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ESTIMATION OF REFERENCE EVAPOTRANSPIRATION USING EMPIRICAL METHODS AND CROPWAT 8.0 MODEL FOR THE SANGLI DISTRICT MAHARASHTRA INDIA

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ABSTRACT

Efficient water resource management is critical for optimizing agricultural productivity, especially in water-scarce regions. Reference evapotranspiration (ET_0) serves as a key parameter for estimating crop water requirements and improving irrigation scheduling. This study estimates ET_0 for Sangli district, Maharashtra, using fourteen empirical methods and the CROPWAT 8.0 model, which employs the FAO-recommended Penman-Monteith equation. Historical meteorological data, including air temperature, relative humidity, wind speed, solar radiation, and precipitation, were collected and analyzed. The empirical methods evaluated include Stephens-Stewart, Hargreaves-Samani, Jensen-Haise, Schendel, Abtew, and others. Their performance was assessed based on regression coefficients (R^2), slope, and intercept values against the Penman-Monteith estimates.

The study results indicate that all fourteen empirical methods provided reasonable ET_0 estimates, though with significant variations. Among them, the Schendel method demonstrated the highest accuracy, with a slope of 1.5388 and an intercept of -0.5799, closely matching the Penman-Monteith estimates. The Hargreaves-Samani method performed well, yielding a slope of 0.8663 and an intercept of -0.214. The Jensen-Haise method exhibited the highest regression coefficient, confirming its predictive reliability. Other methods such as Temperature Radiation (slope = 0.2970), McGuinness and Bordne (slope = 0.2616), and Global Radiation (slope = 0.1149) showed varying degrees of accuracy. The regression analysis further confirmed that empirical methods can serve as viable alternatives when complete meteorological data is unavailable.

The findings emphasize the importance of selecting appropriate ET_0 estimation methods based on regional climatic conditions to ensure accurate irrigation planning. The study also underscores the effectiveness of the CROPWAT 8.0 model for precise crop water requirement estimation. Future research should explore integrating remote sensing data and machine learning techniques to enhance ET_0 prediction accuracy and improve water resource management strategies in arid and semi-arid regions.
***Keywords*:** Reference evapotranspiration, CROPWAT 8.0, empirical methods, Penman-Monteith, water resource management.

Introduction

Water is a fundamental resource for sustaining life, ecosystems, and agricultural productivity. With the rapid growth of population and economic development, water availability and distribution have become critical concerns globally. India, one of the most populous countries, is expected to witness a stabilization of its population around 1640 million by

2050. Consequently, the gross per capita water availability is projected to decline from 1820 m³/yr in 2001 to approximately 1140 m³/yr by 2050 (CWC, 2019). The total estimated water demand for various sectors is expected to reach 1450 km³/yr, surpassing the current utilizable water potential of 1122 km³/yr. This scenario underscores the urgent need to develop and implement sustainable water resource management strategies, including augmentation through non-conventional sources, conservation techniques, and efficient irrigation planning (Steduto *et al.,* 2012).

Agriculture remains the largest consumer of freshwater resources, with irrigation accounting for nearly 80% of total water withdrawals in India (Jensen *et al.,* 1990; Abdullah and Malek, 2016). The expansion and modernization of irrigation infrastructure have become imperative to ensure food security and economic stability. However, water scarcity remains a limiting factor in the expansion of irrigated agriculture. Efficient irrigation planning necessitates accurate estimation of crop water requirements, primarily governed by evapotranspiration (ET), which serves as a crucial parameter in hydrological and agricultural studies. Evapotranspiration integrates both evaporation from soil and plant transpiration, making it a pivotal factor influencing runoff, irrigation scheduling, and soil moisture dynamics (Shuttleworth, 1993; Wang *et al.,* 2007). Understanding and quantifying ET is essential for water resource planning, irrigation system design, and climate change impact assessments. (Banik *et al.,* 2016)

Direct measurement of ET at a large scale is challenging due to the need for sophisticated instrumentation, extensive fieldwork, and significant financial investments (Allen *et al.,* 1998; Subedi & Chávez, 2015). As a result, numerous empirical models have been developed to estimate ET using meteorological parameters such as temperature, relative humidity, solar radiation, wind speed, and atmospheric pressure. Among these, the FAO Penman-Monteith method is widely recognized as the most accurate and reliable approach for estimating reference evapotranspiration (ET_0) under diverse climatic conditions (Allen *et al.,* 1998). Several computational tools, including CROPWAT (Smith, 1992; Bouraima *et al.,* 2015) and CRIWAR, utilize the Penman-Monteith equation to facilitate irrigation planning and water management strategies. In regions facing water stress, the selection of an appropriate ET estimation method plays a pivotal role in optimizing irrigation scheduling and minimizing water losses (ME, J. 1990; Hargreaves & Samani, 1985).

The state of Maharashtra, particularly the Sangli district, is experiencing increasing pressure on its groundwater resources due to excessive extraction and erratic monsoonal rainfall. Groundwater depletion, coupled with the rising demand for irrigation, necessitates the adoption of precise irrigation scheduling techniques. Irrigation scheduling methods are broadly categorized into soil-based, plant-based, and meteorologically-based approaches. Among these, plant-based monitoring is gaining prominence due to its ability to integrate soil moisture status with atmospheric demand, thereby providing real-time feedback for irrigation management. Since crop evapotranspiration (ETc) directly influences irrigation requirements, its accurate estimation is crucial for optimizing water use efficiency. (Singh *et al.,* 2011; Kumar *et al.,* 2012)

In the present study, reference evapotranspiration (ET_0) for Sangli district was estimated using fourteen empirical methods and compared with the FAO Penman-Monteith model via CROPWAT 8.0. (Cai *et al.,* 2007; Vozhehova *et al.,* 2018)

Materials and Methods

Description of study area

The study area was Sangli district lies between 16°.45' and 17°.33' Northern latitude and 73.41' and 75.41' Eastern longitude. The district is bounded by Satara district on north western side. Southern is bordered by Belgaum and Bijapur district of Karnataka state at centres and east Kolhapur district and Ratnagiri district lay on West of Sangli district. The total area of the district 8601.5 sq.km. (Veer *et al.,* 2024)

The study was conducted under the region's specific agro-climatic conditions, where the average air temperature was 26–27°C, with maximum and minimum temperatures of 35–38°C and 10–12°C, respectively. The average relative humidity ranged between 50–80%, and the wind speed varied from 6–10 km/hr. The annual precipitation in the region was observed to be 500–700 mm.

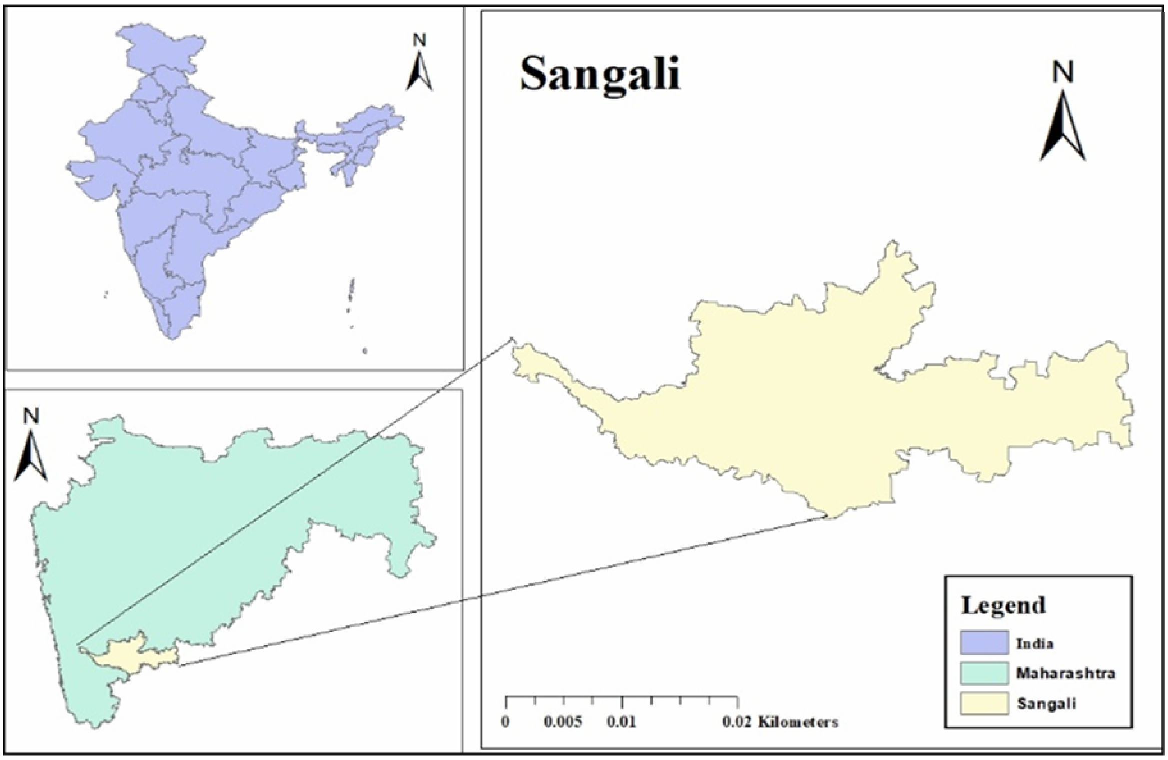

Fig. 1 : Location map of study area

Data set used

Climate data for Sangli district were obtained from the India Meteorological Department, and key meteorological parameters were analysed to support the assessment of reference evapotranspiration (ET_0). The calculated parameters include the average minimum and maximum air temperatures (°C), average relative humidity (%), wind speed (km/day), sunshine duration (hours), and average solar radiation (W/m²).

Methodology

The methodology of this study comprised two main steps: data collection and estimation of reference evapotranspiration (ET_0). The first step involved collecting weather data for the Sangli district (Fig. 2.1), including monthly observations of air temperature, relative humidity, wind speed, solar radiation, and precipitation. These meteorological parameters were utilized for the calculation of ET_0 using various empirical methods and the CROPWAT 8.0 model, which applies the FAO Penman-Monteith equation as the standard reference method. (Allen *et al.,* 2021) The comparative analysis of different ET estimation methods aimed to determine the most suitable approach for the region's specific agro-climatic conditions.

Empirical Methods for Calculation of Reference Evapotranspiration from Climatic Data

Several empirical methods have been developed for estimating reference evapotranspiration (ET_0) using different climatic parameters such as temperature, relative humidity, wind speed, and solar radiation. The following methods have been considered in this study:

Hargreaves-Samani Method

The Hargreaves-Samani method is a temperature-based empirical approach developed from the Christiansen equation. It simplifies evapotranspiration estimation by eliminating coefficients for wind speed and relative humidity, making it widely applicable under various climatic conditions. (Hargreaves & Samani, 1985) It is expressed as:

$$\mathbf{ETO = 0.0023 \times R_a \times (T_{max} - T_{min})^{0.5} \times (T_{mean} + 17.8)}$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

T_{mean} = Mean temperature (°C)

T_{max} = Maximum temperature (°C)

T_{min} = Minimum temperature (°C)

Ra = Extra-terrestrial radiation (MJ/m²/day)

Hargreaves-Samani Droogers and Allen Method

This method, a modification of the original Hargreaves-Samani approach, is particularly useful when only air temperature data are available. It has been used in irrigation and water resource systems for estimating historical evapotranspiration. (Doorenbos and Pruitt, 1977) The equation is given as:

$$ETO = 0.0025 \times R_a \times (T_{max} - T_{min})^{0.5} \times (Tmean + 16.8)$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

T_{mean} = Mean temperature (°C)

T_{max} = Maximum temperature (°C)

T_{min} = Minimum temperature (°C)

Ra = Extra-terrestrial radiation (MJ/m²/day)

Schendel Method

This method was based on climate parameters such as Temperature and Relative Humidity. The given below equation was suggested by Schendel for reference evapotranspiration.

$$ETO = [((16 \times Tmean) / RH)]$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

T_{mean} = Mean temperature (°C)

RH = Relative Humidity (%)

Global Radiation Method

This method was mainly based on solar radiation. The given below equation was the usual form of the Global radiation equation.

$$ETO = 0.9 + 0.115 \times Rs$$

Where,

ET_0 = Reference evapotranspiration ($mmday^{-1}$)

Rs = solar radiation (MJ/m²/day)

Temperature Radiation Method

This method was based on climate parameters such as solar radiation and mean temperature. The given below equation was the usual form of the Temperature radiation equation.

$$ET_0 = (Rs \times Tmean) / (\lambda \times 56)$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

T_{mean} = Mean temperature (°C)

λ = latent heat of vaporization (MJ/kg)

Rs-Radiation method

This method was mainly based on solar radiation. The given below equation was the usual form of the Rs-Radiation equation.

$$ETo = (-0.611) + 0.149 \times Rs + 0.079 \times Ta$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

Rs = solar radiation (MJ/m²/day)

Ra = Extra-terrestrial radiation (MJ/m²/day)

$Rs = 0.16 \times Ra \times [\ (Tmax - Tmin)^{0.5}]$

Stephens-Stewart method

Stephens and Stewart introduced a radiation method adjusted for mean monthly temperature and calibrated it against 30 months of evapotranspiration data.

This method was called the "Fractional Evaporation-Equivalent of Solar Energy" method by Stephens and Stewart, but it was essentially the same form as the original Jensen and Haise method that has been used frequently under western conditions. The given below equation was suggested by Stephens-Stewart for reference evapotranspiration. (McGuinness and Bordne, 1972)

$$ETO = 0.4047 \times Rs\ [(0.01476 \times Tmean) + 0.0724]$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

Rs = solar radiation (MJ/m²/day)

T_{mean} = Mean temperature (°C)

McGuinness and Bordne Method

This method was based on Climate parameters such as Solar Radiation and mean Temperature. The given below equation was suggested by McGuinness and Bordne for reference evapotranspiration. (McGuinness and Bordne, 1972)

$$ET_0 = (Ra / \lambda) \times [((Tmean + 5)/68)]$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

λ = latent heat of vaporization (MJ/kg)

Ra = Extra-terrestrial radiation (MJ/m²/day)

T_{mean} = Mean temperature (°C)

Abtew Method

The Abtew method (Abtew, 1996) primarily relies on solar radiation and is given as:

$$ET_o = Rs / \lambda$$

Where,

ET_0 = Reference evapotranspiration (mm/day)

λ = latent heat of vaporization (MJ/kg)

Rs = solar radiation (MJ/m²/day)

Regression Analysis

Regression analysis was conducted to establish relationships between estimated and observed ET_0 values.

The Regression coefficient is

$$R^2 = \frac{(n\sum(xy) - (\sum x)(\sum y))^2}{(n\sum(x) - (\sum x)(\sum y)(\sum y))}$$

The Regression coefficient is the constant that presents the rate of change of one variable as a function of changes in the others. It is slope of Regression line. The R^2 value will always lies between 0 to + 1.

CROPWAT model: A Simulation Program on reference evapotranspiration

CROPWAT 8.0 model was a program that uses the Penman-Monteith method for calculating reference evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations.

Reference evapotranspiration (ETO) calculation methodology

ETO/ Climate Data Input and Output

The climate module was selected by clicking on the "Climate / ETO" icon in the module bar located on the left of the main CROPWAT window. The data window opens with the default data type (monthly / decade / daily values); it was possible to quickly change to another data type by using the drop-down menu from the "New" button on the toolbar. The module was primary for data input, requiring information on the meteorological station together with climatic data.

ETO / Climate Data Saving

After checking the data for possible errors, climate/ ET_0 data was saved by selecting the "Save" button on the toolbar or the "File" > "-Save" menu item. It was required to give an appropriate name to the data set which easily be recognized later. In this study, the name Sangli, referring to the climate station of plain region from which data has been taken, were used.

Monthly ETo Penman-Monteith - E:\CROPWAT PROJECT\SANGLI.pen

Country: Location 1 — Station: SANGLI

Altitude: 549 m. — Latitude: 16.85 °N — Longitude: 74.60 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14.3	30.6	48	184	9.5	19.4	4.73
February	15.4	33.1	44	189	10.1	22.0	5.59
March	18.6	36.2	40	216	10.8	25.0	6.99
April	21.6	37.9	44	259	8.9	23.2	7.58
May	22.7	37.4	53	343	8.5	22.6	7.89
June	22.3	31.6	70	391	6.1	18.8	5.63
July	21.6	27.9	80	424	5.4	17.8	4.29
August	21.1	28.0	79	372	5.0	17.1	4.13
September	20.5	29.4	75	297	6.2	18.3	4.50
October	20.1	31.0	63	196	6.5	17.4	4.56
November	17.1	30.1	56	206	5.7	14.7	4.32
December	14.6	29.7	51	206	8.5	17.5	4.54
Average	**19.2**	**31.9**	**59**	**274**	**7.6**	**19.5**	**5.40**

Fig 2 : Climate data for Sangli District

Results and Discussions

This chapter reports the reference evapotranspiration rates estimated using different empirical equations and the CROPWAT model and provides a comparison of the estimated reference evapotranspiration values.

Estimation of reference evapotranspiration using different Empirical methods

The weather data collected from the meteorological department was used to estimate reference evapotranspiration using different empirical methods, as presented in Table 1. It was observed that the highest total reference evapotranspiration was estimated to be 7.7233 mm/year using the Schendel equation, while the lowest total reference evapotranspiration was estimated to be 15.78 mm/year using the Stephens-Stewart equation.

Table 1: Reference evapotranspiration values using different empirical methods

Month	HS	HSD & Allen	Schendel	GR	TR	Rs	Ss	Mc G And Bordne	Abtew
Jan	4.13	4.38	8.59	1.7	1.28	11.68	1.17	2.19	1.65
Feb	4.97	5.24	10.61	1.82	1.6	2.58	1.44	2.61	1.88
March	5.96	6.33	12.8	1.94	2	2.95	1.78	3.16	2.21
April	6.6	7.02	11.88	2.01	2.26	3.17	1.99	3.52	2.26
May	6.29	5.88	8.72	1.97	2.14	3.07	1.89	3.53	2.19
Jun	4.1	4.35	5.23	1.66	1.32	2.37	1.19	3.12	1.56
Jul	3.25	3.44	4.49	1.53	1.02	2.06	0.92	2.96	1.28
Aug	2.62	3.38	4.45	1.54	1.03	2.06	0.94	2.9	1.3
Sep	3.74	3.97	4.7	1.62	1.17	2.2	1.07	2.81	1.47
Oct	4.08	4.34	5.7	1.68	1.3	2.33	1.18	2.67	1.57
Nov	3.95	4.2	7.3	1.65	1.52	2.27	1.14	2.35	1.54
Dec	3.84	4.07	8.21	1.64	1.17	2.17	1.07	2.08	1.5
Average (mm/day)	**4.4608**	**4.7166**	**7.7233**	**1.73**	**1.4842**	**3.2425**	**1.315**	**2.825**	**1.7008**

Estimation of reference evapotranspiration using CROPWAT model

The climate data served as the essential input for the CROPWAT simulation program, which required the following parameters: (a) minimum and maximum temperature, (b) humidity, (c) wind speed, and (d) sunshine hours. The data used for CROPWAT was obtained from the India Meteorological Department, and the average values over all the years were calculated before being input into the CROPWAT model. The climate output obtained from CROPWAT is presented in Table 2.

Table 2 : Reference evapotranspiration of Sangli district obtained CROPWAT model

Month	CROPWAT
Jan	4.73
Feb	5.59
Mar	6.99
Apr	7.58
May	7.89
Jun	5.63
Jul	4.29
Aug	4.13
Sep	4.5
Oct	4.56
Nov	4.32
Dec	4.54

Regression Analysis of Empirical Methods for Reference Evapotranspiration Estimation

Table 3 presents the regression coefficients (R^2) obtained for various empirical methods used to estimate reference evapotranspiration. The Abtew method exhibited the highest R^2 value (0.3377), indicating better agreement with the observed data, followed by the Schendel (0.329) and Hargreaves-Samani Droogers and Allen (0.304) methods. The Global Radiation (0.3182), Rs-Radiation (0.317), and Stephens-Stewart (0.2842) methods also demonstrated moderate correlations. In contrast, the McGuinness and Bordne method showed the lowest R^2 value (0.1126), suggesting a weaker predictive performance.

Table 3 : Values Regression coefficients

Sr. No	Method	Regression Coefficient (R^2)
1.	Hargreaves-Samani	0.2775
2.	Hargreaves-Samani Droogers and Allen	0.304
3.	Schendel	0.329
4.	Global Radiation	0.3182
5.	Temperature Radiation	0.2175
6.	Rs-Radiation	0.317
7.	Stephens-Stewart	0.2842
8.	McGuinness and Bordne	0.1126
9.	Abtew	0.3377

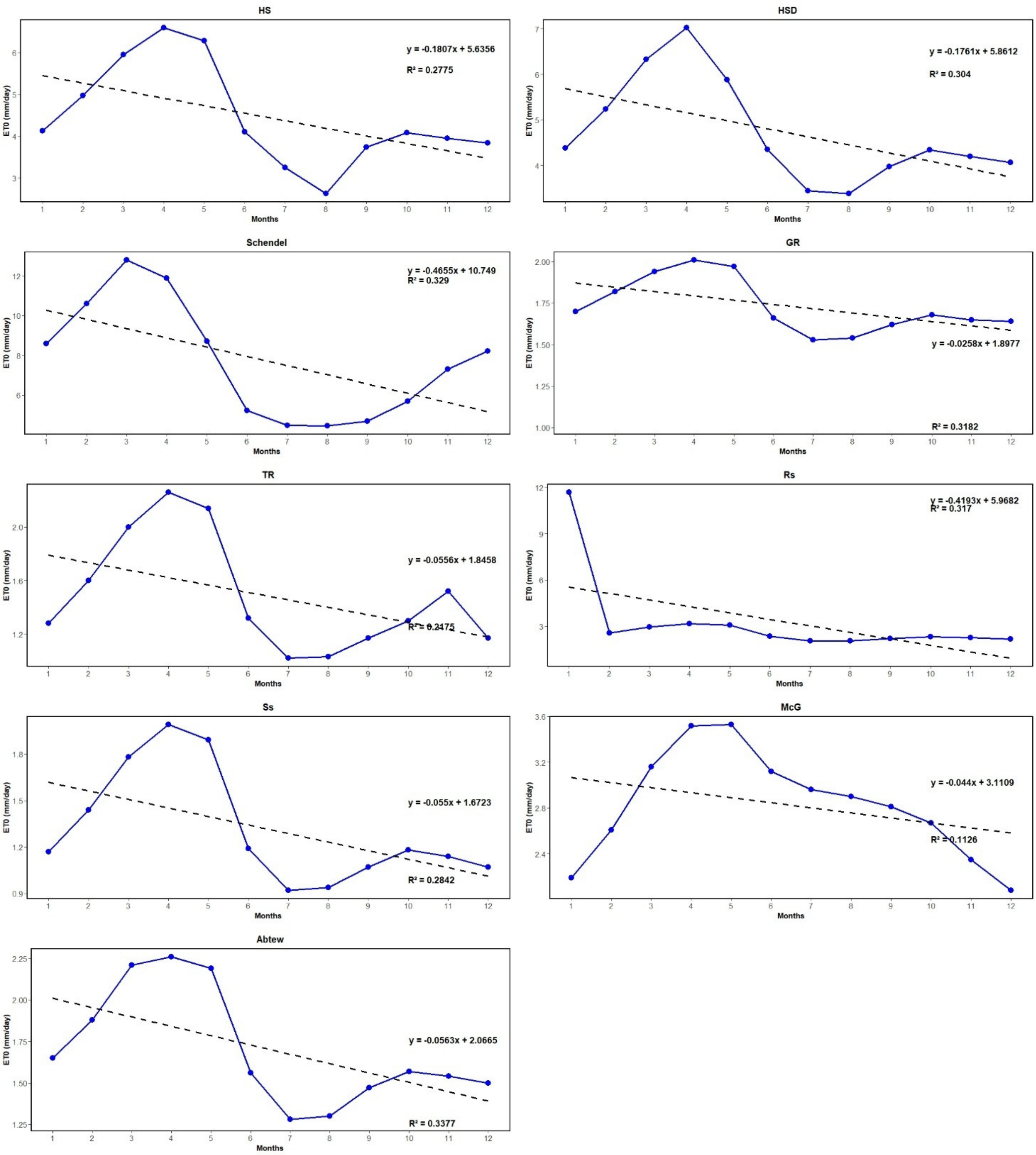

Fig. 3 : Monthly Variation of Reference Evapotranspiration (ET_0) Using Different Empirical Methods with Trend Lines

(HS: Hargreaves-Samani, HSD: Hargreaves-Samani D&A, Schendel: Schendel Method, GR: Global Radiation Method, TR: Temperature Radiation Method, Rs: Rs-Radiation Method, Ss: Stephens-Stewart Method, McG: McGuinness & Bordne Method, Abtew: Abtew Method)

Comparison of Slope and Intercept of the regression equations for Empirical methods

Based on the results presented in Table 4, the Schendel method demonstrated the best performance, yielding a slope ≥ 1, followed by the Hargreaves-Samani, Hargreaves-Samani Droogers and Allen, Temperature Radiation, Stephens-Stewart, McGuinness and Bordne, Abtew, Global Radiation, and Rs-Radiation methods, with respective slope values of 1.5388, 0.8663, 0.7858, 0.2970, 0.2653, 0.2616, 0.2426, 0.1149, and 0.0266.

Furthermore, the Schendel method exhibited the most favorable intercept value, followed by the Hargreaves-Samani, Temperature Radiation, Stephens-Stewart, Abtew, Hargreaves-Samani Droogers and Allen, Global Radiation, McGuinness and Bordne, and Rs-Radiation methods. The corresponding intercept values were -0.5799, -0.214, -0.1189, -0.1169, 0.3914, 1.1099, 1.4130, and 3.8869, respectively.

Table 4: Slope and intercept of the regression equations for empirical method

Sr. No	Methods	Equation form	M (Slope)	C (Intercept)
1.	Hargreaves-Samani	Y=0.8663 x -0.214	0.8663	-0.214
2.	Hargreaves-Samani Droogers and Allen	Y=0.7858 x +0.4763	0.7858	0.4763
3.	Schendel	Y=1.5388 x-0.5799	1.5388	-0.5799
4.	Global Radiation	Y=0.1149 x + 1.1099	0.1149	1.1099
5.	Temperature Radiation	Y=0.297 x- 0.1189	0.2970	-0.1189
6.	Rs-Radiation	Y=0.0266x+3.8869	0.0266	3.8869
7.	Stephens-Stewart	Y=0.2653x – 0.1169	0.2653	-0.1169
8.	McGuinness and Bordne	Y=0.2616x+1.4130	0.2616	1.4130
9.	Abtew	Y=0.2426x + 0.3914	0.2426	0.3914

Conclusion

Based on the findings of this study, the following conclusions were drawn,

1. The analysis demonstrated that using locally determined parameter values, all nine selected empirical methods provided acceptable yearly reference evapotranspiration (ET_0) estimates compared to the Penman-Monteith method for the study region. It is important to note that these nine methods represent the best-performing empirical models selected from their respective categories.
2. Regression analysis between Penman-Monteith ET_0 estimates and the nine empirical methods ranked their performance in the following order: Stephens-Stewart, Hargreaves-Samani, Hargreaves, Temperature Radiation, Hargreaves-Samani Droogers and Allen, Abtew, Global Radiation, Schendel, and McGuinness.
3. Among these methods, the Jensen-Haise method exhibited the highest regression coefficient (R^2), indicating its superior performance in capturing the relationship with Penman-Monteith estimates.
4. Regarding the slope and intercept of the regression equations, the Abtew method demonstrated the best performance, followed by Hargreaves-Samani Droogers and Allen, McGuinness and Bordne, and Global Radiation methods.

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