ISSN: 1984-5529

Científica

Jaboticabal

v.46, n.2, p.143–150, 2018

http://dx.doi.org/10.15361/1984-5529.2018v46n2p143-150

Comparative performance of empirical methods to estimate the reference evapotranspiration in Aquidauana, MS, Brazil

Comparação do desempenho de métodos para a estimativa da evapotranspiração de referência, em Aquidauana-MS

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Recebido em: 28-03-2017; Aceito em: 21-02-2018

Abstract

Estimating the reference evapotranspiration is quite useful when managing irrigation, as before picking the right method; it is necessary to analyse local's climatic conditions. Therefore, the aim of this study was to evaluate the performance of empirical methods to estimate ET_0, comparing them with FAO reference evapotranspiration from Penman-Monteith equation, for the region of Aquidauana, Brazil. The empirical methods used were Camargo (CM), Hargreaves-Samani (HS), Jensen-Haise (JH) and Priestley & Taylor (PT). The climatic variables were obtained from a station of the National Institute of Meteorology (INMET), located in Aquidauana, MS, collected between January of 2008 and December of 2014. In order to compare the values of ET_0 obtained from the empirical equations with the standard method of Penman-Monteith, it was considered the following parameters: regression equation (a and b), coefficient of determination (R^2), Willmott's index (d) and C-index (c), as both for dry and rainy period. The method of Priestley & Taylor was the one that presented the closest value to Penman-Monteith equation, followed by the method of Jensen-Haise. The methods of Hargreaves-Samani and Camargo are not recommended to the region of Aquidauana, MS.

Additional keywords: climatic elements; irrigation management; Penman-Monteith equation.

Resumo

Estimar a evapotranspiração de referência (ET_0) é bastante útil para o manejo da irrigação, pois para selecionar o melhor método a ser utilizado é necessário analisar as variáveis climáticas disponíveis no local. O objetivo deste trabalho foi avaliar o desempenho dos métodos empíricos para estimativa da ET_0, comparando com o método-padrão de Penman-Monteith, para a região de Aquidauana-MS. Os métodos de análise utilizados foram: Camargo (CM), Hargreaves-Samani (HS), Jensen-Haise (JH), Priestley & Taylor (PT), e as variáveis climáticas foram obtidas na rede de estações do Instituto Nacional de Meteorologia (INMET), situado em Aquidauana-MS, entre janeiro de 2008 e dezembro de 2014. Para se comparar os valores de ET_0 estimados por meio das equações empíricas com os do método-padrão, foram considerados os seguintes parâmetros: equação de regressão (a e b), coeficiente de determinação (r^2), índice de concordância (d) e o índice de desempenho (c), tanto para o período seco como para o chuvoso. O método de Priestley & Taylor obteve o valor mais próximo do método-padrão de Penman-Monteith dentre os analisados neste trabalho, sendo seguido pelo Jensen-Haise. Os métodos de Hargreaves-Samani e Camargo são desaconselhados para a região de Aquidauana-MS.

Palavras-chave adicionais: elementos climáticos; manejo de irrigação; Penman-Monteith.

Introduction

The hydrological cycle consists in a constant water exchange between the ground surface and the atmosphere. The surface evapotranspiration is defined according to Araujo et al. (2011) as the amount of water loss evaporated and transpirated from a surface covered by vegetation during any period of time.

The reference evapotranspiration (ET_0) is an important meteorological parameter, not only as a climatic element of water demand used for meteorological studies, but also an important tool for the agriculture, especially when managing irrigation supply (Carvalho et al., 2011).

According to Pereira et al. (2002), ET_0 is the amount of water that would be used by a surface covered by a 8 to 15 cm tall grass vegetation in active growth, fully covering the ground surface and with no lack of water.

There are many methods to estimate ET_0, ranging from empirical ones which are the simplest to those filled with more scientific basement. This diversity of methods is due to the response of water transference in the soil-plant-atmosphere system under different edaphoclimatic conditions (Carvalho et al., 2011). As the empirical methods use data from local meteorological stations, they are set to better suit the study model in some cases (Pereira et al., 2002).

Among all methods to estimate ET_0, the Penman-Monteith equation is recommended by FAO as the standard method for the estimative of ET_0, as well as, when calibrating empirical methods due to present great performance even when applied in different climatic conditions. However, due to require plenty of climatic data, the use of the FAO method may not be possible in certain locations (Palaretti et al., 2014).

Therefore, before picking the right method to estimate ET_0, it is necessary to know which climatic elements are available as the use of a certain method is totally dependent on them availability (Araujo et al., 2007).

The use of empirical methods throughout available climatic data can be an alternative to local farmers when growing crops under irrigation supply. Thus, the aim of this study was to evaluate the performance of empirical methods to estimate ET_0 for the region of Aquidauana, State of Mato Grosso do Sul, Brazil.

Material and methods

The climatic data was collected between 1st January of 2008 and 31st December of 2014, and it was obtained from the National Institute of Meteorology (INMET), located in Aquidauana in the coordinates 20° 20' 8" S and 55° 48' 15" W with average elevation of 191 m. The region climate is classified according to Köppen as Aw, tropical sub-humid with an average annual precipitation of 1231 mm.

It was used climatic data daily collected, such as air temperature (°C), relative air humidity (%), wind speed at 2 m above soil surface ($m\ s^{-1}$) and average solar radiation ($MJ\ m^2\ day^{-1}$). The data was then divided in two seasonal periods, rainy (October to March) and dry (April to September).

In order to estimate ET_0, the following methods were tested and compared to the Penman-Monteith equation: Camargo, Hargreaves-Samani, Jensen-Haise, and Priestley & Taylor.

Penman-Monteith Method (PM)

Recommended by FAO as the standard method, the Penmam-Monteith equation (equation 1) considers some constant parameters, such as grass height set in 0.12 m from the surface, stomatal resistance of 70 $s\ m^{-1}$ and albedo of 0.23. The value of heat flow in the soil was considered zero (Allen et al., 1998). The following equation below shows the method.

$$ET_0PM = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{med}+273.16} U_2(e_s - e_a)}{\Delta + \gamma(1+0.34U_2)} \quad (1)$$

Wherein: ET_0PM is the reference evapotranspiration according to Penman-Monteith method ($mm\ d^{-1}$), Δ is the declination of the curve of water vapour saturation ($kPa\ ^oC^{-1}$), R_n is the radiation balance ($MJ\ m^{-2}\ d^{-1}$), G is the soil heat flow ($MJ\ m^{-2}\ d^{-1}$), γ is the psychrometric constant ($kPa\ ^oC^{-1}$), U_2 is the average wind speed at 2 m above the soil surface ($m\ s^{-1}$), T_{med} is the average air temperature (°C), e_s is the vapour pressure saturation, and e_a is the actual vapour pressure (kPa).

Camargo Method (CM)

Camargo (1971), based on results obtained from the method of Thornthwaite, proposed a method based only on data from average air temperature and extraterrestrial solar radiation shown by equation 2 below.

$$ET_0CM = K\ R_a\ T_{med}\ ND \quad (2)$$

Wherein: ET_0CM is the reference evapotranspiration according to Camargo method ($mm\ d^{-1}$), R_a is the incoming extraterrestrial solar radiation above the atmosphere on the 15th day of each month ($mm\ d^{-1}$ equivalent evaporation), T_{med} is the average daily temperature of period (°C), ND is the number of days in the observed period, and K is the adjustment factor.

The adjustment factor (K) varies with the annual average temperature of the place, according to the established limits in Table 1.

Hargreaves-Samani Method (HS)

This method was developed by Hargreaves & Samani (1985), in California, USA, under semi-arid conditions where the data was obtained from a lysimeter covered by grass (Pereira et al., 1997) and described according to equation 3.

$$ET_0HS = 0.00135\ kt\ R_a(T_{max} - T_{min})^{0.5}(T_{med} + 17.8) \quad (3)$$

Wherein: ET_0HS is the reference evapotranspiration according to Hargreaves-Samani ($mm\ d^{-1}$), kt is the coefficient used in continental regions (0.162) (dimensionless), Ra is the extraterrestrial radiation ($mm\ d^{-1}$ equivalent evaporation), T_{max} is the maximum air temperature (°C), T_{min} is the minimum air temperature (°C), T_{med} is the average air temperature (°C).

Table 1 - Adjustment factor value (K) in relation to the annual average temperature.

Ta(ºC)	< 23.5	23.6 to 24.5	24.6 to 25.5	25.6 to 26.5	26.6 to 27.5	> 27,5
K Value	0.01	0.0105	0.011	0.0115	0.012	0.013

According to Camargo & Camargo (2000).

Jensen-Haise Method (JH)

Jensen and Haise developed equation (4) to estimate ET_0 in arid regions (Pereira et al., 1997).

$$ET_0JH = R_s(0.025T_{med}+0.08) \quad (4)$$

Wherein: ET_0JH is the reference evapotranspiration according to Jensen-Haise method (mm d^{-1}), R_S is the solar radiation converted into units of evaporated water (mm d^{-1}), T_{med} is the average daily air temperature (°C).

Priestley & Taylor Method (PT)

This method is also used in to estimate ET_0 as it is quite similar to the method of Penman-Monteith. In the Priestley & Taylor equation (5), the balance of radiation is corrected by an empirical coefficient "α", known as a parameter of Priestley & Taylor (1972), which incorporates the additional energy to the process of evapotranspiration coming from the aerodynamic term.

$$ET_0PT= \frac{\alpha \frac{(\Delta+\gamma)}{\gamma}(R_n - G)}{\lambda} \quad (5)$$

Wherein: ET_0PT is the reference evapotranspiration according to Priestley & Taylor method (mm d^{-1}), α is the Priestley & Taylor parameter (1.26) (dimensionless), R_n is the radiation balance (MJ m^{-2} d^{-1}), Δ is the declination of the curve of water vapour saturation (kPa $^oC^{-1}$), γ is the psychrometric constant (kPa $^oC^{-1}$), and λ is the latent heat flow (2.5 MJ kg^{-1}).

Data analysis

The performance analysis was run comparing the ET_0 values obtained by the empirical methods with the Penman-Monteith standard method. Correlation and linear regression analysis were performed to obtain the coefficients of equation (Y = a + bx) and coefficient of determination (R^2). For the accuracy of empirical methods, the statistical analysis was done to determine the concordance index (d) of Willmott et al. (1985), performance index (c), obtained respectively by equations 6 and 7, and the values of the C-index, interpreted according to Table 2 (Camargo & Sentelhas, 1997).

$$d = 1 - \frac{\sum_{i=1}^{n}(Pi - Oi)^2}{\sum_{i=1}^{n}\left(|Pi - \bar{O}| + |Oi - \bar{O}|\right)^2} \quad (6)$$

Wherein: d is the concordance index, Pi is the values estimated by methods (mm d^{-1}), Oi is the values estimated by the standard method - Penman-Monteith (mm d^{-1}), $\bar{O}$ is the mean values estimated by the standard method (mm d^{-1}).

$$C = r\, d \quad (7)$$

Wherein: C is the performance index, r is the correlation coefficient, and d is the concordance index.

The indication of the best methods to estimate ET_0 for the Aquidauana county, MS, Brazil, was carried out according to the criteria proposed by Camargo & Sentelhas (1997) (Table 2), establishing priority and ascending order for the methods that presented the highest performance index (C), greater than 0.65.

Table 2 - Interpretation of the performance index (C) to estimate ET_0.

C	Classification
> 0.85	Great
0.76-0.85	Very good
0.66-0.75	Good
0.61-0.65	Median
0.51-0.60	Tolerable
0.41-0.50	Bad
≤ 0.40	Terrible

The validation of the models was obtained according to the mean absolute error (MAE) and root mean square error (RMSE). All statistical calculations were performed with the software Microsoft Office Excel®.

Results and discussion

The Table 3 shows the averages of the reference evapotranspiration (ET_0) for Aquidauana, MS, Brazil, monthly obtained by the methods of Camargo (ET_0CM); Hargreaves-Samani (ET_0HS); Jensen-Haise (ET_0JH); Priestley & Taylor (ET_0PT) and Penman-Monteith (ET_0PM).

Therefore, by the means of daily ET_0 data for the dry period (Table 4) and the comparison of the methods evaluated with the standard method, it was observed that among all empirical methods analyzed, the one that presented better performance was the ET_0PT, with performance index value "C", which is classified as very good, presenting correlation coefficient (r) of 0.90 - very strong, performance coefficient (C) of 0.85 and concordance coefficient (d) of 0.949.

Table 3 - Averages of reference evapotranspiration (ET_0) in Aquidauana, MS, Brazil.

Month	ET_0HS	ET_0CM	ET_0JH	ET_0PT	ET_0PM
	mm d^{-1}				
January	5.51	5.01	6.72	5.53	4.86
February	5.23	4.82	6.79	5.52	4.81
March	4.79	4.27	6.36	5.07	4.42
April	4.14	3.45	5.09	3.96	3.60
May	3.25	2.56	3.89	2.97	2.78
June	2.93	2.25	3.19	2.40	2.39
July	3.30	2.35	3.90	2.81	2.89
August	4.25	2.93	4.43	3.36	3.62
September	4.99	3.83	5.47	4.21	4.53
October	5.47	4.55	6.18	4.96	4.79
November	5.75	4.91	6.97	5.66	5.11
December	5.79	5.19	7.59	6.12	5.44
Mean	4.62	3.84	5.55	4.38	4.10
MI-PM*	0.52	-0.26	1.45	0.28	-

MI-PM: Difference between the means of reference evapotranspiration of empirical methods with the mean of the Penman-Monteith standard method of FAO-56.

Table 4 - The performance of empirical methods to estimate daily ET_0 during dry period, between 2008 and 2014 in Aquidauana, MS, Brazil.

Methods	d	R	C	Performance
CM	0.720	0.686	0.494	Bad
HS	0.828	0.783	0.648	Median
JH	0.811	0.913	0.741	Good
PT	0.949	0.904	0.858	Very good

CM: Camargo method; HS: Hargreaves-Samani method; JH: Jensen-Haise method; PT: Priestley & Taylor method; r: correlation coefficient; d: concordance coefficient; C: performance coefficient.

Then, the method that presented satisfactory performance index was ET_0JH with good performance, presenting values of r, C and d equal to 0.91 – very strong, 0.74 and 0.811, respectively. The ET_0HS and ET_0CM methods presented average and bad performance. It was found low values of r, C and d coefficient for ET_0CM method with 0.68, 0.49 and 0.720, respectively.

For the regression parameters (Figure 1), there is a superiority of the ET_0PT and ET_0JH methods compared to the others, with determination coefficient value (R^2) of 0.8170 and 0.8343, respectively (Figures 1D and 1C). Thus, in this parameter as in the other coefficients, the closer to the unit, the closer is the method to the standard one.

The figure 1D shows that the Priestley and Taylor's trend line almost overlapped the tendency line of the standard method, giving therefore a good adjustment. On the other hand, in the others methods, such as ET_0HS and ET_0CM, it was observed low values of R^2, 0.6124 and 0.4701, respectively, indicating lack of adjustment for the region of Aquidauana.

According to the results observed in Table 5 for rainy period, the methods that presented the best adjustments were ET_0PT and ET_0JH, being classified as "Great" by performance coefficient (C), obtaining values of 0.95 and 0.94, respectively. In addition, they also presented the highest values in the correlation coefficient (r), 0.95 for ET_0PT and 0.97 for ET_0JH, indicating strong correlation with the standard method.

Table 5 - The performance of empirical methods to estimate the daily ET_0 during rainy period, between 2008 and 2014 in Aquidauana, MS, Brazil.

Methods	d	r	C	Performance
CM	0.984	0.473	0.466	Bad
HS	0.988	0.659	0.652	Median
JH	0.970	0.971	0.942	Great
PT	0.995	0.957	0.952	Great

CM: Camargo method; HS: Hargreaves-Samani method; JH: Jensen-Haise method; PT: Priestley & Taylor method; r: correlation coefficient; d: concordance coefficient; C: performance coefficient.

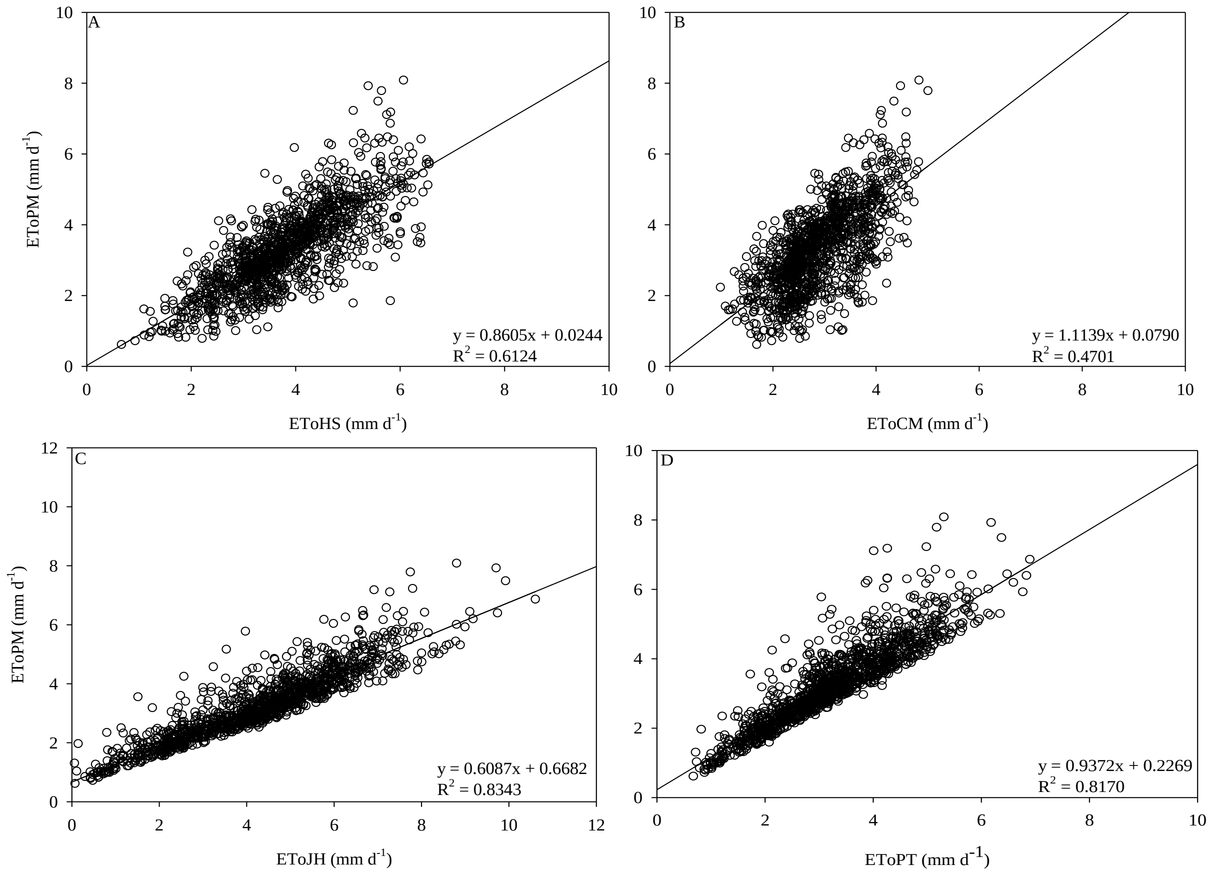

Figure 1 - Linear regression between daily values of reference evapotranspiration (ET_0) during dry period, estimated by comparing the empirical methods of Hargreaves-Samani (A), Camargo (B), Jensen-Haise (C), and Priestley & Taylor (D) to the standard method of Penman-Monteith, between 2008 and 2014 in Aquidauana, MS, Brazil.

According to the results presented in the Table 5, only ET_0HS and ET_0CM methods are not recommended to the region of Aquidauana, MS, Brazil, for presenting performance index (c) below 0.65 (Camargo & Sentelhas, 1997). Also, presenting low values of correlation coefficient (r) indicates low correlation with the standard method.

In the rainy period the methods ET_0PT and ET_0JH presented better performances in comparison to the other empirical methods (Figure 2), with determination coefficient values (R^2) of 0.9154 and 0.9428, respectively (Figures 2D e 2C), presenting better adjustment than in the dry period.

The ET_0CM was the only method that showed an angular coefficient above 1 and also a low value of determination coefficient (R^2) in the two seasonal periods (Figure 1) and (Figure 2). In all the parameters analyzed, there is a lower performance for the Camargo method when estimating ET_0 in the region of Aquidauana.

Souza et al. (2014) found similar results in the region of Santa Tereza, ES, Brazil, where Priestley and Taylor method presented better evaluation when compared to the standard method in the two periods, dry and rainy. They also observed that the Camargo method obtained a lower classification when estimating ET_0.

Borges Júnior et al. (2012) also observed a result quite close to the Penman-Monteith when using the method of Priestley & Taylor in the seasonal periods of spring-summer and autumn-winter. The empirical method provided high values of correlation coefficient (0.92 and 0.97) and reliability index (0.87 and 0.93), which indicates “great” performance for the Garanhuns micro-region, PE, Brazil, in the Southern Agreste Pernambucano. Fietz & Fisch (2008) claimed "very good" performance of this method in the region of Dourados, MS, Brazil.

In relation to cumulative and absolute frequency compared to the relative error, the Priestley and Taylor (ET_0PT) and Jensen-Haise (ET_0JH) methods presented better results, with lower values of percentage relative error (Figure 3).

According to Tanaka et al. (2016), the mean absolute error (MAE) indicator represents the deviation of the averages and provides information about the performance of the model. Thus, in the rainy period (Figure 4A), the ET_0HS and ET_0JH methods underestimated the pattern. On the other hand, the ET_0CM and ET_0PT methods overestimated the standard method, presenting better performance. For the dry period, the ET_0HG, ET_0JH and ET_0PT methods underestimated while the ET_0CM method overestimated the standard method of Penman-Monteith.

Similarly, the smaller the value of the statistical indicator square root of the root square mean error (RMSE), the better is the performance of the model tested. Both for rainy (Figure 5A) and dry period (Figure 5B), the ET_0PT method was the one that presented the best performance.

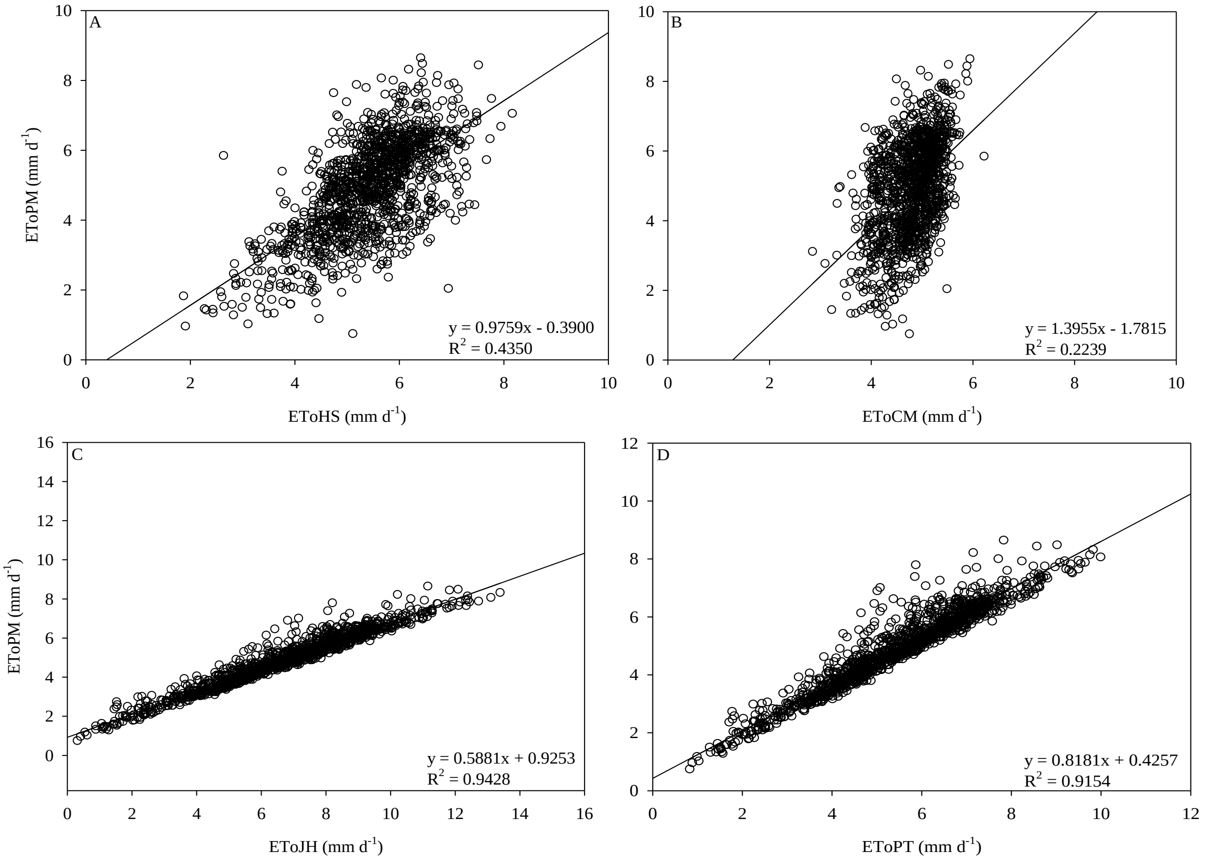

Figure 2 - Linear regression between daily values of reference evapotranspiration (ET_0) in the rainy period, estimated by comparing the empirical methods of Hargreaves-Samani (A), Camargo (B), Jensen-Haise (C), and Priestley & Taylor (D) to the standard method of Penman-Monteith, between 2008 and 2014 in Aquidauana, MS, Brazil.

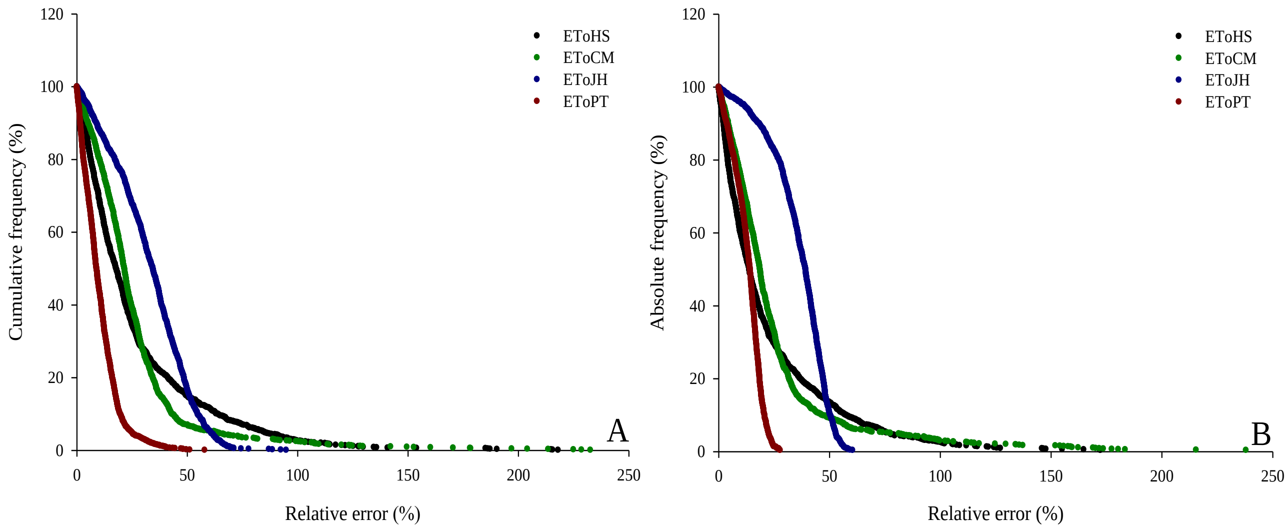

Figure 3 - Cumulative and absolute frequency and relative error of the methods of Hargreaves-Samani (ET_0HS), Camargo (ET_0CM), Jensen-Haise (ET_0JH), and Priestley & Taylor (ET_0PT), in dry and rainy periods in Aquidauana, MS, Brazil.

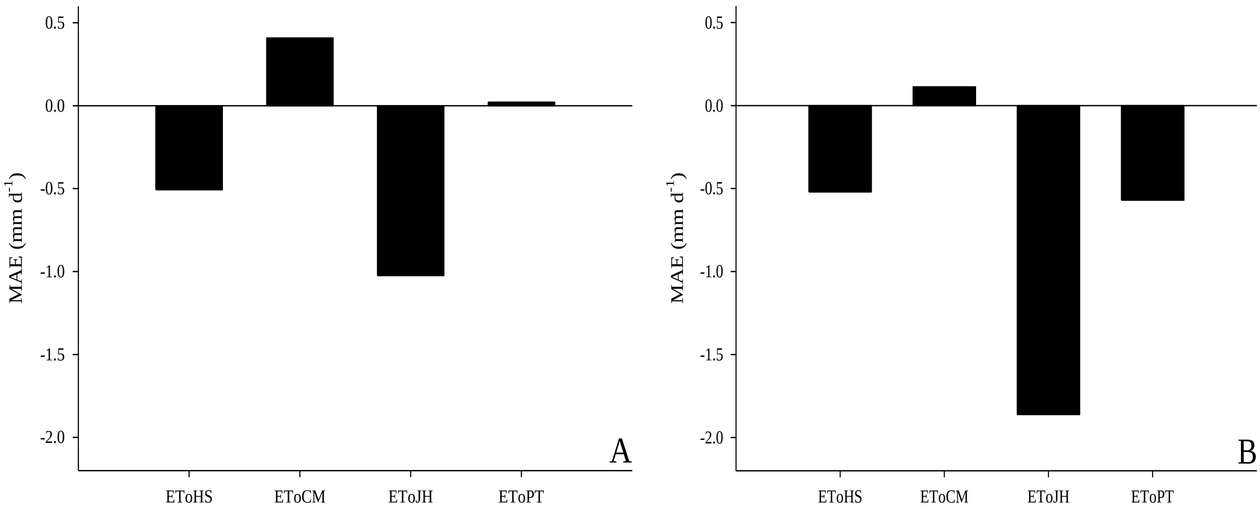

Figure 4 - Mean absolute error (MAE) (mm d^{-1}) of rainy (A) and dry periods (B), estimated by comparing the empirical methods of Hargreaves-Samani (ET_0HS), Camargo (ET_0CM), Jensen-Haise (ET_0JH), and Priestley & Taylor (ET_0PT) to the standard method of Penman-Monteith, between 2008 and 2014 in Aquidauana, MS, Brazil.

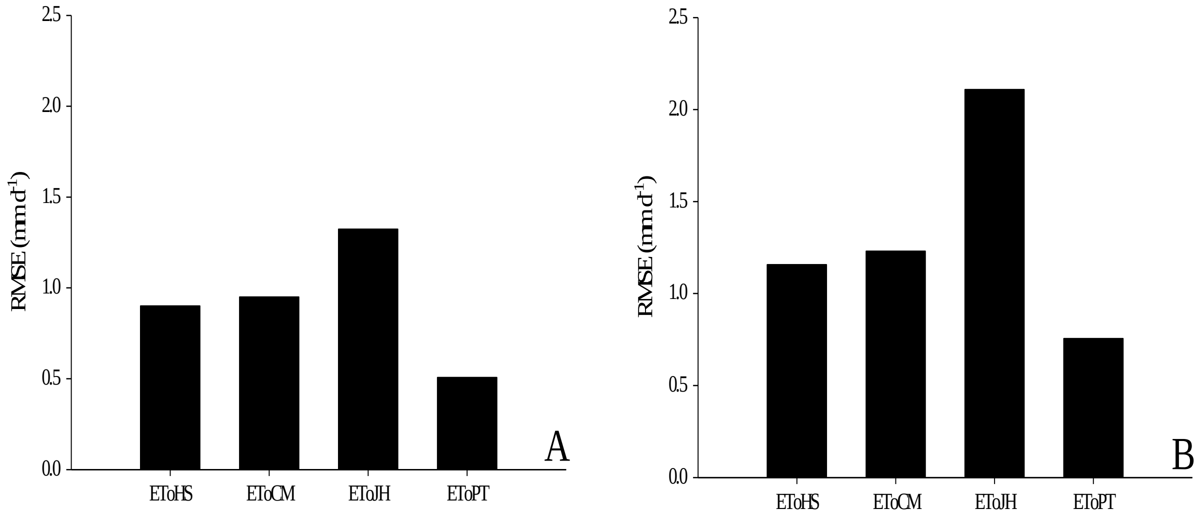

Figure 5 - Root mean square error (RMSE) (mm d^{-1}) of rainy (A) and dry periods (B), estimated by comparing the empirical methods of Hargreaves-Samani (ET_0HS), Camargo (ET_0CM), Jensen-Haise (ET_0JH), and Priestley & Taylor (ET_0PT) to the standard method of Penman-Monteith, between 2008 and 2014 in Aquidauana, MS, Brazil.

Thus of all parameters evaluated, the Priestley and Taylor (ET_0PT) and Jensen-Haise (ET_0JH) methods presented the best performance for the estimate of reference evapotranspiration for the region of Aquidauana, MS, Brazil.

Conclusion

The Priestley & Taylor and Jensen-Haise methods are recommended to estimate the reference evapotranspiration (ET_0), for being the methods that most approached to the standard method in the dry (April to September) and rainy (October to March) periods in Aquidauana, MS, Brazil. The methods ET_0HS and ET_0CM are not recommended for the region of Aquidauana, MS, Brazil for presenting low performance index.

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