

Estimating Sunshine Hours and Reference Evapotranspiration Under Limited Data Conditions In Northeast India

Pankaj Kumar Pandey¹ Vanita Pandey² Madhusudan Mishra³, Prem Ranjan⁴

^{1,2,4}*Department of Agricultural Engineering,*

³*Department of Electronics and Communication Engineering,
North Eastern Regional Institute of Science & Technology,
Nirjuli, Arunachal Pradesh*

**Corresponding Author: (P.K. Pandey)*

Abstract

The standard Penman-Monteith equation is the most widely used technique for determining reference evapotranspiration (ET_0). However, the Penman-Monteith model requires a lot of meteorological data that is unavailable for specific regions. In the northeast regions of India, there is an unavailability of solar radiation or sunshine hour data. Thus, this study aims to determine the sunshine hour data with the help of the other weather parameters which are usually available. Four equations were derived to estimate the sunshine hour (n_e), and ET_0 values were estimated using standard FAO-56 Penman-Monteith and four other models, namely: Hargreaves-Samani (1985), Turc (1961), Blaney-Criddle (1977), and Makkink (1957), whose performance were compared with ET_0 estimates obtained using estimated sunshine hours (n_e) for the region of Jorhat, Assam. The results of the four derived equations were detected to give high values of R^2 , which indicated good agreement with the ET_0 estimates of the FAO-56-P-M method. The results of these four equations gave better performance than the four ET_0 models. The overall best performance was obtained using Eq.13 (n_{e4}), which used four meteorological parameters, and gave values of statistical indices: MSE= 0.014 mm d⁻¹, RMSE= 0.120 mm d⁻¹, R^2 = 0.969 and MAPE =3.081%.

Keywords: Reference Evapotranspiration, FAO-56 Penman-Monteith Model, Sunshine Hours, empirical models

1. Introduction

Efficient water resource management will improve crop productivity and minimize

drainage, groundwater pollution, and other related problems. Evapotranspiration is the water loss from plant and soil surface to the atmosphere; it is the essential stage of the hydrological cycle. Evapotranspiration depends on the type of vegetation, land use, and, thus, the amount of water leaving the drainage basin. Because the water lost through the leaves comes from the roots, plants with deep roots can more regularly transpire water. Various factors affect evapotranspiration, including air moisture, wind velocity, temperature, and solar radiation. Precise estimation of evapotranspiration is vital in various applications such as irrigation scheduling, climate change studies, and many other hydrological-related studies (Bastiaanssen, 1995; Pandey and Pandey, 2014).

Reference evapotranspiration (ET_0) refers to the rate of water leaving from a green grass covered uniformly at a certain height. According to **Allen et al., (1998)**, reference evaporation is explained as the evapotranspiration rate from an imaginary crop with a projected crop elevation of 0.12 m and a static canopy resistance at 70 seconds per meter and 0.23 albedo, which would bear a close resemblance to evapotranspiration from a widespread exterior of green grass cover of identical elevation, aggressively rising, wholly screening the ground and with no shortage of water. There are various methods of estimating reference evapotranspiration (ET_0): direct method and estimating evapotranspiration based on climatological data. The ICID and FAO of the United Nations have proposed the FAO-56 Penman-Monteith method as the standard method for computing reference evapotranspiration (ET_0) (**Allen et al., 1998**). Estimating reference evapotranspiration using the FAO-56 P.M model requires the temperature of the air, solar radiation, wind velocity, and relative humidity data (**Allen et al., 1998**). For the estimation of reference evapotranspiration using the FAO-56 P.M model, the main restriction is the non-availability of required weather data in most weather stations. Besides, even if there is, the data superiority cannot always be definite (**Almorox et al., 2015, Pandey et al., 2016**).

The literature survey revealed that various studies around the globe proved the superiority of the FAO-56-P-M model under various climatic conditions, such as **Tellen (2017)** evaluated six methods of ET_0 in Yaoundé, Mexico, **Gao et al. (2017)** evaluated various limiting data ET_0 models under different climatic conditions of China, **Sudheer et al. (2017)** examined various ET_0 modes in South India, **Tabari et al. (2013)** evaluated ten models in Iran. There are numerous reported studies on evaluating and calibrating limited data-required models against standard FAO-56-PM models around the globe.

Only one study by **Abd El-Wahed and Snyder (2015)** developed different models for estimating sunshine hours (n_e) based on average monthly temperature, wind velocity, and relative humidity, which were then utilized to calculate reference ET_0 using FAO56-PM. The ET_0 estimated by the developed equations was more accurate than the ET_0 estimated using the FAO-recommended Hargreaves equation. We believe the parametric calibration approach is better than limited data models, as different models were developed under different assumptions and specific climatic conditions.

For research studies, there is a demand for high accuracy in measuring wind velocity and solar radiation data. Only a few weather stations can determine and produce solar

radiation and wind velocity data in the North-East region of India (**Pandey et al. 2016**). Some of these records have inaccurate data due to inaccuracy and errors in the measuring instruments. Thereby showing difficulty in determining the ET_0 of the region by the standard FAO-56 Penman-Monteith model, which requires the use of parameters like solar radiation and wind velocity.

On the other hand, most of the weather stations in the region have properly recorded data on precipitation, relative humidity, and temperature (**Pandey et al., 2016**). This is due to the heavy impact of the said parameters on the climatic characteristics of the NE regions. **Abd El-Wahid and Snyder (2015)** compared the performance of their developed model only with one limiting data model (**Hargreaves et al., 1982**). This study's main aim is to extend and generalize **Abd El-Wahid and Snyder's (2015)** findings by comparing the estimated sunshine duration approach to ET_0 estimation with commonly recommended limited data models under the humid climate of Northeast India.

2 Materials and Methods

2.1 Study Area and Data Collection

This study was conducted in the location of Jorhat, Assam, India. The latitude and longitude of the study area are 26.7509° N and 94.2037° E. It lies at the height of 116 m above mean sea level. The climatic condition of Jorhat is classified as warm and temperate. Usually, the summers are rainier than the winters. The average annual temperature is 24 °C. The average annual rainfall is 2324 mm.

2.2 FAO-56 Penman-Monteith Model (F56-P-M):

The FAO Penman-Monteith (F56-P-M) method is the standard method for estimating reference evapotranspiration. This process estimates the potential evapotranspiration from a reference surface with covering and aerodynamic resistances characteristic of a wide-ranging area of a fit, 0.12m tall, aseptic cool-season grass of unchanging height, vigorously budding, entirely veiling the floor and with sufficient water. The daily canopy resistance is maintained at $r_c=70$ seconds per meter, the albedo of 0.23, and the aerodynamic resistance is $r_a = 208/u_2$, where u_2 , is the average wind velocity at a 2 m elevation over the grass (**Allen et al., 1998**). The F56-P-M method is suggested by the United Nations Food and Agriculture Organization as a standard method for estimating ET_0 and assessing other ET_0 models. The F56-P-M equation to compute reference evapotranspiration, as given by **Allen et al. (1998)**, is:

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \frac{900}{T + 273} U (e_s - e_a)}{\Delta + \gamma (1 + 0.34U)} \quad \text{Eq. (1)}$$

2.3 Developing equations for estimating sunshine hours (n_e):

In our study, monthly averages of daily mean temperature (T), relative humidity (RH), wind velocity (U) and precipitation (P) were utilized to compute estimated sunshine hours (n_e). The Excel software was used to calculate the least squares linear

regressions between n as a dependent variable and the other weather data as independent variables to acquire equations for estimating n_e . The equations for n_e were then used to compute monthly ET_0 estimates with the standard F56-P-M equation. Then, the calculated ET_0 values were compared with the ET_0 estimates computed using monitored n to ascertain the equation giving the best outcome for monthly ET_0 . Finally, the ET_0 estimates obtained through values of n_e were compared with several temperature-based ET_0 models to the F56-P-M model.

2.4 Description of selected ET_0 empirical models:

2.4.1 Hargreaves and Samani Method (1985) (HRSM):

The Hargreaves and Samani equation (Hargreaves and Samani, 1982; 1985)

$$ET_0 = 0.0009384 \times R_a \times (T_{avg} + 17.8) \times (T_{max i} - T_{min i})^{0.5} \quad \text{Eq. (2)}$$

2.4.2 Makkink (1957) (Mk) Method:

The Makkink equation (Makkink, 1957) can be described as follows:

$$ET_0 = 0.61 \left(\frac{\Delta}{\Delta + \gamma} \right) \left(\frac{R_s}{2.45} \right) - 0.12 \quad \text{Eq. (3)}$$

2.4.3 Turc Model:

The Turc method (Turc, 1961) can be described as:

$$ET_0 = a_T 0.013 \left(\frac{T_{avg}}{T_{avg} + 15} \right) \left(\frac{23.8856 R_s + 50}{\lambda} \right) \quad \text{Eq. (4)}$$

2.4.4 Blaney-Criddle (1950) (BC) Model:

The Blaney-Criddle models can be described as follows:

$$ET_0 = k_p (0.46 T_{avg} + 8.13) \quad \text{Eq. (5)}$$

Where, ET_0 = reference evapotranspiration (mm d^{-1}), R_n = net radiation ($\text{MJ m}^{-2} \text{d}^{-1}$), $(e_s - e_a)$ = difference between the saturation vapour pressure e_s (kPa) and the actual vapour pressure e_a (kPa), Δ = slope of the saturation vapour pressure-temperature curve ($\text{kPa } ^\circ\text{C}^{-1}$), γ = psychrometric constant ($\text{kPa } ^\circ\text{C}^{-1}$), u_2 = wind speed at 2 m height (m s^{-1}), T = mean daily air temperature ($^\circ\text{C}$), G = monthly soil heat flux density ($\text{MJ m}^{-2} \text{d}^{-1}$), T_{avg} = Average temperature ($^\circ\text{C}$), $T_{max i}$ = maximum air temperature ($^\circ\text{C}$), $T_{min i}$ = minimum air temperature ($^\circ\text{C}$), R_a = extra-terrestrial radiation ($\text{MJ m}^{-2} \text{d}^{-1}$), λ = latent heat transfer = 2.45 (MJ kg^{-1}), K_p, a_T , are the empirical coefficients

2.5 Evaluations of Models based on Statistical Indices:

The ET_0 estimates we obtained from different models and the estimates of ET_0

obtained from the F56-P-M model, whose values of solar radiation were computed from the developed equations, were evaluated statistically against the ET_0 estimates of the standard F56-P-M equation. The primary objective is to choose the minimal error equation so that estimated values are closer to the standard values of F56-PM. Observed and predicted values were tested for different error indices as mentioned below:

2.5.1 The determination coefficient (R^2):

$$R^2 = \frac{\left(\sum_{i=1}^n x_i y_i \right)^2}{\sum_{i=1}^n x_i^2 \sum_{i=1}^n y_i^2} \quad \text{Eq. (6)}$$

2.5.2 Mean Squared Error (MSE):

It measures the average of the squared differences obtained between the actual and estimated values. The value of the MSE obtained is always greater than zero. Moreover, the values of MSE obtained, which are closer to zero, are better.

$$MSE = \frac{1}{n} \sum_{i=1}^n (X_i - Y_i)^2 \quad \text{Eq. (7)}$$

2.5.3 Root Mean Square Error (RMSE):

RMSE is used to evaluate how well the model has performed. It does so by calculating the difference between the observed and predicted values obtained by the models. It also compares the variations of values obtained by the models. The value of RMSE obtained is always greater than zero; if the value of RMSE obtained is zero, it shows a perfect fit between the observed and predicted values.

$$RMSE = \sqrt{\frac{\sum_{i=1}^k (Y_i - X_i)^2}{k}} \quad \text{Eq. (8)}$$

2.5.4 Mean Absolute Percentage Error (MAPE):

Mean absolute percentage error (MAPE) is a statistical measure used to measure forecasting accuracy; it gives the accuracy in percentage. It is measured by measuring the per cent error for each observed and predicted value, and the average of all the per cent errors gives the average absolute percentage error or mean absolute percentage error (MAPE). The MAPE is given by:

$$MAPE = \frac{1}{n} \sum_{i=1}^n \left(\frac{X_i - Y_i}{X_i} \right) \quad \text{Eq. (9)}$$

3.0 Results and Discussion:

The value of reference evapotranspiration (ET_0) is calculated using the data collected by the standard method explained in F56-PM. The data collected includes maximum and minimum temperature, rainfall, sunshine hours, maximum and minimum relative humidity, and wind velocity. As explained in Eq. (1), the mentioned data are the minimum data required to estimate F56-P-M ET_0 .

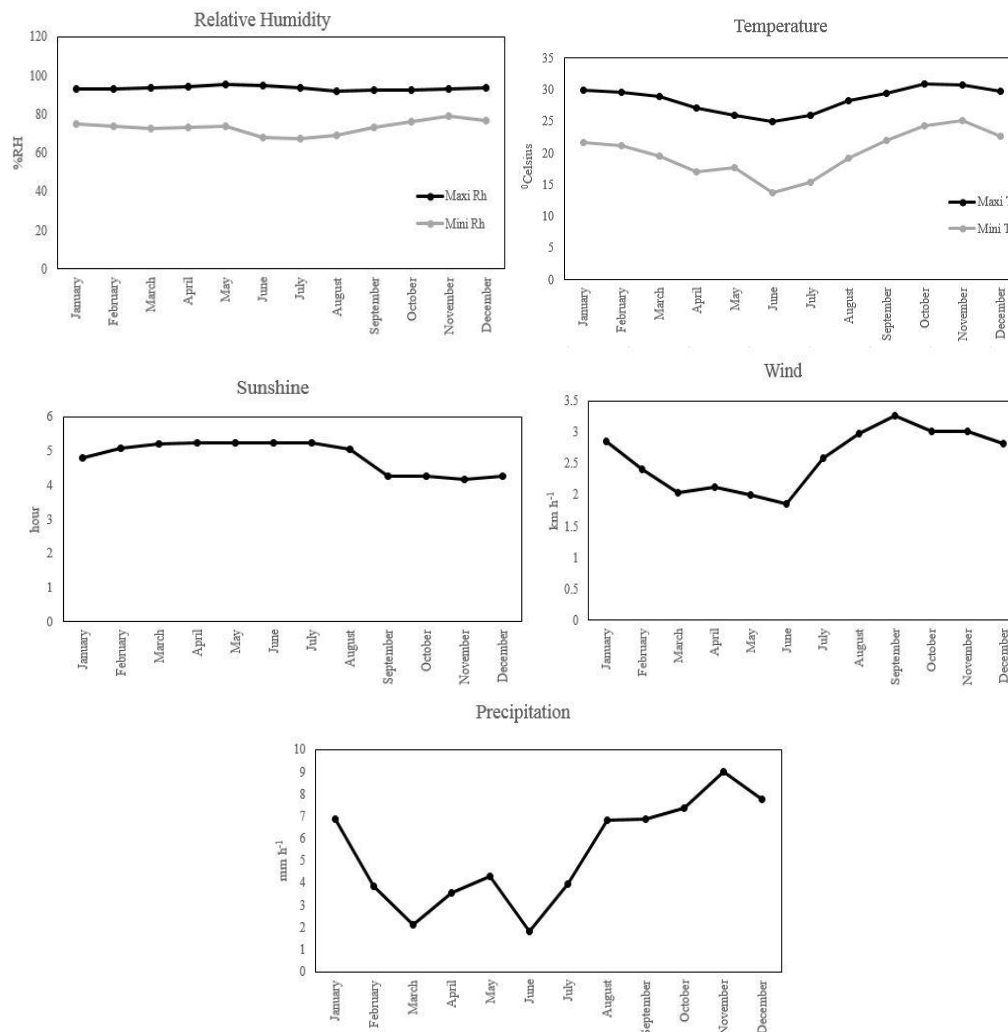


Figure 1: Monthly averages over Jorhat station of daily means of sunshine hours (n), wind (U , km/h), precipitation (mm d^{-1}), temperature (T , $^{\circ}\text{C}$), relative humidity (RH, %) from the year 2010-2020.

3.1 Developed equations to estimate sunshine hours (n_e):

The linear regressions (Eq. 10– Eq.13) given below were developed in this study to estimate sunshine duration (n_e) with the help of data from the station of Jorhat, Assam.:

$$n_{e1} = -0.564 + 0.4297 (T_{\max i}) - 0.3465 (T_{\min i}) \quad \text{Eq. (10)}$$

$$n_{e2} = -0.5532 + 0.4268 (T_{\max i}) - 0.341 (T_{\min i}) - 0.006 (P) \quad \text{Eq. (11)}$$

$$n_{e3} = 2.97 + 0.369 (T_{\max i}) - 0.298 (T_{\min i}) - 0.034 (Rh_{\text{avg}}) \quad \text{Eq. (12)}$$

$$n_{e4} = 4.753 + 0.346 (T_{\max i}) - 0.278 (T_{\min i}) - 0.03 (Rh_{\max i}) - 0.015 (Rh_{\min i}) - 0.10 (U) - 0.004 (P) \quad \text{Eq. (13)}$$

Analysis of **Fig. 1** depicts a change in weather parameters for the following months ranging from (January-December) to are shown. The monthly change of weather parameters was recorded for ten years (2003-2013). It shows an average wind speed of 2.58 km h^{-1} , an average rainfall of 5.35 mm d^{-1} , an average sunshine hour of 4.82 hr d^{-1} , and an average mean temperature of 24.18°C and an average mean relative humidity of 83.29% for the following years. The maximum average sunshine hour, precipitation, wind speed, maximum temperature, and maximum relative humidity were observed as 5.23 h d^{-1} for April, 9.01 mm d^{-1} for November, 3.26 km h^{-1} for September, 30.93°C for October and 95.29% for May respectively. The minimum average sunshine hour, precipitation, wind speed, minimum temperature, and minimum relative humidity were observed as 4.16 h d^{-1} for November, 1.83 mm d^{-1} for June, 1.85 km h^{-1} for June, 13.66°C for June and 67.16% for July respectively.

Table 1 depicts that **Eq. (13)** comprising meteorological parameters ($T_{\max i}$, $T_{\min i}$, R , $Rh_{\max i}$, $Rh_{\min i}$, and U) had the most significant influence ($R^2 = 0.703$) on sunshine duration than the rest of the derived equations. After that, the ET_0 was computed using the observed n and the n_e values from the four derived equations by the standard F56-P-M method. **Eq. (11)** and **Eq. (12)** were found to give very close R^2 values, i.e., 0.692 and 0.695 , respectively. **Eq. (13)** gave the minor error values for MSE, RMSE and MAPE, while **Eq. (10)** gave the highest error values.

Table 1: Statistical performance of the derived equations for n_e against n

Statistical Indices	Eq. 10 (n_{e1})	Eq. 11 (n_{e2})	Eq. 12 (n_{e3})	Eq. 13 (n_{e4})
R^2	0.687	0.692	0.695	0.703
MSE (mm d^{-1})	0.391	0.385	0.380	0.371
RMSE (mm d^{-1})	0.625	0.620	0.617	0.609
MAPE (%)	10.074	9.961	9.903	9.717

3.2 Performance evaluation of the results of derived equations for n_e and the four ET_0 estimation models used

3.2.1 Comparison of ET_0 values of F56-P-M and ET_0 estimated using n_{e1} :

The study conducted in the warm and temperate region of Jorhat District, Assam, showed that the ET_0 estimates obtained using **Eq. (10)**, n_{e1} , were in good agreement with the F56-P-M ET_0 estimates. Regarding **Table 2**, the respective evaluation indices' values were low statistical error (MSE= 0.015 mm d^{-1} , RMSE= 0.124 mm d^{-1}). This equation exhibited the lowest performance compared to the other derived equations for n_e , though the differences are minor. This may be because only maximum and minimum temperatures ($T_{\max i}$, $T_{\min i}$) were used as variable parameters

to estimate sunshine duration. As per **Fig. 2**, a high R^2 value is obtained with a reliable linear regression equation

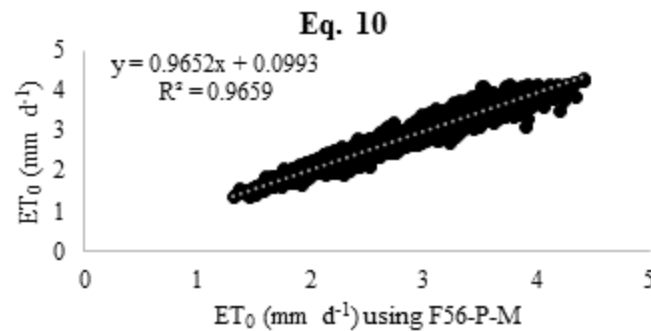


Figure 2: Comparison between ET_0 values of F56-P-M Equation and those obtained using n_{e1} for the study site.

3.2.2 Comparison of ET_0 values of F56-P-M and ET_0 estimated using n_{e2} :

Table 2 and **Fig. 3** revealed the statistical evaluation of the ET_0 estimates obtained using **Eq. (11)**, n_{e2} , against the ET_0 estimates obtained using n . **Eq. (11)** showed better fitting (MSE= 0.015 mm d⁻¹, MAPE = 3.189%). This equation exhibited better performance in comparison to that of **Eq. (10)** and **(12)** in terms of R^2 and RMSE but was outperformed by **Eq. (13)** in all the indices. However, as previously stated, the differences were minimal. Here, the precipitation parameter (R) was included with the maximum and minimum temperature (T_{max} , T_{mini}) parameters. By observing the results, we can say that adding the precipitation parameter had minimal impact on the estimation of sunshine duration, n_e .

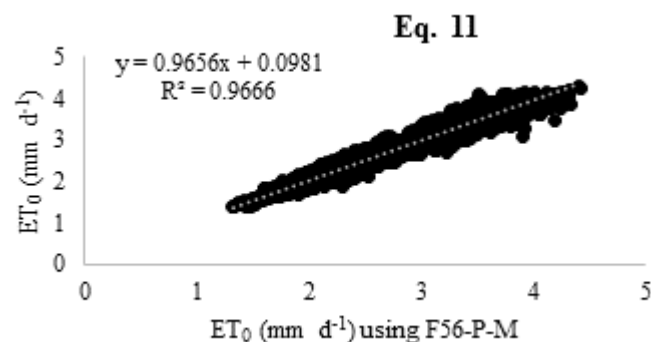


Figure 3: Comparison between ET_0 values of F56-P-M Equation and those obtained using n_{e2} for the study site.

3.2.3 Comparison of ET_0 values of F56-P-M and ET_0 estimated using n_{e3} .

The parameters used for this equation were mean relative humidity (Rh_{avg}) and maximum and minimum temperatures (T_{max} , T_{mini}) to estimate n_e . As shown in **Table 2**, **Eq. (12)** results gave the second lowest MAPE value of 3.133%. This

equation performed similarly to **Eq. (10)** in R^2 , MSE, and RMSE but gave better MAPE values than **Eq. (11)**. Hence, this equation gave the second lowest result among the n_e equations. Here, by observation of the results, we can say that the addition of the mean relative humidity parameter had a lesser impact on the estimation of sunshine duration, n_e as compared to the addition of the rainfall parameter. As per **Fig. 4**, a similarly high R^2 value is obtained whose linear regression equation shows a good agreement between the compared values.

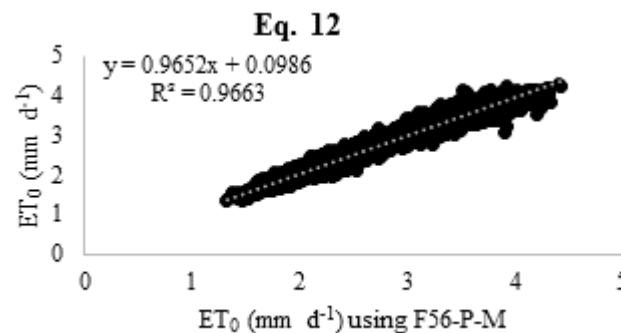


Figure 4: Compares ET_0 values of the F56-P-M equation and those obtained using the n_{e3} study site.

3.2.4 Comparison of ET_0 values of F56-P-M and ET_0 estimated using n_{e4} :

The performance of **Eq. (13)** was evaluated by comparing the ET_0 estimates computed using n_{e4} with that of ET_0 estimates computed using n . To **Table 2**, the MAPE value of this equation was 3.081%, which was the lowest. It also gave the lowest RMSE and MSE values. Hence, this equation gave the best overall performance among the equations derived to estimate sunshine duration. As per **Fig. 5**, a high R^2 value, *i.e.*, 0.9685, is observed with the most reliable linear regression equation. Here, the meteorological parameters used to estimate sunshine duration, n_{e4} , were maximum and minimum temperature ($T_{\max}$, $T_{\min}$), precipitation (R), maximum and minimum relative humidity ($Rh_{\max}$, $Rh_{\min}$), and wind speed (U). Thus, we can understand from the results that better accuracy and agreement were obtained by adding more parameters to estimate sunshine duration (n_e).

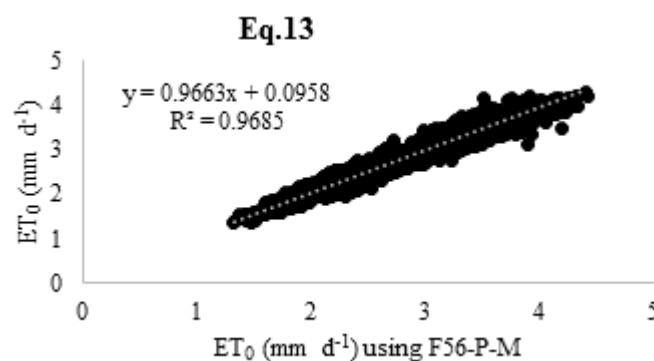


Figure 5: Comparison between ET_0 values of F56-P-M Equation and those obtained using n_{e4} for study site

The values of statistical indices: R^2 , RMSE (mm d^{-1}), MAPE (%) and MSE (mm d^{-1}) for observed ET_0 values compared to estimated ET_0 values by the derived equations are given in **Table 2**. As per the results in **Table 2**, it can be observed that the differences between the values of the performance indices are minimal. Similar values for MSE were obtained by **Eq. (10)**, **Eq. (11)** and **Eq. (12)**. Similarly, R^2 and RMSE values of **Eq. (10)** and **Eq. (12)** can be seen. Since **Eq. (13)** gave the lowest RMSE, MSE and MAPE values and the highest R^2 value, we can say that **Eq. (12)** gave the best ET_0 estimates and can be considered the best overall performing equation. On the contrary, **Eq. (10)** gave the highest MAPE value and thus can be considered the poorest equation. The **Eqs. (10)-(12)** outperformed four ET_0 estimation models, *i.e.*, Hargreaves, Turc, Blaney-Criddle and Makkink.

Table 2: Statistical performance of estimated ET_0 values obtained using n_e against F-56PM ET_0 values.

Statistical Indices	Eq.10 (n_{e1})	Eq. 11 (n_{e2})	Eq. 12 (n_{e3})	Eq. 13 (n_{e4})
R^2	0.966	0.967	0.966	0.969
MSE (mm d^{-1})	0.015	0.015	0.015	0.014
RMSE (mm d^{-1})	0.124	0.123	0.124	0.120
MAPE (%)	3.229	3.189	3.133	3.081

3.3 Comparison of ET_0 values of F56-P-M and ET_0 estimated using Makkink (1957) (Mk) Equation:

Regarding **Table 3**, among the ET_0 models used, the Makkink Equation gave the second lowest MAPE value of 6.357%. Likewise, it also secured the second-lowest RMSE and MSE values. The Makkink model was ranked the second-best model based on its statistical performance. This model gave a low RMSE value for the present study area with a humid climate (**Gao et al., 2017**). As per **Fig. 6**, a high value of R^2 with an acceptable linear regression equation was observed.

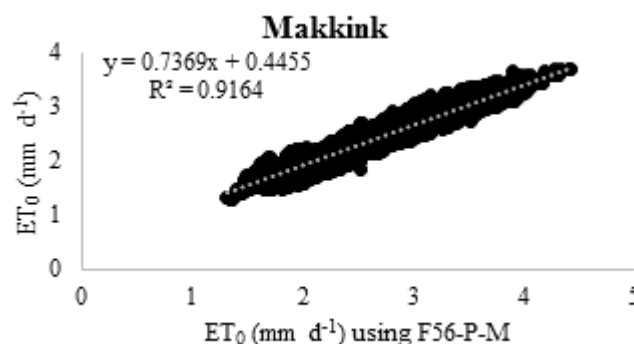


Figure 6: Comparison between ET_0 values of F56-P-M Equation and Makkink equation for Jorhat station.

3.4 Comparison of ET_0 values of F56-P-M and ET_0 values estimated using Blaney-Criddle (1950) (BC) Equation:

The Blaney-Criddle model gave the least matching ET_0 values against the F56-P-M ET_0 values among the four ET_0 estimation models evaluated. As per **Table 3**, this model gave the highest MAPE value of 10.548%. It also gave the highest MSE and RMSE values. Concerning **Fig. 7**, a very low R^2 value of 0.7323 and a poor fitting can be seen, indicating poor agreement between the compared values. Hence, the application of this model is not recommended for estimating ET_0 values for the present study area.

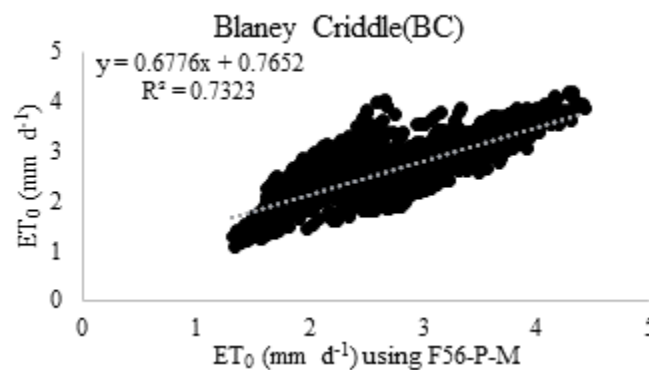


Figure 7: Comparison between ET_0 values of F56-P-M Equation and BC equation for Jorhat station.

3.4 Comparison of ET_0 values of F56-P-M and ET_0 estimated using Turc's (1961) equation:

As the study area has a humid subtropical climate, the Turc model performed moderately well in estimating ET_0 values. This model was ranked the best among the four models evaluated per the performance indices values, as shown in **Table 3**. It gave low MSE and RMSE values. It agreed with the ET_0 estimates obtained by the F56-P-M method ($R^2 = 0.952$), as per **Fig. 8**. The mean absolute percentage error (MAPE) value was 4.560%.

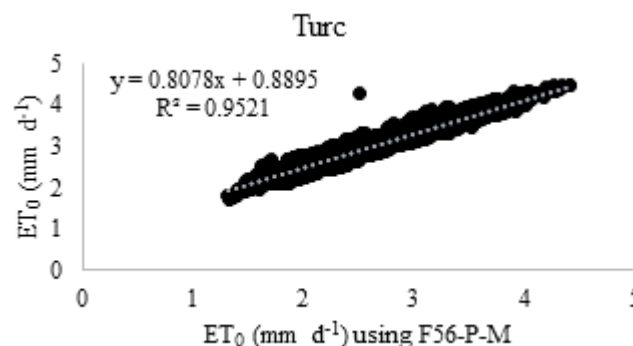


Figure 8: Comparison between ET_0 values of F56-P-M Equation and Turc equation for Jorhat station.

3.5 Comparison of ET_0 values of F56-P-M and ET_0 estimated using Hargreaves and Samani (1985) (HRSM) Equation:

The Hargreaves model exhibited poor performance in estimating ET_0 values for the station of Jorhat, Assam. In comparison with the methods used, based on the statistical performance table (Table 3), it gave the second lowest R^2 value, *i.e.*, 0.794 and the second lowest MAPE value, *i.e.*, 9.462%. It also gave the second lowest RMSE and MSE values. Literature has suggested that this model performs poorly for humid regions (Jensen *et al.* 1990); likewise, this model was ranked the second poorest ET_0 estimation model after the BC model. It can also be observed from Fig. 9, which shows a poor linear fitting.

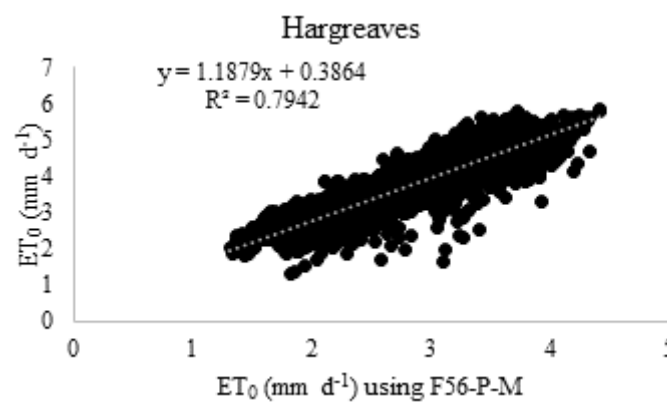


Figure 9: Comparison between ET_0 values of F56-P-M Equation and HRSM equation for Jorhat station.

The values of statistical indices: R^2 , RMSE (mm d^{-1}), MAPE (%) and MSE (mm d^{-1}) for observed ET_0 values compared to estimated ET_0 values by the four selected models are given in Table 3. As per the results in Table 3, it can be observed that, with the highest R^2 value and lowest RMSE, MSE and MAPE values, the Turc model gave the best performance among the ET_0 models selected. On the contrary, the Blaney-Criddle model showed the overall poorest result.

Table 3: Statistical performance of estimated ET_0 values obtained using four ET_0 models against F56-P-M ET_0 values.

Statistical Indices	Mk (n)	BC (n)	Turc (n)	HRSM (n)
R^2	0.916	0.732	0.952	0.794
MSE (mm d^{-1})	0.038	0.122	0.022	0.093
RMSE (mm d^{-1})	0.195	0.349	0.148	0.306
MAPE (%)	6.357	10.548	4.560	9.462

Four ET_0 models (Blaney-Criddle, Hargreaves, Turc and Makkink) were used to estimate ET_0 using the observed n value. The mean annual ET_0 values for the years 2003–2013 computed are shown in **Table 4**. Based on **Table 4**, the variances between ET_0 computed using n_e and n for the station were minimal. The models Turc and Hargreaves gave higher ET_0 values, with Hargreaves giving the highest estimates. The ET_0 values of **Eq. (10)** & **Eq. (11)** were almost identical, showing that adding the rainfall data with temperature data to estimate sunshine hours had little to no influence on the result.

Table 4: Mean Annual ET_0 computed values for the Jorhat station:

Year	F56-P-M (n)	Eq. 10 (n_{e1})	Eq. 11 (n_{e2})	Eq. 12 (n_{e3})	Eq. 13 (n_{e4})	Mk (n)	BC (n)	Turc (n)	HRSM (n)
2003	2.84	2.85	2.85	2.85	2.85	2.49	2.64	3.16	3.64
2004	2.72	2.73	2.73	2.72	2.71	2.44	2.36	3.06	3.61
2005	2.87	2.87	2.87	2.87	2.86	2.53	2.61	3.18	3.72
2006	2.80	2.80	2.80	2.80	2.80	2.49	2.60	3.13	3.68
2007	2.92	2.89	2.89	2.89	2.90	2.63	2.78	3.29	3.90
2008	2.76	2.78	2.78	2.78	2.77	2.45	2.61	3.09	3.59
2009	2.87	2.89	2.89	2.90	2.89	2.53	2.79	3.18	3.79
2010	2.94	2.93	2.93	2.93	2.93	2.60	2.86	3.25	3.86
2011	2.92	2.91	2.91	2.91	2.92	2.63	2.87	3.27	3.89
2012	2.92	2.91	2.91	2.90	2.91	2.66	2.85	3.31	3.97
2013	2.95	2.96	2.96	2.95	2.96	2.68	2.80	3.34	4.06

4 Conclusions

In the North-East region of India, only a few weather stations produce solar radiation and wind speed data (Pandey *et al.* 2016). Hence, in this study, the objective was to determine the sunshine hour data with the help of the other weather parameters which are usually available. Four equations were derived to estimate the sunshine hour (n_e), and ET_0 values were estimated using standard FAO-56 Penman-Monteith and four other models, namely: Hargreaves-Samani (1985), Turc (1961), Blaney-Criddle (1977), and Makkink (1957), whose performance were compared with ET_0 estimates obtained using estimated sunshine hours (n_e) for the region of Jorhat, Assam. The performance results of these four derived equations performed better than the four selected ET_0 empirical models. The four derived equations were detected to give high values of R^2 , ranging from 0.966 to 0.969, which indicated good agreement with the ET_0 estimates of the F56-P-M method. The overall best performance was obtained using **Eq. (13)** (n_{e4}), with statistical indices: MSE = 0.014 mm d⁻¹, RMSE = 0.120 mm d⁻¹, R^2 = 0.969 and MAPE = 3.081%. Of the four ET_0 estimation models used, the Hargreaves and the Blaney-Criddle models showed very poor performance. The Makkink model attained moderately good ET_0 estimates. The Turc model gave the best agreement with the ET_0 estimates of the F56-P-M method. The results of the four derived equations gave better performance than the Makkink, the Turc, the Blaney-

Criddle and the Hargreaves-Samani models. **Eq. (13)** was ranked as the overall best model with the highest R^2 value (0.969) and lowest performance error values, i.e., MAPE = 3.081%, MSE= 0.014 mm d⁻¹ and RMSE = 0.120 mm d⁻¹.

References

- [1] Abd el-wahed, Mohamed H., and Snyder, L.R. 2015. Calculating sunshine hours and reference evapotranspiration in arid regions when solar radiation data are limited. *Irrigation and Drainage* 64.3: 419-425.
- [2] Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. 1998. Crop Evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome* 300.9: D05109.
- [3] Almorox, J, Quej, V.H. and Martí, P. 2015. Global performance ranking of temperature-based approaches for evapotranspiration estimation considering Köppen climate classes. *Journal of Hydrology* 528: 514-522.
- [4] Bastiaanssen, W.G.M. 1995. Regionalization of surface flux densities and moisture indicators in composite terrain: A remote sensing approach under clear skies in Mediterranean climates. Wageningen University and Research
- [5] Blaney, H. F., & Criddle, W. D. 1962. Determining consumptive use and irrigation water requirements (No. 1275). US Department of Agriculture.
- [6] Gao, F., Feng, G., Ouyang, Y., Wang, H., Fisher, D., Adeli, A., & Jenkins, J. 2017. Evaluation of reference evapotranspiration methods in arid, semiarid, and humid regions. *JAWRA Journal of the American Water Resources Association* 53(4): 791-808.
- [7] Hargreaves, G.H., and Zohrab, A.S. 1982. Estimating potential evapotranspiration. *Journal of the irrigation and Drainage Division* 108(3): 225-230.
- [8] Hargreaves, G.H., and Zohrab, A.S. 1985. Reference crop evapotranspiration from temperature. *Applied engineering in agriculture* 1(2): 96-99.
- [9] Jensen, M.E., Burman, R.D. and Allen, R.G. 1990. Evapotranspiration and irrigation water requirements. ASCE.
- [10] Makkink, G. F. 1957. Testing the Penman formula by means of lysimeters. *Journal of the Institution of Water Engineers* 11: 277-288.
- [11] Pandey, V, Pandey P.K, and Mahanta, A.P. 2014. Calibration and performance verification of Hargreaves Samani equation in a humid region. *Irrigation and drainage* 63(5): 659-667.
- [12] Pandey, P.K., Dabral, P.P., and Pandey, V. 2016. Evaluation of reference evapotranspiration methods for the northeastern region of India. *International Soil and Water Conservation Research* 4(1): 52-63.
- [13] Sudheer, C. V., Viswanadh, G. K., & Ramana, G. V. 2017. Comparative study on estimation of various evapotranspiration techniques with Penman-Monteith method. *International Journal of Civil Engineering and Technology (IJCIET)* 8(8): 677-685

- [14] Tabari, H., Grismer, M. E., & Trajkovic, S. 2013. Comparative analysis of 31 reference evapotranspiration methods under humid conditions. *Irrigation Science*, 31(2):107-117.
- [15] Tellen, V. A.A.2017. Comparative analysis of reference evapotranspiration from the surface of rainfed grass in Yaounde, calculated by six empirical methods against the penman-monteith formula. *Earth Perspectives*, 4(1): 1-8.
- [16] Turc, L. 1961.Evaluation de Besoins en eau D'irrigation, ET Potentielle. *Annual Agronomy* 12:13-49.