REFERENCE EVAPOTRANSPIRATION ESTIMATED WITH LIMITED CLIMATE DATA COMPARED WITH ALTERNATIVE MODELS IN THE SEMI-ARID REGION

EVAPOTRANSPIRAÇÃO DE REFERÊNCIA ESTIMADA COM DADOS CLIMÁTICOS LIMITADOS COMPARADA COM MODELOS ALTERNATIVOS NO SEMIÁRIDO

Antonia Raquel de Morais Alcântara[1]* [ID], **Ana Célia Maia Meireles[2]** [ID], **João Cauã Custódio Xenofonte[1]** [ID], **Sirleide Maria de Menezes[3]** [ID], **Ana Alice Cardoso Carneiro[1]** [ID], **Carlos Wagner Oliveira[2]** [ID], **José Bandeira Brasil[3]** [ID]

[1] Center for Agrarian Sciences and Biodiversity, Federal University of Cariri, R. Icaro de Sousa Moreira, 126, Crato, CE, Brazil.
[2] Professor, Center for Agrarian Sciences and Biodiversity, Federal University of Cariri, R. Icaro de Sousa Moreira, 126, Crato, CE, Brazil.
[3] Center for Agrarian Sciences and Biodiversity, Federal University of Cariri, R. Icaro de Sousa Moreira, 126, Crato, CE, Brazil.

ABSTRACT: Accurate knowledge of reference evapotranspiration (ETo) is fundamental for the hydrological and agroclimatic planning of a region. Therefore, the objective of this study was to evaluate the estimate of reference evapotranspiration (ETo) by the Penman-Monteith-FAO (PM) model with limited data, and to compare it with alternative methods for the semi-arid region of Cariri, CE, Brazil. A period of climate data from 2021 to 2023 was used. For the evaluation, ETo was estimated by the PM method with all climatic data and compared with combinations of missing climatic data, and also with the alternative methods of Hargreaves and Samani, Jensen and Haise, and Makkink. ETo estimates were analyzed with statistical indices. According to the results, for the condition of missing solar radiation and wind speed data, the PM model can be used to estimate ETo for the study site. When the number of missing variables is increased, the error of ETo estimates also increases, reducing the accuracy of the models. If it is not possible to use the PM model, the Jensen and Haise model can be used to estimate ETo, since this method proved to be satisfactory and accurate.

KEYWORDS: Water management, missing data, statistical indices, water demand.

RESUMO: O conhecimento preciso da evapotranspiração de referência (ETo) é fundamental para o planejamento hidrológico e agroclimático de uma região. Objetivou-se, portanto, avaliar a estimativa da evapotranspiração de referência (ETo) pelo modelo Penman-Monteith-FAO (PM) com dados limitados, bem como comparar com métodos alternativos para a região semiárida do Cariri-CE. Utilizou-se um período de dados climáticos do período de 2021 a 2023. Para a avaliação, a ETo foi estimada pelo método de PM com todos os dados climáticos e comparada com combinações de dados climáticos faltosos, e ainda com os métodos alternativos de Hargreaves e Samani, Jensen e Haise, e Makkink. As estimativas de ETo Foram analisadas com índices estatísticos. De acordo com os resultados, na condição de dados de radiação solar e velocidade do vento, o modelo PM pode ser usado para estimar a ETo para o local de estudo. Quando o número de variáveis ausentes é aumentado, aumenta-se também o erro das estimativas de ETo, diminuindo a precisão dos modelos. Na impossibilidade de utilização do modelo de PM, o modelo de Jensen e Haise pode ser utilizado para a estimativa da ETo, uma vez que esse método se mostrou satisfatório e preciso.

PALAVRAS-CHAVE: Manejo hídrico, dados climáticos, índices estatísticos, demanda hídrica.

INTRODUCTION

With the intensification of climate change, the rationalization of environmental resources becomes a fundamental criterion to enable intensive and sustainable agricultural production. Thus, it is of great importance to understand the local and regional environmental aspects relevant to the planning of agricultural activities (SILVA et al., 2022).

Efficient irrigation management in agriculture is crucial for the rational use of water. According toMenezes et al. (2024), the optimization of water use in irrigated agriculture is highly relevant in the expansion of agricultural production. Thus, cropping systems must adapt and adopt efficient management practices, aiming to increase the efficiency in the use of water and agricultural inputs (ZHANG et al., 2023).

Evapotranspiration is one of the most important factors in understanding the use of water by plants; it is the basis for irrigation scheduling and for the proper management of water resources (PEREIRA et al., 2020), as well as for crop production and water conservation(AWAL et al., 2020). Knowledge of reference evapotranspiration (ETo) is important to determine the appropriate volume of water needed for irrigation. However, many ETo estimation methods require climate data from weather stations, which are not always easily accessible by producers (FELISBERTO, 2021).

ETo is mainly controlled by climatic factors such as solar radiation, wind speed, and water vapor pressure difference, while crop evapotranspiration (ETc) is influenced by additional factors, including the cultivated species, root depth, plant height, and crop and soil albedos (NEVES, 2019).

These meteorological data are available in several situations, but sometimes they are incomplete due to the lack of appropriate instruments near the production areas (MORAIS et al., 2015). Methods such as Penman-Monteith (PM),

recommended by FAO, are effective under various climatic conditions, but in specific cases, alternative methods may be necessary due to lack of data (ONGARATTO, 2019).

In the absence of some meteorological data necessary for calculating ETo by the PM method, the user can estimate these missing data through the data available on site, or even employ simpler estimation models. However, it is crucial to evaluate the effectiveness and accuracy of these estimates in order to validate the employability of these methods (ALLEN et al., 1998).

In view of the above, the objective of this study was to evaluate the estimate of reference evapotranspiration by the Penman-Monteith-FAO model with limited data and to compare it with alternative methods for the semi-arid region of Cariri, CE, Brazil.

MATERIAL AND METHODS

The study was carried out in the city of Crato, located in the Cariri region of Ceará, Brazil. The region has an average annual rainfall of 1090 mm, with a higher concentration of rainfall in the months from January to May (IPECE, 2017). The average air temperature ranges from 24 to 26°C. The local climate is classified as mild semi-arid hot tropical and sub-humid hot tropical. The climatic data used come from an automatic weather station installed at the Center for Agrarian Sciences and Biodiversity (CCAB), which is part of the Campus of the Federal University of Cariri (UFCA), located at 7°14' S, 39°22' W and 423 m asl.

The period analyzed was from 2021 to 2023, using data on global solar radiation (Rs, MJ m^{-2} d^{-1}), average, maximum and minimum air temperatures (Tavg, Tmax and Tmin, in °C), relative humidity (RH, %) and wind speed (u, m s^{-1}). Data were collected every hour and processed for a daily scale. The meteorological variables used are summarized in Table 1.

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Table 1. Data on maximum (Tmax), minimum (Tmin), and average (Tavg) air temperature, maximum (RHmax), minimum (RHmin), and average (RHavg) relative humidity, wind speed (u), solar radiation (Rs), and precipitation (P), for the period from 2021 to 2023.

Period	Tmax	Tmin	Tavg	RUmax	RUmin	RHavg	u	Rs	P
	-------------- °C -------------			---------------- % ----------------			$m\ s^{-1}$	$MJ\ m^{-2}\ d^{-1}$	mm
Highest	39,0	28,3	31,1	99,9	100,0	94,6	2,9	29,5	107,6
Lowest	23,5	15,4	21,6	27,9	16,6	16,4	0,2	12,4	0,0
Average	32,81	20,8	26,1	81,6	59,0	59,9	1,0	20,5	1,9
Total	-	-	-	-	-	-	-	-	2064,4

ETo calculated by the Penman-Monteith-FAO method was obtained using Equation 1 according to Allen et al. (1998).

$$ETo_{PM-FA0} = \frac{0,408\Delta(Rn-G)+\gamma\left(\frac{900}{t_{med}+273}\right)u_2\,(e_{s}-e_{a})}{\Delta+\gamma\,(1+0,34u_2)} \quad (1)$$

Where: ETo - reference evapotranspiration of grass with stomatal resistance of 70 m s^{-1}, hypothetical crop height set at 0.12 m and albedo of 0.23 (mm day^{-1}); Δ - slope of the saturated water vapor pressure curve (kPa °C^{-1}); Rn - net radiation (MJ m^{-2} day^{-1}); G - soil heat flux (considered null for daily estimates, MJ m^{-2} day^{-1}); γ - psychrometric constant (kPa °C^{-1}); Tavg - average daily air temperature (°C); u2 - wind speed at 2 m height (m s^{-1}); ea - actual water vapor pressure (kPa); es - saturation vapor pressure (kPa); (es - ea) - water vapor pressure deficit (kPa).

The effectiveness of the Penman-Monteith-FAO model in limited-data situations was tested by comparing it with simpler approaches, such as the Hargreaves and Samani (Pereira et al., 1997), Jensen and Haise (1963) and Makkink (1957) methods. To make these comparisons, the following representations (R) were considered: R1 - estimate of global radiation (-Rs, MJ m^{-2}d^{-1}); R2 - constant wind speed (-u, m s^{-1}); R3 - partial water vapor pressure estimated in the absence of relative humidity data (-ea, kPa); R4 - use of only temperature to estimate Rs and ea,

with constant u; R5 - absence of Rs and u; R6 - absence of u and ea; R7 - absence of Rs and ea; R8 - absence of Rs, u and ea; R9 - alternative method of Hargreaves and Samani (HS); R10 - alternative method of Jensen and Haise (JH); and R11 - alternative method of Makkink (MK), the latter calculated according to Equations 2, 3 and 4, respectively.

$$ETo_{HS} = 0,0023 * (t_{avg}+17,8)*(t_{max}+ t_{min})^{0,5} *Q_o \quad (2)$$

$$ETo_{JH}= 0,408*R_s*(0,025*t_{avg}+0,08) \quad (3)$$

$$ETo_{MK}=0,408*R_s*\left(\frac{\Delta}{\Delta+\gamma}\right)+0,12 \quad (4)$$

Where: Rs - global solar radiation converted into units of evaporated water (mm); Tmax - maximum temperature (°C); Tmin - minimum temperature (°C); Tavg - average temperature (°C); Qo - extraterrestrial solar radiation (MJm^{-2} day^{-1}); Δ - slope of the water vapor saturation pressure curve (kPa °C^{-1}); γ - psychrometric constant (kPa °C^{-1}).

The ETo records obtained by the Penman-Monteith-FAO method were compared with the ETo results estimated from missing data and using alternative methods.

The performance of ETo estimates was evaluated by applying simple linear regression and analysis of statistical indices, such as the coefficient of determination (R^2), percentage error (%E), mean bias

error (MBE) and root mean square error (RMSE), as described in Menezes et al. (2024). In addition, the accuracy of the estimates was evaluated based on Pearson's correlation coefficient (r), Willmott's index of agreement (d) and performance index (c), as interpreted by Camargo and Sentelhas (1997).

The reference evapotranspiration (ETo) estimated from the PM-FAO method using missing data of -ea$_{tn3}$had the best results, with R^2 of 0.95, the lowest %E (4.09%), and C index classified as excellent, showing an excellent accuracy compared with the value obtained by the model using all meteorological data (Table 2).

RESULTS AND DISCUSSION

Table 2. Statistical analysis of the Penman-Monteith-FAO method with missing data and alternative models

Variables	R^2	%E	r	d	c	Performance
-Rs(t)	0,7528	36,85	0,87	0,63	0,54	Poor
-ea$_t$$_n$3	0,9463	4,09	0,97	0,98	0,95	Excellent
-u (const.)	0,9367	7,81	0,97	0,96	0,93	Excellent
T	0,6875	21,19	0,83	0,68	0,56	Poor
-Rs(t), -u	0,6918	42,13	0,83	0,58	0,49	Very poor
-Rs(t), -ea	0,7495	40,94	0,87	0,58	0,50	Very poor
-u, -ea	0,8413	18,77	0,92	0,82	0,75	Good
-Rs (t),-u,-ea	0,6726	53,09	0,82	0,49	0,40	Terrible
HG	0,6804	13,08	0,82	0,80	0,66	Good
JH	0,9418	36,89	0,97	0,69	0,67	Good
MK	0,9211	46,83	0,96	0,60	0,57	Poor

-Rs(t): global solar radiation estimated by temperature data, -eatn3: partial water vapor pressure estimated using minimum temperature data minus 3 ºC, -u: wind speed, t: estimate using only temperature data; and the combinations -Rs, -u; -Rs, -ea; - u, -ea; -Rs(t), -u, -ea; and the alternative methods (HG - Hargreaves and Samani; JH - Jensen and Haise; MK - Makkink).

These results indicate that, even in the absence of direct vapor pressure data, the estimate obtained through the adjusted minimum temperature (-ea$_{tn3}$) can accurately reproduce the values of the complete model.

The variable -Rs(t) showed a "poor" performance, with a coefficient of determination R^2 of 0.7528 and %Eof 36.85% (Table 2). Despite having a reasonable correlation (r= 0.87), the accuracy was insufficient. These results differ from those obtained by Menezes et al. (2019), in their study with missing data in the region of Ibimirim, PE, using missing data of Rs(t). These authors obtained a high coefficient of determination (R^2 = 0.86), with performance classified as median and %E of 34.17%, demonstrating good

accuracy when compared with the estimates with all data.

The model with missing data of -u (const.) and the alternative model of JH were robust in explaining the data, with high values of R^2 (0.94 and 0.94) (Table 2). Consequently, the variable -u (const.) showed a relatively low percentage error of 7.81%, while JH exhibited a higher value of 36.89% (Table 2). In their study for the Espírito Santo region, Venancio et al. (2019) observed that the PM-FAO modelshowed highly satisfactory results, with R^2 ranging from 0.94 to 0.96, even in scenarios of absence of wind speed data.

Morais et al. (2015) also found that the PM-FAO method in the absence of wind speed data is effective in estimating ETo, with R^2 values ranging from 0.72 to 0.99. This demonstrates that the use of

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constant values for wind speed can be an efficient alternative in regions where this variable is not directly measured.

When used exclusively with temperature data, the T model showed a "poor" performance, with R^2 0.68 and %E of 21.19% (Table 2). Although it is practical because it only requires temperature data, its accuracy is limited. The results obtained by Lima et al. (2021) corroborate those obtained here, confirming that using only temperature data can overestimate ETo values.

For the condition of -Rs(t) and -u, the R^2 was 0.69, showing a "Very Poor" accuracy in the estimate, with %E of 42.13%. For the condition of -Rs(t) and -ea, the R^2 was 0.75, also classified as a "Very Poor" estimate, with %E of 40.94% (Table 2). The worst results were observed with the condition of -Rs(t), -u and -ea, with R^2 of 0.67 and %E of 53.09%, classifying it as "Terrible" (Table 2).

It was observed that by increasing the number of missing meteorological variables, the error in the ETo estimate also increases. Morais et al. (2015) confirmed that the absence of solar radiation, wind speed, and vapor pressure data resulted in reference evapotranspiration estimates with poor performance. There was low accuracy and significant errors in the estimates, indicating that this combination of missing data is not reliable for estimating ETo.

As observed for the previous statistical indices, the conditions of -ea_{tn3}, -u and the alternative model of JH showed the best results. These conditions lower RMSE, that is, they overestimated the ETo data by 0.31, 0.46 and 1.79 mm day^{-1}, respectively (Figure 1).
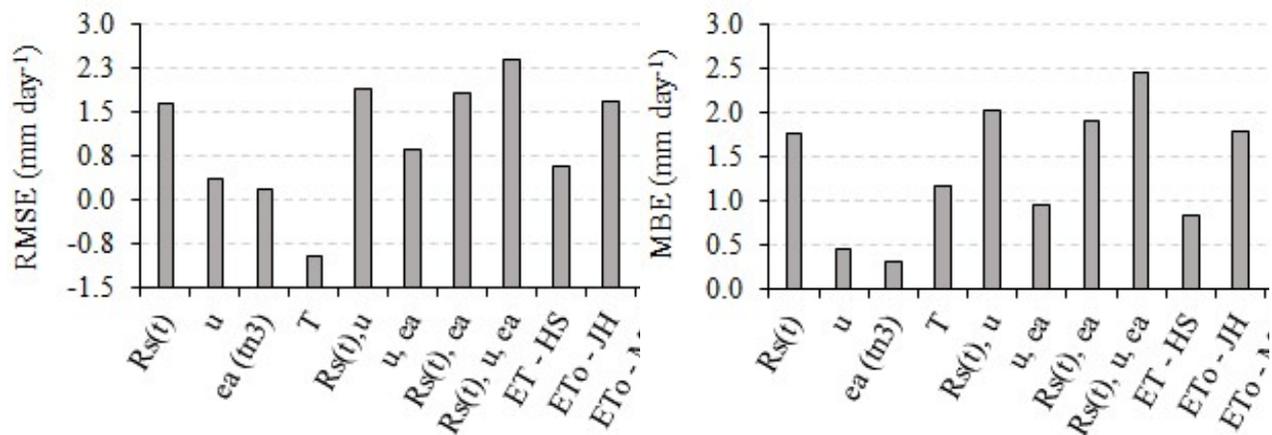

Figure 1. Root mean square error (RMSE, mm day^{-1}) (A) and mean bias error (MBE, mm day^{-1}) (B) for the Penman-Monteith-FAO method with missing data and the alternative methods.

In the case of MBE, the values obtained were 0.18, 0.35 and 1.67 mm day^{-1}, for -ea_{tn3}, -u and JH, respectively (Figure 1). For the other conditions, there are high tendencies to overestimate the ETo estimate, especially for -Rs(t), -u and -ea, reinforcing the tendency to error when the number of missing parameters in the model increases.

The JH method was developed to provide an easy and accurate way to estimate ETo for use in agricultural applications (LIMA et al., 2021)a fact that highlights the importance of this method. Corroborating these results, Liu et al. (2017) also observed that the Jensen and Haise model performed well in estimating ETo for semi-arid regions of China.

CONCLUSIONS

In the limitation of solar radiation and wind speed data only, these variables can be estimated, enabling the use of the Penman-

Monteith-FAO model to calculate ETo for the Cariri region, CE, Brazil.

Increasing the number of missing variables for ETo estimation increases the error and decreases the accuracy of the estimates.

If it is not possible to calculate ETo by the Penman-Monteith-FAO method in the Cariri region, CE, Brazil, the Jensen and Haise model can be used, since it proved to be satisfactory and accurate.

ACKNOWLEDGMENTS

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