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Estimations of reference evapotranspiration using empirical equations for Nossa Senhora da Glória municipaility, Sergipe state

Estimativas da evapotranspiração de refêrencia por equações empíricas para o município de Nossa Senhora da Glória – SE

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Abstract: Studying evapotranspiration is fundamentally important for the correct use of water resources aiming a sustainable management. The objective of this work was to evaluate, compare and recommend one or more methods to estimate evapotranspiration using fewer weather variables for the region of Nossa Senhora da Glória. Data from January 2018 to December 2019 were obtained from the meteorological station in the Embrapa experimental Unit at the Nossa Senhora da Glória campus. The following methods were tested: Blaney-Criddle, Camargo, Linacre, Jensen-Haise, Hargreaves & Samani and Penman-Momteih. This last method is the FAO standard one, and the others were compared to it. Comparisons were performed using the statistical indicators of the Willmott concordance index, plus the coefficients of determination (R^2) and correlation (r), besides the standard error of estimation (SEE) and performance index-c. Regarding the performance index-c, the methods were classified as Blaney-Criddle (very bad), Camargo (bad), Linacre (good), Jensen-Haise (very good) and Hargreaves & Samani (very good). Therefore, the Jensen-Haise was the most suitable method for estimating the reference evapotranspiration with fewer climate variables in the region.

Keywords: Statistical indicators; Penman-Monteith; Water resources.

Resumo: O estudo da evapotranspiração é de fundamental importância na correta utilização dos recursos hídricos, para o gerenciamento de forma sustentável. Com isso, objetivou-se com esse trabalho avaliar, comparar e recomendar um ou mais métodos de estimativa de evapotranspiração com menor número de variáveis meteorológicas para a região de Nossa Senhora da Glória, Sergipe. Os dados de janeiro de 2018 a dezembro 2019, foram obtidos da estação meteorológica localizada na unidade experimental da Embrapa, campus Nossa Senhora da Glória. Foram aplicados os métodos de Blaney-Criddle, Camargo, Linacre, Jensen-Haise, Hargreaves & Samani e Penman-Momteih, que é o padrão da FAO. Os valores estimados por meio destes métodos foram comparados com os obtidos do método de Penman-Monteith, sendo avaliados através dos indicadores estatísticos do índice de concordância de Willmott, coeficiente de determinação (R^2), coeficiente de correlação de Pearson (r), erro padrão de estimativa (SEE) e do índice de desempenho c. Em relação desempenho do índice c, os métodos foram classificados como, Blaney-Criddle (péssimo), Camargo (mau), Linacre (bom), Jensen-Haise (muito bom) e Hargreaves & Samani (muito bom). Portanto o método de Jensen-Haise foi o mais indicado para estimar evapotranspiração de referência com menor número de variáveis climáticas, na região de realização do estudo.

Palavras-chave: Indicadores estatísticos; Penman-Monteith; Recursos hídricos.

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1. Introduction

Studying evapotranspiration is essential in many knowledge areas and fundamental for the proper management of water resources aiming to reduce production costs in agriculture, especially in the municipality of Nossa Senhora da Glória, located in the Brazilian Semiarid region, which is characterized by very long dry seasons. Evapotranspiration is a measurement unit representing water losses in soil and plants via natural evaporation and transpiration phenomena (LOPES et al., 2019).

Evapotranspiration is a crucial component of the water balance since the water passes from the liquid to the gaseous stage during this phenomenon, returning to the atmosphere and interfering with the rainfall process (FALALAKIS and GERMITZI, 2020). Environmental degradation, such as deforestation, air pollution and improper use of water resources, have directly influenced evapotranspiration (FARIDATUL et al., 2020).

When the variation of incident solar radiation and air humidity are affected by rain during rainy seasons, they lead to an inverse ratio between rainfall and evapotranspiration (COLLISCHONN and TUCCI, 2014). According to Souza et al. (2019), deforesting native forests decreased evapotranspiration and precipitation in the rainy season. In 63.89% of the world's territory, there is a negative correlation between air pollution and precipitation, affecting evapotranspiration since particles suspended in the atmosphere reduce the amount of incident solar radiation on the soil. Considering soil is a key factor in evapotranspiration, the lack of solar incidence indirectly reduces water availability for agriculture (GAUTAM et al., 2020).

Four types of evapotranspiration are described in the literature: potential and actual, and those of cropping and reference. They are influenced by various elements, especially vegetation, rainfall, air temperature and humidity, plus wind speed and solar radiation (DANTAS et al., 2018).

Vicente et al. (2018) defined the reference evapotranspiration as the evapotranspiration rate from an extensive land surface covered by a uniformed sward with canopy height varying from 8 to 15 cm. Also, this sward should be in an active growth phase and the soil with excellent moisture conditions.

Reference evapotranspiration is essential to estimate the atmosphere water requirements, which also contributes to determining cropping evaporation. This estimation allows elaborate irrigation and soil fertilization projects, diminishing agricultural losses. Indirect methods can be used to assess the reference evapotranspiration, such as those proposed by Blaney-Criddle (1950), Linacre (1977), Jensen-Haise (1963), Camargo (1971), Hargreaves & Samani (1985) and Penman-Momteih (FAO standard).

Therefore, estimating the reference evapotranspiration is fundamentally important for the correct use of water resources in sustainable management. Based on these premises, the objective of this work was to compare and recommend one or more methods to estimate evapotranspiration using fewer weather variables for the region of Nossa Senhora da Glória, Sergipe state.

2. Methodology

The experimental site comprehended the municipality of Nossa Senhora da Glória (Figure 1), located in the Sergipe state semiarid region (10° 13' 06" S and 37° 25'13" W). This municipality has a 756.7 km^2 area and a 37,324 population. The region's climate is As’ with a warm-dry summer, with a 241-m altitude and annual average temperature of 24.8 °C. The yearly rainfall is 750 mm (ALVARES et al., 2013).

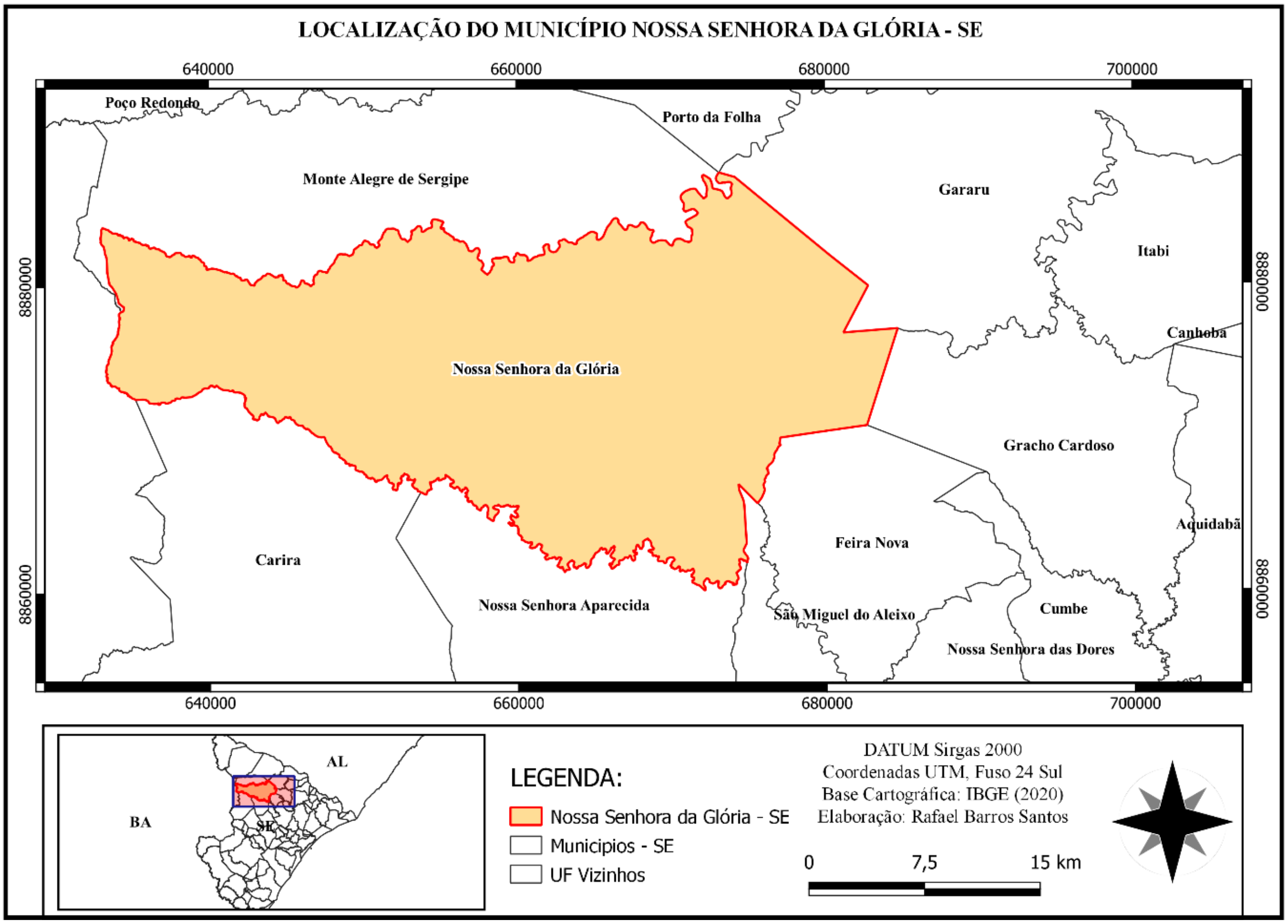

Figure 1 – Geographical location of Nossa Senhora da Glória.
Source: elaborated by the author (2021).

Meteorological data were collected and used from September 2018 to March 2019 and April 2019 to October 2020. They were registered from the automatic meteorological station in the Embrapa experimental unit at the Nossa Senhora da Glória campus, Sergipe state. The meteorological data consisted of air temperature (°C), atmospheric pressure (hPa), air humidity (%), wind speed ($m\ s^{-1}$), radiation balance ($MJ\ m^{-2}\ day^{-1}$), global solar radiation ($MJ\ m^{-2}\ day^{-1}$) and soil heat flux ($MJ\ m^{-2}\ day^{-1}$).

The necessary parameters were calculated from the collected data to process the empirical methods and obtain the daily evapotranspiration (ETo) for each comparable model. The empirical methods used to calculate the ETo were: Blaney-Criddle (1950), Camargo (1971), Linacre (1977), Jensen-Haise (1963), Hargreaves & Samani (1985) and Penman-Momteih (FAO standard).

The method proposed by Camargo (1971) facilities the ETo estimation because it does not requires the average annual temperature (normal climatologic). Equation 1 was used to estimate ETo through this method.

$$ETo = 0{,}01 * Q_o * T_a * ND \quad (1)$$

Where Q_o is the extraterrestrial solar radiation ($mm\ day^{-1}$), T_a is the air temperature during the period, and ND is the number of days.

The method proposed by Linacre (1977) was based on a simplification of that described by Penman-Monteith (Equation 2).

$$\mathrm{ETo} = \frac{\frac{500(T_{med}+0{,}006\mathrm{H})}{100-\varphi}+15(T_{med}-\mathrm{Td})}{80-T_{med}} \tag{2}$$

Where T is the air temperature (°C), φ is the latitude (degrees), H is the altitude (m), and Td is the dew point temperature (° C).

Jensen-Haise (1963) developed an empirical method fitted to semiarid regions, described in Equation 3.

$$\mathrm{ETo} = \mathrm{Rs} * (0{,}025 * \mathrm{T_{med}} + 0{,}078) \tag{3}$$

Where the Rs is the solar radiation (mm $\mathrm{day^{-1}}$), and $\mathrm{T_{med}}$ is the average air temperature.

Blaney-Criddle (1950) developed a method for estimations in the Western USA, specifically in New Mexico and Texas (Equation 4).

$$\mathrm{ETo_{BC}} = \mathrm{cp} * (0{,}46 * \mathrm{T_{med}} + 8{,}13) \tag{4}$$

Where ‘c’ is the adjustment coefficient, P is the total percentage of average monthly photoperiod (°C), and $\mathrm{T_{med}}$ is the average air temperature.

The method of Hargreaves & Samani (1985) is the easiest one to calculate ETo (Equation 5).

$$\mathrm{Eto} = 0{,}0023 * \mathrm{Qo} * (\mathrm{T_{max}} - \mathrm{T_{min}})^{0{,}5}(\mathrm{T_{med}} + 17{,}8) \tag{5}$$

Where $\mathrm{Q_o}$ is the extraterrestrial solar radiation (mm $\mathrm{day^{-1}}$), $\mathrm{T_{max}}$ is the maximal air temperature (°C), $\mathrm{T_{min}}$ is the minimum air temperature (°C), and $\mathrm{T_{med}}$ is the average air temperature (°C).

The method proposed by Penman-Monteith (1998) is one of the most used (Equation 6). It is the FAO standard method.

$$\mathrm{ETo} = \frac{0{,}408\ \mathrm{s}\ (\mathrm{Rn}-\mathrm{G}) + \frac{900\ \mathrm{y}\ \mathrm{U_2}(\mathrm{e_s}-\mathrm{e_a})}{(\mathrm{T_{med}}+275)}}{(\mathrm{s}+\mathrm{y})(1+0{,}34\mathrm{U_2})} \tag{6}$$

Where Rn is the total net daily radiation (MJ $\mathrm{m^{-2}\ day^{-1}}$), G is the soil heat flux (MJ $\mathrm{m^{-2}\ day^{-1}}$), y is the psychrometric constant (0.063 kPa $\mathrm{°C^{-1}}$), T is the average air temperature (° C), and $\mathrm{U_2}$ is the speed wind at 2 m (m $\mathrm{s^{-1}}$). The $\mathrm{U_2}$ represented 75% of the wind speed total value at 2 m, plus 75% of wind speed measured at 10-m height in a meteorological station. The ‘s’ is the slope declination of steam pressure in the air (kPa $\mathrm{°C^{-1}}$) calculated in Equation 7. Moreover, the $\mathrm{e_s}$ is the pressure of steam saturation (kPa) while $\mathrm{e_a}$ is the partial pressure of steam saturation, calculated in Equations 7 and 8.

$$\mathrm{s} = \frac{4098 \times \mathrm{e_s}}{(\mathrm{T}+237{,}3)^2} \tag{7}$$

$$\mathrm{e_s} = 0{,}6108 \times (10)^{\left(\frac{7{,}5\mathrm{T}}{237{,}3+\mathrm{T}}\right)} \tag{8}$$

$$\mathrm{e_a} = \frac{(\mathrm{e_s} \times \mathrm{UR})}{100} \tag{9}$$

We compared the estimated values for ETo in each method to those obtained in FAO standard (PENMAN-MONTEITH, 1998) via the subsequent statistical indicators: coefficient of determination ($\mathrm{R^2}$), coefficient of Pearson linear correlation (r), standard error of estimation (SEE), Willmott concordance index (WILLMOTT et al., 1985) and performance index-c. Sentelhas and Camargo (1997) proposed this last indicator, and the data dispersion near to regression line was measured by the SEE (Equation 10).

$$\mathrm{SEE} = \sqrt{\left(\frac{\sum \mathrm{E_i} - 0_1}{\mathrm{n}-1}\right)} \tag{10}$$

Where $\mathrm{E_i}$ and $\mathrm{O_i}$ are the values estimated in each method (mm $\mathrm{day^{-1}}$), and ‘n’ is the number of observations.

The Willmott index allows for assessing deviations between estimated values in the tested methods and those obtained in the FAO standard (Equation 11). This index varies from zero to one; the lower the deviation better is the performance.

$$d = 1 - \left[\frac{\sum (P_i - O_i)^2}{\sum \left(|P_1 - O \quad| + |O_i - O| \right)^2} \right] \tag{11}$$

Where P_i is the value estimated in the Penman-Monteith method, O_i is the observed value in each tested method, and O is the mean of observed values.

The index-c (Table 1) was calculated by multiplying the coefficient of Pearson linear correlation (r) by the Willmott index (d).

Table 1 – Index-c values for interpretations of estimation performance.

Index-c value	**Performance**
> 0.85	Excellent
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Intermediate
0.51 a 0.60	Passable
0.41 a 0.50	Bad
≤ 0.40	Very bad

Source: Camargo and Sentelhas (1997).

3. Results and Discussion

The statistical indicators can be observed in Figure 2. Both coefficients of determination (R^2) and the graphics of linear regressions were performed in the comparisons between the FAO standard (Penman-Monteih, 1998) and the other methods. The Blaney-Criddle showed the lowest R^2 plotted with the standard method, approximately 13% (Figure 2b). The Camargo method was the second worst, but with R^2 adjusted at almost 66% (Figure 4e). This result probably occurred due to using only meteorological variables of air temperature plus the extraterrestrial solar irradiation predicted by Camargo (1971). Lima et al. (2021) registered a low fit of the Camargo method to the Penman-Monteih standard, with just 26% of R^2 when they studied ETo estimations based on air temperature models at the Estreito municipality, Maranhão state.

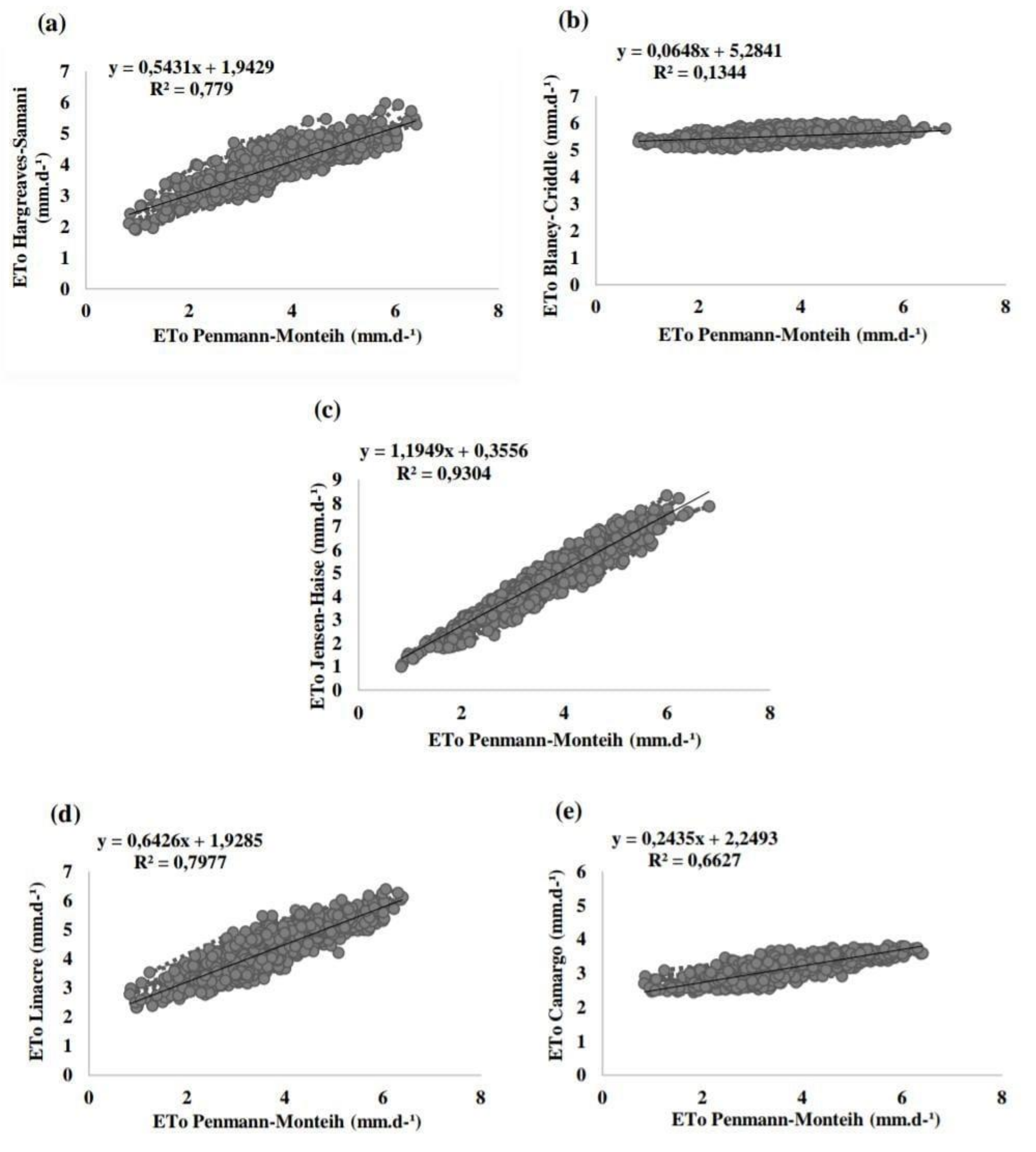

Figure 2 – Graphic representation of the linear regression between daily reference evapotranspiration values (ETo) estimated with the Penman-Monteih/FAO standard (x-axis) compared to those obtained with the methods proposed by Hargreaves & Samani (a), Blaney-Criddle (b), Jensen-Haise (c), Linacre (d), Camargo (e), besides the determination coefficients (R^2). The experimental period lasted from 09/12/2018 to 10/27/2020.
Source: Authors themselves (2021).

The Jensen-Haise was the fittest method to the Penman-Monteih/FAO standard, with an R^2 of 93% (Figure 2c). Such performance may be related to the experimental site weather conditions. Lopes et al. (2018) observed R^2 results of about 92% for the Jensen-Haise method adjusted to this standard when the authors estimated ETo in Areia municipality, Paraíba state. It is worth pointing out that Areia has the same climate classification as Nossa Senhora da Glória (As). In this context, Sales et al. (2018) evaluated the ETo in São Mateus at Espírito Santo state and reported an R^2 value of 99%.

Moreover, Hargreaves & Samani and Linacre methods displayed comparable R^2 values, approximately 78 and 80%, respectively (Figures 2a and 2d). Dantas et al. (2016) found similar results, with almost 82% of R^2.

The SEE results are registered in Table 2, as well as those of Pearson correlation coefficients (r) and index-c, which worked as a parameter to classify the methods' performance.

The Hargreaves & Samani method showed the lowest SEE value (0.48), followed by Camargo (0.75), Linacre (0.77), Jensen-Haise (1.03) and Blaney-Criddle methods (1.34) (Table 2). In this context, Rocha et al. (2015) found different results when comparing methods to estimate ETo. They reported 1.20 for the Hargreaves & Samani method, a very higher value than we found. According to the authors, such performance may be related to a lower yearly temperature in the experiment location, at Garanhuns, Pernambuco state. This municipality presents an annual average of 20 °C while Nossa Senhora da Glória shows 24.8 °C historically, which may justify such discrepancies between the methods.

The highest coefficient of Pearson linear correlation was observed in the Jensen-Haise method (r = 0.96). Lima et al. (2019) reported comparable results when assessing bioclimatic equations to calculate the ETo in Conceição do Araguaia, a municipality of Pará state, with a 0.88 coefficient for the Jensen-Haise method. This method probably adjusted well to Nossa Senhora da Glória municipality because it was developed to estimate ETo in arid and semiarid regions (RIBEIRO, SIMEÃO & SANTOS, 2016; SANTANA et al., 2019).

Linacre and Hargreaves & Samani's methods were similar regarding their Pearson correlations with Penman-Monteith/FAO standard (r = 0.89 and r =0.88, respectively), while the Camargo method was relatively inferior (r = 0.81). Conversely, the Blaney-Criddle method had the lowest correlation with the standard (r = 0.37), a weak correlation. This inefficient performance may be associated with using tabulated data to calculate the ETo, probably leading to errors (CUNHA et al., 2013).

Table 2 – Statistical indicators of Pearson correlation coefficients (r), standard error of estimation (SEE) and index-c value to classify the estimation performance.

Method	SEE	r	Index-c value	Performance
Camargo	0.75	0.81	0.44	Bad
Linacre	0.77	0.89	0.75	Good
Jensen-Haise	1.03	0.96	0.79	Very good
Blaney-Criddle	1.34	0.37	0.03	Very bad
Hargreaves & Samani	0.48	0.88	0.76	Very good

Source: Camargo and Sentelhas (1997).

The Jensen-Haise and Hargreaves & Samani's methods were classified as very good regarding their performances to estimate ETo, with index-c values of 0.79 and 0.76, respectively. Santos et al. (2017) noted different results than ours, observing 0.71 and 0.60 for these two methods evaluated in Petrolina municipality, Pernambuco state. Dissimilar weather conditions may have affected results since the Petrolina climate is classified as BSwh (ALVARES et al., 2013), with rainy summer seasons, contrasting sharply with Nossa Senhora da Glória, which shows dry summer seasons. The Linacre method had a good classification with a 0.75 index-c value (Table 2), different from those results reported by Souza (2020). The author classified this method as very bad and registered an index-c value of 0.25 when calculating ETo in Rio Branco, the capital of Acre state. The tropical rainy weather of this Amazon region is very different from that of Nossa Senhora da Glória, a semiarid zone showing a warm-dry season. Regarding the Camargo method, its bad classification probably is associated with the equation simplicity, when just the air temperature and extraterrestrial solar irradiation were used to calculate the ETo, leading to a low precision (SANTANA et a., 2018).

Results presented in Table 2 revealed the Blaney-Criddle as the worst method, with a very bad performance and 0.03 index-c value. Santos et al. (2017) found similar results: a very bad performance plus a 0.30 index-c value because the experimental site had stable temperatures like in Nossa Senhora da Glória. Conversely, Barros et al. (2018) reported a good performance plus a 0.69 index-c value for the Blaney-Criddle method in a trial carried out at Jacaré Curituba municipality, located in the Baixo São Francisco region.

4. Final considerations

The Jensen-Haise method demonstrated the best performance, compared to the others, for estimating reference evapotranspiration for Nossa Senhora da Glória municipality, Sergipe State.

The Hargreaves-Samani method was a good alternative to estimate reference evapotranspiration for the experimental site by utilizing variables such as extraterrestrial solar irradiation besides average, maximal and minimal air temperatures.

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