ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

DESEMPENHO DE MÉTODOS DE ESTIMATIVA DE EVAPOTRANSPIRAÇÃO DE REFERÊNCIA NA REGIÃO SUL DE GOIÁS

ARIELA ALEXANDRE INOCÊNCIO RIZO[1] E CICERO JOSÉ DA SILVA[2]

[1] Discente do curso de Agronomia, Instituto Federal de Educação, Ciência e Tecnologia Goiano – Campus Morrinhos, Rodovia BR153, KM633 Zona Rural, 75650-000, Morrinhos, Goiás, Brasil. E-mail: arielarizo@gmail.com.
[2] Professor doutor, Instituto Federal de Educação, Ciência e Tecnologia Goiano – Campus Morrinhos, Rodovia BR153, KM633 Zona Rural 75650-000, Morrinhos, Goiás, Brasil. E-mail: cicero.silva@ifgoiano.edu.br.

1 RESUMO

O presente estudo teve como objetivo avaliar o desempenho dos métodos de estimativa de evapotranspiração de referência na região sul de Goiás. Foram coletados dados meteorológicos de cinco localidades no sul de Goiás, as quais foram: Catalão, Rio verde, Morrinhos, Jataí e Itumbiara. Foram analisadas cinco equações: Turc, Hargreaves e Samani, Priestley & Taylor, Camargo e Makkink, tomando como referência o método padrão de Penman-Monteith-FAO. Todos os dados coletados foram analisados em planilhas no Microsoft Excel®, onde as comparações foram realizadas considerando o período anual e também a sazonalidade do período seco e chuvoso. As comparações de desempenho diário dos métodos de ETo foram realizadas por meio de análise de correlação, por regressão linear e índices estatísticos. O melhor método analisado de acordo com os resultados obtidos na escala anual e no período seco e chuvoso foi o de Turc apresentando desempenho ótimo para todas as localidades. Os piores métodos foram os de Hargreaves e Samani e Camargo, os quais obtiveram desempenhos igualmente péssimos em todos os parâmetros analisados. A partir destes resultados podemos realizar as adequações nos métodos com desempenhos inferiores, podendo torná-los viáveis para uso nas localidades estudadas.

Palavras-chave: água, irrigação, Penman-Montheith, métodos.

RIZO, A. A. I. E DA SILVA, C. J.
PERFORMANCE OF EVAPOTRANSPIRATION ESTIMATION METHODS OF REFERENCE IN THE SOUTHERN GOIÁS REGION

2 ABSTRACT

This study aimed to evaluate the performance of reference evapotranspiration estimation methods in the southern region of Goiás. Meteorological data were collected from five locations in southern Goiás, in which were Catalão, Rio Verde, Morrinhos, Jataí and Itumbiara. Five equations were analyzed: Turc, Hargreaves and Samani, Priestley & Taylor, Camargo and Makkink using the standard Penman-Monteith-FAO method as a reference. All data collected were analyzed in spreadsheets in Microsoft Excel®, where comparisons were made considering the annual period and the seasonality of the dry and rainy period. Comparisons of daily performance of ETo methods were performed through correlation analysis, linear regression

Recebido em 13/01/2021 e aprovado para publicação em 21/12/2021
DOI: http://dx.doi.org/10.15809/irriga.2022v27n2p242-255

and statistical indexes. The best method analyzed according to the results obtained in the annual scale and in the dry and rainy periods was that of Turc, presented an excellent performance for all locations. The worst methods were those of Hargreaves and Samani and Camargo, which obtained equally poor performances in all analyzed parameters. From these results, we can make adjustments to the methods with lower performances and can make them viable for use in the study locations.

Keywords: water, irrigation, Penman-Monteith, methods.

3 INTRODUCTION

When planning an irrigation project that aims for optimal productivity through efficient water utilization, it is crucial to determine water consumption through evapotranspiration estimates, allowing for more precise irrigation at different stages of plant development. Evapotranspiration determines plant water consumption and, consequently, the irrigation depth to be applied (SILVA; FOLEGATTI, 2001; COSTA et al., 2018; OLIVEIRA; SILVA; RAMOS, 2020).

Reference evapotranspiration (ETo) is defined as the evapotranspiration rate for a large surface with a uniform grass cover height of 0.12 m, aerodynamic reference surface height of 70 sm $^{-1,}$ albedo of 23%, active growth of 0.08 to 0.12 m and no water deficit (ALLEN et al., 1998). Owing to its high accuracy and excellent results in a wide range of climatic conditions, the Penman–Monteith–FAO method is considered the standard for determining reference evapotranspiration (ETo) because it accurately replaces grass lysimeters in determining ETo. However, the equation is difficult to use because of the complexity of the calculations and the requirement for meteorological data, especially at the field level for rural producers. The method uses temperature (T), relative humidity (RH), solar radiation (RS), and wind speed (V) data in its estimate (MEDEIROS, 2002).

Over the years, several ETo estimation methods have been developed. This is due to the limitations of the meteorological or climatic elements required in the methods, their suitability for more specific regions, and the pursuit of simplicity and ease of use. Studies using statistical techniques to compare ETo estimation methods, evaluating those with the greatest applicability in the study location, have commonly been developed (LIMA et al., 2019). However, the results vary greatly among studies because each region has different climatic characteristics, making it difficult for users to decide on the appropriateness of which method to adopt (CRUZ et al., 2017). This fact corroborates the information of Pereira et al. (2009), who recommend that before applying a method to a given location, it is necessary to verify its performance and, when necessary, perform calibrations to minimize estimation errors.

Among the best-known alternative methods for calculating ETo, replacing the Penman–Monteith–FAO standard method (ALLEN et al., 1998), we can mention the methods of Blaney and Criddle–1950 (ALLEN; PRUITT, 1986), Camargo (1971), adapted by Camargo et al. (1999), Priestley and Taylor (1972), Hargreaves and Samani (1985), Makkink (1957) and Turc (1961), among others. However, these methods were developed under diverse climatic and crop management conditions, requiring their calibration for application in regions with climates different from those in which they were developed. Even annual seasonality can influence the performance of these equations, which is why an equation may perform well in winter and poorly in summer (MELLO et al., 2017). According to Pereira et al. (2009), ETo estimation methods that employ the use of solar radiation perform better than methods that use only air temperature.

Thus, the objective of this work was to evaluate the performance of simplified empirical equations for estimating reference evapotranspiration in the southern region of Goiás in relation to the standard Penman–Monteith–FAO method.

4 MATERIAL AND METHODS

The research was carried out at the Instituto Federal Goiano – Campus Morrinhos GO. The meteorological stations selected for the present study were Morrinhos (- 17°44'42 ”S, -49°06'06 ”S, altitude of 751'06 ”W, altitude of 751 meters), Catalão (-18°9'17 ”S, -47°55'39 ”W, altitude of 901 meters), Itumbiara (-18°24'35 ”S, -49°11'31 ”W, altitude of 491 meters), Rio Verde (-17°47'7 ”S, -50°57' 53 ”W, altitude of 780 meters) and Jataí (-17°55'25 ”S, -51°43'03 ”W, altitude of 670 meters), with a data series of at least 10 years as selection criteria.

The data obtained contained information on meteorological variables such as precipitation (mm), relative humidity (%), wind speed (ms $^{-1}$), maximum and minimum temperature (°C), and global solar radiation (MJ m $^{-2}$), which were obtained from the website of the Weather Forecast and Climate Studies Center (INFOCLIMA, 2019). The recorded data were then accumulated into daily data via pivot tables in Microsoft Excel®, and the meteorological series were organized individually by location in spreadsheets.

ETo) values were calculated via the following equations:

Penman–Monteith method-FAO (ALLEN et al., 1998) (Equations 01--07):

$$ETo = \frac{0{,}408 \cdot \Delta(Rn - G) + \gamma \cdot \frac{900}{T + 273{,}16} \cdot U_2 \cdot (es - ea)}{\Delta + \gamma \cdot (1 + 0{,}34 \cdot U_2)} \quad (01)$$

$$\Delta = \frac{4098 \cdot \left[0{,}6108 \cdot \exp^{\left(\frac{17{,}27 \cdot T}{T + 237{,}3}\right)}\right]}{(T + 237{,}3)^2} \quad (02)$$

$$\gamma = 0{,}665 \cdot 10^{-3} \cdot P_{atm} \quad (03)$$

$$P_{atm} = 101{,}3 \cdot \left(\frac{293 - 0{,}0065 \cdot Altitude}{293}\right)^{5{,}26} \quad (04)$$

$$e°(T) = 0{,}6108 \cdot \exp^{\left(\frac{17{,}27T}{T + 237{,}3}\right)} \quad (05)$$

$$es = \frac{e°(T_{max}) + e°(T_{mín})}{2} \quad (06)$$

$$ea = \frac{UR \cdot es}{100} \quad (07)$$

where Δ is the slope of the vapor pressure curve (kPa °C $^{-1}$); Rn is the net radiation balance (MJ m $^{-2}$ day $^{-1}$); G is the ground heat flux (MJ m $^{-2}$ day $^{-1}$), which is negligible for long time intervals, $\geq$1.0 days; γ is the psychrometric constant (kPa °C $^{-1}$); T is the mean daily air temperature, a 2,0 mat height (°C); U_2 is the wind speed a 2,0 mat height (ms $^{-1}$); es is the vapor pressure deficit (kPa); exp is the base of the natural logarithm; e P_{atm} is the atmospheric pressure (kPa) as a function of altitude in meters; e° (T) is the vapor saturation pressure (kPa) at air temperature (°C); es is the arithmetic mean of the vapor saturation pressures at the maximum ($_{Tmax}$) and minimum ($_{Tmin}$) air temperatures; and RH is the average relative humidity (%).

The Camargo method (1971) (CM) considers the effective temperature as proposed by Camargo et al. (1999) - (Equation 8):

$$ETo = 0,01.\frac{Qo}{2,45}.(1,08.T\max - 0,36.T\min).ND \quad (08)$$

where Qo is the extraterrestrial solar radiation (MJ.m $^{-2}$.d $^{-1}$); Tmax is the maximum daily temperature (oC); Tmin is the minimum daily temperature (oC); and ND is the number of days in the period.

Turc (1961) method (TC) (Equations 09 and 10):

$$ETo = a_t.0,013.\left(\frac{T_{med}}{T_{med}+15}\right).\left(\frac{\left(\frac{Rs}{0,0238846}\right)+50}{\lambda}\right) \quad (09)$$

$$a_t = 1 + \frac{50 - UR}{70} \quad (10)$$

where ETo is the reference evapotranspiration according to the Turc method (mm day $^{-1}$); Tmed is the average air temperature, in °C; RS is the global solar radiation (MJ m $^{-2}$ d $^{-1}$); λ is the latent heat of vaporization (2.45 MJ mm $^{-1}$); RH is the relative humidity (%); and at is the relative humidity factor. If the relative humidity (RH) is greater than or equal to 50%, at = 1.0; otherwise, it is calculated via dimensionless equation (14):

Hargreaves and Samani (1985) method (HS) – (Equation 11):

$$ETo = \alpha \times Q_o \times (T + 17,8)^{\beta} \times \sqrt{T_{max} - T_{min}} \quad (11)$$

ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

where ETo is the reference evapotranspiration (mm d $^{-1}$); an empirical parameter, with an original value of 0.0023; Qo is the radiation at the top of the atmosphere (MJ m $^{-2}$ d $^{-1}$); T is the average temperature (oC); Tmax is the maximum temperature (oC); Tmin is the minimum temperature (oC); and β is an exponential empirical parameter, with an original value of 0.5.

Priestley and Taylor (1972) – (PTy) method (Equations 12 to 14):

$$ETo = \alpha . W . \frac{(Rn - G)}{2{,}45} \quad (12)$$

$$W = 0{,}407 + 0{,}0145.T \text{ (For } 0\ ^{\circ C} < T < 16\ ^{\circ}C) \quad (13)$$

$$W = 0{,}483 + 0{,}01.T \text{ (For } T > 16\ ^{\circ}C) \quad (14)$$

where Priestley is the Taylor parameter or coefficient; Rn is the net radiation (MJ m $^{-2}$ day $^{-1}$); G is the soil heat flux (MJ m $^{-2}$ day $^{-1}$); W is the weighting factor dependent on air temperature (T, in °C); S is the tangent to the vapor pressure saturation curve (kPa ^{o} C $^{-1}$); and g is the psychrometric constant (kPa o C $^{-1}$).

Makkink's method (1957) – (MK) (Equations 15 and 16):

$$ETo = 0{,}61.W.R_s - 0{,}12 \quad (15)$$

$$W = \left(0{,}392 + 3.10^{-5}.Z\right) + 0{,}01172.T - 0{,}0001.T^2 \quad (16)$$

where Rs is the total daily solar radiation measured (MJ m $^{-2}$ day $^{-1}$) and W is the weighting factor (dimensionless), which is calculated on the basis of the average temperature of the period (Tm, 0C) and the altitude of the location (m).

The ETo values for each method were determined via the software reference evapotranspiration calculator (REF-ET®, v. 4.1, free software), which uses the meteorological data required for each ETo determination method. ETo estimation methods not covered by the REF-ET software, such as the method of Camargo et al. (1999), were calculated via a spreadsheet developed in Microsoft Excel® ^{for} this purpose.

After calculating the ETo values (mm day $^{-1}$) with each estimation method, they were organized in a Microsoft Excel® spreadsheet. From then on, a comparative analysis of the ETo determination methods was performed, taking the ETo values determined by Penman–Monteith–FAO as a standard or reference for comparison. The comparisons were made considering the annual period and the seasonality of the dry period (May--October) and rainy period (November--April). The daily performance comparisons of the ETo methods were performed through correlation analysis via linear regression and statistical indices, such as Willmott's concordance index (WILLMOTT et al., 1985), "d" (Equation 17), Pearson's correlation coefficient, "r" (Equation 18), and confidence or performance coefficient, "c" (CAMARGO; SENTELHAS, 1997) (Equation 19).

Recebido em 13/01/2021 e aprovado para publicação em 21/12/2021
DOI: http://dx.doi.org/10.15809/irriga.2022v27n2p242-255

$$d = 1 - \frac{\sum_{i=1}^{n}(Pi - Oi)^2}{\sum_{i=1}^{n}\left[\left(Pi - O\right) + \left(O1 - O\right)\right]^2} \quad (17)$$

where d is the agreement or adjustment index; Pi is the reference evapotranspiration obtained via the state method (mm.day $^{-1}$); Oi is the reference evapotranspiration obtained via the standard method (Penman - Monteith -FAO) (mm.day $^{-1}$); O is the average of the ETo values obtained via the standard method (Penman - Monteith -FAO) (mm.day $^{-1}$); and n is the number of observations.

$$r = \frac{\sum_{i=1}^{n}\left(X_i - X_m\right).\left(y_i - y_m\right)}{\sqrt{\sum_{i=1}^{n}\left(X_i - X_m\right)^2}\ .\sqrt{\sum_{i=1}^{n}\left(y_i - y_m\right)^2}} \quad (18)$$

where r is Pearson's correlation coefficient; X_i is the reference evapotranspiration obtained via the method considered (mm.day $^{-1}$); X_m is the average reference evapotranspiration obtained via the method considered (mm.day $^{-1}$); y_i is the reference evapotranspiration obtained via the standard method (Penman - Monteith - FAO) (mm.day $^{-1}$); and y_m is the average reference evapotranspiration obtained via the standard method (Penman - Monteith - FAO) (mm.day $^{-1}$).

$$c = r.d \quad (19)$$

where c is the confidence or performance coefficient, r is Pearson's correlation coefficient, and d is Willmott's concordance index.

The “c” index of Camargo and Sentelhas (1997) varies from 0 to 1.0 for the performance of the ETo determination method. When “c” >0.85, excellent performance; 0.76 to 0.85, very good; 0.66 to 0.75, good; 0.61 to 0.65, average; 0.51 to 0.60, poor; 0.41 to 0.50, bad; and <0.40, terrible.

Through these analyses, potential performance equations were defined for annual periods and winter and summer periods compared with the standard Penman–Monteith–FAO method for the southern region of Goiás.

5 RESULTS AND DISCUSSION

The ETo values ranged from 3.15 to 5.91 mm.d $^{-1,}$ indicating performances between Poor and Excellent. In general, the Camargo, Makkink and Turc equations underestimate the ETo values compared with the standard method, whereas Hargreaves and Samani and Priestley-Taylor overestimate them (Table 01).

Table 1. Statistical analyses comparing evapotranspiration estimation methods with the standard Penman method Montheith (PM) FAO in five municipalities in the southern region of Goiás on an annual scale.

Municipalities	Methods	r	d	w	Performance	ETo (mm.d $^{-1}$)
Catalan	PM FAO	-	-	-		4.03
	Hargreaves	0.57	0.58	0.33	Terrible	5.40
	Priestley & Taylor	0.87	0.90	0.78	Very good	4.52
	Camargo	0.36	0.69	0.25	Terrible	3.53
	Makkink	0.93	0.84	0.79	Very good	3.29
	Turkish	0.93	0.97	0.92	Excellent	3.91
Itumbiara	PM FAO	-	-	-		4.12
	Hargreaves	0.52	0.54	0.28	Terrible	5.81
	Priestley & Taylor	0.81	0.90	0.73	Good	4.60
	Camargo	0.41	0.75	0.31	Terrible	3.75
	Makkink	0.89	0.82	0.73	Good	3.32
	Turkish	0.91	0.97	0.88	Excellent	4.01
Jataí	PM FAO	-	-	-		3.88
	Hargreaves	0.51	0.54	0.28	Terrible	5.91
	Priestley & Taylor	0.82	0.89	0.73	Good	4.38
	Camargo	0.46	0.81	0.37	Terrible	3.78
	Makkink	0.89	0.82	0.74	Good	3.15
	Turkish	0.89	0.97	0.88	Excellent	3.79
Hills	PM FAO	-	-	-		4.06
	Hargreaves	0.49	0.53	0.26	Terrible	5.68
	Priestley & Taylor	0.83	0.89	0.73	Good	4.56
	Camargo	0.40	0.74	0.29	Terrible	3.68
	Makkink	0.90	0.83	0.75	Good	3.31
	Turkish	0.91	0.97	0.89	Excellent	3.95
Green river	PM FAO	-	-	-		4.03
	Hargreaves	0.48	0.44	0.21	Terrible	5.75
	Priestley & Taylor	0.80	0.88	0.70	Good	4.40
	Camargo	0.36	0.76	0.27	Terrible	3.71
	Makkink	0.88	0.83	0.73	Good	3.16
	Turkish	0.90	0.97	0.87	Excellent	3.81

Willmott's concordance index; c - Confidence coefficient; ETo - Reference evapotranspiration

The method that demonstrated the best performance on an annual scale was Turc, regardless of the municipality where it was tested, with its "c" indices having a minimum value of 0.87, classified as excellent. The level of agreement "d" was excellent (d = 0.97), and Pearson's correlation coefficient, "r", ranged from

0.90--0.93, in addition to presenting a low value of ETo underestimation in relation to the standard method, which ranged from 0.09--0.22 mm d $^{-1}$ (Table 01).

With satisfactory performance, the Makkink and Priestley–Taylor methods were classified as very good in the municipality of Catalão and good for the other municipalities. Both methods obtained a strong correlation index "d," ranging from 0.82 to 0.90 (Table 1).

The Hargreaves and Samani and Camargo ETo estimation methods proved to be inefficient at an annual scale, presenting poor performance at all the tested locations, verifying that the “c” index did not exceed 0.37. Compared with the standard Penman–Monteith–FAO method, the Hargreaves method overestimated the ETo values by an average of 1.68 mm.d. $^{-1}$ (42%), and the Camargo method underestimated the ETo values by an average of 0.334 mm.d. $^{-1}$ (8%) (Table 01).

For the estimation methods for the seasonality of the winter and summer periods, a very large variation was observed between the methods in the rainy season, where the average ETo varied between 3.31 and 5.56 mm.d $^{-1}$, and in the dry season, where it varied even greater than 2.97 to 6.28 mm.d $^{-1}$ (Table 2). This shows the variation between one method and another depending on the location where it is tested.

Table 2. Statistical analyses comparing evapotranspiration methods in the rainy and dry seasons using the standard Penman method as a reference. Monteith FAO.

Municipalities	M	Rainy season					Dry period				
		r	d	w	ETo	Desem .	r	d	w	Eto	Desem .
Catalan	PM	-	-	-	4.04	-	-	-	-	4.01	
	HG	0.74	0.66	0.49	5.19	Bad	0.51	0.51	0.26	5.61	Terrible
	PTy	0.98	0.88	0.86	4.79	Excellent	0.87	0.94	0.83	4.26	Very good
	CM	0.46	0.73	0.34	3.89	Terrible	0.52	0.67	0.35	3.16	Terrible
	Mk	0.99	0.91	0.89	3.43	Excellent	0.92	0.78	0.71	3.14	Good
	Turkish	0.99	0.99	0.98	4.06	Excellent	0.91	0.96	0.88	3.76	Excellent
Itumbiara	PM	-	-	-	4.17	-	-	-	-	4.08	
	HG	0.66	0.60	0.40	5.56	Terrible	0.53	0.47	0.25	6.06	Terrible
	PTy	0.97	0.87	0.84	4.95	Very good	0.82	0.94	0.76	4.26	Very good
	CM	0.48	0.76	0.36	4.13	Bad	0.55	0.75	0.41	3.37	Terrible
	Mk	0.98	0.89	0.87	3.52	Excellent	0.87	0.77	0.67	3.13	Good
	Turkish	0.98	0.99	0.97	4.21	Excellent	0.89	0.95	0.84	3.80	Very good
Jataí	PM	-	-	-	3.96	-	-	-	-	3.81	
	HG	0.64	0.54	0.35	5.54	Terrible	0.51	0.36	0.18	6.28	Terrible
	PTy	0.97	0.85	0.83	4.72	Very good	0.81	0.93	0.75	4.05	Good
	CM	0.48	0.77	0.37	4.10	Bad	0.56	0.84	0.47	3.47	Terrible
	Mk	0.98	0.88	0.87	3.34	Excellent	0.86	0.80	0.69	2.97	Good
	Turkish	0.99	0.99	0.97	3.99	Excellent	0.88	0.96	0.84	3.59	Very good
Hills	PM	-	-	-	4.09	-	-	-	-	4.03	
	HG	0.67	0.61	0.41	5.40	Bad	0.50	0.46	0.23	5.95	Terrible
	PTy	0.97	0.86	0.84	4.87	Very good	0.82	0.93	0.76	4.26	Very good
	CM	0.49	0.75	0.37	4.03	Bad	0.53	0.73	0.39	3.34	Terrible
	Mk	0.98	0.90	0.88	3.48	Excellent	0.88	0.77	0.67	3.14	Good
	Turkish	0.98	0.99	0.98	4.13	Excellent	0.89	0.95	0.85	3.78	Very good
Green River	PM	-	-	-	4.03	-	-	-	-	4.03	
	HG	0.61	0.52	0.32	5.44	Terrible	0.52	0.40	0.21	6.06	Terrible
	PTy	0.97	0.84	0.82	4.68	Very good	0.79	0.92	0.73	4.12	Good
	CM	0.42	0.74	0.31	4.03	Bad	0.48	0.77	0.37	3.39	Terrible
	Mk	0.98	0.89	0.87	3.31	Excellent	0.84	0.77	0.65	3.02	Median
	Turkish	0.98	0.99	0.97	3.95	Excellent	0.87	0.95	0.82	3.67	Very good

** M – Methods; r – Pearson's correlation coefficient; d – Willmott's concordance index; c – Confidence coefficient; ETo – Reference evapotranspiration; Desem. – Performance; PTy - Priestley & Taylor; HG – Hargreaves; CM – Camargo; Mk – Makkink; PM - Penman Monteith FAO

In general, all methods performed best during the rainy season. The Turc and Makkink methods performed optimally at all locations where they were tested, with confidence coefficients or performance "c" values ranging from 0.87--0.98 (Table 2). The Makkink method, in particular, performed better during the rainy season than during the annual period. The Priestley & Taylor method performed well during the rainy season, with confidence indices ranging from good to very good. The Camargo, Hargreaves, and Samani equations performed poorly during the rainy season and were classified as poor to very poor, regardless of the municipality (Table 2).

In the dry season, the tested methods generally performed worse than the standard Penman–Monteith–FAO method did, regardless of the municipality where they were tested. During the dry season, the Turc method also outperformed the standard Penman–Monteith–FAO method, performing excellently (Catalão) to very well in the other locations. The Priestley & Taylor equation also proved stable during the dry season, regardless of the location tested, with its confidence index ranging from very good to good. During the dry season, the Makkink method performed well in all locations where it was tested, except in Rio Verde, where it performed moderately. The Camargo–Hargreaves and Samani equations performed poorly during the dry season, ranking them as poor to very poor, regardless of the municipality (Table 2).

The Priestley & Taylor and Turc methods proved to be quite stable regardless of the time of year they were tested, with little variation in the mean ETo values and confidence interval "c" compared with the standard method. The Hargreaves and Samani methods, on the other hand, overestimate the ETo values, regardless of the time of year and location of testing, compared with the standard Penman–Monteith–FAO method.

The fact that the Turc model takes into account radiation, temperature, and photoperiod values promotes good performance. Similar results were obtained in Rio Verde, Goiás, and Chapadão do Sul, Mato Grosso do Sul, with excellent and very good performance, respectively (CRUZ et al., 2017; CUNHA; MAGALHÃES; CASTRO, 2013). A study by Lima et al. (2019) concluded that in all Brazilian climates, the Turc method tends to remain unstable throughout the year and is considered the best method, in agreement with the results obtained in the present study.

The performance variation between the dry and rainy seasons presented by the Makkink method certainly occurred because of its development origin in the Netherlands, where the climate is unstable with variations over short periods (MAKKINK, 1957). This fact corroborates the information of Silva et al. (2018), who state that for better method performance, the equation coefficients should be adjusted according to the location. Similar results to those of this work were described by Melo and Fernandes (2012) in Uberaba, MG, where the Makkink method underestimates the ETo compared with the standard method in any period of the year but presents the best performance index, classified as "good".

The stable performance presented by the Priestley–Taylor method in this work is consistent with those observed by Silva et al. (2011) in Uberlândia, MG, who obtained a performance index classified as "Excellent", a fact that, according to the authors, occurred because this method resembles the Penman–Monteith–FAO method. However, the results differ from those of the studies carried out in Jataí - GO by Cruz et al. (2017), in which the method was considered the worst among those studied, with its performance classified as "poor".

The poor performance of the Hargreaves and Samani methods in this work is certainly due to their origin in California, where the climate is semiarid with little rainfall and a warmer climate than in the present study, which may have influenced their poor performance (HARGREAVES; SAMANI, 1985). Similar results were obtained in Jataí by Fernandes et al. (2012), in which the method overestimated ETo values and obtained unsatisfactory performance. This fact corroborates the results reported by Rigone et al. (2013) in Aquidauana, Mato Grosso do Sul, where the authors reported that the Hargreaves and Samani method was unsatisfactory and was not recommended for the regions studied, as it overestimated the ETo values. Oliveira et al. (2007) obtained similar results in Goiânia and reported that the method tends to overestimate ETo values at any time of year. However, the results obtained in Uberaba by Alencar et al. (2011) demonstrated that the method is close to the standard method in the rainy and dry seasons and is classified as the best method. Divergent results were also found in studies carried out in Uberaba, MG, by Melo and Fernandes (2012), who reported that the method underestimates ETo values in relation to the standard method.

The Camargo method was developed on the basis of hundreds of locations; however, it performed poorly in this study. These results corroborate those of studies (OLIVEIRA et al., 2013; OLIVEIRA et al., 2015; FIETZ; SILVA; URCHEI, 2005) in Aquidauana and Dourados, Mato Grosso do Sul, and Rio Paranaúba, Minas Gerais, respectively. In these studies, the method underestimated the ETo values. However, discordant results were reported in Jacupiranga, São Paulo, where the Camargo method performed better than the standard method (BORGES; MEDIONDO, 2007).

When all methods are analyzed, considering the periods of the year, the results obtained in Aquidauana, MS, coincide with those of the present study, except for the Camargo method (RIGONE et al., 2013).

The results obtained in this research corroborate the observations of Pereira, Vila Nova and Sedyiama (1997), who state that empirical methods for estimating ETo, owing to their simplicity and ease of application, should not be discarded, as they are often the only methods with potential for use.

6 CONCLUSIONS

The best method analyzed on an annual scale was Turc, which performed excellently for all locations. The worst methods were Hargreaves, Samani and Camargo, which performed equally poorly.

During the rainy season, the methods that stood out for their efficiency were Makkink and Turc, which maintained optimal performance across all locations. During the dry season, only Turc's method demonstrated excellent results. In both the rainy and dry seasons, the worst methods were those of Hargreaves and Samani and Camargo.

In general, the method was implemented in the studied locations considering the conditions of the annual period and the rainy and dry periods. The Turc method stands out from the other methods because it is optimal under any condition.

The methods of Priestley and Taylor and Makkink demonstrated average results; with possible calibration, they have the capacity to become excellent methods for the locations studied.

7 THANKS

WE thank the Instituto Federal Goiano for their support in implementing and conducting the experiments and processing the scientific article.

8 REFERENCES

ALENCAR, LP; DELGADO, RC; ALMEIDA, TS; WANDERLEY, HS Comparison of different methods for estimating daily reference evapotranspiration for the Uberaba region. **Brazilian Journal of Agricultural Sciences** , Recife, v. 6, n. 2, p. 337-343, 2011.

ALLEN, RG; PRUIT, WO Rational use of the FAO Blaney – Criddle formula. **Journal of Irrigation and Drainage Engineering** , New York, vol. 112, no. 2, p. 139-155, 1986.

ALLEN, RG; PEREIRA, LS; RAES, D.; SMITH, M. **Crop evapotranspiration** : guidelines for computing crop water requirements. Rome : FAO, 1998. 300 p. (Irrigation and Drainage Paper , 56).

BORGES, AC; MENDIONDO, EM Comparison between empirical equations for estimating reference evapotranspiration in the Jacupiranga River basin, SP. **Brazilian Journal of Agricultural and Environmental Engineering** . Campina Grande, v. 11, n. 3, p. 293-300, 2007.

CAMARGO, AP **Water balance in the State of São Paulo** . Campinas: Agronomic Institute, 1971. 24 p. (Bulletin, 116).

CAMARGO, AP; SENTELHAS, PC Performance evaluation of different methods for estimating potential evapotranspiration in São Paulo State, Brazil. **Brazilian Journal of Agrometeorology** , Santa Maria, v. 5, n. 1, p. 89-97, 1997.

Thornthwaite equation to estimate potential evapotranspiration in arid and superhumid climates , based on the daily temperature range. **Brazilian Journal of Agrometeorology** , Santa Maria, v. 7, n. 2, p. 251-257, 1999.

COSTA, JA; RODRIGUES, GP; SILVA, ND; LOPES SOBRINHO, OSP; COSTA, LDA Evaluation of methods for estimating reference evapotranspiration for Alag oas. **Agrometeoros** , Passo Fundo, v. 25, n. 1, p. 173-179, 2018.

CRUZ, GHT; SANTOS, LC; SILVA, SCSM; REIS, EF Performance of reference evapotranspiration estimation methods for the municipality of Rio verde - GO. **Brazilian Journal of Irrigated Agriculture** , Fortaleza, v. 11, n. 6, p. 1854-1861, 2017.

CUNHA, FF; MAGALHÃES, FF; CASTRO, M.A. Methods for estimating reference evapotranspiration for Chapadão do Sul-MS. **Journal of Agricultural Engineering** , Viçosa, MG, v. 21, n. 2, p. 159-172, 2013.

FERNANDES, DS; HEINEMANN, AB; PAZ, RLF; AMORIM, A. O. Regional and local calibration of the Hargreaves equation for estimating reference evapotranspiration. **Agronomic Science Journal** , Botucatu, v. 43, n. 2, p. 246-255, 2012.

FIETZ, CR; SILVA, FC; URCHEI, MA Estimation of daily reference evapotranspiration for the Dourados region, MS. **Brazilian Journal of Agrometeorology** , Santa Maria, v. 13, n. 2, p. 250-255, 2005.

HARGREAVES, G.H.; SAMANI, ZA Reference crop evapotranspiration from temperature . **Journal of Applied Engineering in Agriculture** , St. Joseph, vol. 1, no. 2, p. 96-99, 1985.

INFOCLIMA. **Meteorological Data** . Available at: https://www.cnpaf.embrapa.br/infoclima/A ccessed on: September 10, 2019.

LIMA, JGA; VIANA, PC; SOBRINHO, JE; COUTO, JPC Comparison of ETo estimation methods and sensitivity analysis for different Brazilian climates. **Irriga** , Botucatu, v. 24, n. 3, p. 538-551, 2019.

MAKKINK, GF Ekzameno de la formula de Penman . **Netherlands Journal of Agricultural Science** , Wageningen , v. 5, no. 3, p. 290-305, 1957.

MEDEIROS, AT **Estimation of reference evapotranspiration from the Penman–Monteith equation, lysimetric measurements and empirical equations,**

in Piraipaba , CE . 2002. Thesis (Doctorate in Irrigation and Drainage) – "Luiz de Queiroz" College of Agriculture, University of São Paulo, São Paulo, 2002.

MELLO, AJS; ROZENO, GS; SILVA, JAR; MELLO, M. L. Performance evaluation of different methods for estimating daily reference evapotranspiration for the city of Ituiutaba, MG. **Scientific Horizon** , Uberlândia, v. 11, n. 2, p. 1-12, 2017.

MELO, GL; FERNANDES, ALT Evaluation of empirical methods to estimate reference Evapotranspiration in Uberaba, State of Minas Gerais, Brazil . **Agricultural Engineering** , Jaboticabal, v. 32, n. 5, p. 875-888, 2012.

OLIVEIRA, ER; SILVA, TC; RAMOS, RFO Reference evapotranspiration in Januária-MG by the class "A" tank and Hargreaves-Samani methods . **Colloquium Agrariae** , Presidente Prudente , v. 16, no. 1, p. 48-54, 2020.

OLIVEIRA, GQ; LOPES, A. S.; JUNG, LH; NAGEL, PL; BERTOLI, DM Performance of reference evapotranspiration estimation methods based on air temperature, in Aquidauana-MS. **Brazilian Journal of Irrigated Agriculture** , Fortaleza, v. 5, n. 3, p. 224-234, 2013.

OLIVEIRA, LFC; CARVALHO, DF; ROMÃO, PA; CORTÊS, FC Comparative study of reference evapotranspiration estimation models for some locations in the State of Goiás and the Federal District . **Tropical Agricultural Research** , Goiânia, v. 31, n. 2, p. 122-126, Nov. 2007.

OLIVEIRA, VMR; DANTAS, GF; PALARETTI, LF; DARLI, AB; SANTOS, MG; FISCHER FILHO, JA Reference evapotranspiration estimate in the Paranaíba River region-MG. **Irriga** , Botucatu, v. 20, n. 4, p. 790-798, 2015.

PEREIRA, AR; VILLA NOVA, NA; SEDYIAMA, GC **Evapo (transpiration)** . Piracicaba: FEALQ, 1997. 183 p.

PEREIRA, DR; YANAGE, SNM; MELLO, CR; SILVA, AM; SILVA, LA Performance of reference evapotranspiration estimation methods for the Serra da Mantiqueira region, MG, **Ciência Rural** , Santa Maria, v. 39, n. 9, p. 2488-2493, Dec. 2009.

PRIESTLEY, CHB; TAYLOR, RJ On the assessment of surface heat flux on evaporation using large scale parameters. **Monthly Weather Review** , Washington, DC, vol. 100, no. 2, p. 81-92, 1972.

RIGONE, ER; OLIVEIRA, GQ; BISCARO, GA; QUEIROZ, MVBM; SILVA LOPES, A. Seasonal performance of reference evapotranspiration in Aquidauana, MS. **Journal of Agricultural Engineering Reveng** , Viçosa, MG, v. 21, no. 6, p. 547-562, 2013.

SILVA, JR; HELDWEIN, AB; HINNAH, FD; BRAND, SI; PUHL, AJ; LEONARDI, M. Adjustment of the reference evapotranspiration estimation equations for Bento Gonçalves and Lagoa Vermelha - RS. **Brazilian Journal of Irrigated Agriculture** , Fortaleza, v. 12, n. 7, p. 3096-3107, 2018.

SILVA, LDB; FOLEGATTI, MV Determination of evapotranspiration of Tanzania grass using an automatic Bowen ratio system and a weighing lysimeter . *In* : BRAZILIAN CONGRESS OF AGROMETEOROLOGY, 12th; LATIN AMERICAN MEETING OF AGROMETEOROLOGY, 3rd, 2001, Fortaleza. **Proceedings** [...]. Jaboticabal, Agric. Eng., 2001. p. 705-712.

SILVA, VJ; CARVALHO, HP; SILVA, CR; CAMARGO, R.; TEODORO REF Performance of different methods for estimating daily reference evapotranspiration in Uberlândia, MG. **Bioscience Journal** , Uberlândia , v. 27, n. 1, p. 95-101, 2011.

TURC, L. Estimation of besoins in eau d'irrigation , evapotranspiration potentielle , formula climatique simplifiee et mise . **Journal Annual Agronomic** , Paris , v. 12, no. 1, p. 13-49, 1961.

WILLMOTT, C.J.; ACKLESON, SG; DAVIS, JJ; FEDDEMA, K.; KLINK, DR Statistics for the evaluation and comparison models. **Journal of Geophysical Research** , Ottawa, vol. 90, no. 5, p. 8995-9005, 1985.