RESEARCH ARTICLE

Evaluation of Hargreaves–Samani and Valiantzas Solar Radiation Models for FAO-56 Reference Evapotranspiration Estimation in Salem (Valapadi), Tamil Nadu, India.

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ABSTRACT

Reference evapotranspiration (ET_0) is a key parameter for irrigation scheduling and agricultural water management, but estimating it using the FAO-56 Penman–Monteith method requires solar radiation data, which are often unavailable in many regions. This study evaluated the performance of the Hargreaves–Samani (HS) and Valiantzas (VAL) solar radiation models for estimating ET_0 in Valapadi, Salem district, Tamil Nadu, using 25 years (2000–2025) of meteorological data obtained from the NASA POWER database. Results indicated that the mean measured solar radiation was 23.48 MJ m^{-2} day^{-1}, while HS and VAL models estimated 23.40 MJ m^{-2} day^{-1} and 22.27 MJ m^{-2} day^{-1}, respectively. The mean ET_0 calculated using measured radiation was 5.78 mm day^{-1}, closely matched by HS-based ET_0 (5.79 mm day^{-1}), whereas VAL slightly underestimated ET_0 (5.58 mm day^{-1}). Statistical analysis showed strong agreement with measured ET_0 values (HS: R^2 = 0.894, VAL: R^2 = 0.982). These results demonstrate that both models can effectively estimate ET_0 under limited data conditions, supporting irrigation planning in data-scarce regions.

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INTRODUCTION:

Reference evapotranspiration (ET_0) represents the atmospheric demand for water from a standardized reference surface and is a critical parameter for irrigation scheduling, crop water requirement estimation, and agricultural water management. Accurate estimation of ET_0 plays a vital role in optimizing water-use efficiency and improving agricultural productivity, particularly in regions with limited water resources. The FAO-56 Penman–Monteith method is widely accepted as the standard method for estimating reference evapotranspiration because it integrates the physical processes governing evapotranspiration and has been validated across a wide range of climatic conditions worldwide *(Allen et al., 1998).*

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Although the FAO-56 Penman–Monteith method provides reliable estimates of evapotranspiration, its application requires a complete set of meteorological parameters, including solar radiation, air temperature, relative humidity, and wind speed. In many agricultural regions, especially in developing countries, such comprehensive meteorological data are not always available due to limited weather-monitoring infrastructure and the absence of reliable radiation-measuring instruments. Solar radiation observations are particularly scarce because radiation sensors require specialized equipment and regular maintenance. Consequently, the lack of solar radiation data limits the application of the FAO-56 Penman–Monteith method in many agricultural areas *(Samani, 2000; Djaman et al., 2016)*.

This challenge is evident in several parts of Tamil Nadu, India, where agricultural meteorological stations often record basic parameters such as temperature and humidity but lack consistent measurements of solar radiation. Since solar radiation is one of the most important drivers of evapotranspiration, its absence introduces significant uncertainty in estimating evapotranspiration and in irrigation planning. To address this limitation, several simplified empirical approaches have been developed to estimate solar radiation using more readily available climatic variables such as air temperature and relative humidity.

One of the most widely used simplified approaches is the Hargreaves–Samani model, which estimates solar radiation based on the difference between daily maximum and minimum air temperatures *(Hargreaves & Samani, 1982)*. Because this model requires only temperature data, it has been extensively applied in regions where radiation measurements are unavailable. However, the accuracy of the Hargreaves–Samani model may vary with local climatic conditions, particularly in humid or tropical regions, where atmospheric moisture influences the solar radiation reaching the surface *(Samani et al., 2011).*

To improve the performance of temperature-based radiation estimation models, Valiantzas proposed several simplified formulations of evapotranspiration and radiation estimation models using limited meteorological data *(Valiantzas, 2006, 2013a, 2013b, 2013c, 2013d)*. These approaches were developed to improve evapotranspiration estimation in situations where complete meteorological data are not available. Later studies further refined these models and demonstrated their applicability under different climatic conditions *(Valiantzas, 2015; Valiantzas, 2018b)*. In particular, Valiantzas (2017) proposed a modification of the Hargreaves–Samani model that incorporates relative humidity as an additional parameter. By accounting for atmospheric moisture conditions, the modified model aims to improve the accuracy of radiation estimates, especially in climates where humidity significantly influences solar radiation attenuation.

Previous studies have shown that simplified evapotranspiration estimation methods based on limited meteorological data can provide reasonable approximations of the FAO-56 Penman–Monteith method when applied under appropriate climatic conditions *(Djaman et al., 2016; Valipour, 2014)*. Several comparative studies have also demonstrated that simplified Penman-based and temperature-based models can produce acceptable ET_0 estimates under data-limited conditions *(Valiantzas, 2012, 2014a, 2014b; Kisi, 2014)*. These findings indicate that simplified radiation and evapotranspiration models can serve as practical alternatives in regions lacking complete meteorological observations.

Evaluating the performance of these simplified radiation models is therefore important for determining their applicability in regions with incomplete meteorological datasets. Many studies conducted in different climatic regions have demonstrated that temperature-based and humidity-based radiation models can provide acceptable evapotranspiration estimates when radiation measurements are unavailable, although their accuracy often depends on regional climatic characteristics and local calibration *(Kisi, 2014; Valiantzas, 2018b).*

Recent studies conducted in Tamil Nadu have also evaluated the applicability of simplified radiation estimation models that use temperature and humidity as inputs. For example, a study in Coimbatore demonstrated that both the Hargreaves–Samani and Valiantzas models provide reliable estimates of solar radiation and FAO-56 Penman–Monteith evapotranspiration when meteorological data are limited *(Rashwin et al., 2025)*.

Similarly, under semi-arid conditions in India, the performance of the Hargreaves–Samani and Valiantzas models was assessed using long-term meteorological data, confirming that these models can effectively estimate solar radiation using temperature and humidity parameters *(Ramachandran et al., 2022).*

These findings highlight the potential of simplified radiation models to support evapotranspiration estimation and irrigation planning in regions where direct solar radiation measurements are unavailable.

The present study focuses on Valapadi in the Salem district of Tamil Nadu, India (11.6686° N latitude and 78.4067° E longitude), located at an elevation of approximately 305 m above mean sea level. The region experiences a tropical climate characterized by relatively high temperatures and moderate humidity throughout the year. Agriculture in the Salem region relies heavily on effective water management, making accurate estimates of evapotranspiration essential for irrigation planning and sustainable agricultural practices. However, the limited availability of solar radiation measurements in the region restricts the application of the standard FAO-56 Penman–Monteith method.

Therefore, there is a need to evaluate alternative approaches to estimating solar radiation that can provide reliable evapotranspiration estimates with limited meteorological data. This study aims to assess the applicability of simplified radiation estimation models for evapotranspiration calculation in Valapadi, Salem. By comparing evapotranspiration estimates obtained using simplified radiation models with those derived from measured solar radiation within the FAO-56 Penman–Monteith framework, the study seeks to determine whether these models can serve as reliable alternatives for evapotranspiration estimation in data-limited environments.

METHODS AND MATERIALS:

Meteorological data required for estimating reference evapotranspiration using the FAO-56 Penman–Monteith (FAO-56 PM) method were obtained from the NASA POWER database for 25 years, from January 2000 to December 2025, corresponding to the geographical location of Valapadi in Salem district, Tamil Nadu, India. The study area is located at approximately 11.6686° N latitude and 78.4067° E longitude, with an elevation of 305 meters above mean sea level (MSL). The dataset includes key meteorological parameters such as maximum and minimum air temperatures, relative humidity, and solar radiation, which are required for estimating reference evapotranspiration and evaluating simplified solar radiation models.

Estimation of Solar Radiation

Hargreaves-Samani R_S formula based on T (HS R_S [T])

Hargreaves and Samani (1982) recommended a simplified equation to estimate solar radiation:

$$R_S = 0.16 * R_A (T_{max} - T_{min})^{0.5} \quad (1)$$

Where,

R_A is extra-terrestrial radiation [MJ m-2 day-1].

T_{max} is the maximum temperature [°C]; and

T_{min} is the minimum temperature [°C].

The radiation (R_A) for each day of the year and at different latitudes can be estimated from the solar constant, the solar declination, and the time of the year using the following equation.

$$R_A = \frac{24\ (60)}{\pi} G_{SC}\, d_r [\omega_s \sin(\emptyset) \sin(\delta) + \cos(\emptyset) \cos(\delta) \sin(\omega_s)]$$

(2)

Where,

R_A is extraterrestrial radiation [MJ m-2 day-1],
G_{SC} is solar constant = 0.0820 MJ m-2 min-1,
d_r is the inverse relative distance Earth-Sun,
ω_s is sunset hour angle [rad],
φ is latitude [rad] and
δ is solar declination [rad].

Valiantzas' R_S formula based on T and RH (Val Rs [T & RH])

Hargreaves' model for estimating the solar radiation as a function of RH (Hargreaves and Allen, 2003) is given as follows:

$$R_S \propto (1 - {}^{RH}/_{100})^x \quad (3)$$

Where x is an empirical exponent.

By combining the relevant equations, solar radiation (Rs) can be expressed as a function of air temperature and relative humidity. Valiantzas (2017) estimated the regression coefficients via a calibration procedure using a global climate dataset. The dataset included monthly meteorological observations from the FAO CLIMWAT database *(Smith, 1993)*, representing climatic conditions across several countries and a wide range of environments. Based on this analysis, Valiantzas proposed a simplified empirical formulation that estimates solar radiation using temperature and relative humidity data. This modified version of the Hargreaves–Samani model incorporates both temperature and humidity variables, thereby improving the estimation of solar radiation under varying atmospheric conditions.

$$Rs = 0.338 * R_A * (T_{max} - T_{min})^{0.3} * (1 - \frac{RH}{100})^{0.2} \quad (4)$$

In Eq. (4), a value of 1.001 was used instead of 1 to avoid a numerical singularity that occurs when the ratio RH/100 equals 1. Hence, the final form of Valiantzas R_S equation is given as:

$$Rs = 0.338 * R_A * (T_{max} - T_{min})^{0.3} * (1.001 - \frac{RH}{100})^{0.2} \quad (5)$$

Estimation of Reference Evapotranspiration

To calculate this daily water demand, the FAO-56 framework relies on the following comprehensive mathematical relationship:

$$ET_0 = \frac{0.408 * \Delta(R_n - G) + \gamma \frac{900}{[T+273]} * u * (e_s - e_a)}{\Delta + \gamma(1 + 0.34u2)} \quad (6)$$

Where,

ET_0 is reference evapotranspiration [mm day-1],

R_n is net radiation at the crop surface [MJ m-2 day-1],

G is soil heat flux density [MJ m-2 day-1],

T is the mean daily air temperature [°C],

U is wind speed at 2 m height [m s-1],

e_s is saturation vapor pressure [kPa],

e_a is actual vapor pressure [kPa],

$e_s - e_a$ is saturation vapor pressure deficit [kPa],

Δ is the slope of the vapor pressure curve [kPa °C-1],

γ is the psychrometric constant [kPa °C-1]

Comparison of methods

Comparisons were made between the measured solar radiation and the solar radiation derived using the HS Rs [T] model and the Val Rs [T & RH] models separately. In addition, a comparison was made between the reference evapotranspiration estimated from the FAO56-PM equation, using measured Rs values and solar radiation derived from the HS Rs [T] model and the Val Rs [T & RH] models, applied separately

In this study, a comparison is made using simple error analysis and linear regression.

$$Y = S.X \quad (7)$$

Where,

S is the regression coefficient (slope of the line),

Y is the reference measured values of R_S, and

X = corresponding estimates of R_S by the comparison formula.

The indices used in the error analysis are the standard error estimate (SEE) and the long-term average ratio (rt).

$$SEE = \sqrt{\frac{\sum_1^n (Y_i - X_i)^2}{n-1}} \quad (8)$$

$$rt = \frac{X_{av}}{Y_{av}} \quad (9)$$

Where,

Y_i is the reference measured value at i^{th} data point.

X_i is the corresponding estimate by the comparison formula.

n is the total number of observations.

X_{av} and Y_{av} are the long-term average values of the tested models and the reference values, respectively.

RESULTS AND DISCUSSION

Evaluation of Solar Radiation Estimation Models

The primary objective of this study was to evaluate the performance of two empirical models, namely the Hargreaves–Samani (HS) model and the Valiantzas (VAL) model, for estimating solar radiation (Rs) under the climatic conditions of Valapadi, Salem district, Tamil Nadu, India. These models were evaluated using readily available meteorological parameters obtained from the NASA POWER dataset. The performance of these models was assessed by comparing estimated solar radiation with measured data and by examining their influence on FAO-56 Penman–Monteith reference evapotranspiration (ET_0) estimates.

Solar Radiation Estimation

The mean solar radiation values indicate that both the Hargreaves–Samani (HS) model (23.40 MJ m^{-2} day^{-1}) and the Valiantzas (VAL) model (22.27 MJ m^{-2} day^{-1}) slightly underestimate the observed solar radiation (23.48 MJ m^{-2} day^{-1}). The HS model shows only a small underestimation, whereas the VAL model exhibits a larger deviation from the measured values.

The variability of solar radiation estimates was analyzed using the coefficient of variation (CV%). The measured solar radiation showed a CV of 8.06%, while the HS model produced a CV of 8.38%, indicating that the HS estimates closely follow the variability pattern of the measured data. In contrast, the VAL model exhibited a higher CV of 11.44%, indicating greater variability in the radiation estimates it produced.

The higher variability observed in the VAL model may be attributed to the inclusion of relative humidity as an additional parameter in the radiation estimation process. Since relative humidity varies seasonally and responds to atmospheric moisture conditions, it introduces additional fluctuations in the solar radiation estimates, thereby increasing the overall variability of the model output.

Reference Evapotranspiration Estimation

The mean reference evapotranspiration (ET_0) values calculated using the FAO-56 Penman–Monteith method with different radiation inputs are also very similar. The mean ET_0 obtained using measured solar radiation is 5.78 mm day^{-1}, while ET_0 estimated using HS radiation is 5.79 mm day^{-1}, indicating a very close agreement between the two methods. The ET_0 calculated using VAL radiation is slightly lower at 5.58 mm day^{-1}, suggesting a minor underestimation.

The variability of ET_0 estimates also reflects the variability in the radiation inputs. The coefficient of variation for ET_0 calculated using measured radiation is 14.85%, while HS-based ET_0 shows a slightly lower CV of 14.45%, indicating stable evapotranspiration estimates. In contrast, the VAL-based ET_0 exhibits a higher CV of 17.24%, consistent with the greater variability observed in VAL solar radiation estimates.

Overall, the results indicate that the Hargreaves–Samani model provides solar radiation estimates that closely track the variability of measured radiation, yielding evapotranspiration estimates nearly identical to those obtained from measured data. The Valiantzas model, while slightly underestimating radiation and evapotranspiration values, captures greater variability due to the influence of relative humidity. These findings suggest that both models can be used as alternative approaches to estimating evapotranspiration in regions where measured solar radiation data are limited, although the HS model shows slightly better agreement with observed values in the Valapadi region.

Table 1. Summary of Solar Radiation and Reference Evapotranspiration

Index	R_s(Measured) MJ m^{-2} day^{-1}	R_s HS MJ m^{-2} day^{-1}	R_s Val MJ m^{-2} day^{-1}	FAO Et_0 (Measured R_s) mm day^{-1}	FAO Et_0 (HS R_s) mm day^{-1}	FAO Et_0 (Val R_s) mm day^{-1}
Mean	23.48	23.40	22.27	5.78	5.79	5.58
STD	1.89	1.96	2.55	0.86	0.84	0.96
Min	19.30	16.41	16.08	3.77	3.28	3.24
Max	26.05	26.02	26.45	6.91	7.12	6.95
25%	21.78	22.83	19.86	4.93	5.25	4.68
50%	24.46	23.78	23.24	6.16	6.03	5.95
75%	24.80	24.58	24.08	6.51	6.42	6.40

Table 2. Statistics of Solar Radiation and Reference Evapotranspiration

S.No	Comparison Type	R^2	SEE	rt
1	Measured Radiation vs Hargreaves-Samani Radiation	0.37	1.71	1
2	Measured Radiation vs Valiantzas Radiation	0.89	1.57	0.95
3	FAO Eto Measured Radiation vs FAO Eto with Hargreaves-Samani Radiation	0.89	0.28	1.00
4	FAO Eto with Measured Radiation vs FAO Eto with Valiantzas Radiation	0.98	0.26	0.96

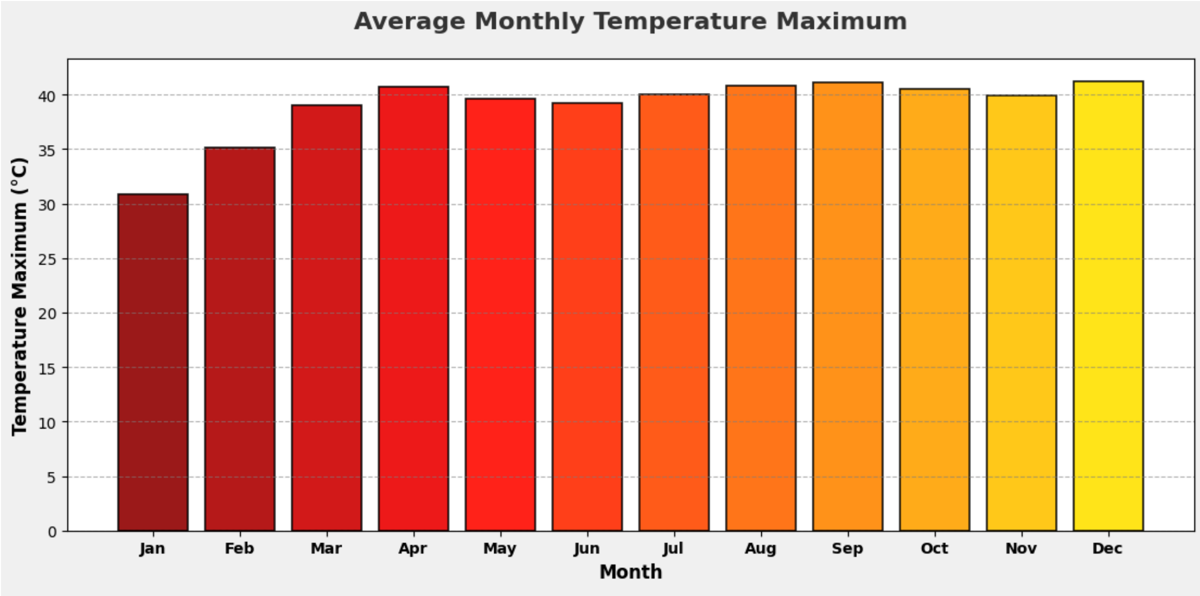


Figure 1: Mean Monthly Maximum Temperature for the study area

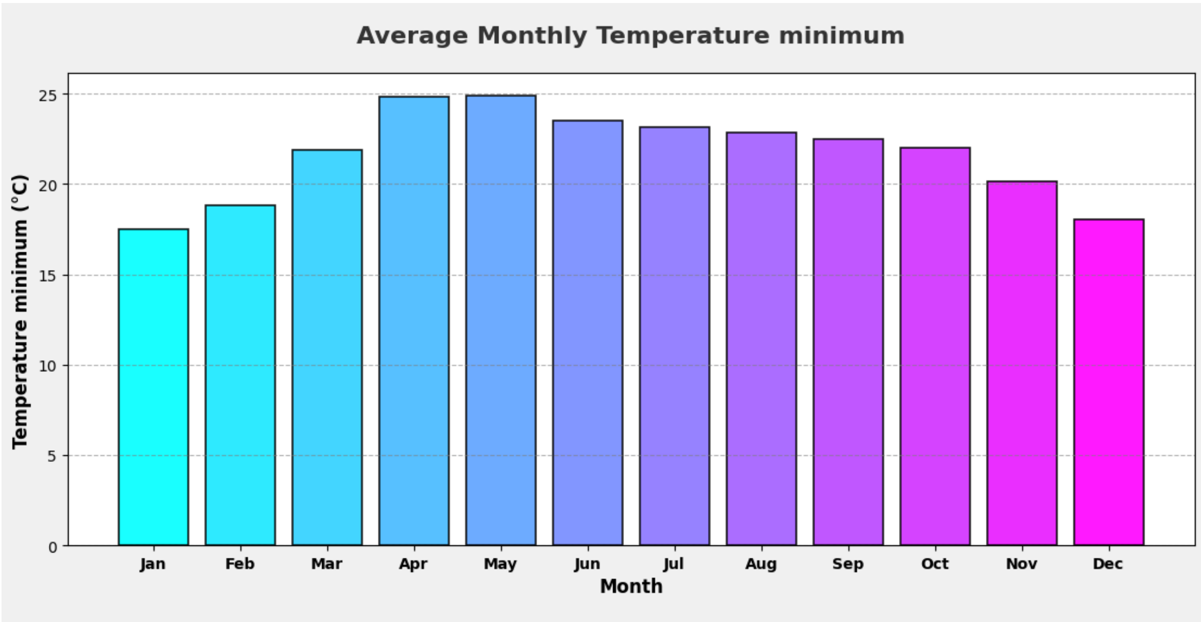


Figure 2: Mean Monthly Minimum Temperature for the study area

Seasonal Pattern of Measured Solar Radiation

The measured solar radiation in the Valapadi region shows a clear seasonal variation throughout the year, influenced primarily by solar geometry, cloud cover, and monsoonal weather conditions. The annual mean measured solar radiation during the study period was 23.48 MJ m^{-2} day^{-1}, with values ranging from 19.30 MJ m^{-2} day^{-1} to 26.05 MJ m^{-2} day^{-1}.

Higher solar radiation levels are typically observed during the summer months (March–June) when the region experiences clear skies and high solar elevation angles. During this period, daily radiation values frequently range between 24.5 and 26.0 MJ m^{-2} day^{-1}, corresponding closely with the upper quartile value of 24.80 MJ m^{-2} day^{-1} and the observed maximum of 26.05 MJ m^{-2} day^{-1}.

In contrast, solar radiation decreases during the monsoon season (July–October) due to increased cloud cover, atmospheric moisture, and rainfall associated with southwest and northeast monsoon systems. During this period, radiation values generally fall within the range of 21.5 to 23.0 MJ m^{-2} day^{-1}, with a lower quartile of 21.78 MJ m^{-2} day^{-1}.

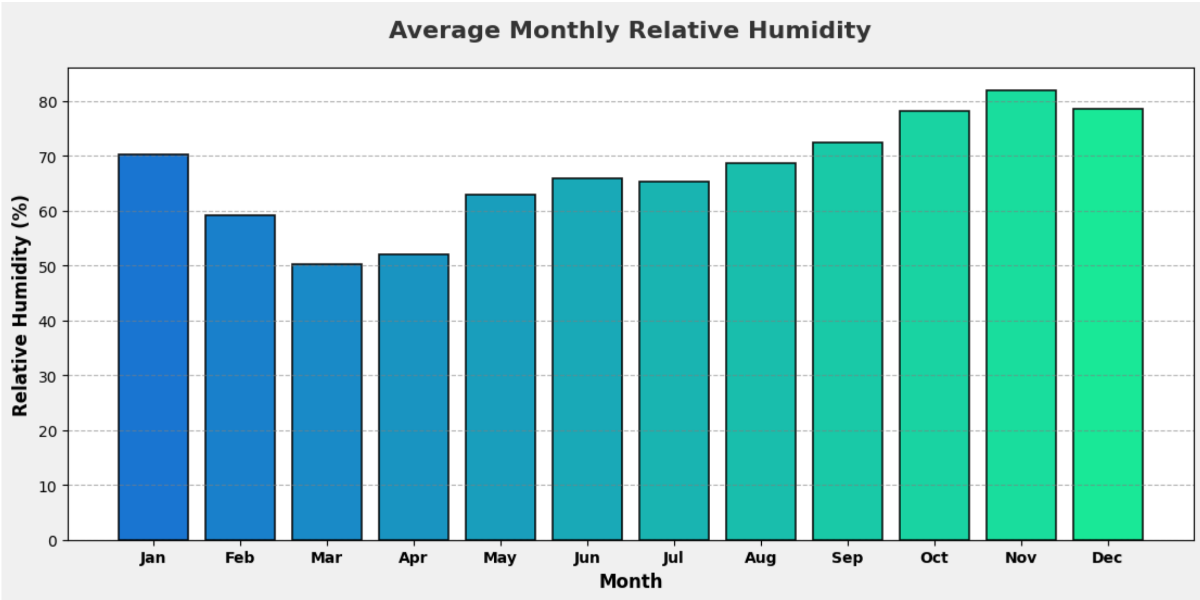


Figure 3: Mean Monthly Relative Humidity for the study area

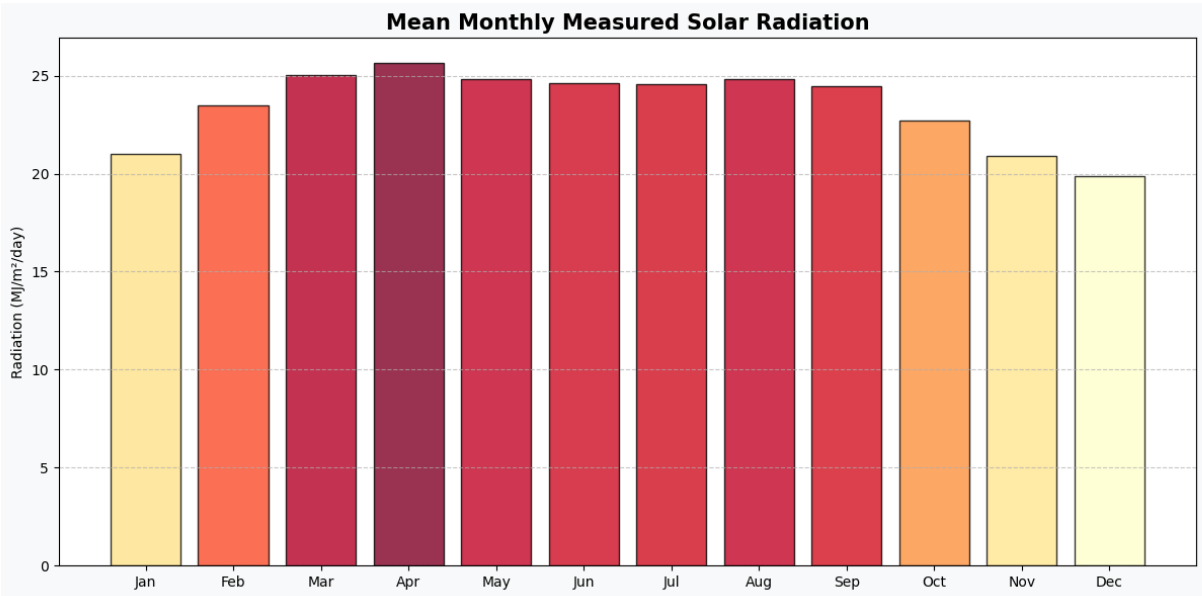


Figure 4: Mean Monthly Measured Solar Radiation for the study area

During the winter season (November–February), solar radiation gradually increases again as cloud cover decreases and atmospheric conditions stabilize. Radiation values during this period generally range from 23.0 to 24.5 MJ m^{-2} day^{-1}, close to the median of 24.46 MJ m^{-2} day^{-1}.

Overall, the seasonal distribution of measured solar radiation in Valapadi shows higher radiation in summer, moderate levels in winter, and relatively lower radiation during the monsoon period. This seasonal variability directly influences evapotranspiration rates and highlights the importance of accurate solar radiation estimation for reliable evapotranspiration modeling in the region.

Daily and Monthly Variation of Reference Evapotranspiration (ET_0)

The daily variation in reference evapotranspiration (ET_0) in the Valapadi region reflects seasonal changes in solar radiation, air temperature, and atmospheric moisture. Based on the FAO-56 Penman–Monteith method using measured solar radiation, the average daily ET_0 during the study period was 5.78 mm day^{-1}, with values ranging from 3.77 mm day^{-1} to 6.91 mm day^{-1}.

The distribution of ET_0 values indicates moderate variability throughout the year, with a standard deviation of 0.86 mm day⁻¹. The interquartile statistics show that 25% of the ET_0 values were below 4.93 mm day^{-1}, and 75% were below 6.51 mm day^{-1}, indicating that most daily evapotranspiration values fall within this range. The median ET_0 value of 6.16 mm day^{-1} indicates that evapotranspiration demand is relatively high for a significant portion of the year, owing to the warm climatic conditions in the Salem region.

The seasonal variation of ET_0 follows the typical tropical climatic pattern observed in Tamil Nadu. Higher evapotranspiration rates are generally observed during the summer months (March–June) when air temperature and solar radiation are at their peak. During this period, ET_0 values frequently approach the upper range of 6.5 to 6.9 mm day^{-1}, reflecting high atmospheric evaporative demand.

During the monsoon season (July–October), ET_0 values tend to decrease due to increased cloud cover, higher humidity levels, and reduced solar radiation. As a result, evapotranspiration values typically fall within the range of 5.0 to 5.8 mm day^{-1} during this period.

The winter season (November–February) shows the lowest evapotranspiration values due to relatively lower temperatures and reduced solar radiation. During this period, ET_0 values may decrease to approximately 3.8–5.0 mm day^{-1}, which corresponds closely with the observed minimum value of 3.77 mm day^{-1}.

The monthly ET_0 pattern shows a gradual increase from winter to summer, reaching maximum levels during the pre-monsoon period, followed by a decline during the monsoon months. This seasonal trend is consistent with the observed variations in solar radiation and temperature in the Valapadi region. Overall, the results indicate that evapotranspiration demand remains relatively high throughout the year, emphasizing the importance of accurate ET_0 estimation for irrigation management and water resource planning in the region.

Comparison of Measured Solar Radiation with Hargreaves–Samani and Valiantzas Models

The performance of the Hargreaves–Samani (HS) and Valiantzas (VAL) models for estimating solar radiation (Rs) was evaluated by comparing estimated values with measured solar radiation data for the Valapadi region. The comparison was carried out using statistical indicators including the coefficient of determination (R^2), standard error of estimate (SEE), and ratio statistic (rt).

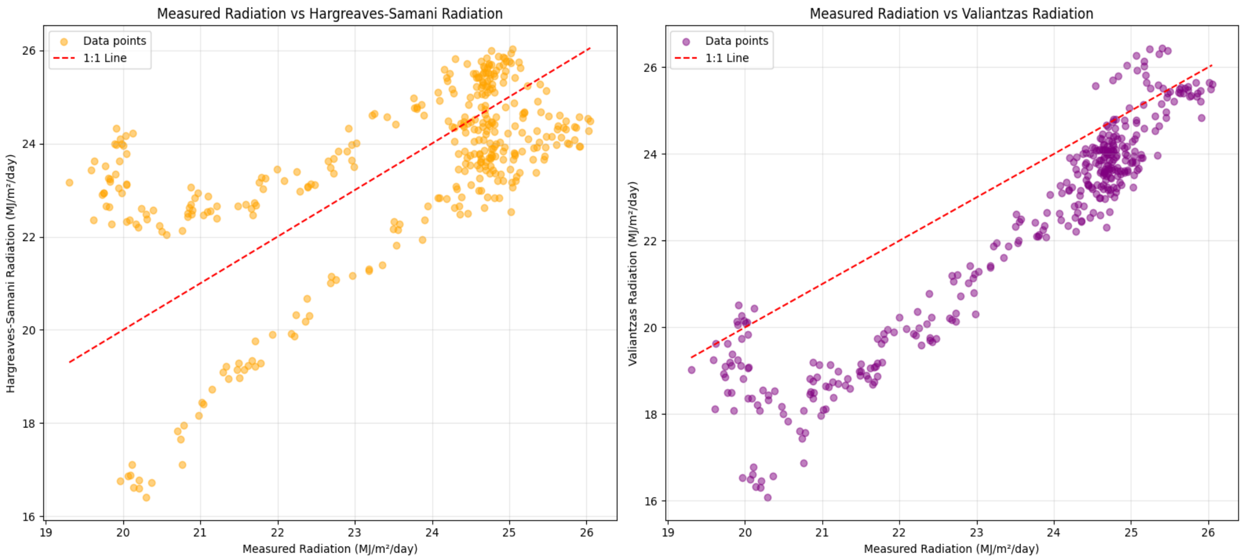
The measured solar radiation during the study period had a mean of 23.48 MJ m^{-2} day^{-1}, a standard deviation of 1.89 MJ m^{-2} day^{-1}, and values ranging from 19.30 to 26.05 MJ m^{-2} day^{-1}. The HS model produced a mean radiation estimate of 23.40 MJ m^{-2} day^{-1}, which is very close to the measured mean value, indicating a minimal mean deviation of approximately 0.34%. The VAL model produced a slightly lower mean radiation value of 22.27 MJ m^{-2} day^{-1}, corresponding to an underestimation of approximately 5.15% compared with the measured radiation.

In terms of variability, the HS model exhibited a standard deviation of 1.96 MJ m^{-2} day^{-1}, comparable to that observed in the measured radiation data. In contrast, the VAL model showed higher variability, with a standard deviation of 2.55 MJ m^{-2} day^{-1}, indicating greater sensitivity to meteorological inputs, such as relative humidity, included in the model formulation.

The statistical performance indicators further highlight differences in model performance. The comparison between measured radiation and HS-estimated radiation produced a coefficient of determination (R^2) of 0.3697, indicating a relatively weak linear correlation between the two datasets. The standard error of estimate (SEE) for the HS model was 1.71 MJ m^{-2} day^{-1}, indicating a moderate deviation of the estimated values from the observed radiation. However, the ratio statistic (rt) of 0.9964 indicates that the HS model reproduces the overall magnitude of solar radiation very closely to the measured values.

In contrast, the Valiantzas model demonstrated a much stronger relationship with measured radiation, with an R^2 of 0.8874, indicating a high degree of correlation between estimated and observed radiation. The SEE value of 1.57 MJ m^{-2} day^{-1} is slightly lower than that of the HS model, suggesting improved predictive accuracy. The rt value of 0.9483 indicates a small systematic underestimation of solar radiation by the VAL model.

Overall, the results indicate that while the Hargreaves–Samani model reproduces the mean magnitude of solar radiation very closely, it shows weaker correlation with measured radiation values. In contrast, the Valiantzas model demonstrates a significantly stronger correlation with measured radiation and lower prediction error, although it slightly underestimates the mean radiation levels. These findings suggest that including relative humidity in the Valiantzas model improves its ability to capture variability in solar radiation under the climatic conditions of the Valapadi region.



5a) **5b)**

Figure 5a – 5b: Comparison of Daily Solar Radiation Estimated by Hargreaves-Samani and Valiantzas' Model Versus Measured Solar Radiation for the study area

FAO Reference Evapotranspiration (ET_0) Using Measured, HS, and Valiantzas Radiation

Reference evapotranspiration (ET_0) for the study area was estimated using the FAO-56 Penman–Monteith method with three different solar radiation inputs: measured solar radiation (Rs), Hargreaves–Samani estimated radiation (HS Rs), and Valiantzas estimated radiation (Val Rs). The ET_0 estimates were compared to evaluate the impact of radiation estimation models on evapotranspiration calculations.

The mean ET_0 calculated using measured solar radiation was 5.78 mm day^{-1}, while the ET_0 estimated using HS-derived radiation was 5.79 mm day^{-1}, indicating an almost identical average evapotranspiration estimate between the two approaches. In contrast, the ET_0 estimated using Valiantzas radiation was slightly lower at 5.58 mm day^{-1}, indicating a small underestimation relative to the measured radiation-based ET_0.

The variability of ET_0 estimates was evaluated using the standard deviation and coefficient of variation (CV). The ET_0 derived from measured radiation exhibited a standard deviation of 0.86 mm day^{-1} and a CV of 14.85%, indicating moderate variability in evapotranspiration demand. The HS-based ET_0 showed a similar variability with a standard deviation of 0.84 mm day^{-1} and a CV of 14.45%, suggesting that the HS model closely reproduces the variability observed in the measured radiation-based ET_0 estimates. The VAL-based ET_0 exhibited slightly higher variability, with a standard deviation of 0.96 mm day^{-1} and a CV of 17.24%, reflecting the greater variability introduced by radiation estimates from the Valiantzas model.

Statistical comparison further confirms the strong agreement between the evapotranspiration estimates derived from measured and model-estimated radiation. The relationship between measured radiation-based ET_0 and HS radiation-based ET_0 showed a coefficient of determination (R^2) of 0.8936, indicating a strong correlation between the two datasets. The standard error of estimate (SEE) was 0.2818 mm day^{-1}, and the ratio statistic (rt) was 1.0014, indicating that the HS model reproduces ET_0 values almost identical to those obtained using measured radiation.

Similarly, the comparison between measured radiation-based ET_0 and VAL radiation-based ET_0 showed an even stronger relationship with an R^2 value of 0.9821, indicating excellent agreement between the two datasets. The SEE value was 0.2593 mm day⁻¹, and the rt value of 0.9648 indicates a slight underestimation of ET_0 when using Valiantzas radiation.

Overall, the results demonstrate that both the Hargreaves–Samanian and Valiantzas radiation models can be effectively used within the FAO-56 Penman–Monteith framework for estimating reference evapotranspiration in the Valapadi region. While the HS model reproduces ET_0 magnitudes very closely to those obtained using measured radiation, the Valiantzas model shows stronger statistical correlation with measured ET_0 values, indicating its ability to better capture radiation variability under the climatic conditions of the study area.

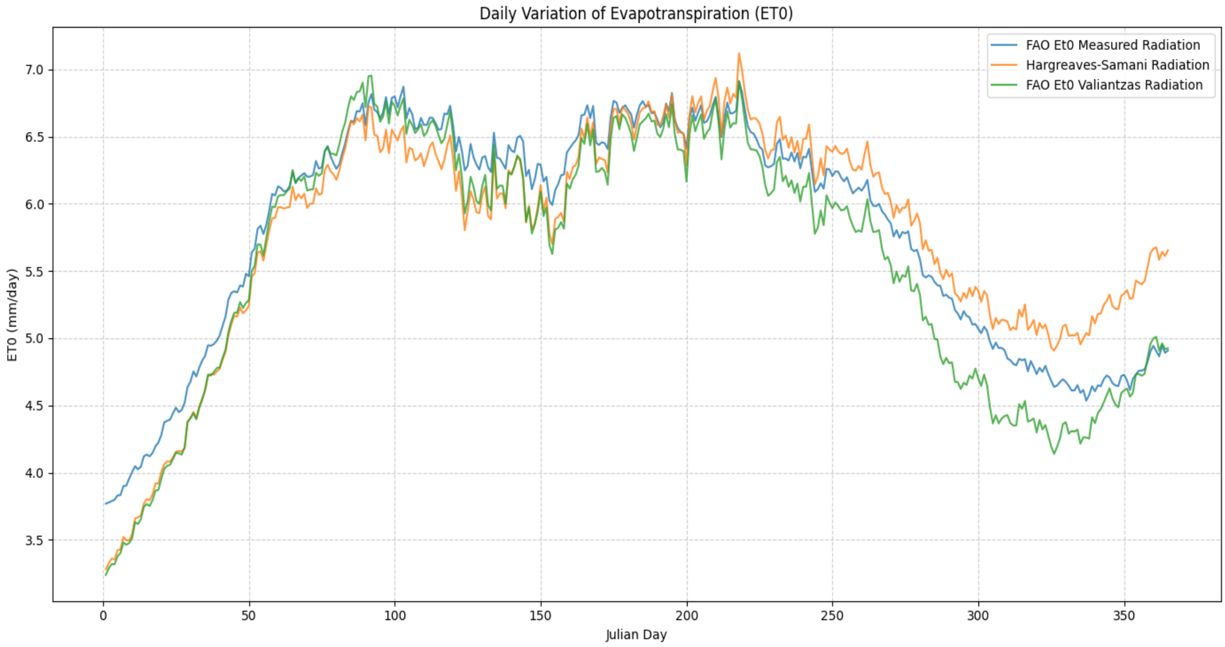


Figure 6: Comparison of FAO-56 ET_0 calculated using measured, HS, and Valiantzas radiation in the study area.

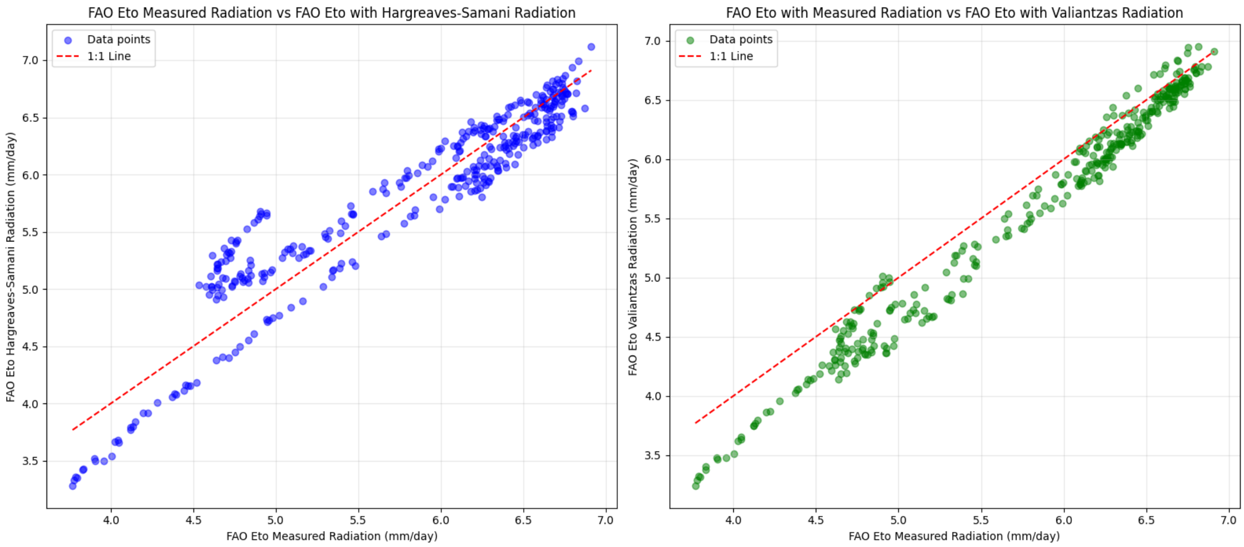


Figure 7a – 7b: Comparison of daily FAO ET_0 estimated by substituting measured and Solar Radiation obtained from the Hargreaves–Samani's Model and Valiantzas' Model

CONCLUSION:

This study evaluated the performance of the Hargreaves–Samani (HS) and Valiantzas (VAL) solar radiation estimation models for estimating reference evapotranspiration using the FAO-56 Penman–Monteith (PM) method in the Valapadi region of Salem district, Tamil Nadu. The analysis was conducted using 25 years of meteorological data (2000–2025) obtained from the NASA POWER database.

The results indicate that both HS and VAL models can reasonably estimate solar radiation under the climatic conditions of the study area. The HS model produced a mean solar radiation of 23.40 MJ m^{-2} day^{-1}, which is very close to the measured mean of 23.48 MJ m^{-2} day^{-1}, whereas the VAL model slightly underestimated radiation, with a mean of 22.27 MJ m^{-2} day^{-1}. Statistical evaluation showed that the VAL model had a stronger correlation with measured radiation (R^2 = 0.887), whereas the HS model exhibited a lower correlation (R^2 = 0.369) but reproduced the overall magnitude of radiation more closely.

When incorporated into the FAO-56 Penman–Monteith equation, both radiation models produced evapotranspiration estimates comparable to those obtained using measured radiation. The mean ET_0 calculated using measured radiation was 5.78 mm day^{-1}, while HS-based ET_0 was 5.79 mm day^{-1}, and VAL-based ET_0 was 5.58 mm day^{-1}. The HS model showed very close agreement with measured ET_0 values (R^2 = 0.894, rt ≈ 1.001), indicating minimal bias. The VAL model demonstrated an even stronger statistical relationship with measured ET_0 (R^2 = 0.982) but showed a slight tendency to underestimate evapotranspiration.

Overall, the findings suggest that both HS and VAL radiation estimation models can serve as effective alternatives for evapotranspiration estimation when measured solar radiation data are unavailable. However, the Hargreaves–Samani model provides ET_0 estimates that are very close to measured values, whereas the Valiantzas model captures radiation variability more effectively by including relative humidity. These results highlight the practical applicability of simplified radiation models for estimating evapotranspiration in data-limited agricultural regions such as Valapadi, Salem, thereby supporting improved irrigation planning and water resource management.

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Conflict of Interests

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Ethics Statement:

Ethical approval was not required for this study because the research was based solely on publicly available meteorological data obtained from the NASA POWER database. The study did not involve human participants, animals, or any experimental procedures requiring ethical clearance.

Originality and Plagiarism:

The authors declare that this manuscript is an original work and has not been published previously, either in whole or in part, in any other journal or publication. All sources of information used in the study have been properly cited and acknowledged. The authors confirm that the manuscript is free from plagiarism and complies with the ethical standards of scientific publishing.

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All authors have read and approved the final version of the manuscript and consent to its publication in the journal. The authors confirm that the work is original and has not been published elsewhere, nor is it under consideration for publication in any other journal.

Competing Interests:

The authors declare that they have no known competing financial interests, personal relationships, or other conflicts of interest that could have appeared to influence the work reported in this manuscript.

Data Availability:

The data supporting the findings of this study are derived from the NASA POWER (Prediction of Worldwide Energy Resources) database and are included within the manuscript in summarized form. Additional datasets and analysis files used during the current study are available from the corresponding author upon reasonable request.

Author Contributions:

Ragul Gowtham H. conceived and designed the study, collected and analysed the meteorological data, performed the evapotranspiration and solar radiation model evaluations, interpreted the results, and prepared the original manuscript draft. A. Anto Rashwin contributed to the research methodology, data analysis, review of the results, and manuscript editing. J. Ramachandran provided technical guidance on evapotranspiration modelling, statistical analysis, and critically reviewed the manuscript. S.K. Raj Kishore contributed to the study design, interpretation of findings, supervision of the research work, and final manuscript review and approval. All authors read and approved the final manuscript.

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