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Short communication

Comparative evaluation of evapotranspiration models with lysimeter data in Ranchi

JOSNA MURMU[1], R. LATHA[2*], B. S. MURTHY[2] and MANOJ KUMAR[1]

[1]*Department of Environmental Sciences, Central University of Jharkhand, Brambe-835205, Ranchi, Jharkhand, India*
[2]*Indian Institute of Tropical Meteorology, Pune, India*
**Corresponding author email: josnamurmu15@gmail.com*

In the Earth's water cycle, evapotranspiration (ET) plays a dynamic role, and is responsible for the availability of freshwater resources, water management for irrigation, and the climate feedback mechanism (Phad *et al.,* 2019; Mehta and Pandey 2015). The method of obtaining ET varies from direct measurement techniques, using lysimeters, to energy balance measurements based on flux profile, Bowen-ratio, and eddy correlation techniques (Srivastava *et al.,* 2018). ET is dependent on many climatic parameters and LULC (Murmu *et al.,* 2025). The FAO56-PM method is considered relatively more accurate as it is based on physics involving all controlling parameters. Estimating ETo over different crops and different climatic conditions is not possible due to insufficient data. Moreover, a crop coefficient is required to find actual ET from ETo. Hence, some empirical formulae have been developed to estimate ETo which are categorized as Temperature (T) based, radiation-based based or hybrid involving both. Recently, machine learning models have been used by many researchers (Naidu and Majhi, 2019; Naresh *et al.,* 2023). For different climatic conditions, different methods are suitable as inferred by comparing with the FAO56-PM method, taken as a reference (Phad *et al.,* 2019; Dar *et al.,* 2017).

Such studies are not available for the Ranchi region; hence, this study was undertaken to evaluate five methods for ET_O estimation using FAO56-PM (Allen *et al.,* 1998), Hargreaves (Hargreaves and Samani, 1985), Schendel (Schendel, 1967), Christiansen (Christiansen, 1968) and Turc (Turc, 1961) models.

Birsa Agricultural University (BAU), Kanke (23°26′ N, 85°19′ E; 625 m AMSL), was selected for this study. BAU is primarily an agricultural field with soil type at all sites is red sandy loam. The major crops cultivated in this region include mustard, wheat, and vegetables during winter, pulses and lentils in pre-monsoon, and paddy and sugarcane during the monsoon. Most of the agriculture is rain-fed, with supplemental irrigation from wells or borewells where available. ETo was calculated for three representative months corresponding to winter (January), pre-monsoon (June), and post-monsoon (November) seasons across multiple years (2011, 2013, 2015, and 2016).

Before analysis, all datasets underwent rigorous quality control procedures. Outliers and spurious peaks were identified statistically (values exceeding ±1 standard deviation from the mean) and removed. Missing values were replaced with the corresponding mean values of the time series. The lysimeter-measured ET at BAU for the year 2011 was used for validation. The reference daily evapotranspiration (ETo) was estimated using five widely recognized empirical models (Table 1). The weighing lysimeter at BAU, Kanke, was used as the ground-truth reference for ET measurements. The lysimeter, installed in a cropped field, provides continuous measurements of actual evapotranspiration (ETa) and serves as the benchmark against which model performance was assessed (data provided by IMD). Input data were prepared following FAO-56 Penman–Monteith (FAO56-PM) procedures (Allen *et al.,* 1998) to ensure consistency and comparability before applying the empirical models.

To evaluate model performance, monthly mean anomalies (ETA) were computed for each model as: $ET_A = (ETo - ET_L) / ETo$, where ETo is the reference evapotranspiration estimated by a given empirical model, and ET_L is the lysimeter-measured ET. This metric represents the relative deviation (bias) of model-estimated ETo from lysimeter observations. Positive values indicate overestimation, whereas negative values indicate underestimation by the model. By comparing monthly mean anomalies across years, we assessed the seasonal and interannual consistency of each model and identified the empirical formulation best suited for the Ranchi region under different climatic conditions.

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Table 1: Empirical equations used for ETo calculation

Methods	Empirical equation	Variable used	Remarks	Reference
FAO-56 Penman -Monteith (FAO-PM)	$ET_o = \frac{0.408\Delta(R_n - G)\,\gamma \frac{900}{Tmean + 273}\, u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$	Rn, G, Tmean, RH, u, e_s, e_a, Δ, γ	Combination-based method	Allen *et al.,* (1998).
Hargreaves and Samani method (HAR)	$\mathrm{ETo} = \left(0.0023\frac{R_s}{2.45}\right)\mathrm{TD}^{0.5}(T_{mean} + 17.8)$	Rn, Tmean, TD	Temperature-based method	Hargreaves and Samani (1985)
Schendel method (SCH)	$\mathrm{ETo} = 16\left(\frac{T_{mean}}{RH}\right)$	Tmean, RH	Temperature-based method	Schendel (1967)
Christiansen method (CHRIS)	ETo= 0.385Rn	Rn	Radiation-based method	Christiansen (1968)
Turc method (TURC)	$\mathrm{ETo} = 0.013\left(\frac{T_{mean}}{T_{mean} + 15}\right)(R_s + 50)$	Tmean, Rn	Radiation based method	Turc (1961)

Note: ETo = Reference evapotranspiration [mm day^{-1}], R_n = Net radiation [MJ m^{-2} day^{-1}], G = Soil heat flux density [MJ m^{-2} day^{-1}], Tmean = Mean daily air temperature at 2 m height [°C], u_2 = Wind speed at 2 m height [m s^{-1}], e_s = Saturation vapor pressure [kPa], e_a = Actual vapor pressure [kPa], e_s - e_a = Saturation vapor pressure deficit [kPa], Δ = Slope vapor pressure curve [kPa °C^{-1}], γ = Psychrometric constant [kPa °C^{-1}], TD= Difference between the maximum temperature and minimum temperature.

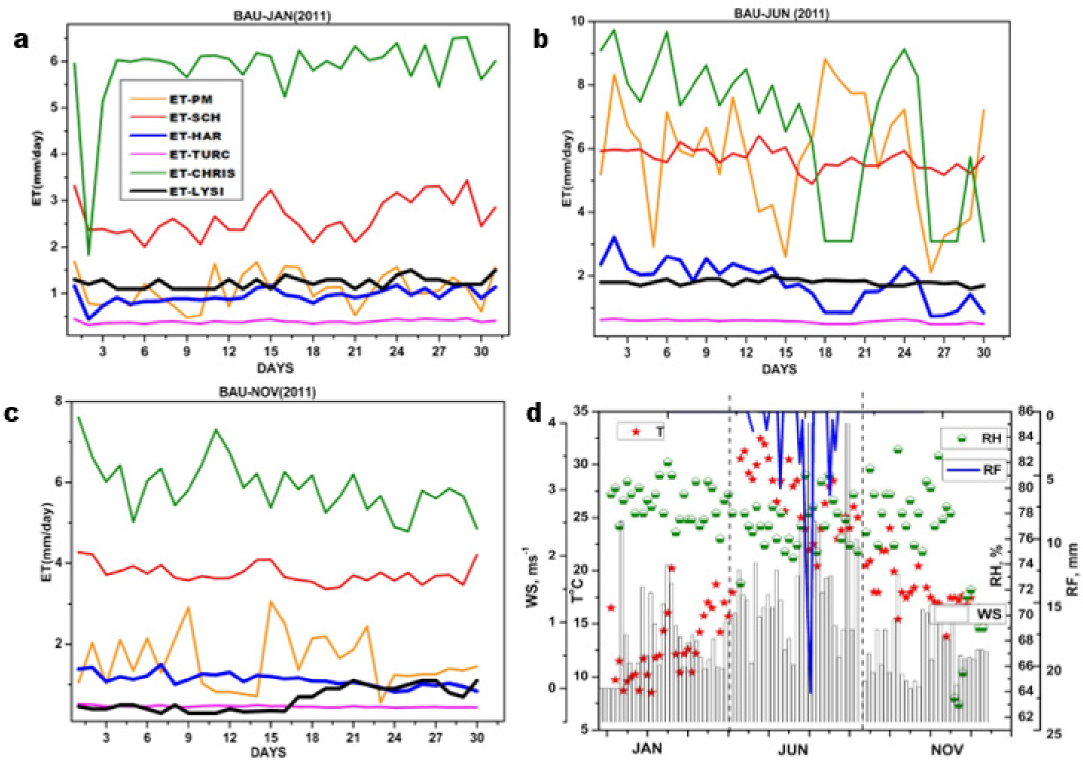

Fig. 1: Comparison of ET estimated by 5 models against lysimeter observations at BAU in a) January, b) June, c) November in 2011 and d) Daily mean temperature (T), relative humidity (RH), wind speed (WS), rainfall (RF)

Comparison of ET estimated by different methods

Five empirical models were used for ETo estimation and compared with lysimeter ET. As shown in Fig. 1, in January, FAO56-PM (ET-PM) and Hargreaves (ET-HAR) are comparable to ET_L while Christiansen (ET-CHRIS), Schendel (ET-SCH) models have overestimated and Turc (ET-TURC) underestimated. In June and November, ET-HAR is relatively better compared to other models.

It is evident from Fig. 1(d) that BAU has high RH throughout. BAU experiences relatively high wind speeds. It is to be noted that lysimeter is located at BAU where mustard crops were grown in November to March. Model-estimated ETo is to be multiplied by crop coefficient to get actual ET for any crop for irrigation needs (Mehta and Pandey 2015). Overall, it appears that HAR and SCH models, based on easy to measure T, RH, and solar radiation, are appropriate for ET estimation in the Ranchi region compared to TURC and CHRIS models. However, SCH method indicates a significant overestimation with very good match in trends. FAO56-PM model performed relatively better,

Table 2: Anomalies (monthly mean deviation from lysimeter observations) for BAU station in different years

Methods ⇩	2011			2013			2015			2016		
	Jan	June	Nov	Jan	June	Nov	Jan	June	Nov	Jan	June	Nov
FAO-56 Penman– Monteith	-0.3	0.7	0.5	-1.9	-0.9	-1.1	-0.3	0.1	-1.2	-0.5	-0.3	-2.2
Hargreaves method	0.5	0.7	0.8	0.1	0.7	0.5	0.7	0.7	0.5	0.6	0.6	0.2
Schendel method	-0.3	-0.2	0.4	-0.9	-0.4	-0.3	0.0	-0.5	-0.6	-0.1	-0.9	-1.1
Christiansen method	0.8	0.7	0.9	0.7	0.7	0.8	0.8	0.6	0.7	0.8	0.5	0.6
Turc method	-2.2	-2.2	-0.4	-4.8	-1.6	-2.7	-1.4	-2.3	-3.4	-2	-3.8	-5.5

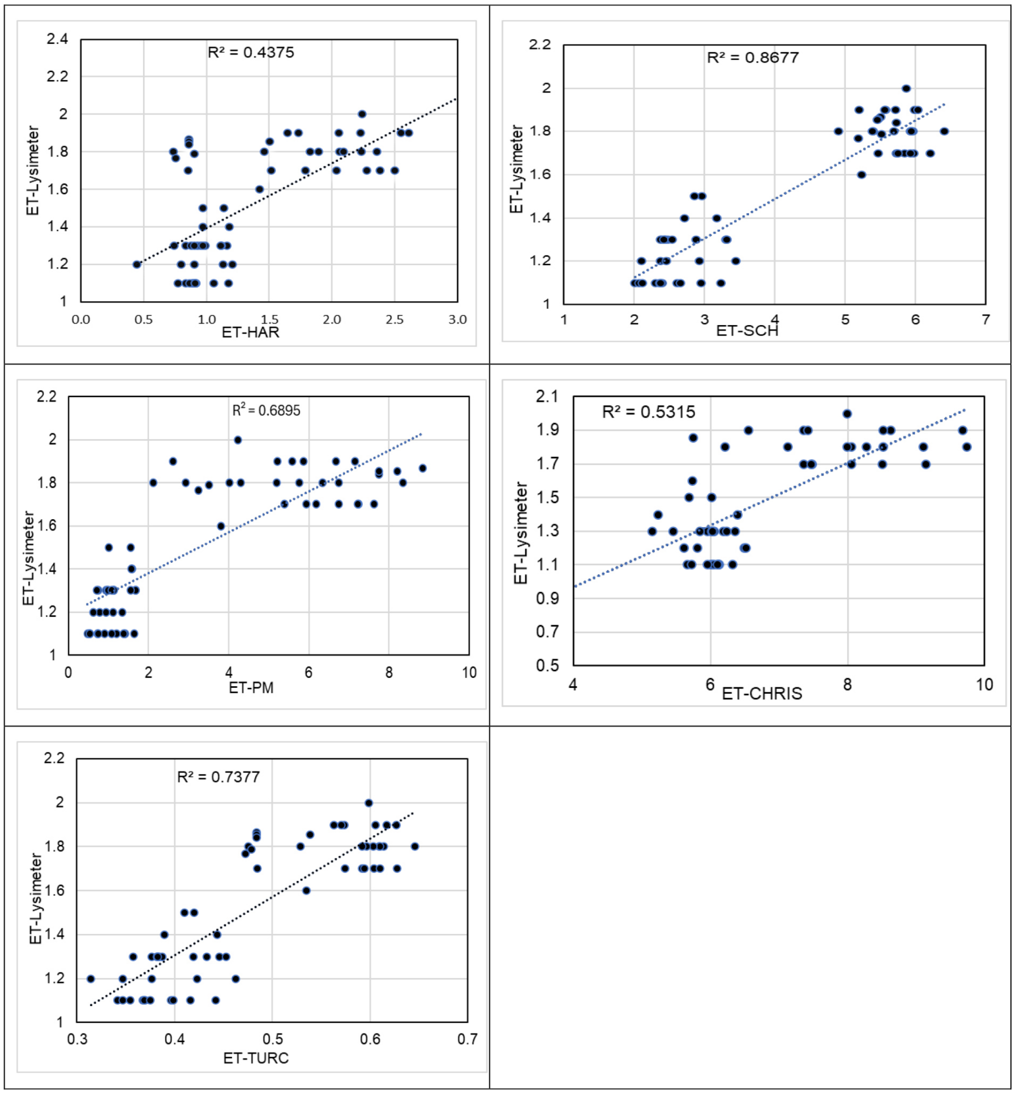

Fig. 2: Comparison of daily-ET estimated by different models (HAR, PM, SCH, TURC, CHRIS) and ET by lysimeter

but it requires many parameters those are not routinely measured in observatories (Liu *et al.,* 2017; Tomar, 2022; Tahashildar *et al.,* 2017). Monthly mean difference of ET by each model from that of ET_L indicates which one of the models is the best option for the estimation of ET.

The monthly mean deviation of ETo from ET_L for each model is tabulated in Table 2 for BAU, based on the anomaly values it may be said that one empirical model for ET may not suit all seasons. At BAU site, SCH is relatively better than PM and HAR. Overall, in the Ranchi region HAR and SCH are found to be better than other models with HAR performing better. It is also suggested that other methods are also alternative options for the region according to their availability of data and climatic conditions.

Overall, HAR and SCH models provided the most reliable estimates for the Ranchi region, with HAR demonstrating slightly better performance on average, particularly during the pre-monsoon and post-monsoon months. Fig. 2 shows scatter diagrams of various model comparisons of Daily-ET (ET-HAR, ET-PM, ET-SCH, ET_TURC, ET-CHRIS) against lysimeter-measured ET (ET-Lysimeter). ET-lysimeter has a range of 0.5 – 2.2 while ET-HAR has a range, 0.5 – 2.5. ET-PM, ET-SCH, ET-TURC and ET-CHRIS have ranges of 0.5 – 9, 2 – 7, 0.3 – 0.7 and 5 – 10 respectively. ET is overestimated by all models except HAR while TURC has underestimated ET. However, correlation coefficient (R^2) between model-ET and lysimeter-ET is better for SCH (0.8677), TURC (0.7377), PM (0.6895) compared to HAR (0.4375) and CHRIS (0.5315). Considering both absolute ET range and R^2, it can be stated that HAR is reasonably better than other models.

This study evaluated five empirical models for ETo estimation and compared them against lysimeter-measured ET at BAU, Ranchi. The analysis was conducted for three distinct seasons (winter, pre-monsoon, and post-monsoon). Results of anomalies show that the Hargreaves (HAR) and Schendel (SCH) models perform better than Christiansen and Turc models, with HAR providing the most consistent estimates across seasons. Given its minimal data requirements (temperature and radiation), HAR is particularly well-suited for semi-arid and data-scarce regions such as Ranchi. Considering both ET-range and R^2 between models and Lysimeter-ET, it can be stated that HAR is a reasonably better model for Ranchi.

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Data availability: Data will be made available on request for research purpose

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