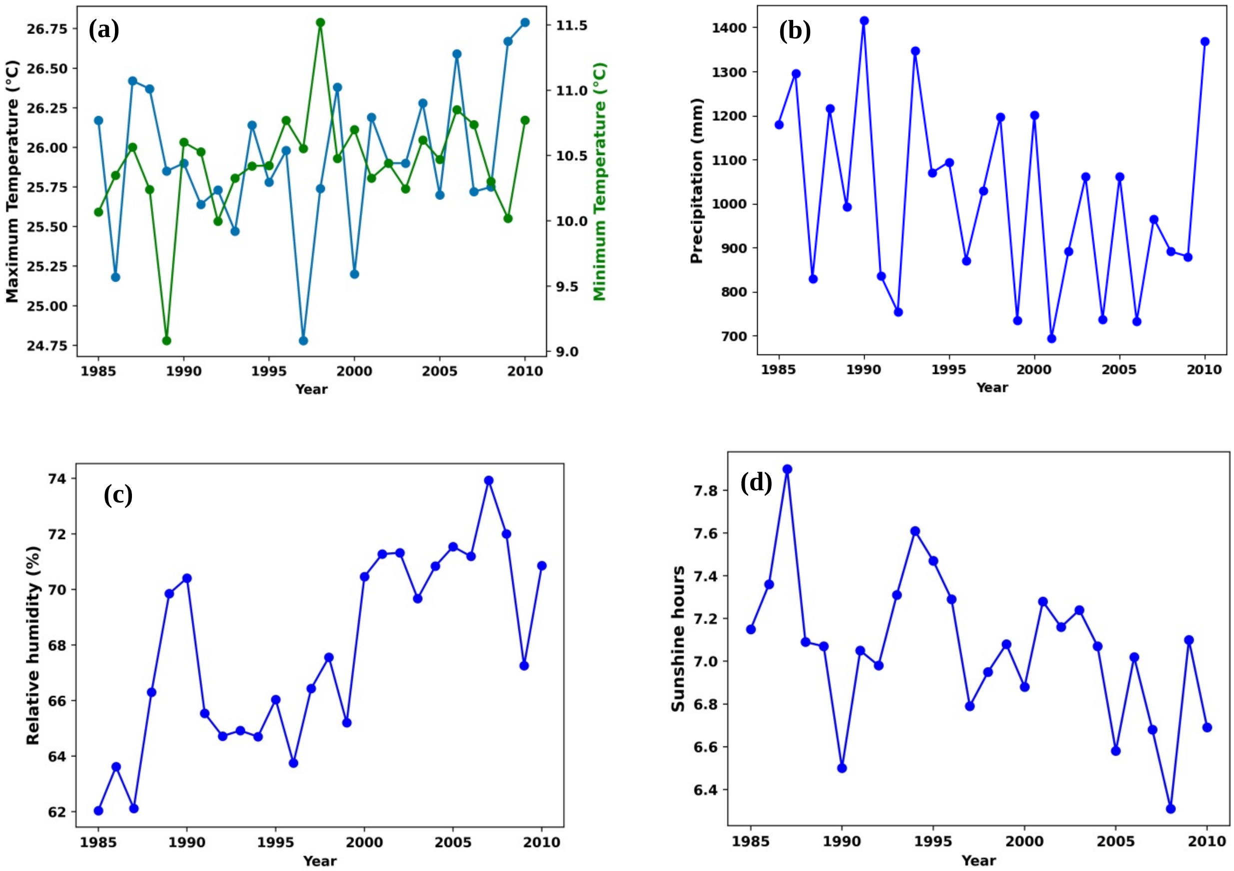
$$PBIAS = \frac{\sum_{i=1}^{n} ETo_{FAO56PM} - ETo}{\sum_{i=1}^{n} ETo_{FAO56PM}} \times 100 \quad (5)$$

It is expressed as percentage, positive values show model underestimation bias, while negative values show model overestimation bias.

5 Results and discussion

5.1 Weather parameter during the study period

Trends and magnitude of climatic parameters, including average monthly maximum temperature (T_{max}), minimum temperature (T_{min}), sunshine hour, relative humidity and monthly rainfall for study site is shown in (Figure 4). The annual rainfall of site varies from 693 mm to 1415 mm with an average rainfall 1013 mm during the study period (Kumar et al., 2021d). T_{max} ranged from 24.7℃ to 26.7℃ with average T_{max} is equal to 25.93℃ and T_{min} ranged from 9.08℃ to 11.5℃ with average T_{min} is equal to 10.4℃.



(a) T_{max}. and T_{min}; (b) Precipitation; (c) Relative humidity; (d) Hours of sunshine

Figure 4 Trend of the Climate variables used

5.2 Variation of average daily ETo on monthly basis

All 14 ETo model showed that average daily ETo (mm day^{-1}) across different month increases from January and reaches its peak during May and then decreases in November and December. The average daily ETo for every month calculated from different ETo model is given in (Figure 5). The maximum and minimum daily average ETo was found to be in the month of May and January by all ETo model except CIMIS Penman (ETo) with average value of 5.19 mm day^{-1} and 1.65 mm day^{-1} respectively.

5.3 Variation of seasonal ETo

Table 1 shows the seasonal ETo calculated from different model. The maximum seasonal ETo was found to for JJAS followed by MAM, ON and DJF respectively across all model. The average daily ETo (mm day^{-1}) for different month was calculated using fourteen model. The variation of ETo value is represented using Boxplot as shown in Figure 6. In which the highest values of ETo were verified between the months of May and June, and the lowest in the months of January and December. The seasonal ETo (mm) value calculated from different model was 500 mm (JJAS), 385 mm (MAM), 100 mm (ON), 55 mm (DJF) and annual is shown in Figure 7.

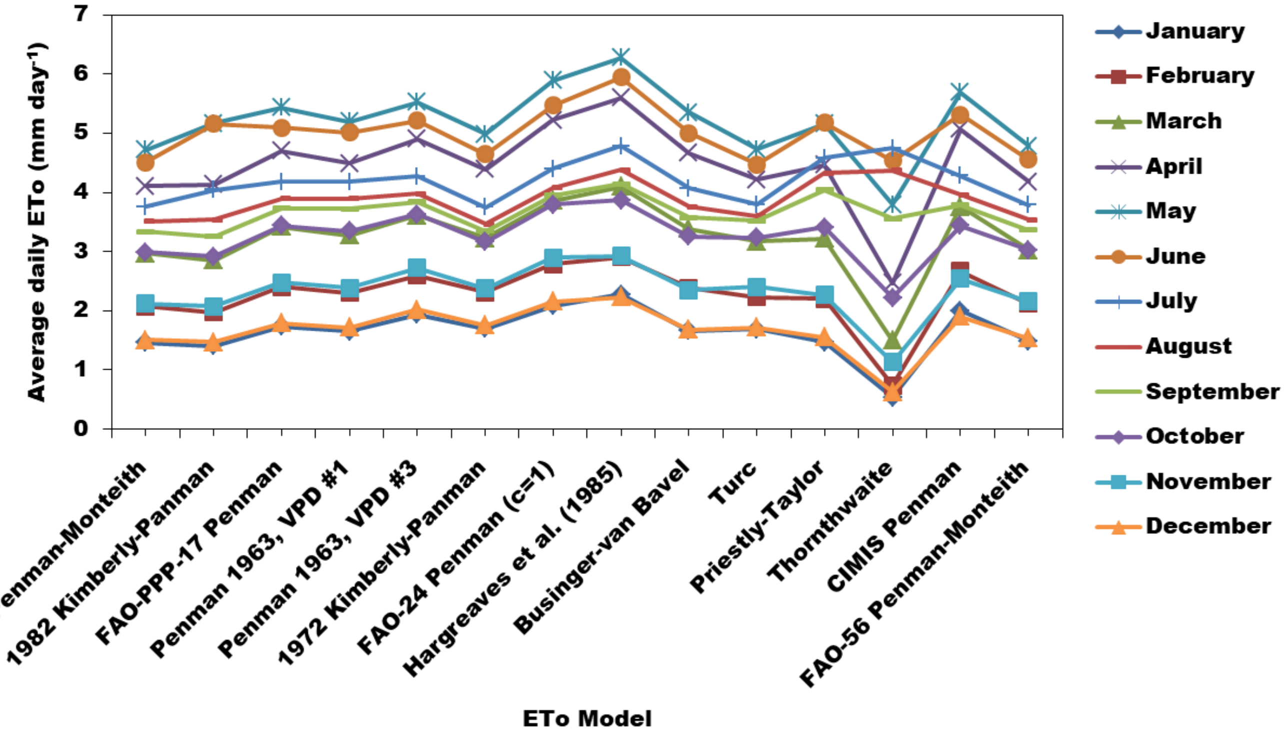


Figure 5 Average daily ETo average (mm day^{-1}) variation during different month

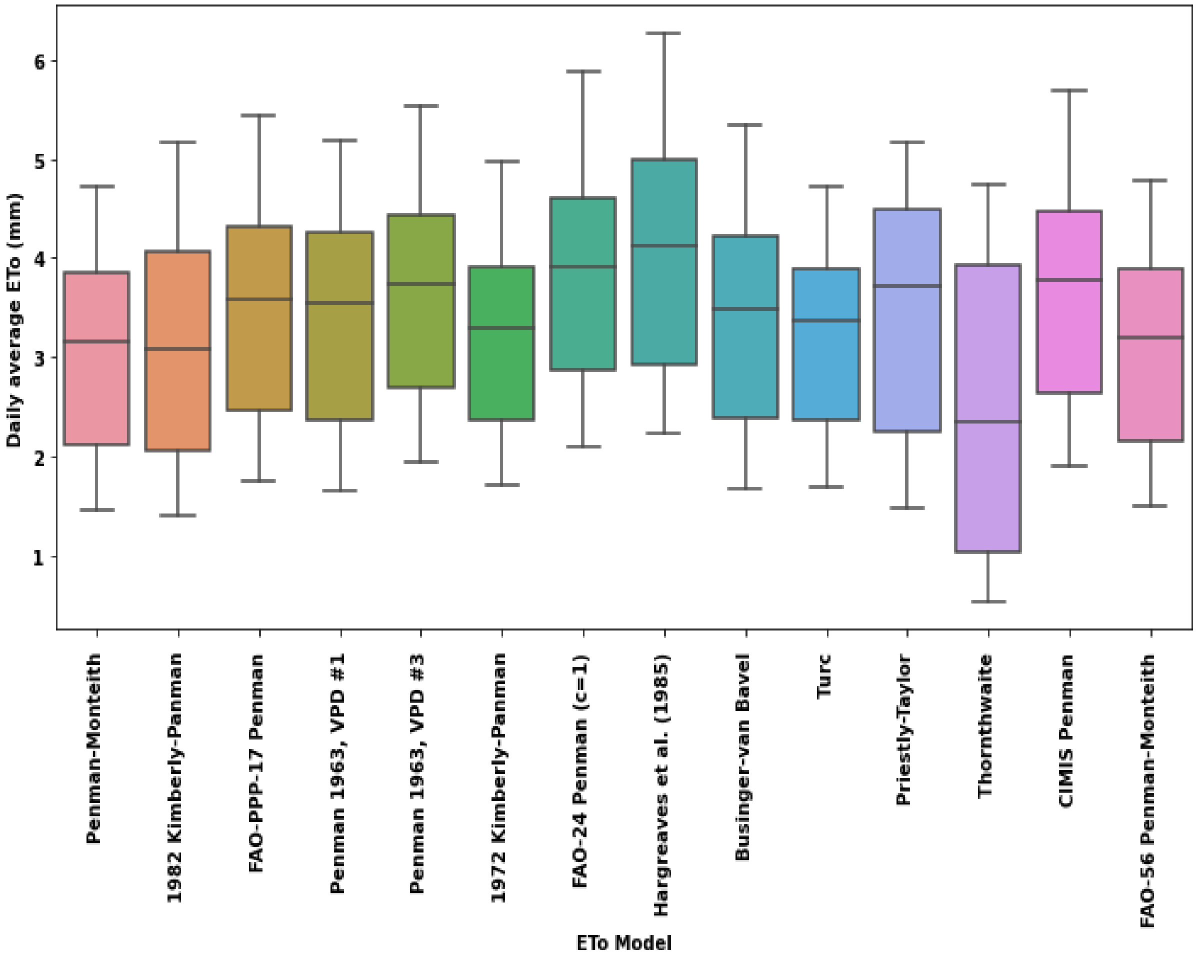


Figure 6 Average monthly evapotranspiration totals obtained by various methods

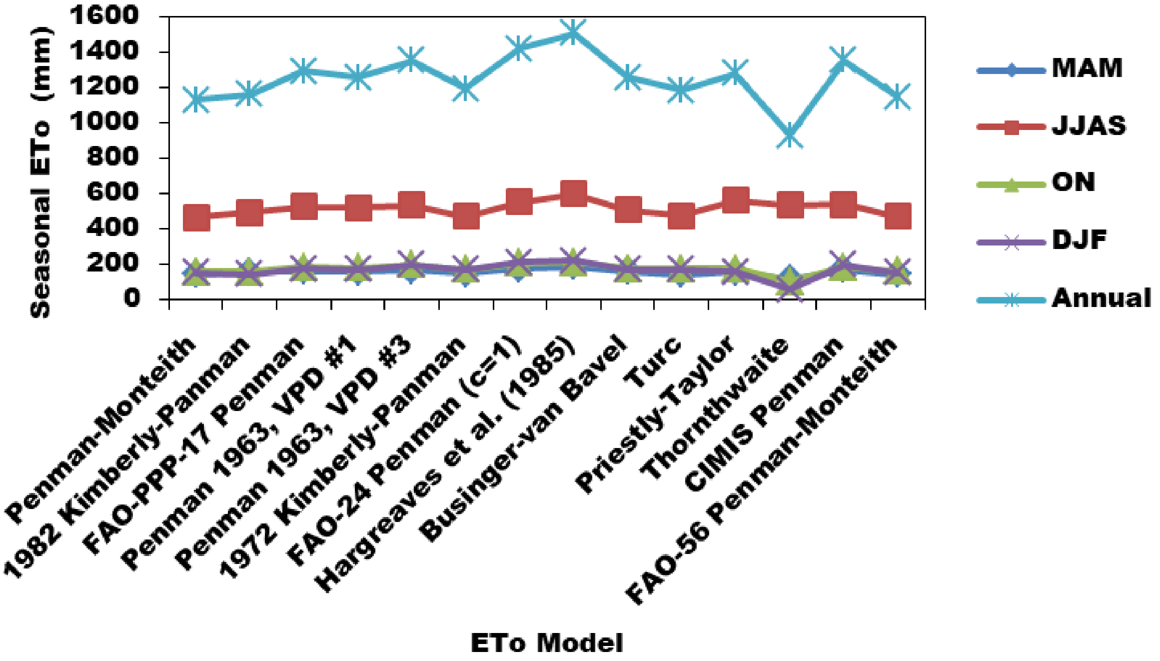


Figure 7 Average seasonal evapotranspiration totals obtained by various methods

5.4 Evaluation of the potential evapotranspiration model to the FAO56PM

Monthly average daily ETo (mm day^{-1}) were estimated using fourteen different ETo models. The monthly average daily statistics between the measured and simulated ETo are presented in Table 2. Considering the coefficient of determination (R^2) between FAO56PM and thirteen other methods, Penman Monteith (PM) model perform the best with R^2 value of 0.96 followed by 1972 Kimberly- Penman (ETo) (0.94). Among various model considered under combined method, PM performed the best with the highest value of NSE (0.98), the lowest value of $|RE|$ (0.01), the lowest value of NRMSE (1% day^{-1}) and a highest value of R^2 (0.96). Turc (ETo) was in the second place with NSE of 0.97, R^2 of 0.97, $|RE|$ (0.04) and NRMSE of 5%. Although the R^2 value of 1972 Kimberly-Penman (ETo) was equal to 0.94, the results of other performance indicator showed poor performance, which is in accordance with the findings of the previous study in North Eastern Region of India (Pandey et al., 2016).

Table 2 Statistical indices of Relationship between the monthly potential evapotranspiration (ETo) estimates of each model with FAO 56 Penman Monteith potential evapotranspiration for the study site

Methods	NRMSE (%)	NSE	RE	R^2
Penman-Monteith	1	0.98	-0.01	0.96
1982 Kimberly-Panman	6	0.96	0.01	0.94
FAO-PPP-17 Penman	11	0.87	0.12	0.87
Penman 1963, VPD #1	8	0.92	0.09	0.92
Penman 1963, VPD #3	15	0.75	0.17	0.75
1972 Kimberly-Panman	5	0.97	0.04	0.94
FAO-24 Penman (c=1)	2	0.57	0.23	0.57
Hargreaves et al. (1985)	25	0.38	0.31	0.40
Businger-van Bavel	8	0.92	0.09	0.92
Turc	5	0.97	0.04	0.95
Priestly-Taylor	12	0.87	0.11	0.87
Thornthwaite	24	0.54	-0.19	0.54
CIMIS Penman	15	0.75	0.18	0.75

5.5 PBIAS for seasonal and annual

Overestimation and underestimation error for seasonal and annual ETo is shown in Table 1 PBIAS suggested that for MAM Penman-Monteith (ETo) and 1972 Kimberly-Panman (ETo) overestimated whereas others model underestimated. However, Penman-Monteith (ETo) showed underestimation in DJF. 1972 Kimberly-Panman (ETo) showed overestimation for all the season except DJF.

Table 1 Annual and seasonal ETo (mm) PBIAS (%) during (1985-2010)

Methods	MAM	JJAS	ON	DJF	Annual
Penman-Monteith	-1.65	-0.84	-1.35	0.67	-0.84
1982 Kimberly-Penman	1.3	4.87	-3.66	-5.71	1.09
FAO-PPP-17 Penman	13.07	10.82	14.25	15.13	12.5
Penman 1963, VPD #1	8	10.24	10.65	10.18	9.87
Penman 1963, VPD #3	17.07	13.47	22.66	27.29	17.87
1972 Kimberly-Penman	-1.9	-6.9	-0.15	9.57	-2.21
FAO-24 Penman (c=1)	24.8	17.34	29.15	36.65	23.79
Hargreaves et al. (1985)	33.11	26.29	31.16	44.14	31.24
Businger-van Bavel	11.69	7.56	8.12	11.35	9.04
Turc	1.08	0.93	8.87	9.85	3.69
Priestly-Taylor	7.1	18.9	9.45	1.52	12.32
Thornthwaite	35.23	12.97	-35.27	-62.99	-16.28
CIMIS Penman	20.96	13.74	15.38	27.46	17.57

The present research evaluates the performance of thirteen ETo model with FAO56PM model in mid Himalayan region of Uttarakhand. The performance of different ETo model were compared using different statistical parameter whose values is given in Table 2. It can be interpreted from the Table 2 that out of different model among combined method PM have good agreement as they have small NRMSE and RE and value of R^2 close to unity, similar results agreed with the result found in the present study across different parts of world such as India (Pandey et al., 2016; Debnath et al., 2015; Bandyopadhyay et al., 2012), China (Xu et al., 2006; Yang et al., 2011), USA (Sharma and Irmak, 2012; Ha et al., 2011). Pandey and and Pandey (2016) in a study on “Evaluation of temperature-based Penman–Monteith (TPM) model under the humid environment” comparing the standard FAO56PM with TPM found R^2=0.84. The present study presented R^2= 0.96, demonstrating the quality of the result. The present study result stating that Penman-Monteith model was found to be most applicable alternative to FAO56PM, which is supported by the result found by Bandyopadhyay et al. (2012).The result found in this study recommends that the PM model is better alternative for computing ETo in place of FAO56PM in the study area. The superior performance of combined based model found in this research is in accordance with the outcomes in other humid environment, for example, (George and Raghuwansi, 2012; Tabari et al., 2013; Yoder et al., 2005). PM model was found closer to FAO56PM which is under the recommended limit as suggested by Hargreaves and Allen (2003). The values of NRMSE and RE were in concurrence with Lang et al. (2017). Among temperature-based method only Hargreaves can be used as an alternative to FAO56PM to estimate ETo, but it was not the best method in study area. Several researchers (Chen et al., 2005; Lu et al., 2005; Nikam et al., 2014) found Thornthwaite performed the worse. In the present study, Thornthwaite also performed the worse. The studies mention that this model uses only one input parameter and the smaller the number of parameters in a model, the lower its performance, which is why, in the present study, its low performance was also verified.

6 Conclusion

This study evaluated the performance of thirteen ETo estimation models compared to the standard FAO56PM model, in the middle Himalayan region of Uttarakhand. Among the different models analyzed, those based on radiation showed that they can be applied to the study site, under conditions of limited data. However, temperature-based methods in this category performed poorly. Among all the best ETo models under the combination method is Kimberly-Penman 1972 followed by Kimberly-Penman 1982 and under the radiation-based method the Turc method was considered adequate. In general, the reason behind the performance of the combination method is that it incorporates the climatic radiation component and the physiological factor. The result of this study will be useful for the irrigation manager, the researcher and the agricultural community to choose a more accurate ETo model in this region under limiting data conditions.

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References

Allen, R. G., M. Tasumi, and R. Trezza. 2007. Satellite-based energy balance for mapping evapotranspiration with internalized calibration (METRIC)—Model. *Journal of Irrigation and Drainage Engineering*, 133(4): 380-394.

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration: guidelinse for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome, Italy: FAO.

Almorox, J., and C. Hontoria. 2004. Global solar radiation estimation using sunshine duration in Spain. *Energy Conversions and Management*, 45(9-10): 1529-1535.

Bandyopadhyay, A., A. Bhadra, R. K. Swarnakar, N. S. Raghuwanshi, and R. Singh. 2012. Estimation of reference evapotranspiration using a user-friendly decision support system: DSS_ET. *Agricultural and Forest Meteorology*, 154-155: 19-29.

Chen, D., G. Gao, C. Xu, J. Guo, and G. Ren. 2005. Comparison of the Thornthwaite method and pan data with the standard Penman–Monteith estimates of reference evapotranspiration in China. *Climate Research*, 28(2): 123-132.

Debnath, S., S. Adamala, and N. S. Raghuwanshi. 2015. Sensitivity analysis of FAO-56 Penman-Monteith method for different agro-ecological regions of India. *Environmental Processes*, 2(4): 689-704.

Ding, R., S. Kang, F. Li, Y. Zhang, and L. Tong. 2013. Evapotranspiration measurement and estimation using modified Priestley-Taylor model in an irrigated maize field with mulching. *Agricultural and Forest Meteorology*, 168: 140-148.

George, B. A., and N. S. Raghuwanshi. 2012. Inter-comparison of reference evapo- transpiration estimated using six methods with data from four climatological stations in India. *Journal of Indian Water Resources Society*, 32(3-4): 15-21.

Ha, W., P. H. Gowda, T. Oommen, T. H. Marek, D. O. Porter, and T. A. Howell. 2011. Spatial interpolation of daily reference evapotranspiration in the Texas high plains. In *World Environmental and Water Resources Congress 2011: Bearing Knowledge for Sustainability*, 2796-2804. Palm Springs, California, United States, 22-26 May.

Hargreaves, G. H., and R. G. Allen. 2003. History and evaluation of Hargreaves evapotranspiration equation. *Journal of Irrigation and Drainage Engineering*, 129(1): 53-63.

Hargreaves, G.L. Hargreaves, G.H., and Riley J.P. 1985. Agricultural benefits for Senegal river basin. *Journal of Irrigation and Drainage Engineering*. 111: 113–124.

Jhorar, R. K., A. A. M. F. R. Smit, W. G. M. Bastiaanssen, and C. W. J. Roest. 2011. Calibration of a distributed irrigation water management model using remotely sensed evapotranspiration rates and groundwater heads. *Irrigation and Drainage*, 60(1): 57-69.

Khoob, A. R. 2008. Comparative study of Hargreaves's and artificial neural network's methodologies in estimating reference evapotranspiration in a semiarid environment. *Irrigation Science*, 26(3): 253-259.

Kumar, U., S. C. Panday, J. Kumar, V. S. Meena, M. Parihar, S. Singh, J. K. Bisht, and L. Kant. 2021a. Comparison of recent rainfall trend in complex hilly terrain of sub-temperate region of Uttarakhand. *MAUSAM*, 72(2): 349-358.

Kumar, U., B. Sahoo, C. Chatterjee, and N. S. Raghuwanshi. 2020. Evaluation of simplified surface energy balance index (S-SEBI) method for estimating actual evapotranspiration in Kangsabati reservoir command using Landsat 8 imagery. *Journal of the Indian Society of Remote Sensing*, 48(10): 1421-1432.

Kumar, U., S. Singh, J. K. Bisht, and L. Kant. 2021b. Use of meteorological data for identification of agricultural drought in Kumaon region of Uttarakhand. *Journal of Earth System Science*, 130(3): 121.

Kumar, U., A. Srivastava, N. Kumari, B. Sahoo, C. Chatterjee, and N. S. Raghuwanshi. 2021c. Evaluation of spatio-temporal evapotranspiration using satellite-based approach and lysimeter in the agriculture dominated catchment. *Journal of the Indian Society of Remote Sensing*, 49: 1939-950.

Kumar, U., Rashmi, Chatterjee, C, and Raghuwanshi, N.S. 2021d. Comparative Evaluation of Simplified Surface Energy Balance Index-Based Actual ET against Lysimeter Data in a Tropical River Basin. *Sustainability*, 13: 13786.

Lang, D., J. Zheng, J. Shi, F. Liao, X. Ma, W. Wang, X. Chen, and M. Zhang. 2017. A comparative study of potential evapotranspiration estimation by eight methods with FAO

Penman–Monteith method in southwestern China. *Water*, 9(10): 734.

Lu, J., G. Sun, S. G. McNulty, and D. M. Amatya. 2005. A comparison of six potential evapotranspiration methods for regional use in the southeastern United States. *Journal of the American Water Resources Association*, 41(3): 621-633.

Nikam, B. R., P. Kumar, V. Garg, P. K. Thakur, and S. P. Aggarwal. 2014. Comparative evaluation of different potential evapotranspiration estimation approaches. *International Journal of Research in Engineering and Technology*, 3(6): 544-552.

Oki, T., and S. Kanae. 2006. Global hydrological cycles and world water resources. *Science*, 313(5790): 1068-1072.

Pandey, P. K., P. P. Dabral, and V. Pandey. 2016. Evaluation of reference evapotranspiration method for the north-eastern region of India. *International Soil and Water Conservation Research*, 4(1): 52-63.

Pandey, P. K., and V. Pandey. 2016. Evaluation of temperature-based Penman–Monteith (TPM) model under the humid environment. *Modeling Earth Systems and Environment*, 3(2): 152.

Pant, G. B. 2003. Long-term climate variability and change over monsoon Asia. *Journal of Indian Geophysical Union*, 7(3): 125-134.

Qiu, R., S. Kang, F. Li, T. Du, L. Tong, F. Wang, R. Chen, J. Liu, and S. Li. 2011. Energy partition and evapotranspiration of hot pepper grown in greenhouse with furrow and drip irrigation methods. *Scientia Horticulturae*, 129(4): 790-797.

Senay, G. B., M. Budde, J. P. Verdin, and A. M. Melesse. 2007. A coupled remote sensing and simplified surface energy balance approach to estimate actual evapotranspiration from irrigated fields. *Sensors*, 7(6): 979-1000.

Sharma, V., and S. Irmak. 2012. Mapping spatially interpolated precipitation, reference evapotranspiration, actual crop evapotranspiration, and net irrigation requirements in Nebraska: Part I. Precipitation and reference evapotranspiration. *Transactions of the ASABE*, 55(3): 907-921.

Singh, P., K. S. Ramasastri, and N. Kumar. 1995. Topographical influence on precipitation distribution in different ranges of westerns Himalayas. *Hydrology Research*, 26(4-5): 259-284.

Singh, R. K., and P. S. Pawar. 2011. Comparative study of reference crop evapotranspiration (ETO) by different energy based method with FAO 56 Penman-Monteith method at New Delhi, India. *International Journal of Engineering Science and Technology*, 3(10): 7265-7269.

Tabari, H., M. E. Grismer, and S. Trajkovic. 2013.Comparative analysis of 31 references evapotranspiration methods under humid conditions. *Irrigation Science*, 31(2): 107-117.

Wagle, P., N. Bhattarai, P. H. Gowda, and V. G. Kakani. 2017. Performance of five surface energy balance models for estimating daily evapotranspiration in high biomass sorghum. *ISPRS Journal of Photogrammetry and Remote Sensing*, 128: 192-203.

Wisser, D., S. Frolking, E. M. Douglas, B. M. Fekete, C. J. Vörösmarty, and A. H. Schumann. 2008. Global irrigation water demand: Variability and uncertainties arising from agricultural and climate data sets. *Geophysical Research Letters*, 35(24): L24408.

Xu, C., L. Gong, T. Jiang, D. Chen, and V. P. Singh. 2006. Analysis of spatial distribution and temporal trend of reference evapotranspiration and pan evaporation in Changjiang (Yangtze River) catchment. *Journal of Hydrology*, 327(1-2): 81-93.

Yang, Z., Q. Liu, and B. Cui. 2011. Spatial distribution and temporal variation of reference evapotranspiration during 1961-2006 in the Yellow River Basin, China. *Hydrological Sciences Journal*, 56(6): 1015-1026.

Yoder, R. E., L. O. Odhiambo, and W. C. Wright. 2005. Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid southeast United States. *Applied Engineering in Agriculture*, 21(2): 197-202.