Comparison of Empirical Methods to Estimated Reference Evapotranspiration

Vivi Fitriani[1], Cahyoadi Bowo[1], Marga Mandala[1], La Gandri[2*]

[1] Soil Science Department, Faculty of Agriculture University Of Jember, Jember, Indonesia.
[2] Environment Science Department, Halu Oleo University, Kendari, Indonesia.
Email*) : lagandri@uho.ac.id

Received:
27 February 2024

Revised:
19 August 2024

Accepted:
2 September 2024

Published:
29 September 2024

DOI:
10.29303/jrpb.v12i2.629

ISSN 2301-8119, e-ISSN 2443-1354

Available at
http://jrpb.unram.ac.id/

Abstract: Evapotranspiration plays an important role in agricultural water management and crop modelling. Estimating reference Evapotranspiration (ETo) using meteorological variables, both theoretical and empirical methods, is highly recommended considering the availability of weather data in several locations. The estimation method recommended as the standard method is FAO Penman Monteith (FAOPM), but due to the limited meteorological data in a region and the difficulty and complexity of FAOPM, it is recommended to use the empirical method which is easier and only requires a few simple meteorological variables. The aim of this research is to compare and evaluated empirical methods for estimating ETo against the FAOPM. The statistical analysis using in this research are RSME, MAE, coefficient Correlation, NSE, Average bias, index of agreement, and confidence index (c). Evaluation for the best models based on statistic analyzed shows that several empirical methods show terrible performance in estimating the monthly average ETo (mm/day), which are Thornthwaite-Mather, Hargraves-Samani, Makkink, Hamon, Romaneko, and Kharauffa. Modified Blaney-Criddle method showed a good performance method, while PM_{AWS} showed very good performance The Turc and Hansen method showed excellent performance with RMSE, MAE, NSE, and C values for the Turc method, are 0.12, 0.11, 0.78, 0.92 respectively, and for the Hansen method are 0.12, 0.1, 0.8, and 0.89 respectively.

Keywords: empirical methods; FAO penman monteith; reference evapotranspiration

INTRODUCTION

Background

The presence of water in the atmosphere, hydrosphere and lithosphere has a significant impact on the earth's ecosystem. Almost the majority of the plant body is composed of water, in fact approaching 95% of the mass of the plant itself. Water in plants at any time expresses its distribution during the plant's growth period, carrying nutrients and providing a moist surface for the gas exchange process during photosynthesis(Huntley, 2023). According to FAO in the book Irrigation Water Management (Brouwer & Heibloem, 1986), In agricultural cultivation, every plant needs soil, water, air and light to grow. Soil provides stability for plants as well as storing water and nutrients for plants which can be taken up through the roots, sunlight provides energy, and air is used for breathing. Unlike others, plants really need water. Roots are very important in the process of transporting water along with nutrients from the soil for plant growth, both water and nutrients have interactions that can have a positive or even negative impact on plants(Li & Kang, 2020). Water sources for plants are rainfall, irrigation, and both. To calculate how much water is plant needs, it can be estimated by knowing how much water is lost from the plant body in the process of transpiration and the soil surface in the form of evaporation. The loss of water through transpiration and evaporation for plants occurs simultaneously, known as evapotranspiration.

Evapotranspiration plays an important role in agricultural water management and crop modeling (Paredes et al., 2021; Valipour & Guzmán, 2022) is an important component in the land water after rainfall in the context of crop irrigation and is a multivariate phenomenon influenced by various hydrological variables including planning and determining irrigation programs and designing irrigation systems(Aydın, 2021). Evapotranspiration provides an overview and information regarding the amount of water lost from vegetation and vegetation tissue, where the type of vegetation has a significant influence on the amount of evapotranspiration. The amount of water from the evapotranspiration process returns to the atmosphere due to the influence of climatic and plant physiological factors (Ahmad Fausan et al., 2021)

FAO Irrigation and drainage paper 56 (Allen et al., 1998) in assessing the rate of Evapotranspiration, there are several things that need to be considered, the influence of climate and plant factors. The evapotranspiration rate calculated based on a reference surface with sufficient water conditions (no shortage) is called reference plant evapotranspiration or reference evapotranspiration (ETo). The concept of reference evapotranspiration (ETo) was developed by Doorenbos & Pruitt, (1977) with the definition of the amount of water used by the presence of vegetation on a surface covered by grass with a uniform height of 8 to 15 cm taking into account water loss through evaporation and transpiration of plants, actively growing, completely cover the ground, and without water limitations. As a reference, The standard grass reference is used in the form of a hypothetical grass and/or alfalfa reference plant "A hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m-1 and an albedo of 0.23, closely resembling the evaporation of an extension surface of green grass of uniform height, actively growing and thoroughly watered" (Ndulue & Ranjan, 2021; L. S. Pereira et al., 2021).

The ETo rate can be measured directly using a lysimeter, but from an economic and equipment perspective this measurement is very expensive and difficult to carry out, therefore estimating ETo using meteorological variables in the form of theoretical or empirical methods is highly recommended considering the availability of weather data in several locations. Estimates of ETo rate using empirical methods have been widely developed in specific locations with climatological (Ghamarnia et al., 2015). Daily meteorological variables used in estimating ETo are temperature, relative humidity, solar radiation, and wind speed at 2m height above the surface (Weiss et al., 2021). Changes in meteorological variables have an impact on changes in the reference evapotranspiration rate, such as decreasing the duration of sunlight and wind speed can reduce the ETo value (Hu et al., 2021) However, all these meteorological variables are not always completely available in an area and can be calculated, therefore there are several empirical methods that use limited variables that can be used to estimate ETo (Gonzalez del Cerro et al., 2021).

Meteorological researchers around the world have developed several empirical equations to calculate the ETo rate, but due to the different conditions in each part of the world, no method has been established perfectly. The development of empirical methods which are quite popular are based on certain categories, that are temperature, radiation, air humidity and mass transfer (Qiu et al., 2019; Thongkao et al., 2022; Weiss et al., 2021). FAO Penman-Monteith (FAO_{PM}) is recommended as the standard method for calculating ETo. This method was chosen because the calculation results are very close to the ETo value of grass at the evaluated location, are physically based, and explicitly combine physiological and aerodynamic parameters. Additionally, this procedure has been developed to estimate missing climate parameters (Ghamarnia et al., 2015). However, not all data required in the FAO_{PM} is available in a certain area. So it is important to explore various empirical methods with simple calculations, and based on the availability of meteorological data in the study area. Many studies have been carried out to evaluate various empirical methods developed throughout the world to find out how accurate these methods are in estimating the ETo rate in the area studied as done by (Althoff et al., 2019; Bin Poyen et al., 2016; Renner et al., 2019; Shirmohammadi-Aliakbarkhani & Saberali, 2020) with FAO_{PM} used as a standard method to evaluate the performance of the methods.

Aims

Several previous studies only evaluated the empirical method against the standard method (FAO PM) by looking at the error values produced and the correlation relationship, so in this research we added an index of agreement, and confidence index to determine the performance of each empirical methods and found the best empirical method(s). The aim of this research is to compare and evaluate 11 empirical methods for estimating ETo against the FAO_{PM} for the Sumbersari district, Jember Regency, East Java. The novelty of this research is we found out the best of an empirical method (s) from the comparation with a simple formula that is most suitable for estimating the average monthly ETo in the study area.

METHOD

Material

The data used in this research are daily meteorological variables obtained from the AWS observation station belonging to the Soil Physics and Conservation Laboratory, Soil Science Department, Faculty of Agriculture, University of Jember, located at 8°9'44''S 113°42'58''E at an altitude of 135 meters above sea level, from July 2022 until June 2023. The meteorological data accordance with the number of sensors on AWS, which are air Temperature (T), air Humidity (RH), solar radiation (Rs), and wind Speed at 2 m above the surface (U_2) its is used as input variables for estimated the rate of Reference Evapotranspiration with empirical method. Data processing using Microsoft Excel 2010.

Methods

ETo estimation uses FAO_{PM} as the standard method and 11 other empirical methods, where based on mass transfer (Kahruffa and Romaneko), temperature basis (Hargreaves-Samani, Thornthwaite, and Hamon), radiation basis (Jensen–Haise, Hansen, Makkink, Priestley–Taylor and Turc), and ETo from AWS itself using the Original Penman Monteith equation. The formulas of the equations are presented in TABLE 1 along with their references.

Table 1. The Formulas of Evapotranspiration Equations

Empirical Methods	Formula	Sources
FAO Penman-Monteith (FAO_{PM})	$ET_o = \frac{0.408\Delta(R_n-G)+\gamma\frac{900}{T+273}u_2(e_s-e_a)}{\Delta+\gamma(1+0.34u_2)}$ (1)	(Allen et al., 1998)
Priesley-Taylor (PT)	$ETo = \alpha\frac{\Delta}{\Delta+\gamma}(R_n - G)$ (2)	(Gong et al., 2021)
Makkink (Mk)	$ETo = 0.61\left[\frac{\Delta}{\Delta+\gamma}\right]Rs - 0.12$ (3)	(Zhang et al., 2018)
Thornthwaite-Matter (Th)	$ETP = 16\left(10\frac{T_m}{I}\right)^a, T_m > 0^oC$ $a = 6.75\ 10^{-7}I^3 - 7.71\ 10^{-5}I^2 + 0.01791\ I + 0.49239$ $I = \sum_{i=1}^{12}(0.2T_m)^{1.514}$ $ETo_{Th} = ETP\left(\frac{N}{12}\right)\left(\frac{ND}{30}\right)$ (4)	(Manuela Portela et al., 2020)
Hargraves-Samani (HS)	$ETo_{HS} = 0.0023\ Ra\ (Tmax - Tmin)^{0.5}(Ta + 17.8)$ (5)	(Althoff et al., 2019; Talebmorad et al., 2020)

Empirical Methods	Formula	Sources
Turc (Tu)	$ETo = 0{,}013 \frac{Ta}{Ta+15} (Rs + 50)\ if\ RH > 50\%$ (6)	(Aydın, 2021; TURC, 1961)
Hansen (Hn)	$ETo = 0.7 \left[\frac{\Delta}{\Delta+\gamma}\right] Rs$ (7)	(Bourletsikas et al., 2018; Hansen, 1984)
Jensen and Haise (JS)	$ETo = Rs(0{,}0252Ta + 0{,}078)$ (8)	(Jensen & Haise, 1963; Sobrinho et al., 2020)
Hamon (Hm)	$ETo = 0{,}55 \left(\left(\frac{D}{12}\right)^2\right) Pt(25{,}4)$ (9) $Pt = (4{,}95e^{0{,}062Ta})/100$	(Bin Poyen et al., 2016)
Romaneko (Rm)	$ETo = 4{,}5 \left(\left[1 + \left(\frac{Ta}{25}\right)\right]^2\right)\left(1 - \left(\frac{ea}{es}\right)\right)$ (10)	(Bin Poyen et al., 2016; Bourletsikas et al., 2018)
Blaney-Criddle (BC)	$ETo = a + b[p(0{,}46Tm + 8{,}13)]$ (11) $a = 0{,}0043RHmin - \frac{n}{N} - 1.41$ $b = 0.88165 + 0.857596\left(\frac{n}{N}\right) - 0.00454(RHmin) + 0.093803(Ud) - 0.00405(RHmin)\left(\frac{n}{N}\right) - 0.00087(RHmin)(Ud)$	(Thongkao et al., 2022)
Kharuffa (Ka)	$ETo = 0.34\ p\ Ta^{1.3}$ (12)	(Bartolomeu & Catine, 2019; Sasireka et al., 2017; Sobrinho et al., 2020)

where

ET_o = Referens Evapotranspiration (mm/day),
R_n = Netto Radiation at surface plant(MJ/m²/day),
Rs = Incoming solar Radiation ($\frac{mm}{day}$),
Ra = Extraxterestial Radiation ($\frac{mm}{day}$),
G = Ground Heat Flux (MJ/m²/day),
T_a or T_m= mean air temperature at 2 m (°C),
T_{min} = minimum Air temperature (°C),
T_{max} = Maximum Air Temperature (°C),
RH = Relative Humidity (%),
u_2 = wind speed at 2 meter (m/s),
e_s = Saturated Water Vapor Pressure (kPa),
e_a = Actual Water Vapor Pressure (kPa),
Δ = slope vapour pressure curve (kPa °C-1),
γ = psychrometric constant (kPa °C-1),
D = possibly hours in day $\left(\frac{x}{12h}\right)$,
Pt = The saturated water vapor density at the daily mean temperature.

Two-Parameter Statistical Analysis

The Statistic analysis used to compare the result of estimation ETo using empirical method against FAO_{PM} as standard ETo estimation. The statistical test used is a two parameters statistical test. ETo from FAO_{PM} as Observed (O) and ETo from Empirical Method as Prediction (P), n as number of sampel

Correlation coefficient (r)

$$\boldsymbol{r} = \frac{\sum_i^n (P_i - \bar{P})(O_i - \bar{O})}{\sqrt{\sum_i^n (P_i - P)^2}\,\sqrt{(O_i - O)^2}} \qquad (13)$$

Where:
O = Value of ETo from FAO_{PM}
P = Value of ETo from Empirical Method
n = Number of sampel
i = Data Number from 1,2,3….n

The correlation coefficient value is used to determine both the spread and distribution of predicted data on observational data with a range of -1 ≤ r≥1. A value of 0 indicates there is no relationship or correlation between predictions and observations, while a value of 1 indicates that the dispersion of predicted data is the same as the distribution of observed data, while A correlation coefficient of -1 describes a perfect negative, or inverse (Shaw et al., 2018).

Nash–Sutcliffe efficiency (NSE)

The NSE index is also called the agreement index, which is used to evaluate a model with a value range of -∞≤NSE≤1. The index is used to see how well the distribution of data (scatterplot) from observations and models fits the 1:1 line, where if NSE = 1 indicates a perfect value from the comparison, NSE = 0 indicates the prediction model has the same accuracy as the average value of the observations, whereas Negative NSE states that the model is unacceptable (Dlouhá et al., 2021).

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O_i})^2}\right] \qquad (14)$$

Where:
O = Value of ETo from FAO_{PM}
P = Value of ETo from Empirical Method
n = Number of sampel
i = Data Number from 1,2,3….n

Root Mean Square Error (RMSE), Mean Absolute Error (MAE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (P_i - O_i)^2}{n}} \qquad (15)$$

$$MAE = \frac{1}{n}\sum_i^n |P_i - O_i| \qquad (16)$$

Where:
O = Value of ETo from FAO_{PM}
P = Value of ETo from Empirical Method
n = Number of sampel
i = Data Number from 1,2,3….n

MAE and RMSE formulas have been widely used to evaluate the accuracy of system (Wang & Lu, 2018). According Harwell, (2019), RMSE represents the variance or standard deviation of parameter estimates, with small deviation values indicating the accuracy of the estimates from the model. MAE is used for optimal parameter selection of a given model, model validation, comparison between several models and evaluation estimates (Karunasingha, 2022).

Average Bias (b) and Index of Agreement (d)

$$b = n^{-1} \sum_{i=1}^{n} (P_i - O_i) \qquad (17)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (|P_i - O| + |O_i - \bar{O}|)^2} \right] \qquad (18)$$

Where:
O = Value of ETo from FAO_{PM}
P = Value of ETo from Empirical Method
n = Number of sampel
i = Data Number from 1,2,3….n

Determining the accuracy of the measurement method is carried out by calculating the average bias and index of agreement (d) (H. R. Pereira et al., 2018). Willmott et al., (2012) using an index of agreement as statistical index of model performance, it is dimensionless which the bound value range is -1.0 to 1.0. The agreement value of 1 indicates a perfect match between Observed and prediction, while -1 to 0 indicates no agreement at all.

Confidence Index (c)

The concordance index (Table 2) is a measure of the effectiveness of the method used to estimate the observed ETo value, taking into distribution of the data relative to the 1:1 line. To analyze the reliability of each method, the confidence index (c) proposed by CAMARGO & SENTELHAS (1997) is used, which is the result of multiplying r and d (c = r.d) (De Melo & Fernandes, 2012).

Table 2. Classification of Confidence Index (c)

"c" Value	Performance of Method
>0,85	Excellent
0.76 to 0,85	Very Good
0.66 to 0.75	Good
0.61 to 0.65	Medium
0.51 to 0.60	Tolerable
0.41 to 0.50	Bad
< 0.41	Terrible

Remarks : (De Melo & Fernandes, 2012; Steidle Neto et al., 2015)

RESULT AND DISCUSSION

Analysis of the reference evapotranspiration rate (ETo) is carried out in 2 stages, the first stage is calculating the ETo rate using the FAO Penman-Monteith (FAOPM), Penman-Monteith (PM), Blaney-Criddle (Bc), Thornthwaite-Matter(Th), Priestley- Taylor (PT), Hargreaves-Samani (HS), Makkink (Mk), Turc(Tu), Hansen(Hn), Jensen & Haise(JH), Hamon(Hm), Romaneko (Rm), and Kharuffa (Ka). For ETo calculations using Penman Monteith (PM_{AWS}) used the ETo value from AWS, while other methods use meteorological data obtained from AWS.

The Second Stage is to compare the results of empirical method calculations with the results of FAOPM calculations as a standardized. Calculation of the daily average ETo is based on the total ETo for a month and then averaged to become a daily average in moth. Estimates of the daily average ETo for each month are carried out because the bias resulting from the daily ETo calculation results can be reduced, thereby allowing for lower error values.

Estimated Of ET_O

Several factors influence the rate of ETo from agricultural cultivated plants, which are plant factors, weather/climate, and soil management, where climate factors have a significant influence such as solar radiation, air temperature, relative humidity, and wind speed. Meteorological data acquired from Automatic Weather Stations used in calculating the ETo rate is one hour data, with a range from July 2022 to June 2023.

Table 3. ETo Estimation in mm/day for monthly Period

Time	*Empirical Methods*												
	FAO_{PM}	**PM_{AWS}**	**PT**	**Th**	**HS**	**Mk**	**Tu**	**Hn**	**JH**	**Hm**	**Rm**	**Ka**	**BC**
Jul'22	2.34	2.25	2.75	3.21	4.02	1.91	2.54	2.33	3.26	3.32	4.63	0.58	2.60
Aug'22	2.81	2.51	3.27	3.51	4.44	2.29	2.94	2.77	3.91	3.50	4.92	0.72	2.91
Sep'22	2.89	2.79	3.42	3.63	4.86	2.32	2.97	2.80	3.99	3.71	4.63	0.69	2.77
Oct'22	2.47	2.35	3.01	3.07	4.81	1.92	2.56	2.34	3.32	3.57	3.25	0.45	2.35
Nov'22	2.32	2.10	2.86	3.18	4.99	1.79	2.42	2.19	3.13	3.52	3.49	0.44	2.29
Dec'22	2.62	2.41	3.19	3.40	5.03	2.07	2.71	2.51	3.59	3.48	3.89	0.54	2.64
Jan'23	2.55	2.35	3.04	3.23	4.96	1.94	2.58	2.37	3.40	3.55	3.90	0.53	2.61
Feb'23	2.28	2.07	2.74	2.88	4.94	1.69	2.31	2.07	2.97	3.60	3.61	0.44	2.33
Mar'23	2.69	2.56	3.22	4.11	5.15	2.11	2.76	2.56	3.69	3.83	4.64	0.62	2.73
Apr'23	2.40	2.28	2.89	3.65	4.66	1.88	2.51	2.29	3.30	3.74	4.09	0.50	2.44
May'23	2.50	2.33	2.97	3.96	4.37	2.06	2.70	2.50	3.58	3.56	5.11	0.64	2.76
Jun'23	2.37	2.23	2.76	3.54	4.07	1.92	2.55	2.34	3.33	3.46	4.86	0.58	2.71
Mean	2.52	2.35	3.01	3.45	4.69	1.99	2.63	2.42	3.46	3.57	4.25	0.56	2.60
min	2.28	2.07	2.74	2.88	4.02	1.69	2.31	2.07	2.97	3.32	3.25	0.44	2.29
max	2.89	2.79	3.42	4.11	5.15	2.32	2.97	2.80	3.99	3.83	5.11	0.72	2.91
Median	2.49	2.34	2.99	3.46	4.84	1.93	2.57	2.36	3.37	3.56	4.36	0.56	2.63
Std. Deviation	0.20	0.20	0.22	0.36	0.38	0.19	0.20	0.22	0.30	0.14	0.62	0.09	0.20
Variance	0.04	0.04	0.05	0.13	0.14	0.04	0.04	0.05	0.09	0.02	0.39	0.01	0.04
N	12	12	12	12	12	12	12	12	12	12	12	12	12

Remarks : Data Analysis, 2023

This data series are converted into daily data and then the average ETo rate is calculated for each month. The Result of monthly periods ET_O estimation from empirical methods and its description show in Table 3. The average ETo rate is calculated for each month, based on 12 months of analyzed data, FAO_{PM} rate estimation results show an average value of 2.52 mm/day, with a minimum value of 2.07 mm/day in February 2023, and a maximum value of 2.89 mm/day in September 2022. From several empirical methods analyzed, it was found that the Kharuffa method gave very low ETo values with a range of 0.44 mm/day to 0.72 mm/day with an average of 0.56 mm/day. Meanwhile, the Hargreaves-Samani empirical method provides a high estimate, with an average of 4.69 mm/day, with a range of ETo rates between 4.02 mm/day found in July 2022 to 5.51 mm/day found in March 2023. The highest average was also found in the Romaneko method with a value of 4.25 mm/day, with the largest ETo estimate found in May 2023 with a value of 5.11 mm/day.

Comparison of empirical methods for estimating ETo against FAO PM

Statistical analysis of two parameters is used to compare the results of ETo rate calculations using the empirical method against the standard FAO Penman-Monteith method, which are NSE, RMSE, Mean Absolute Error (MAE), and the average bias method (b) as well as the evaluation method using r, d, and c. The results of the statistical evaluation of empirical methods for the daily average period for monthly data are presented in Table 4 and Figure 1. Based on the following table 4, it is found that the RMSE value from the comparison of the empirical method with the standard method ranges from 0.12 to 2.20, the smallest RMSE value is produced by Tu and Hn while the highest RMSE is obtained by the HS method. Likewise for MAE, the Tu and Hn methods give the lowest error values, 0.11 and 0.10 respectively, while the highest MAE is obtained by HS which is 2.17. The PMaws and modified BC methods also show low error values, that 0.18 and 0.16 for RMSE, and 0.17 and 0.12 for MAE. The smaller of RMSE and MAE values (when compared with FAO_{PM}) showed a low error rate in the method. A low error value can indicate the accuracy of the empirical method in estimating ETo (based on the estimated ETo value from the FAO_{PM} method).

Based on the average bias value (b) in table 4, several empirical methods such as the PT, Th, HS, JH, Hm, Tu, Rm and BC methods show positive bias values, which means that the method overestimates ETo when compared with FAO_{PM}, Meanwhile, empirical methods that underestimate in estimating ETo (negative b value) are the PM_{AWS}, Mk, Hn, and Ka methods. The smallest average bias value, even positive or negative, was found in the PM_{AWS}, Hn, Tu, and BC methods, this value shows that the ETo value estimated by this method is quite close to the ETo value estimated by FAO_{PM}.

From figure 1 we could see how strong the relationship between each other empirical methods and $FAO_{PM.}$ A Stronger Correlations will be seen from how closely the data points following the red regression line. The R^2 value shows how well the model data fits the linear regression model. The closer the R^2 value is to 1, the better the fit of the model. The highest correlation coefficient was found in the JH, PT, Tu, PM_{aws}, Hn, Mk methods with values of 0.97, 0.97, 0.96, 0.95, 0.95, 0.95 respectively and have a better fit of model, while the lowest correlation coefficient were found in HS, Hm, and Rm with values of 0.25, 0.37, 0.41 respectively.

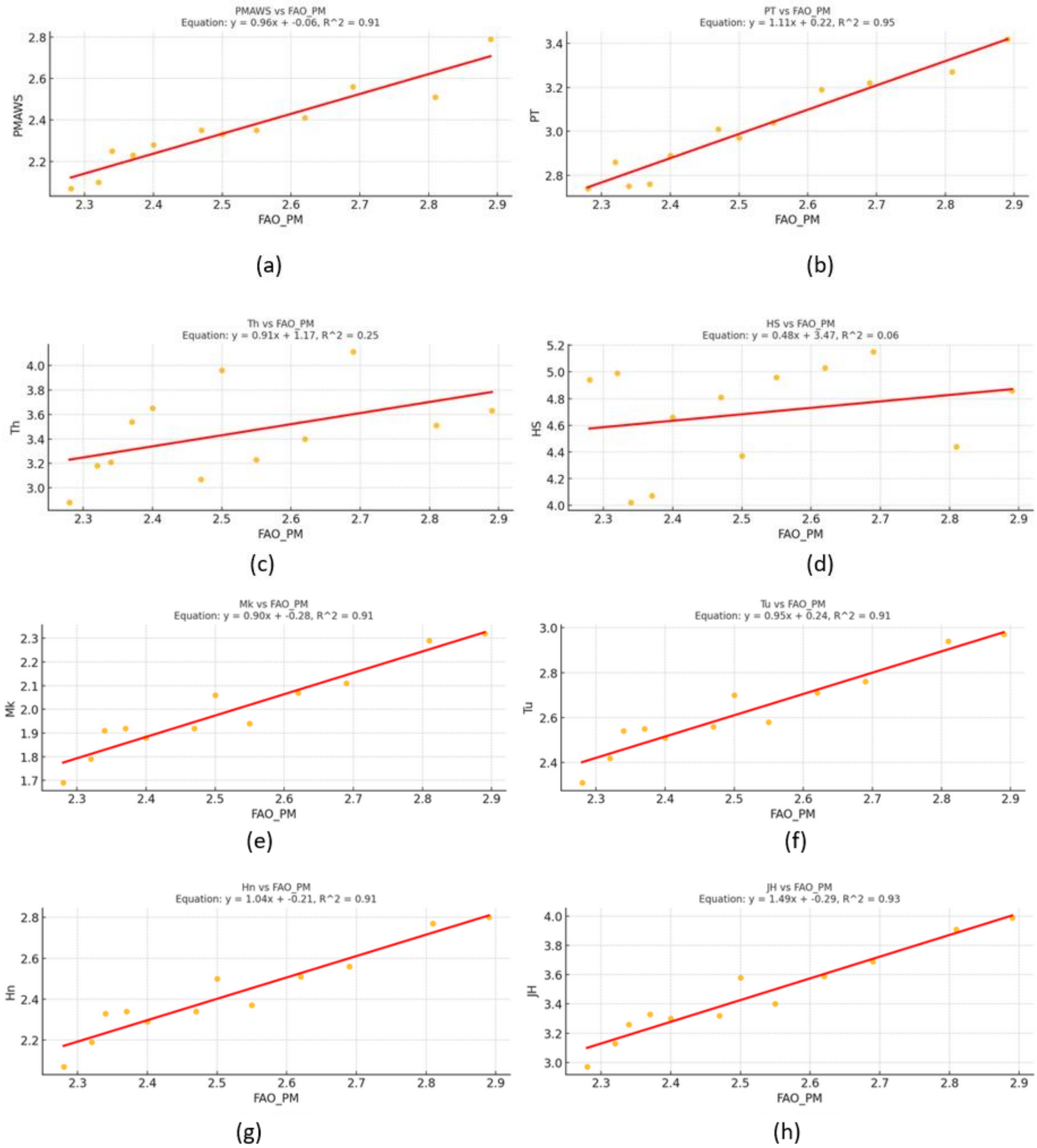
Analysis of Index of Agreements (d) that indicated the model performance show that Tu, Hn, BC and PM_{aws} show great agreement with FAO_{PM} result in estimated ETo with value of 0.96, 0.94, and 0.92 respectively. Ka and Mk showed very low value of **d,** which are 0.01 and 0.06 respectively.

Table 4. Result Of Comparison Empirical Method against FAO_{PM} in estimated ETo

Metode	Performance							
	r	NSE	RMSE	MAE	b	d	c	Classification
PM_{AWS}	0.95	0.53	0.18	0.17	-0.17	0.82	0.78	V. Good
PT	0.97	-5.28	0.66	0.66	0.49	0.65	0.63	Medium
Th	0.5	-35.05	1.58	1.54	0.93	0.36	0.18	Terrible
HS	0.25	-69.31	2.2	2.17	2.17	0.28	0.07	Terrible
Mk	0.95	-3.13	0.53	0.53	-0.53	0.06	0.05	Terrible
Tu	0.96	0.78	0.12	0.11	0.11	0.96	0.92	**Excellent**
Hn	0.95	0.8	0.12	0.1	-0.1	0.94	0.89	**Excellent**
JH	0.97	-11.87	0.94	0.93	0.93	0.54	0.52	Tolerable
Hm	0.37	-11.87	0.94	0.93	1.05	0.54	0.2	Terrible
Rm	0.41	-11.87	0.94	0.93	1.73	0.54	0.22	Terrible
Ka	0.78	-55.03	1.97	1.96	-1.96	0.01	0.01	Terrible
BC	0.73	0.64	0.16	0.12	0.07	0.92	0.68	Good

Remarks: Data Analysis, 2023

Model evaluation based on **r**, **d**, and **c** values shows that several empirical methods show very poor performance (Terrible) in estimating the monthly average ETo (mm/day), which are Thornthwaite-Mather, Hargraves-Samani, Makkink, Hamon, Romaneko, and Kharauffa. Even though the Makkink and Kharauffa methods have a high correlation value **r**, this value is not enough to state the accuracy of the method because the **d** value is found to be very low.



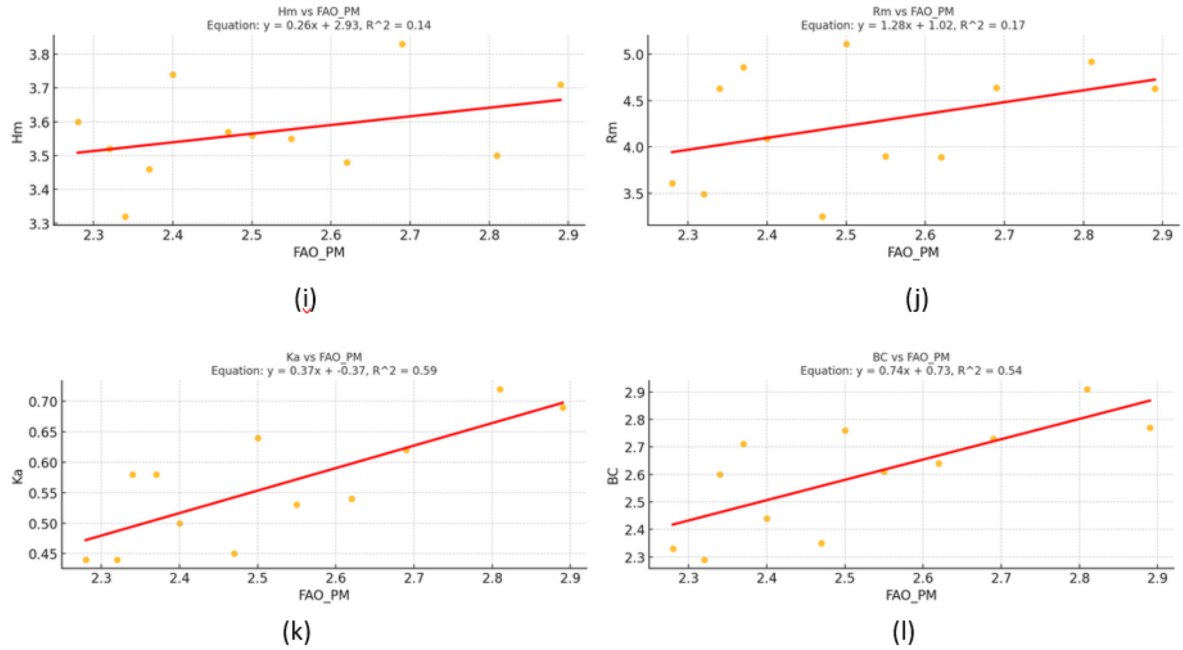


Figure 1. R^2, Slope and Intercep values from the estimated ETo value (mm/day) of the empirical method (x-axis) against the FAO_{PM} standard method (y-axis). (e) Mk vs $FAO_{PM,}$ (f) Tu vs $FAO_{PM,}$ (g) Hn vs FAO_{PM}, (h) JH vs $FAO_{PM,}$ (i) Hm vs FAO_{PM}, (j) Rm vs FAO_{PM}, (k) Ka vs FAO_{PM}, and (l) BC vs FAO_{PM}

DISCUSSION

To calculate the level of data dispersion that is the tendency of values of a variable to scatter away from the mean use standard deviation (SD). Standard deviation is a measurement that is designed to find the disparity between the calculated mean(Ayeni, 2014). In other words, SD indicates how accurately the mean represents sample data(Lee et al., 2015). Based on table 3. ETo value from FAO_{PM} to Blaney-Criddle have a small SD than mean value, its means ETo estimated from empirical methods have good data dispersion. Besides that, several empirical methods that estimate ETo value are overestimated when compared with the standard method (FAO_{PM}) indicated from **b** value, that are Thornthwaite-Mather, Romaneko, Jansen-Haise, and Hargreaves-Samani methods, similar result for Hargreaves-Samani reported by Aydın, (2021), while empirical methods that underestimated ETo are found in the Kharuffa, Hamon, and Makkink methods, this is In line with was reported by Sasireka et al., (2017) that Kharuffa with original method show underestimated when compared with FAO PM. As previously mentioned, NSE and R^2 are used to see the suitability of the data distribution (data spread) in the 1:1 trend plot between the Empirical and FAO PM methods. In table 4, it can be seen that the PM_{AWS}, PT, Tu, Hm, and BC methods have an NSE value range between 0 and 1, this showed the level of accuracy and data distribution is almost similar and in accordance with the estimated ETo value in FAO_{PM}, this finding is in accordance that reported by Bourletsikas et al., (2018), that PT, Tu, and BC showed good NSE values. HS showed very low of R^2, its mean this two method had bad relationship with FAO_{PM}, In other region as Rahuri, that was reported by P. B. JADHAV et al., (2015) that HS showed bad relationship based on low value of R^2 too.

Model evaluation based on **r**, **d**, and **c** values shows that several empirical methods show very poor performance (Terrible) in estimating the monthly average ETo (mm/day), which are Thornthwaite-Mather, Hargraves-Samani, Makkink, Hamon, Romaneko, and Kharauffa, as the findings reported by Manik et al., (2017), that the Makkink method shows poor performance against FAO_{PM} in estimating ETo in Lampung Province, Likewise, HS, Tn, Rm and Ka method was reported by Sasireka et al., (2017) that based on evaluation with FAO PM, this method produces very high errors, so it needs recalibration in order to produce better performance than before. But in other side, the research was conducted by Adlan et al., (2021) at Aceh City were evaluating the ETo empirical method, found that the Makkink and Hargreave-Samani methods had good accuracy compared to the FAO_{PM} and Jansen-Haise methods had good R^2 value but also show very high errors. Makkink and Hargreaves-Samani which used a temperature and solar radiation in estimated ETo rate also presented good acting at North are of Bahia, Brazil that was reported by Oliveira et al., (2010). These differences in findings could be caused by differences in the conditions of each study area, such as topographic conditions, geographical and astronomical location, and also heterogeneous land cover condition (Suwarman et al., 2021), which can influence the local climate in that region, so that one empirical method can work well for that region but may not suitable for other regions, because empirical method developed based on the specific climate of a region.

Based on the model performance evaluation, it was found that the Turc and Hansen method as the best result when compare with FAO_{PM} for estimating monthly average ETo values (mm/day) in Sumbersari District, where this method provides extraordinary performance values (Excellent), this is reinforced by the RMSE, MAE and b findings which show the smallest values, accurate NSE (table 4) and very good data trends against the FAO_{PM} method (Figure 1), Similar results were also reported by Santos et al., (2019) in the study Assessment of empirical methods for estimation of reference evapotranspiration in the Brazilian Savannah, that the Turc method is the best empirical method when meteorological data are not sufficiently available to use the standard FAO_{PM} methods, as line with reported by Araújo Lima et al., (2019), that that Turc is an empirical method that produces the best performance in estimating ETo in the Brazilian region, especially in the equatorial region, where Turc showed low error values and high R^2 (0.96 and 0.97) in the two equatorial regions of Brazil. Reported by Bourletsikas et al., (2018) that Turc can be considered as best performed method to calculation ETo in that study area with term that have a low error like RMSE and MAE. In Indonesia, especially at Nagan Raya District was reports by Adlan et al., (2021) that Turc method in four years observation showed best value of R^2 (0,988) and low error value (RMSE and MAE). With these findings and compared with other research, supports the results obtained in this research that the Turc method is the best empirical method and is recommended for estimating ETo for the Indonesian region, especially in the Sumbersari District as a research area.

Hansen method as one of the excellent performances in estimated ETo in this study area show similarity result with Xystrakis & Matzarakis, (2011), that in Southern Greece, this method was one of the best method with least average error in monthly mean ETo estimate. In other side, Djaman et al., (2017) also reported that Hansen method in semiarid conditions showed good average R^2 value (0,74) but also underestimated ETo and from 10 methods was evaluated, Hansen is in 5th position in high RMSE and MBE error values which are 0.92 and -0.75 respectively. Several method that showed a good result are PM_{AWS} method with very good performance, the Blaney-Criddle method with good performance, Priestly Taylor with medium performance and Jansen Haise with tolerable performance. Blaney-Criddle as temperature base method show good performance and that have been reported by several researchers (Heydari et al., 2014). Rahimikhoob & Hosseinzadeh, (2014) reported that in assessment of BC equation, this method could use in estimated ETo, but for better performance it must be calibrated by adjusting climatic conditions in each area. From that research, after calibrated its was reported that BC showed the Performance improvements. Priestley Taylor showed a medium performance, which was also reported by Itolima & Ify, (2017), that producing the least overestimation and showed a good rank compared with FAO_{PM}. Some methods with medium and tolerable performance showed good enough result evaluation, but if this method need to be used, it must do modifications through calibration so as to improve its performance, this is in line with (Bourletsikas et al., 2018; Hernández-Bedolla et al., 2023; Rahimikhoob & Hosseinzadeh, 2014; Sasireka et al., 2017) where do the modification for the equation from empirical method to improve the method's performance in estimating ETo through calibrating the Constanta with regression analysis. The calibration also can used to improved performance of Turc and Hansen even this method already showed the excellent performance, just to increase the accurate results that represent the study area.

CONCLUSION

The empirical method with excellent performance are Turc and Hansen, very good performance is PM_{AWS}, while good performance is Blaney Criddle, Medium and Tolerable performance are Jansen-Haise and Priestly-Taylor, and terrible performance are Thornthwaite-Mather, Hargrave-Samani, Makkink, Hamon, Romaneko, and Kharauffa. The empirical method recommended for estimating the ETo rate in Sumbersari District are Turc and Hansen method, which are The Turc and Hansen method showed excellent performance with RMSE, MAE, NSE, and C values for the Turc method, are 0.12, 0.11, 0.78, 0.92 respectively, and for the Hansen method, are 0.12, 0.1, 0.8, and 0.89 respectively.

The performance of empirical method can be improved through modification by calibrated the Constanta with large time series data and based on climatic condition of study area. The choice of method can be based on the availability of meteorological data in the study area and simple method.

ACKNOWLEDGMENTS

Acknowledgments to the University of Jember for funding the research, to the Soil Science department and to colleagues who have contributed, so that this research can be completed well. This research was funded by the University of Jember through Beginner Lecturer Research Grant No. 3440/UN25.3.1/LT/2023.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest with any party. The funders had no role in the study design; in the collection, analysis, or interpretation of data; and in script writing

REFERENCES

Adlan, Setiawan, B. I., Arif, C., & Saptomo, S. K. (2021). Evaluation of the Standard Evapotranspiration Rate Estimation Method (ETo) Using the Microsoft Excel Visual Basic Programming Language in Nagan Raya District, Aceh. *Jurnal Teknik Sipil Dan Lingkungan*, *6*(1), 35–48. https://doi.org/10.29244/jsil.6.1.35-48

Ahmad Fausan, Setiawan, B. I., Arif, C., & Saptomo, S. K. (2021). Evaporation and Evapotranspiration Model Analysis Using Mathematical Modeling in Visual Basic in Maros Regency. *Jurnal Teknik Sipil Dan Lingkungan*, *5*(3), 179–196. https://doi.org/10.29244/jsil.5.3.179-196

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* (Vol. 17). FAO - Food and Agriculture Organization of the United Nations. https://www.researchgate.net/publication/235704197

Althoff, D., Santos, R. A. dos, Bazame, H. C., Cunha, F. F. da, & Filgueiras, R. (2019). Improvement of Hargreaves–Samani Reference Evapotranspiration Estimates with Local Calibration. *Water*, *11*(11), 2272. https://doi.org/10.3390/w11112272

Araújo Lima, J. G., Carneiro Viana, P., Sobrinho, J. E., & Chaves Couto, J. P. (2019). COMPARAÇÃO DE MÉTODOS DE ESTIMATIVA DE ETO E ANÁLISE DE SENSIBILIDADE PARA DIFERENTES CLIMAS BRASILEIROS. *IRRIGA*, *24*(3), 538–551. https://doi.org/10.15809/irriga.2019v24n3p538-551

Aydın, Y. (2021). Assessing of evapotranspiration models using limited climatic data in Southeast Anatolian Project Region of Turkey. *PeerJ*, *9*, e11571. https://doi.org/10.7717/peerj.11571

Ayeni, A. (2014). *Empirics of Standard Deviation*. https://doi.org/10.13140/2.1.1444.6729

Bartolomeu, F. T., & Catine, A. C. (2019). Efficiency of empirical methods for reference evapotranspiration estimation in the district of Vilankulo, Mozambique. *International Journal of Water Resources and Environmental Engineering*, *11*(4), 76–82. https://doi.org/10.5897/IJWREE2018.0780

Bin Poyen, Er. F., Kumar Ghosh, A., & Khundu, P. (2016). Review on Different Evapotranspiration Empirical Equations. *International Journal of Advanced Engineering, Management and Science (IJAEMS)*, *2*(3). www.ijaems.com

Bourletsikas, A., Argyrokastritis, I., & Proutsos, N. (2018). Comparative evaluation of 24 reference evapotranspiration equations applied on an evergreen-broadleaved forest. *Hydrology Research*, *49*(4), 1028–1041. https://doi.org/10.2166/nh.2017.232

Brouwer, C., & Heibloem, M. (1986). *Irrigation Water Management Training Manual No. 3: Irrigation Water Needs* (Vol. 3). FAO. https://www.fao.org/3/S2022E/s2022e00.htm#Contents

De Melo, G. L., & Fernandes, A. L. T. (2012). EVALUATION OF EMPIRICAL METHODS TO ESTIMATE REFERENCE EVAPOTRANSPIRATION IN UBERABA, STATE OF MINAS GERAIS, BRAZIL. *Engenharia Agricola, Jaboticabal*, *32*(5), 875–888. https://doi.org/DOI: 10.1590/S0100-69162012000500007

Djaman, K., Koudahe, K., Akinbile, C. O., & Irmak, S. (2017). Evaluation of Eleven Reference Evapotranspiration Models in Semiarid Conditions. *Journal of Water Resource and Protection*, *09*(12), 1469–1490. https://doi.org/10.4236/jwarp.2017.912094

Dlouhá, D., Dubovský, V., & Pospíšil, L. (2021). Optimal Calibration of Evaporation Models against Penman–Monteith Equation. *Water*, *13*(11), 1484. https://doi.org/10.3390/w13111484

Doorenbos, J., & Pruitt, W. O. (1977). *Guidelines for predicting crop water requirements*. Food and Agriculture Organization of the United Nations.

Ghamarnia, H., Mousabeygi, F., Amiri, S., & Amirkhani, D. (2015). Evaluation of a Few Evapotranspiration Models Using Lysimeteric Measurements in a Semi Arid Climate Region. *International Journal of Plant & Soil Science*, *5*(2), 100–109. https://doi.org/10.9734/IJPSS/2015/14320

Gong, X., Qiu, R., Ge, J., Bo, G., Ping, Y., Xin, Q., & Wang, S. (2021). Evapotranspiration partitioning of greenhouse grown tomato using a modified Priestley–Taylor model. *Agricultural Water Management*, *247*, 106709. https://doi.org/10.1016/j.agwat.2020.106709

Gonzalez del Cerro, R. T., Subathra, M. S. P., Manoj Kumar, N., Verrastro, S., & Thomas George, S. (2021). Modelling the daily reference evapotranspiration in semi-arid region of South India: A case study comparing ANFIS and empirical models. *Information Processing in Agriculture*, *8*(1), 173–184. https://doi.org/10.1016/j.inpa.2020.02.003

Hansen, S. (1984). Estimation of Potential and Actual Evapotranspiration. *Hydrology Research*, *15*(4–5), 205–212. https://doi.org/10.2166/nh.1984.0017

Harwell, M. (2019). A Strategy for Using Bias and RMSE as Outcomes in Monte Carlo Studies in Statistics. *Journal of Modern Applied Statistical Methods*, *17*(2). https://doi.org/10.22237/jmasm/1551907966

Hernández-Bedolla, J., Solera, A., Sánchez-Quispe, S. T., & Domínguez-Sánchez, C. (2023). Comparative analysis of 12 reference evapotranspiration methods for semi-arid regions (Spain). *Journal of Water and Climate Change*, *14*(9), 2954–2969. https://doi.org/10.2166/wcc.2023.448

Heydari, M. M., Beygipoor, G., Mehdi Heydari, M., Aghamajidi, R., & Heydari, M. (2014). Comparison and evaluation of 38 equations for estimating reference evapotranspiration in an arid region. *Fresenius Environmental Bulletin*, *3*(8a). https://www.researchgate.net/publication/287850018

Hu, X., Chen, M., Liu, D., Li, D., Jin, L., Liu, S., Cui, Y., Dong, B., Khan, S., & Luo, Y. (2021). Reference evapotranspiration change in Heilongjiang Province, China from 1951 to 2018: The role of climate change and rice area expansion. *Agricultural Water Management*, *253*, 106912. https://doi.org/10.1016/j.agwat.2021.106912

Huntley, B. J. (2023). Soil, Water and Nutrients. In *Ecology of Angola* (pp. 127–147). Springer International Publishing. https://doi.org/10.1007/978-3-031-18923-4_6

Itolima, O., & Ify, L. N. (2017). Evaluation of empirical models for estimating reference-evapotranspiration (RET-ET) in humid semi-hot equatorial coastal climate. *International Journal of Water Resources and Environmental Engineering*, *9*(8), 162–177. https://doi.org/10.5897/IJWREE2017.0731

Jensen, M. E., & Haise, H. R. (1963). Estimating Evapotranspiration from Solar Radiation. *Journal of the Irrigation and Drainage Division*, *89*(4), 15–41. https://doi.org/10.1061/JRCEA4.0000287

Karunasingha, D. S. K. (2022). Root mean square error or mean absolute error? Use their ratio as well. *Information Sciences*, *585*, 609–629. https://doi.org/10.1016/j.ins.2021.11.036

Lee, D. K., In, J., & Lee, S. (2015). Standard deviation and standard error of the mean. *Korean Journal of Anesthesiology*, *68*(3), 220. https://doi.org/10.4097/kjae.2015.68.3.220

Li, X., & Kang, Y. (2020). Agricultural utilization and vegetation establishment on saline-sodic soils using a water–salt regulation method for scheduled drip irrigation. *Agricultural Water Management*, *231*, 105995. https://doi.org/https://doi.org/10.1016/j.agwat.2019.105995

Manik, T. K., Sanjaya, P., & Rosadi, R. A. B. (2017). Comparison of Different Models in Estimating Standard Evapotranspiration in Lampung Province, Indonesia. *International Journal of Environment, Agriculture and Biotechnology*, *2*(5), 2309–2318. https://doi.org/10.22161/ijeab/2.5.5

Manuela Portela, M., Santos, J., & Marinho de Carvalho Studart, T. (2020). Effect of the Evapotranspiration of Thornthwaite and of Penman-Monteith in the Estimation of Monthly Streamflows Based on a Monthly Water Balance Model. In *Current Practice in Fluvial Geomorphology - Dynamics and Diversity*. IntechOpen. https://doi.org/10.5772/intechopen.88441

Ndulue, E., & Ranjan, R. S. (2021). Performance of the FAO Penman-Monteith equation under limiting conditions and fourteen reference evapotranspiration models in southern Manitoba. *Theoretical and Applied Climatology*, *143*(3–4), 1285–1298. https://doi.org/10.1007/s00704-020-03505-9

Oliveira, G. M. de, Leitão, M. de M. V. B. R., Bispo, R. de C., Santos, I. M. S., & Almeida, A. C. de. (2010). Comparação entre métodos de estimativa da evapotranspiração de Referência na região norte da bahia. *Revista Brasileira de Agricultura Irrigada*, *4*(2), 104–109. https://doi.org/10.7127/rbai.v4n206100

P. B. JADHAV, S. A. KADAM, & S. D. GORANTIWAR. (2015). Comparison of methods for estimating reference evapotranspiration (ETo) for Rahuri region. *Journal of Agrometeorology*, *17*(2), 204–207. https://doi.org/10.54386/jam.v17i2.1007

Paredes, P., Trigo, I., de Bruin, H., Simões, N., & Pereira, L. S. (2021). Daily grass reference evapotranspiration with Meteosat Second Generation shortwave radiation and reference ET products. *Agricultural Water Management*, *248*, 106543. https://doi.org/10.1016/j.agwat.2020.106543

Pereira, H. R., Meschiatti, M. C., Pires, R. C. de M., & Blain, G. C. (2018). On the performance of three indices of agreement: an easy-to-use r-code for calculating the Willmott indices. *Bragantia*, *77*(2), 394–403. https://doi.org/10.1590/1678-4499.2017054

Pereira, L. S., Paredes, P., Hunsaker, D. J., López-Urrea, R., & Jovanovic, N. (2021). Updates and advances to the FAO56 crop water requirements method. *Agricultural Water Management*, *248*, 106697. https://doi.org/10.1016/j.agwat.2020.106697

Qiu, R., Liu, C., Cui, N., Wu, Y., Wang, Z., & Li, G. (2019). Evapotranspiration estimation using a modified Priestley-Taylor model in a rice-wheat rotation system. *Agricultural Water Management*, *224*, 105755. https://doi.org/10.1016/j.agwat.2019.105755

Rahimikhoob, A., & Hosseinzadeh, M. (2014). Assessment of Blaney-Criddle Equation for Calculating Reference Evapotranspiration with NOAA/AVHRR Data. *Water Resources Management*, *28*(10), 3365–3375. https://doi.org/10.1007/s11269-014-0670-7

Renner, M., Brenner, C., Mallick, K., Wizemann, H. D., Conte, L., Trebs, I., Wei, J., Wulfmeyer, V., Schulz, K., & Kleidon, A. (2019). Using phase lags to evaluate model biases in simulating the diurnal cycle of evapotranspiration: A case study in Luxembourg. *Hydrology and Earth System Sciences*, *23*(1), 515–535. https://doi.org/10.5194/hess-23-515-2019

Santos, L. da C., Cruz, G. H. T., Capuchinho, F. F., José, J. V., & Reis, E. F. dos. (2019). Assessment of empirical methods for estimation of reference evapotranspiration in the Brazilian Savannah. *Australian Journal of Crop Science*, 1094–1104. https://doi.org/10.21475/ajcs.19.13.07.p1569

Sasireka, K., Jagan Mohan Reddy, C., Charan Reddy, C., & Ramakrishnan, K. (2017). Evaluation and Recalibration of Empirical Constant for Estimation of Reference Crop Evapotranspiration against the Modified Penman Method. *IOP Conference Series: Earth and Environmental Science*, *80*, 012062. https://doi.org/10.1088/1755-1315/80/1/012062

Shaw, P. A., Johnson, L. L., & Proschan, M. A. (2018). Intermediate Topics in Biostatistics. In *Principles and Practice of Clinical Research* (pp. 383–409). Elsevier. https://doi.org/10.1016/B978-0-12-849905-4.00027-7

Shirmohammadi-Aliakbarkhani, Z., & Saberali, S. F. (2020). Evaluating of eight evapotranspiration estimation methods in arid regions of Iran. *Agricultural Water Management*, *239*, 106243. https://doi.org/10.1016/j.agwat.2020.106243

Sobrinho, O. P. L., Júnior, W. L. C., Santos, L. N. S. dos, Silva, G. S. da, Pereira, Á. I. S., & Tavares, G. G. (2020). Empirical methods for reference evapotranspiration estimation. *Scientia Agraria Paranaensis*, *19*(3), 203–210. https://doi.org/10.18188/sap.v19i3.21487

Steidle Neto, A. J., Borges Júnior, J. C. F., Andrade, C. L. T., Lopes, D. C., & Nascimento, P. T. (2015). Reference evapotranspiration estimates based on minimum meteorological variable requirements of historical weather data. *Chilean Journal of Agricultural Research*, *75*(3), 366–374. https://doi.org/10.4067/S0718-58392015000400014

Suwarman, R., Junnaedhi, I. D. G. A., & Novitasari, N. (2021). A Study on Characteristics and Comparison of Evaporation Estimation Methods in Bandung. *Journal of Mathematical and Fundamental Sciences*, *53*(2), 182–199. https://doi.org/10.5614/j.fund.math.sci.2021.53.2.2

Talebmorad, H., Ahmadnejad, A., Eslamian, S., Askari, K. O. A., & Singh, V. P. (2020). Evaluation of uncertainty in evapotranspiration values by FAO56-Penman-Monteith and Hargreaves-Samani methods. *International Journal of Hydrology Science and Technology*, *10*(2), 135. https://doi.org/10.1504/IJHST.2020.106481

Thongkao, S., Ditthakit, P., Pinthong, S., Salaeh, N., Elkhrachy, I., Linh, N. T. T., & Pham, Q. B. (2022). Estimating FAO Blaney-Criddle b-Factor Using Soft Computing Models. *Atmosphere*, *13*(10), 1536. https://doi.org/10.3390/atmos13101536

TURC, L. (1961). Evaluation des besoins en eau d'irrigation, evapotranspiration potentielle. *Ann. Agron.*, *12*, 13–49. https://cir.nii.ac.jp/crid/1574231876103538304.bib?lang=en

Valipour, M., & Guzmán, S. M. (2022). Identification of the Meteorological Variables Influencing Evapotranspiration Variability Over Florida. *Environmental Modeling & Assessment*, *27*(4), 645–663. https://doi.org/10.1007/s10666-022-09828-3

Wang, W., & Lu, Y. (2018). Analysis of the Mean Absolute Error (MAE) and the Root Mean Square Error (RMSE) in Assessing Rounding Model. *IOP Conference Series: Materials Science and Engineering*, *324*(1). https://doi.org/10.1088/1757-899X/324/1/012049

Weiss, O., Minixhofer, P., Scharf, B., & Pitha, U. (2021). Equation for Calculating Evapotranspiration of Technical Soils for Urban Planting. *Land*, *10*(6), 622. https://doi.org/10.3390/land10060622

Willmott, C. J., Robeson, S. M., & Matsuura, K. (2012). A refined index of model performance. *International Journal of Climatology*, *32*(13), 2088–2094. https://doi.org/10.1002/joc.2419

Xystrakis, F., & Matzarakis, A. (2011). Evaluation of 13 Empirical Reference Potential Evapotranspiration Equations on the Island of Crete in Southern Greece. *Journal of Irrigation and Drainage Engineering*, *137*(4), 211–222. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000283

Zhang, Q., Cui, N., Feng, Y., Gong, D., & Hu, X. (2018). Improvement of Makkink model for reference evapotranspiration estimation using temperature data in Northwest China. *Journal of Hydrology*, *566*, 264–273. https://doi.org/10.1016/j.jhydrol.2018.09.021