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Assessment and comparison of potential evapotranspiration models for the district of Coimbatore using a statistical modelling approach

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Abstract
Potential evapotranspiration is important in the ecological, hydrological, and drought assessment processes, as well as agricultural production and irrigation management. It is an important source of moisture returned to the atmosphere. To estimate weekly PET (potential evapotranspiration) for Coimbatore in 2019, the FAO Penman-Monteith, Modified Penman, Penman, Priestley Taylor, Blaney Criddle, and Hargreaves models were utilized in this study. The Penman model was shown to be the most relevant, with the least bias and the highest R^2 (Coefficient of determination). Multiple Linear Regression was used to create the models, and Root Mean Squared Error, and coefficient of determination (R^2) were used to compare their performance. Priestley Taylor's model was chosen as the most practical, with the least bias and the highest R^2. Predict the PET for 2020 based on the findings of this study.

Keywords: FAO-penman-monteith, modified penman, multiple linear regression, potential evapotranspiration

1. Introduction
PET (potential evapotranspiration) is a method for calculating how much water is removed from the soil and plant surfaces. PET stands for evaporation and transpiration combined. By determining the potential evapotranspiration, we have been aware of the proper water demand for the crop at a particular time and at specific intervals. It aids in the reduction of water waste in agricultural fields. It helps to nurture the movement of nutrients in plants and enhance the temperature of the plants. The estimation of potential evapotranspiration depends on meteorological parameters like temperature, rainfall, relative humidity, wind speed, sunshine hours, and extra-terrestrial radiation.

The most important component of the hydrologic budget and precipitation is potential evapotranspiration. The water balance method, energy balance method, and open pan evaporimeter can all be used to calculate potential evapotranspiration. PET was calculated utilising remote sensing and GIS availability in modern technologies. However, with the direct field measurement method, it is not appropriate. Empirical models are most commonly used to estimate potential evapotranspiration. Nganthoi Naorem and Th. Kiranbala Devi (2012) calculated monthly PET for ten different empirical models and chose the best model based on statistical parameters such as RMSE (Root Mean Squared Error) and MAE (Mean Absolute Error) with the highest correlation coefficients. The four empirical models were validated by Rajasekhar *et al.* (2015), who found a better link between Penman-Monteith and other models. The six best PET models were derived weekly for Coimbatore in 2019 in this study, and the PET value was further predicted using multiple linear regression.

The goal of this study is to (a) use several empirical models to estimate weekly potential evapotranspiration. (a) To develop the statistical models using multiple linear regression. (c) Compare the performance of the empirical and statistical model based on the statistical criteria.

2. Materials and Methods
2.1 Area of the study
PET estimate was the focus of this research in Coimbatore, a Tamil Nadu district. It is located in Tamil Nadu's far west, near the state of Kerala. Coimbatore is located between latitude 11°0′98″North and longitude 76°57′03″East in the Indian subcontinent. This location is 411 metres above sea level. The vital water resources in this area are Singanallur, Valankulam, Ukaadam Periyakulam, Kurichi Lake, Krishnampathi, Kumaraswami Lake, and

Selvachinthamani. The average maximum temperature is 27.5 °C and 38 °C. The average minimum temperature in this area varies between 14.5 °C and 26.5 °C. This location's average relative humidity is 69.2%. The annual rainfall distribution is 859.5 mm accumulated. May and October are the warmest and wettest months at this location. December is the coldest month in this region.

2.2 Determination of Potential evapotranspiration

Secondary data was used in this study to assess the potential for evapotranspiration. The Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore collected the daily meteorological data in 2019 for Coimbatore. Maximum and minimum temperatures, relative humidity, rainfall, extraterrestrial radiation, wind speed, and sunshine hours are all part of this dataset for Coimbatore.

FAO Penman-Monteith was developed by Howard Latimer Penman and John Monteith to measure the amount of water that plants and soil surfaces remove. Doorenbos and Pruitt (1977) [7] presented their revised version of the Penman model. H.L. Penman's Penman method is a combination of aerodynamics and heat balance. The Priestley Taylor model was a simplified version of the Penman model (1972). It's similar to the Blaney Criddle and Hargreaves model in that it's temperature-based (1985). After calculating the daily PET value in accordance with FAO Irrigation and Drainage Paper 56 guidelines, use the Standard Meteorological Weeks table to convert it to a weekly PET value.

Empirical models were compared in terms of accuracy using statistical criteria such as mean absolute error, mean absolute percent error, root mean square error, residual standard error, and coefficient of determination. FAO Penman-Monteith PET values are the actual values, while the predicted values are derived from the remaining PET values.)

Table 1: Estimation of PET values using empirical models

S. No	Potential evapotranspiration Models	
1	FAO Penman-Monteith	$PET = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$
2	Modified Penman	$PET = c[W * R_n + (1 - W) * f(u) * (e_s - e_a)]$
3	Penman Model	$PET = \frac{\left(\frac{\Delta}{\gamma} * H + E_a\right)}{\left(\frac{\Delta}{\gamma} + 1\right)}$
4	Priestley Taylor	$PET = \alpha \frac{\Delta}{\Delta + \gamma} \frac{R_n}{\lambda}$
5	Blaney Criddle	$PET = p(0.46T_{mean} + 8.13)$
6	Hargreaves Model	$PET = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a$

Source: FAO Irrigation and drainage paper 56 & 24.

2.3 Statistical Modelling Approach: Multiple Linear Regression

A recent study by R. Rangaswamy (2016) explains that multiple linear regression is an extension of simple linear regression. It is defined as the process of developing a model involving dependent and independent variables. It is possible that the relationship between the variables is linear or nonlinear. By incorporating a large number of independent variables at the same time, it aids in the prediction of the value of the dependent variable

If we have n independent variables $X_1, X_2, X_3, \dots \dots, X_n$

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_n X_n + e$$

Where, Y = Dependent variable

α = Intercept

$\beta_1, \beta_2, \beta_3, \dots, \beta_n$ = Partial Regression Coefficients

$X_1, X_2, X_3, \dots, X_n$ = Independent variables.

e = Residual term (or) Error term

Using the R-Software, the model was constructed with the dependent variable being the estimated PET value from various PET models, and the independent variables being the maximum temperature (T max), minimum temperature (T min), maximum relative humidity (RH max), minimum relative humidity (RH min), wind speed (WS), extra-terrestrial radiation (R a), rainfall (RF), and sunshine hours (SSH). The objective is to identify the superior model based on statistical criteria and predict the PET value in 2020.

2.4 Statistical Criteria

$$MAE = \frac{\sum|Actual - Predicted|}{N}$$

$$MAPE = \frac{100}{N} \sum \left|\frac{Actual - Predicted}{Predicted}\right|$$

$$MSE = \frac{\sum(|Actual - Predicted|)^2}{N}$$

$$RMSE = \sqrt{\frac{\sum(Actual - Predicted)^2}{N}}$$

$$RSE = \sqrt{\frac{\sum(Actual - Predicted)^2}{\sum(Actual - \overline{Actual})^2}}$$

3. Results and Discussions

3.1 Enumeration of PET

In this research paper, the potential evapotranspiration for Coimbatore in 2019 was estimated using six different models, each of which was tested. The PET value is calculated with the help of MS.XLs. It is generally agreed that among these models, the FAO Penman-Monteith model should be used as the standard model for computing possible evapotranspiration. Figure 1 depicts the weekly PET value of the FAO Penman-Monteith, Modified Penman, Penman, Priestley Taylor, Blaney Criddle, and Hargreaves models, as well as the weekly PET value of the FAO Penman-Monteith model. A combination of temperature, relative humidity, wind speed, and sunshine hours caused the PET value of the Modified Penman, Priestley Taylor, Blaney Criddle, and Hargreaves model to be higher in the 51st and 52nd weeks of the experiment than in the previous week. After 44 and 45 weeks, the FAO Penman-Monteith model showed a significant increase. In the 45th and 46th weeks, the Penman model performed better. Table 8 depicts the results of a comparative study of empirical models based on statistical criteria such as MAE, MAPE (Mean Absolute Percentage Error), RMSE, RAE (Relative Absolute Error), RSE (Residual Standard Error), and coefficient of determination. The results of the study were compared to each other.

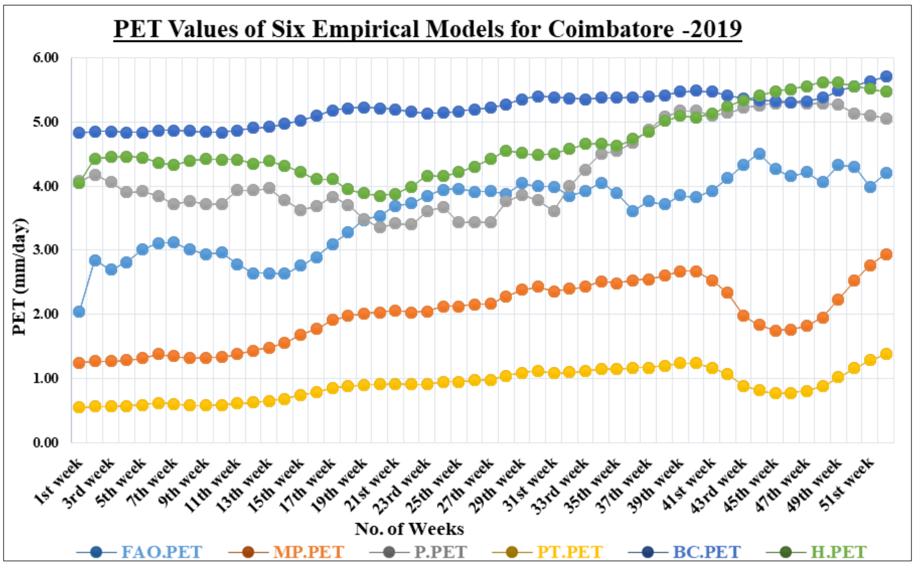

Fig 1: PET values for Coimbatore-2019 based on various Empirical Models

3.2 Multiple Linear Regression (MLR)

The model was created with the dependent variable as the estimated PET value and the independent variable as the independent variable. The independent variables in each empirical model were chosen based on the parameters involved. The model's performance was calculated using the statistical criteria shown in Figure 8.

Model 1

$Y_{Fao\ PM-PET} = -9.625 + 0.122\ T_{max} - 0.0567\ T_{min} - 0.004\ RH_{max} + 0.023\ RH_{min} + 0.0144\ WS - 0.0486 SSH - 0.0007 RF + 0.7279\ R_a$

Table 2: MLR Result of Model 1

Parameters	Coefficients	Standard error	t-stat	P Value
Intercept	-9.625	2.9409	-3.273	0.0026 *
Maximum Temperature(T_{max})	0.122	0.0662	1.850	0.0736
Minimum Temperature(T_{min})	-0.0567	0.0682	-0.831	0.4122
Relative Humidity(RH_{max})	-0.004	0.0209	-0.191	0.8495
Relative Humidity(RH_{min})	0.023	0.0119	1.925	0.0632
Wind speed (WS)	0.0144	0.0226	0.635	0.5300
Sunshine Hours (SSH)	-0.0486	0.0403	-1.205	0.2369
Rainfall (RF)	-0.0007	0.0013	-0.536	0.5955
Extra – Terrestrial radiation(R_a)	0.7279	0.1383	5.265	9.2e-06 *

'*' Indicates 5% significance in table 2

Model 2

$Y_{Modified\ Penman\ PET} = -11.55 - 0.008\ T_{max} + 0.086\ T_{min} + 0.014\ RH_{max} - 0.006\ RH_{min} - 0.031 WS - 0.026\ SSH + 0.001\ RF + 0.851\ R_a$.

Table 3: MLR Result of Model 2

Parameters	Coefficients	Standard error	t-stat	P Value
Intercept	-11.55	1.950	-5.924	1.35e-06 **
Maximum Temperature(T_{max})	-0.008	0.044	-0.184	0.8549
Minimum Temperature(T_{min})	0.086	0.045	1.897	0.0669
Relative Humidity(RH_{max})	0.014	0.014	0.994	0.3278
Relative Humidity(RH_{min})	-0.006	0.008	-0.699	0.4897
Wind speed (WS)	-0.031	0.015	-2.043	0.0493 *
Sunshine Hours (SSH)	-0.026	0.027	-0.970	0.3394
Rainfall (RF)	0.001	0.001	0.737	0.4666
Extra – Terrestrial radiation(R_a)	0.851	0.092	9.285	1.35e-10 **

'*' and '**' Indicates 5% and 1% significance in the table 3.

Model 3

$$Y_{\text{Penman PET}} = 2.4097 - 0.1959\ T_{max} + 0.0902\ T_{min} - 0.0307\ RH_{max} - 0.0148\ RH_{min} - 0.1571\ WS + 0.0706\ SSH - 0.0009\ RF + 0.7503\ R_a$$

Table 4: MLR Result of Model 3

Parameters	Coefficients	Standard error	t-stat	P Value
Intercept	2.4097	3.9838	0.605	0.5495
Maximum Temperature(T_{max})	-0.1959	0.0896	-2.186	0.0362 *
Minimum Temperature(T_{min})	0.0902	0.0924	0.976	0.3363
Relative Humidity(RH_{max})	-0.0307	0.0284	-1.083	0.2870
Relative Humidity(RH_{min})	-0.0148	0.0162	-0.916	0.3664
Wind speed (WS)	-0.1571	0.0307	-5.122	1.4e-05 **
Sunshine Hours (SSH)	0.0706	0.0547	1.292	0.2058
Rainfall (RF)	-0.0009	0.0018	-0.546	0.5891
Extra – Terrestrial radiation(R_a)	0.7503	0.1873	4.006	0.0003**

'*' and '**' Indicates 5% and 1% significance in the table 4.

Model 4

$$Y_{\text{Priestley Taylor PET}} = -5.4697 + -0.0072\ T_{max} + 0.0411 T_{min} + 0.0062 RH_{max} - 0.0029\ RH_{min} - 0.0162 WS - 0.0125\ SSH + 0.00028\ RF + 0.4119\ R_a$$

Table 5: MLR Result of Model 4

Parameters	Coefficients	Standard error	t-stat	P Value
Intercept	-5.4697	0.9192	-5.951	1.25e-06 **
Maximum Temperature(T_{max})	-0.0072	0.0207	-0.347	0.7308
Minimum Temperature(T_{min})	0.0411	0.0213	1.926	0.0631
Relative Humidity(RH_{max})	0.0062	0.0065	0.947	0.3508
Relative Humidity(RH_{min})	-0.0029	0.0037	-0.802	0.4288
Wind speed (WS)	-0.0162	0.0071	-2.289	0.0289 *
Sunshine Hours (SSH)	-0.0125	0.0126	-0.988	0.3304
Rainfall (RF)	0.00028	0.0004	0.678	0.5024
Extra – Terrestrial radiation(R_a)	0.4119	0.0432	9.533	7.20e-11 **

'*' and '**' Indicates 5% and 1% significance in the table 5.

Model 5

$$Y_{Blaney\ Criddel\ PET} = 5.2413 - 0.0659 T_{max} + 0.0902 T_{min} + 0.001\ RF$$

Table 6: MLR Result of Model 5

Parameters	**Coefficients**	**Standard error**	**t-stat**	**P Value**
Intercept	5.2413	0.3161	16.580	< 2e-16 **
Maximum Temperature(T_{max})	-0.0659	0.0115	-5.715	1.53e-06 **
Minimum Temperature(T_{min})	0.0902	6.977	6.977	3.04e-08 **
Rainfall (RF)	0.0001	0.0007	0.145	0.885

'**' Indicates 1% significance in the table 6.

Model 6

$$Y_{Hargreaves\ PET} = -2.0177 + 0.0310 T_{max} - 0.0834 T_{min} - 0.0003 RF + 0.5507 R_a$$

Table 7: MLR Result of Model 6

Parameters	Coefficients	Standard error	t-stat	P Value
Intercept	-2.0177	2.2152	-0.911	0.3684
Maximum Temperature(T_{max})	0.0310	0.0341	0.910	0.3689
Minimum Temperature(T_{min})	-0.0834	0.0348	-2.396	0.0219 *
Rainfall (RF)	-0.0003	0.0013	-0.300	0.7661
Extra – Terrestrial radiation(R_a)	0.5507	0.1391	3.959	0.0003 **

'*' and '**' Indicates 5% and 1% significance in the table 7.

Residual Plots and Normal Probability Plots

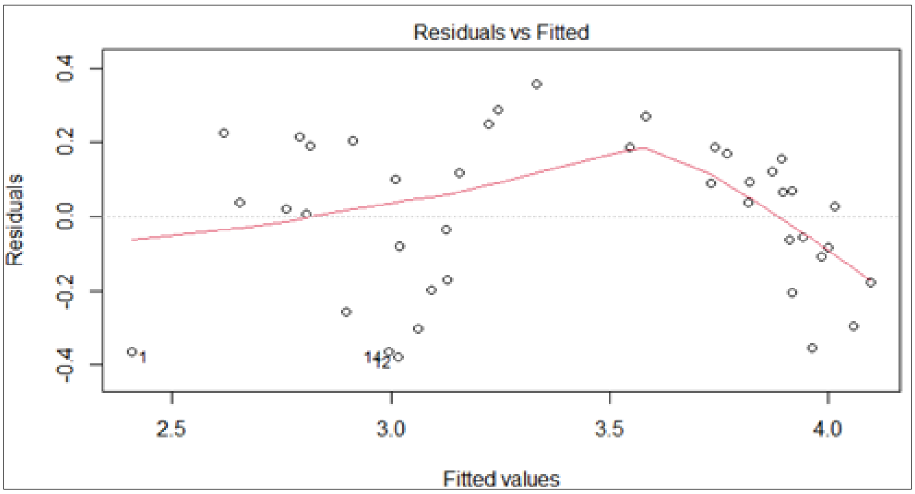

Fig 2(a): Graphics of Residuals vs fitted values of Model 1

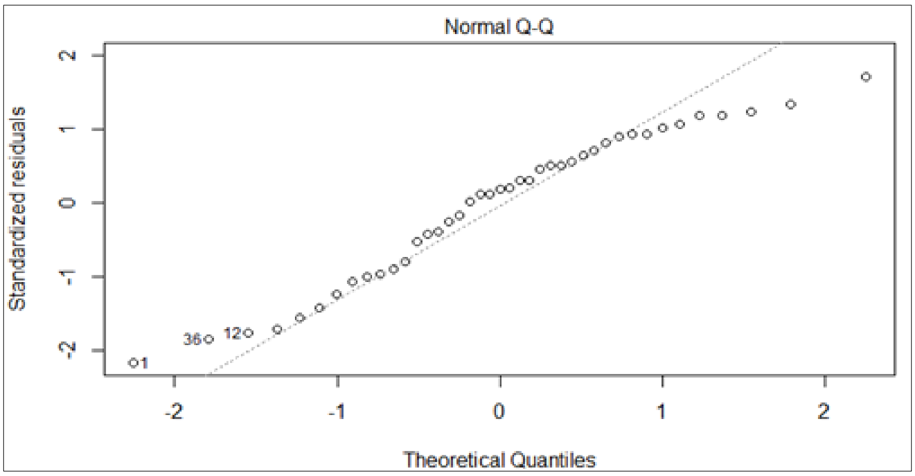

Fig 2(b): Probabilistic Standardized residuals of the Model 1

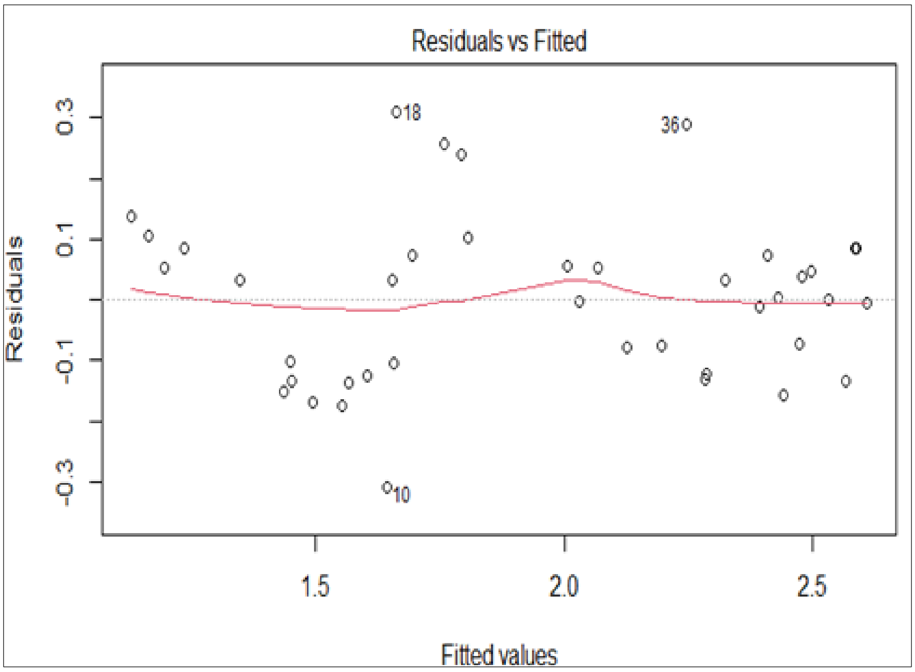

Fig 3(a): Graphics of Residuals vs fitted values of Model 2

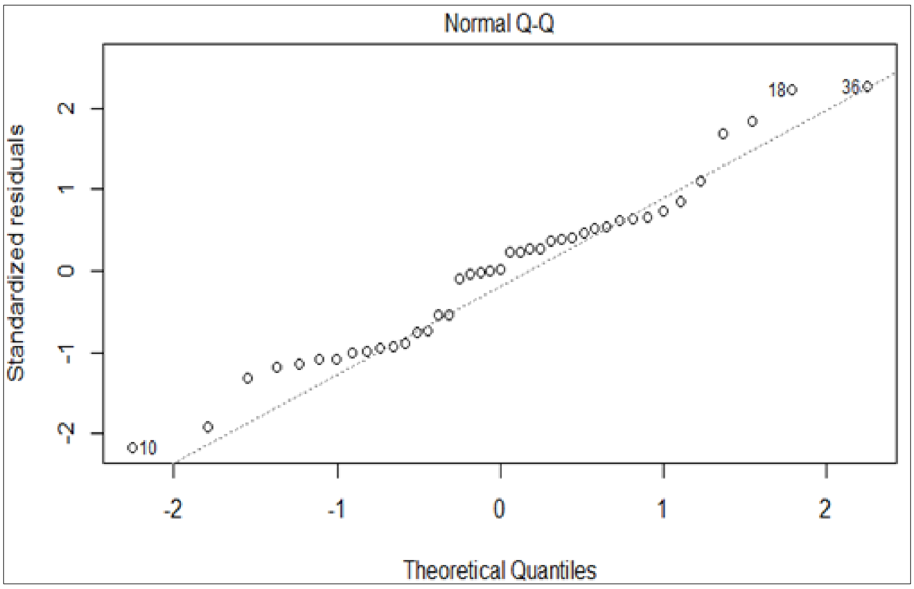

Fig 3(b): Probabilistic Standardized residuals of the Model 2

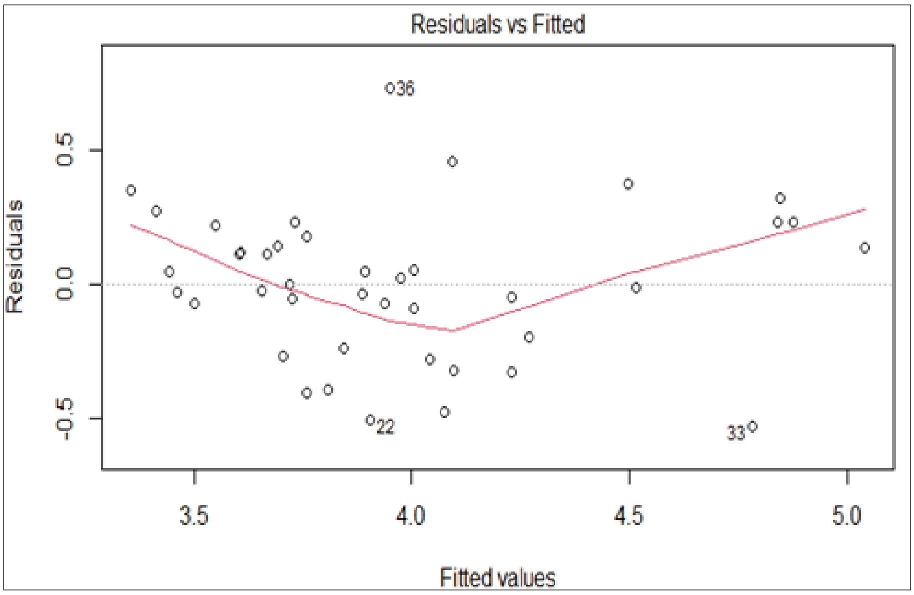

Fig 4(a): Graphics of Residuals vs fitted values of Model 3

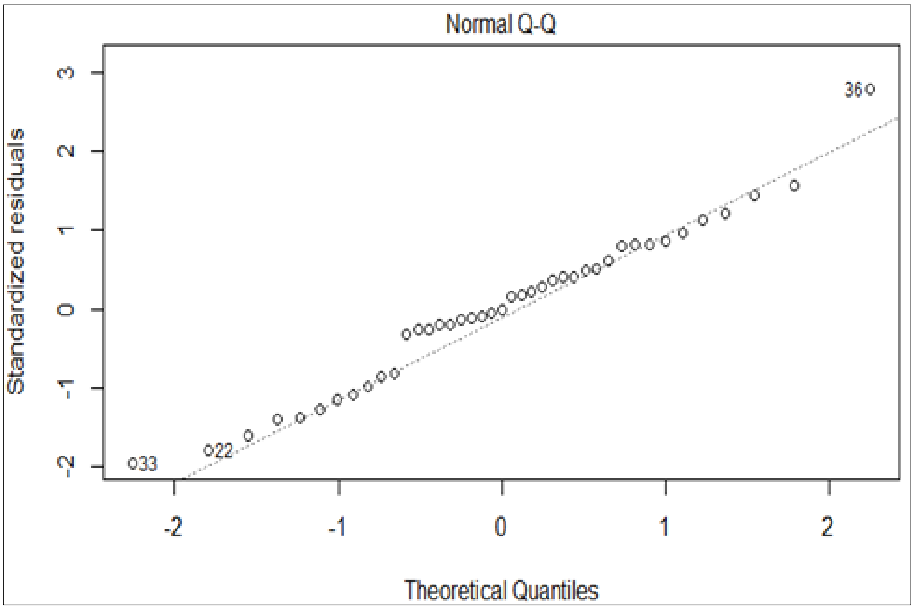

Fig 4(b): Probabilistic Standardized residuals of the Model 3

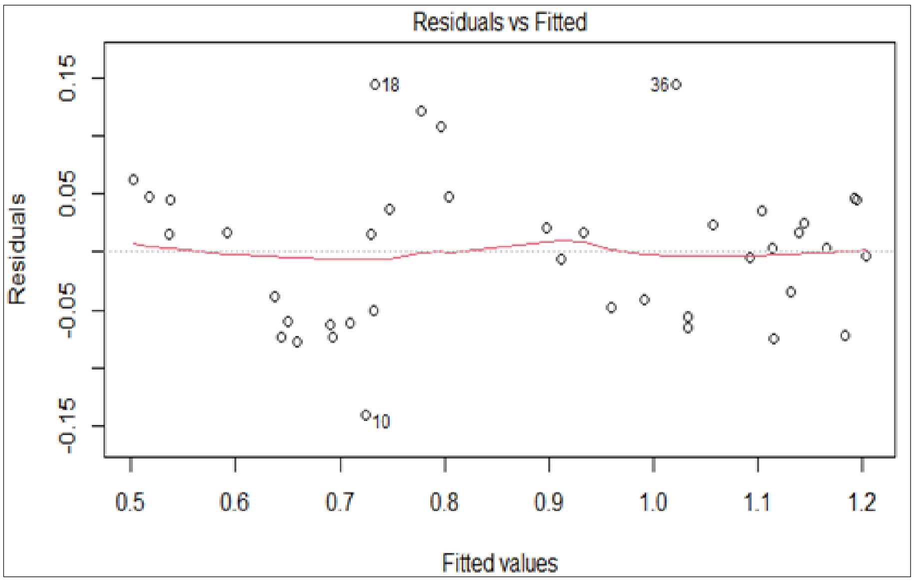

Fig 5(a): Graphics of Residuals vs fitted values of Model 4

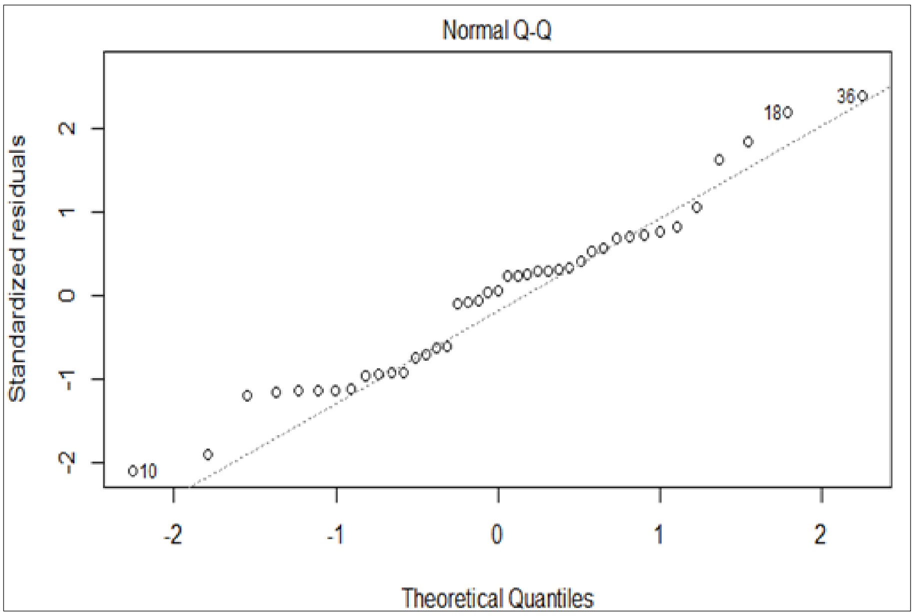

Fig 5(b): Probabilistic Standardized residuals of the Model 4

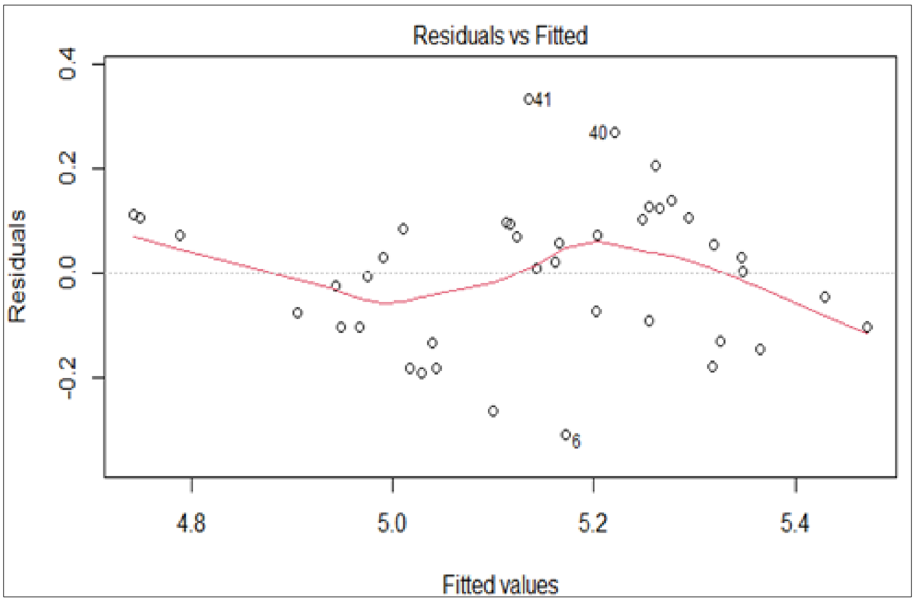

Fig 6(a): Graphics of Residuals vs fitted values of Model 5

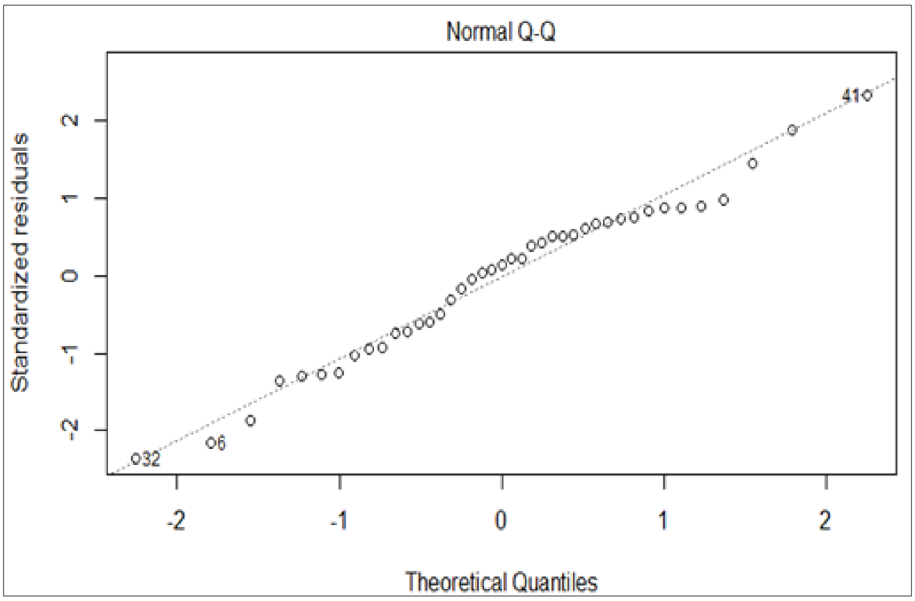

Fig 6(b): Probabilistic Standardized residuals of the Model 5

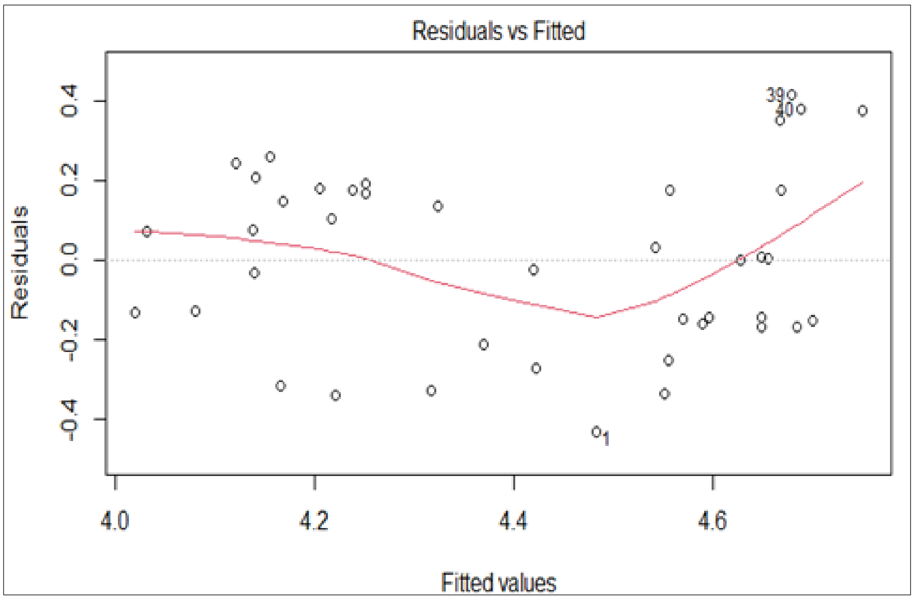

Fig 7(a): Graphics of Residuals vs fitted values of Model 6

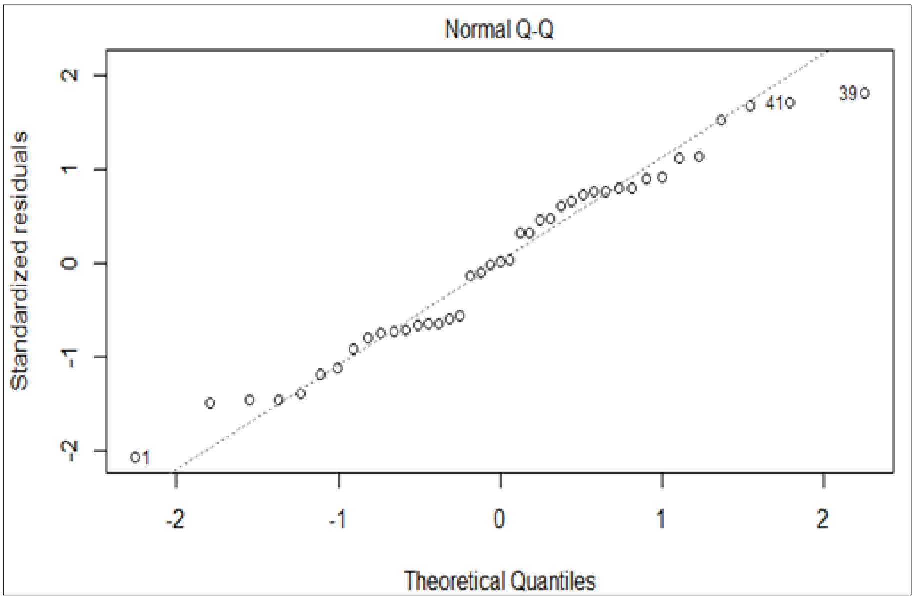

Fig 7(b): Probabilistic Standardized residuals of the Model 6

Figure 2(a)-7 (a) The residuals of the fitted model were interpreted to be distributed normally as shown in Figure 2(b)-7(b), because the points are almost over the line.

Table 8: Analogy study of different empirical models for Coimbatore-2019

Model	R^2	RSE	RAE	RMSE	MAE	MAPE
Modified Penman	0.79	0.4506	23.065	1.6312	1.5823	44.4184
Penman	0.94	0.2509	11.680	0.9083	0.8013	24.1503
Priestley Taylor	0.44	0.7494	39.006	2.7128	2.6759	74.9328
Blaney Criddle	0.78	0.4628	23.708	1.6753	1.6265	48.9634
Hargreaves	0.89	0.3224	15.472	1.1672	1.0614	32.1723

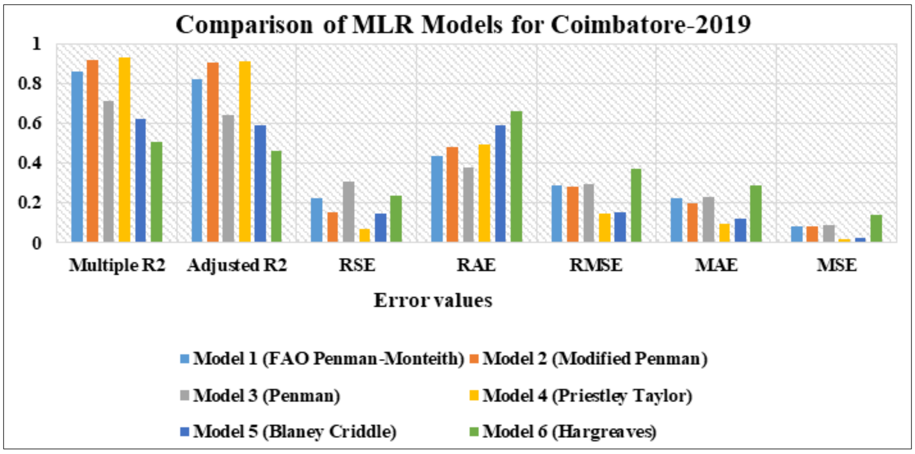

Fig 8: Comparative study of MLR model Performance

As can be seen in Figure 8, model 4 (Priestley Taylor) was found to have a high coefficient of determination and a low bias, making it the most relevant model.

Table 9: Predicted values for Coimbatore-2020

Year	FAO Penman- Monteith	Modified Penman	Penman Method	Priestley Taylor	Blaney Criddle	Hargreaves Method
2020	2.37	1.19	4.26	0.53	4.91	4.48

4. Conclusions

The Six different empirical models were used to estimate potential evapotranspiration in this study. Statistical tools such as RMSE, RSE, RAE, MSE (Mean Squared Error), MAPE, and R^2 were used to identify the best empirical models. Among these empirical models, the Penman model had a lower bias and a higher coefficient of determination, indicating improved performance accuracy. Statistical parameters were used to find the best MLR model. Using the given meteorological data for Coimbatore in 2019, Model 4 (Priestley Taylor) produced the best fit model with the lowest RMSE, RAE, RSE, MAE, and MSE, as well as being highly correlated with the variables. We also predicted 2020 evapotranspiration values. In the future, we can use Artificial Neural Networks and Robust Regression to build and predict the model.

5. Acknowledgements

With the help of the department's head and chairman, this study was carried out at the Department of Physical Sciences and Information Technology at Tamil Nadu Agricultural University Coimbatore.

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