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Study of Different Evapotranspiration Models under Polyhouse and Open Environment in *Tarai* Region of Uttarakhand

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Authors' contributions

This work was carried out in collaboration between both authors. Author AS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author PKS managed the analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The average of mean monthly ET_0 estimated under polyhouse by FAO PM (benchmark) model was 39.44 mm, but that of the FAO Penman, Hargreaves Stanghellini, Priestley-Taylor and FAO Radiation models were 38.37, 18.18, 37.80, 48.17 and 53.87 mm respectively. Whereas, the average of mean monthly ET_o estimated under open environment by FAO PM (benchmark) model was 116.34 mm, but that of the FAO Penman, Hargreaves Stanghellini, Priestley-Taylor and FAO Radiation models were 119.33, 133, 126.41, 113.17 and 117.37 mm respectively. The FAO Penman and Hargreaves model are found to be most and least appropriate models for estimating daily ET_0 under polyhouse. Whereas, FAO Radiation and Stanghellini model observed to be most and the least appropriate models in an open environment for estimating daily ET_0 under polyhouse for the Pantnagar Tarai condition of Uttarakhand.

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1. INTRODUCTION

Efficient use of water is the prime objective of precision irrigation management [1,2]. The widespread aim is to increase water productivity and reduce the adverse impact of the environment on irrigation. Evapotranspiration (ET) plays an important role in maintaining the water balance of the ecosystem. Correct knowledge of evapotranspiration and its estimation plays a vital role in accurate irrigation management, crop production, water resources management, environmental assessment. Reference evapotranspiration (ET_o) has been frequently applied to generate or to calculate the actual evapotranspiration, which is very hard to measure by lysimeter, and water balance method under the open field conditions for all the places. Reference evapotranspiration (ET_o) is advantageous to evaluate the atmospheric water demand of the area and hence can be used in various fields including drought monitoring, irrigation scheduling, and to understanding climate change impacts.

Various models have been described to estimate reference evapotranspiration (ET_o) but due to the availability of the experimental data, it is very hard to select the best one. Therefore, many comparative studies and evaluation of various models have been conducted [3]. Meanwhile, [4] investigated optimally, the method to calculate PET for use in the rainfall-runoff model; [5] summarized historical developments of ET_o methods using standard meteorological data; and [6] considered the simplification of the Penman-Monteith model was having high efficiency in the estimating of ET_o. The FAO Penman-Monteith, method (FAO-PM) has been selected as the standard ET_o method to estimate reference evapotranspiration based on both physiological and aerodynamic conditions under Food and Agriculture Organization (FAO) and World Meteorological Organization (WMO). As a standard method, FAO PM can be used widely in many regions without any extra adjustments of parameters.

2. MATERIALS AND METHODS

The study was planned to compare five widely used reference evapotranspiration (ET_0) models of Priestly Taylor, FAO Radiation, Hargreaves, FAO Penman and Hargreaves with FAO Penman-Monteith (FAO PM) for both polyhouse and open environment. Table 1 lists six ET models that arise most in literature and relevant to be applied for the polyhouse and open environment condition. The experimental polyhouse is 15 meters long with a single span of 6 meters wide. The mean height of polyhouse is 4.2 meter and the polyhouse has a symmetrical roof of 12.5% slope with natural ventilation having side and top ventilation. The microenvironmental parameters were obtained from polyhouse microenvironment monitoring system installed in the polyhouse. All the microenvironmental parameters recorded at 15 minutes time interval were downloaded from the data logger for the estimation of reference evapotranspiration.

The meteorological data for outdoor conditions were obtained from the meteorological observatory located at Crop Research Centre (CRC) at G.B. Pant University of Agriculture and Technology, Pantnagar. The data include daily solar radiation, daily rainfall, maximum and minimum air temperature, class A pan evaporation and average daily relative humidity.

2.1 Regression Analysis

Simple linear regressions were used to determine the correlation between estimated daily reference evapotranspiration (ET_0) by different models with estimated from FAO

Table 1. Different types of ET models used in the study

ET models	Classification
FAO Penman	Combination method based on energy balance
FAO Penman-Monteith	Combination method based on energy balance
Stanghellini	Combination method based on energy balance
FAO Radiation	Radiation based
Priestley-Taylor	Radiation based
Hargreaves	Radiation-temperature based

Penman model from polyhouse and open environment. Linear regressions to determine the correlation of estimated daily ET_0 values with the FAO PM Model values, as follows

$$ET_{O\text{-}DMO} = a\,(ET_{O\text{-}FAO\ PM}) + b \tag{2.1}$$

Where; $ET_{0\text{-}DMO}$ and $ET_{O\text{-}FAOPM}$ represent the value of ET_0 estimated by different models and ET_0 by FAO PM Model, respectively. Whereas, a and b are the regression coefficients [7]. The best prediction method according to linear regression is the one which has the highest coefficient of determination (R^2), b value closest to zero and a value closest to unity. Despite being widely used to assess the "goodness of fit" of evapotranspiration equations, R^2 is oversensitive to extreme values and is insensitive to additive and proportional differences between estimated and measured values. Considering these limitations, R^2 values might misjudge the best method, when used alone. Therefore, method performance was evaluated by using both regression and different indices like RMSE, RE and D. Root mean squared error (RMSE), relative error (RE), agreement index (D) and the coefficient of determination (R^2) were also used for the model's evaluation and calculated as follow:

$$RMSE = \sqrt{\frac{1}{(N)}\sum_{i=1}^{N}(E_i - O_i)^2} \tag{2.2}$$

$$RE = \frac{RMSE}{ET_{Omean}} \times 100 \tag{2.3}$$

$$D = 1 - \frac{\sum_{i=1}^{n}(O_i - E_i)^2}{\sum_{i=1}^{n}(|E_i - O| + |O_i - O|)^2} \tag{2.4}$$

Where; E_i is the estimated ET_0 with different models, O_i is ET_0 estimated with FAO PM Model, at the i^{th} data point and n is the total number of data points. The value of D is 1.00 indicates perfect agreement, whereas, its values of 0.00 indicates a poor agreement [8,9].

3. RESULTS AND DISCUSSION

3.1 Meteorological Parameters and Estimation of the Reference Evapotranspiration under Polyhouse and Open Environment

The meteorological data of the polyhouse and open environment located at Pantnagar, Uttarakhand covering the period from Jan 2015 to Dec 2017 were analyzed to estimate reference evapotranspiration using different evapotranspiration (ET) models.

Linear regressions were used for the comparison to determine the correlation between estimated daily ET_0 by different models. Model performance was evaluated using both regression and different indices RMSE and RE. The daily ET_0 values estimated by different models were compared with those of estimated from FAO Penman-Monteith (FAO PM) model for polyhouse and open environment.

3.1.1 Variation of mean monthly microenvironmental parameters under polyhouse

A summary of mean monthly polyhouse microenvironmental data reveals that the mean monthly maximum temperature values ranged from 34.12°C in January to 60.23°C in June with a coefficient of variation of 2.27%. Similarly, the mean monthly minimum temperature values ranged from 6.07°C in December to 24.80°C in August with a coefficient of variation of 2.33%. Thus, December recorded annual coldest month while June recorded the highest value of mean monthly temperature. The mean monthly maximum relative humidity values ranged from 87.87% in July to 98.65% in August whereas minimum relative humidity prevails in October (31.66%).

3.1.2 Performance of different reference evapotranspiration models under polyhouse

The mean monthly reference evapotranspiration estimated using different models are presented in Table 2. Regarding mean monthly ET_0 values, the highest estimated value was 117.77 mm in March by FAO Radiation model and least value was estimated by Hargreaves model which was 9.16 mm in November. On the other hand, the coefficients of variation of the evaluated models ranged from 41.28% (FAO PM Model) to 63.52% (FAO Radiation Model). The result showed that the average of mean monthly ET_0 estimated by FAO PM (benchmark) model was 39.44 mm, but that of the Penman, Hargreaves and Stanghellini model was 38.37 mm, 18.18 mm and 37.80 mm respectively, indicating underestimation whereas Priestley-Taylor and FAO Radiation model yielded 48.15 mm and 53.87 mm respectively showed overestimation compared to FAO

Penman-Monteith Model. Comparisons for each model were made between monthly reference evapotranspiration values and monthly values estimated using the FAO Penman-Monteith models. The FAO Penman-Monteith model was selected as a benchmark against which comparisons were made because of its global acknowledgement and its assorted use. Fig. 1 shows that the underestimation and overestimation of reference evapotranspiration (ET_o) by different models over the FAO Penman-Monteith model. However, none of the models gave identical results but it has been observed that the values estimated from the Penman model were very close to the FAO Penman-Monteith model. The plot reveals that the Hargreaves model systematically underestimated as much as by 53.90%, giving worst estimates amongst all the tested models while the Penman produced the least underestimate (-2.73%) followed by (-3.99%) Priestley-Taylor model.

The regression relationship between monthly ET_0 estimates for each model against the FAO Penman-Monteith ET_0 and the correlation coefficient (R^2) using the linear regression

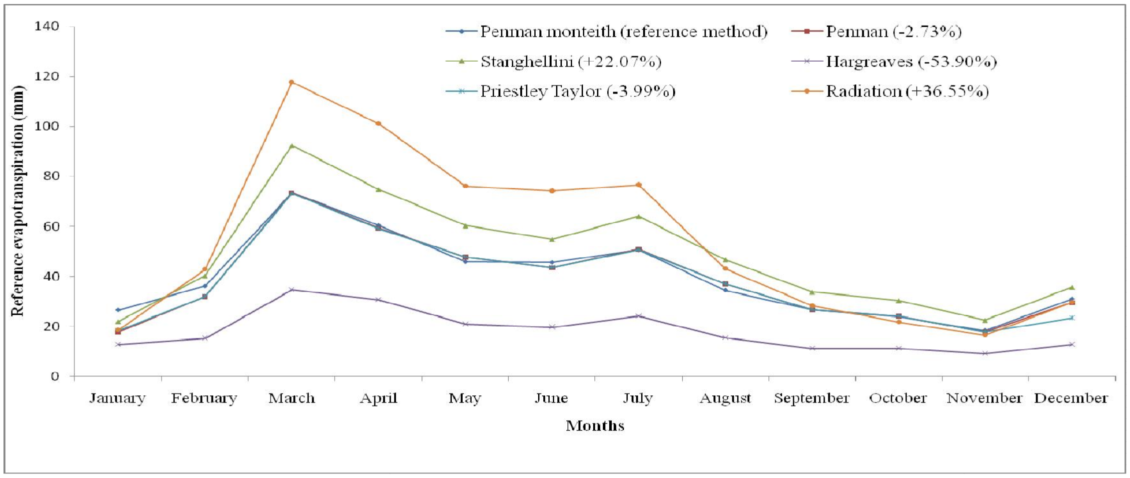

Fig. 1. Trend of Monthly climatology of ET_o values (mm) estimated by five empirically-based models and FAO-56 PM during 2015-2017 under polyhouse. (Positive sign (+) = greater, negative sign (-) = lower, relative to the reference model)

Table 2. Mean monthly reference evapotranspiration estimated using different models under polyhouse (2015 to 2017)

Months	FAO PM	PM	SM	HM	P-T	RAD
January	26.54	17.77	21.98	12.82	18.34	18.57
February	36.13	32.00	40.31	15.29	31.99	42.89
March	73.31	73.28	92.30	34.65	73.25	117.77
April	60.49	59.36	74.76	30.76	59.34	101.13
May	45.95	47.88	60.31	20.94	47.86	76.08
June	45.68	43.62	54.94	19.78	43.60	74.13
July	50.68	50.93	64.15	24.19	50.91	76.52
August	34.49	37.10	46.73	15.43	37.08	43.22
September	26.80	26.78	33.74	11.21	26.77	28.24
October	23.87	24.19	30.47	11.19	24.18	21.76
November	18.35	17.84	22.47	9.16	17.83	16.50
December	31.03	29.64	35.72	12.73	23.29	29.61
SD	16.28	17.14	21.72	8.14	17.46	34.22
SEM	4.70	4.95	6.27	2.34	5.04	9.87
CV (%)	41.28	44.68	45.10	44.76	46.12	63.52
Average	39.44	38.37	48.15	18.18	37.80	53.87

Indicating; FAO PM = FAO Penman-Monteith, PM= Penman model, SM= Stanghellini model, HM= Hargreaves model, P-T = Priestley-Taylor and RAD = Radiation model formula were also made. Table 3 indicate a summary of comparisons between estimated reference evapotranspiration by different models ($ET_{o\text{-}DMO}$) and reference evapotranspiration by FAO Penman-Monteith model ($ET_{o\text{-}FAOPM}$) values of ET_o under polyhouse conditions. In this table, different models are ranked according to their appropriateness. The results indicate that under polyhouse conditions, FAO Penman and Hargreaves models were the most and the least appropriate models, respectively which are similar finding by [10,11]. The slope of the linear regression equation in the FAO Penman model was 0.997 which is near to 1.0 and the R^2 was 0.999, which is also near to 1. The values of the RMSE and RE for the FAO Penman models were (0.0097 and 0.779%). According to the value of A, B, R^2, RSME and RE, the FAO Penman model showed better performance than other models. The Priestley Taylor and Stanghellini models were placed as the second and third best models respectively. [12,13] also found a similar result as mentioned in Table 3.

3.1.3 Variation of mean monthly microenvironmental parameters in the open environment

The results indicate that the mean monthly maximum temperature values ranged from 16.86°C in February to 43.66°C in June with a coefficient of variation of 2.46%. Similarly, the mean monthly minimum temperature values ranged from 2.96°C in December to 23.56°C in August with a coefficient of variation of 2.71%. Thus, December recorded annual coldest month while June recorded the highest value of mean monthly temperature which indicating the annual hottest month. The mean monthly maximum Relative Humidity values ranged from 93.00% in September to 98% in April and June and the least value obtained in April with 18%. The maximum wind velocity was in June which was 8 km/h and minimum 2.41 km/h in December.

3.1.4 Performance of different reference evapotranspiration models under the open environment

The mean monthly reference evapotranspiration estimated using different models are presented in Table 4. Comparisons between ET_0 estimated using FAO Penman-Monteith model with different models on the monthly time scale is shown in Fig. 3. Regarding mean monthly ET_0 values, the highest estimated value was 212.74 mm in April using FAO Radiation model and least value was estimated by Stanghellini model which was 39.91 mm in November.

On the other hand, the coefficients of variation of the estimated models ranged from 37.54% (Hargreaves model) to 48.36% (Stanghellini model). The results showed that the average of mean monthly ET_o estimated by FAO PM (benchmark) model was 116.34 mm, but that of the Priestley Taylor model was 113.17 mm, indicating underestimation. Whereas, remaining all models yielded more and showed overestimation compared to the benchmark model. Comparisons for each model were made between monthly reference evapotranspiration values and monthly values estimated using the FAO Penman-Monteith model. The FAO Penman-Monteith model was selected as a benchmark against which comparisons were made because of its global acknowledgement and its assorted use. Fig. 3 shows that the underestimation and overestimation of reference evapotranspiration (ET_0) by different models over the FAO Penman-Monteith model. The plot reveals that the Priestley Taylor model (-2.75%) was the only one which underestimates the FAO Penman-Monteith model. The remaining all models overestimated the benchmark model. Among all, the Radiation model overestimated least whereas Hargreaves model systematically overestimated as much as by 14.32%, giving worst estimates amongst all the tested models.

Table 3. Ranking and statistical analysis of different daily ET_0 model estimations vs. FAO PM values under polyhouse

Sr. no.	ET_O models	Rank	A	B	R^2	RMSE (mm/day)	RE (%)	D
1	FAO Penman	1	0.99	0.004	0.99	0.0097	0.779	0.992
2	Priestley Taylor	2	1.26	-2.00E-14	1	0.355	2.83	0.923
3	Stanghellini	3	1.78	-0.495	0.91	0.717	5.73	0.808
4	FAO Radiation	4	1.20	0.021	0.57	0.639	5.11	0.788
5	Hargreaves	5	0.27	0.259	0.48	0.775	6.18	0.552

A and B - linear regression coefficients, R^2 - Coefficients of determination, RE- Relative error, RMSE- Root mean squared error, D- agreement index

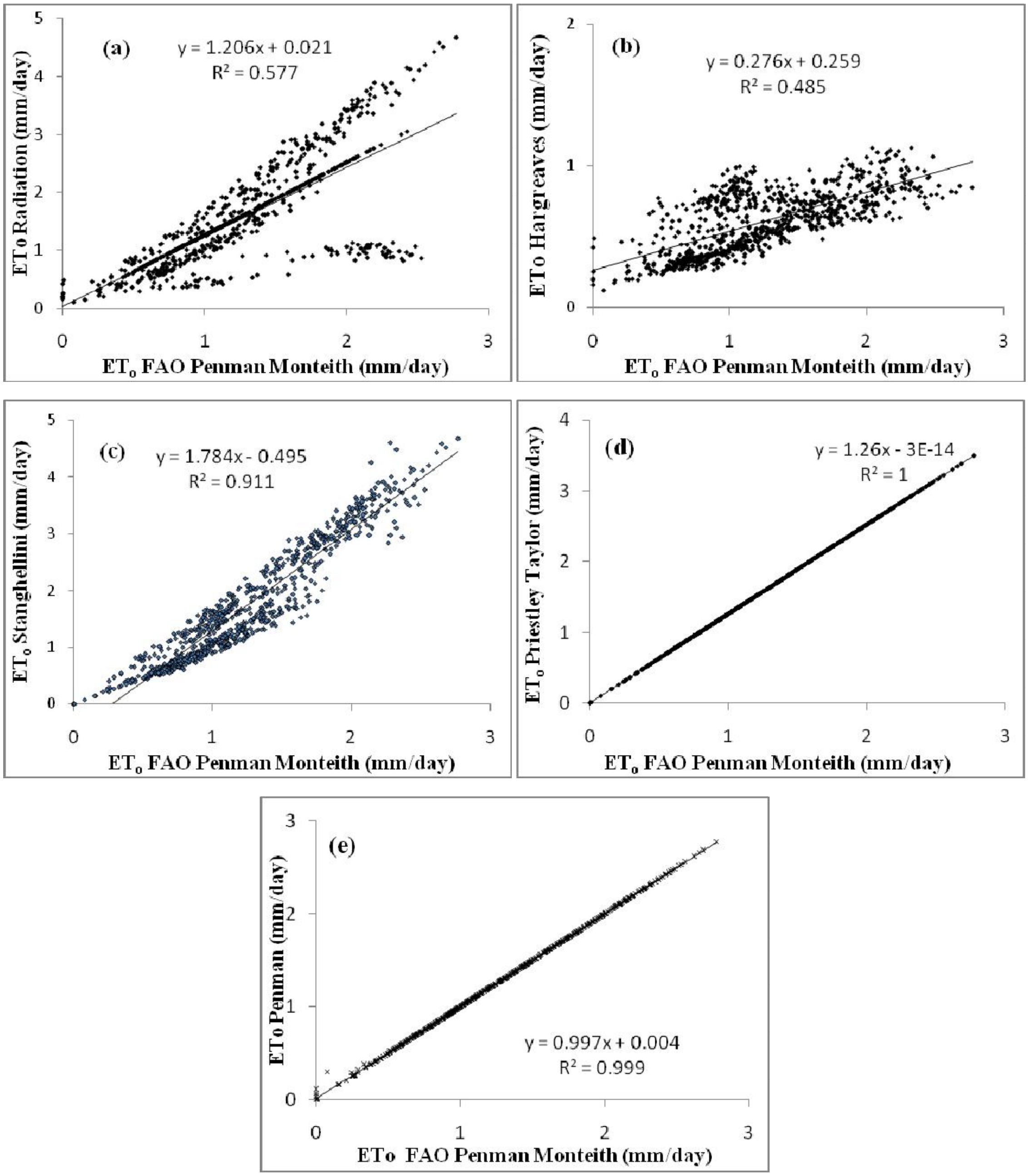

Fig. 2. Comparison of FAO PM model versus (a) Radiation model, (b) Hargreaves, (c) Stanghellini, (d) Priestely-Taylor and (e) Penman model, using regression analysis under polyhouse

The regression relationship between monthly ET_0 estimates for each model against the FAO Penman-Monteith ET_0 and the correlation coefficient (R^2) using the linear regression formula were also made. Table 5 indicates a summary of comparisons between estimated reference evapotranspiration by different models ($ET_{o\text{-}DMO}$) and reference evapotranspiration by FAO Penman-Monteith model ($ET_{o\text{-}FAOPM}$) values of ET_o under open environment. In this table, different models are ranked according to their appropriateness. The results indicate that in the open environment, FAO Radiation and Stanghellini models were the most and the least appropriate models, respectively. The slope of the linear regression equation in the FAO

Radiation model was 1.030, which is close to 1.0. The intercept value was 0.166 which is close to zero and the R^2 was 0.916, which is close to 1. The value of the RMSE and RE for the FAO Radiation were (0.660 and 17.18%) but higher than FAO Penman. According to the value of R^2, RSME and RE, the FAO Penman model showed an even better performance than the FAO Radiation model. But the slope of the straight regression line and the intercept in the FAO Penman model were 0.807 and 0.716 which were not satisfying. So, FAO Penman and Priestley Taylor models were placed as the second and third best models respectively. The results are in agreement with earlier investigators [14,11].

Table 4. Mean monthly reference evapotranspiration estimated using different model under open environment (2015 to 2017)

Months	FAO PM	PM	SM	HM	P-T	RAD
January	50.11	52.94	42.82	64.55	50.69	50.34
February	67.74	72.77	76.20	89.20	67.15	77.32
March	136.24	138.79	198.71	160.13	132.75	158.08
April	188.34	180.32	168.98	207.49	166.99	212.74
May	189.23	174.65	184.00	204.59	163.40	203.49
June	172.04	154.35	168.30	175.07	150.82	170.90
July	152.11	154.42	176.06	158.22	168.40	152.32
August	109.63	113.25	98.56	117.53	123.03	108.48
September	117.89	124.21	123.53	125.22	130.71	130.04
October	109.54	122.67	98.17	140.93	113.03	134.16
November	59.93	70.38	39.91	88.23	54.58	75.59
December	43.21	49.43	56.71	64.84	36.43	43.46
SD	52.78	46.19	58.31	49.93	48.73	56.48
SEM	15.23	13.33	16.81	14.41	14.03	16.30
CV (%)	45.36	39.35	48.36	37.54	42.96	44.68
Average	116.34	119.33	126.41	133.00	113.17	117.37

Indicating; FAO PM = FAO Penman-Monteith, PM= Penman model, SM= Stanghellini model, HM= Hargreaves model, P-T = Priestley-Taylor and RAD =Radiation model

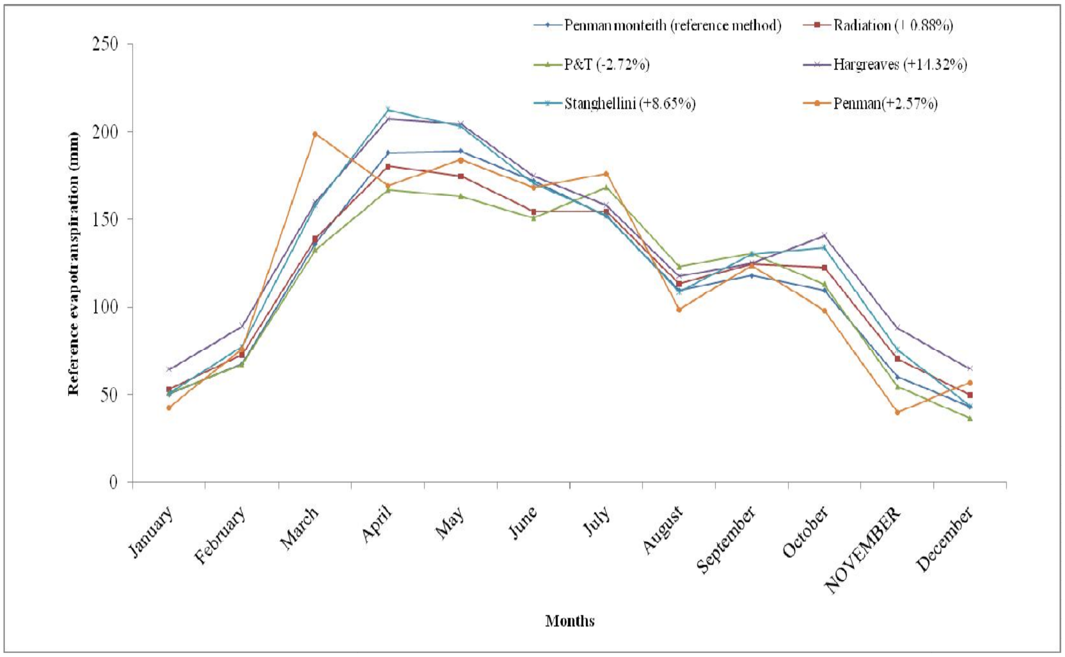

Fig. 3. Trends of monthly climatology of ET_o values (mm) calculated by five empirically-based models and FAO-56 PM during 2015 – 2017 under open environment. (Positive sign (+) = greater, negative sign (-) = lower, relative to the reference model)

Table 5. Ranking and statistical analysis of different daily ET$_0$ model estimations vs. FAO PM values in an open environment

Sr. no	ET$_0$ Models	Rank	A	B	R^2	RMSE (mm/day)	RE (%)	D
1	FAO Radiation	1	1.030	0.166	0.916	0.660	17.18	0.972
2	FAO Penman	2	0.807	0.716	0.945	0.523	13.60	0.967
3	Priestley Taylor	3	0.820	0.477	0.846	0.779	20.25	0.952
3	Hargreaves	4	0.773	1.390	0.846	0.923	23.99	0.931
4	Stanghellini	5	1.378	-0.729	0.832	1.563	40.65	0.892

A and B - linear regression coefficients, R^2 - Coefficients of determination, RE- Relative error, RMSE- Root mean squared error, D –agreement index

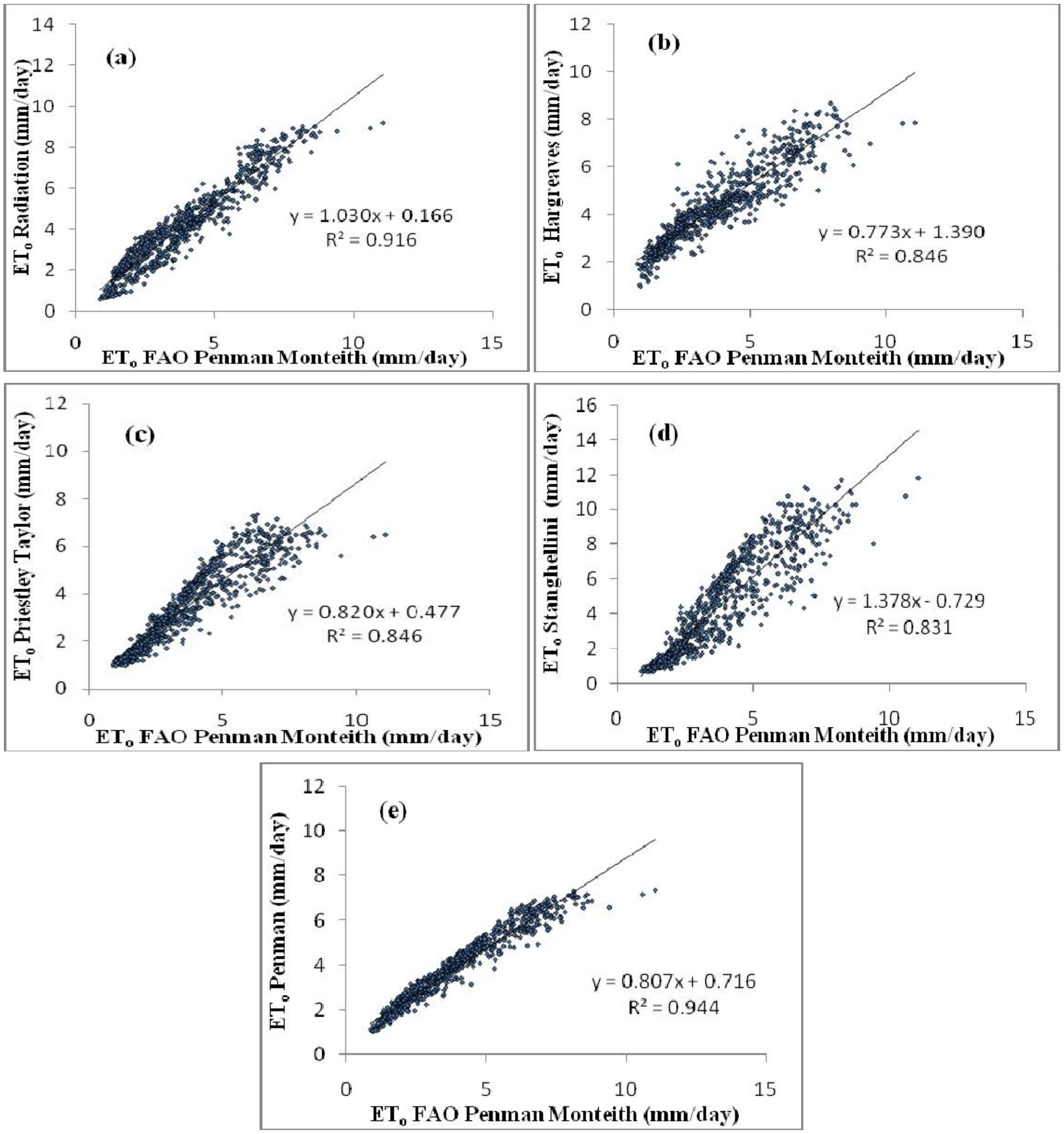

Fig. 4. Comparison of FAO PM model versus (a) Radiation model, (b) Hargreaves, (c) Priestely Taylor (d) Stanghellini, and (e) Penman model, using regression analysis for the open environment

The comparison of different estimated ET$_0$ models with FAO Penman-Monteith model was also made with the scatter plot as shown in Fig. 4.

4. CONCLUSION

This study presents a comparison of the results using five different daily ET_0 estimation methods with $ET_{0\text{-FAO PM}}$ values in polyhouse and outdoor conditions. The results indicate that the FAO Penman and Hargreaves methods are the most and the least appropriate methods for estimating daily ET_0 in polyhouse conditions, respectively. In outdoor conditions, FAO Radiation and Stanghellini methods are the most and the least appropriate methods, respectively. The basic obstacle to widely applying FAO methods is the numerous weather parameters required, which are lacking in many areas. In such areas, simpler empirical methods are needed. Priestley-Taylor and FAO Radiation ranked first among the empirical methods estimating daily ET_0 in polyhouse and outdoor conditions, respectively.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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