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COMPARISON BETWEEN ESTIMATION METHODS OF REFERENCE EVAPOTRANSPIRATION IN BOM JESUS DA LAPA, BA

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ABSTRACT

Among the reference evapotranspiration (ETo) equations, the FAO-56 Penman-Monteith (PM FAO-56) model is considered the most accurate, but this model requires a greater amount of meteorological data. On the other hand, there are other methods that require fewer variables and have shown good precision according to the location. The objective of this work was to evaluate the efficiency of four methods for estimation of daily ETo, comparing them with FAO-56 PM equation in Bom Jesus da Lapa, Bahia, Brazil. To do so, a dataset from 2010 to 2017, acquired at the National Institute of Meteorology (INMET), was used. The models were analyzed by means of statistical indicators: Willmott's concordance index, root mean square error (RMSE), mean bias error (BIAS), coefficient of determination "R²", correlation coefficient "r" and coefficient of confidence "c", in addition to the classification of the coefficient of confidence. The results obtained show that Hargreaves and Samani equation was the only method classified as "good" and is recommended. While the models of Camargo, Priestley and Taylor and Benevides and Lopes are not recommended to calculate ETo in the municipality.

Palavras-Chave:
agrometeorologia
irrigação
Penman-Monteith FAO 56

COMPARAÇÃO DE MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA EM BOM JESUS DA LAPA, BA

RESUMO

Dentre as equações de estimativa de evapotranspiração de referência (ETo), o modelo Penman-Monteith FAO-56 (PM FAO-56) é considerado o mais preciso, entretanto esse modelo requer uma maior quantidade de variáveis meteorológicas. Por outro lado, existem outros métodos que demandam menos variáveis e tem conseguido boa precisão, a depender do local. O objetivo deste trabalho foi avaliar para as condições de Bom Jesus da Lapa, Bahia, a eficiência de quatro métodos para a estimativa da ETo diária, comparando-os com o padrão de PM FAO-56. Para tanto, foi utilizado um conjunto de dados de 2010 à 2017, adquiridos no Instituto Nacional de Meteorologia (INMET). Os modelos foram analisados por meio de indicadores estatísticos: índice de concordância "d" de Willmott, raiz do erro quadrático médio (RMSE), erro sistemático (BIAS), coeficiente de determinação "R²", coeficiente de correlação "r" e coeficiente de confiança "c", além da classificação do coeficiente de confiança. Os resultados obtidos indicam que a equação de Hargreaves e Samani e método de Priestley e Taylor foram classificados como "bom", sendo recomendado. Enquanto os modelos de Camargo e Benevides e Lopes não são metodologias recomendadas para cálculo da ETo no município.

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INTRODUCTION

Irrigated farming activities imply in a large consumption of water. Moreover, its scarcity has become more and more worrying, so, efforts have been used in the development of studies that make possible its economy through the rational use. The municipality of Bom Jesus da Lapa in the State of Bahia presents itself with zoning and classification for investment in agricultural production, where irrigated production is found in large areas as it is located in the São Francisco Basin.

Farming activities are highly dependent on meteorological elements, which make them determining factor for agriculture (Sales *et al*., 2018a). Through these elements, it is possible to obtain knowledge of the evapotranspiration of the agro-ecosystem, whether for irrigation design and / or management, assuming fundamental importance.

One alternative for rationalize the use of water in farming projects is to estimate the crop evapotranspiration (ETc), based on the reference evapotranspiration (ETo) and on the crop coefficient (Kc), so, the water depth needed by the crop can be correctly applied (COSTA *et al*., 2019). Thus, the determination of ETo is imperative to make a water calculation of a crop, and as a result, it may assist in irrigation and river basin management strategies depending on the climatic conditions of each region (Sales *et al*., 2016).

There are several models for determining ETo such as the direct ones, which are represented by lysimeters, and the indirect ones, consisting of empirical mathematical equations. Because of the difficulties of direct measurement of evapotranspiration, as well as its importance in the management of water resources, the choice of a method that estimates it accurately and based on climatological variables available at the study site is essential, because both the climatological variables and the precision of the models factors that restrict their use (FANAYA JÚNIOR *et al*., 2012).

Therefore, before choosing the method to be used to estimate ETo, it is necessary to know which climatic elements are available and, based on that, to check which methods can be applied. This is necessary, since the use of different methods for a particular place of interest depends on these variables and their precision (ARAÚJO *et al*., 2007).

Food and Agriculture Organization of the United Nations (FAO) establishes Penman-Monteith parameterized equation as standard model in the Bulletin 56 of the institution. This physical-physiological model estimate ETo with adequate accuracy, but requires a greater number of meteorological variables, which may not be available in some regions (CONCEIÇÃO, 2013).

Thus, the objective of this work was to evaluate the efficiency of the methods of Camargo, Benevides and Lopes, Hargreaves and Samani and Priestley and Taylor to estimate the daily ETo in the period from 2010 to 2017 for the conditions of Bom Jesus da Lapa (BA), compared to the standard Penman-Monteith method.

MATERIAL AND METHODS

The study was carried out using meteorological data from the municipality of Bom Jesus da Lapa (13º15’18” S and 43º25’05” W and 436 m above sea level), which has a total territorial area of 4,115,511 km² and located in the state of Bahia, in the Northeast of Brazil (Figure 1).

The average annual rainfall index is 833 mm, occurring most intensely between October and March (spring-summer). The climatic type of the region, according to the Köppen-Geiger climatic classification, is the tropical climate with dry winter season (INMET).

For the calculation of ETo, daily climatological data of maximum, minimum and average temperature, relative humidity, solar radiation and wind speed were required. These data were obtained from the automatic meteorological station owned by the National Institute of Meteorology (INMET) from January 1, 2010 to December 31, 2017.

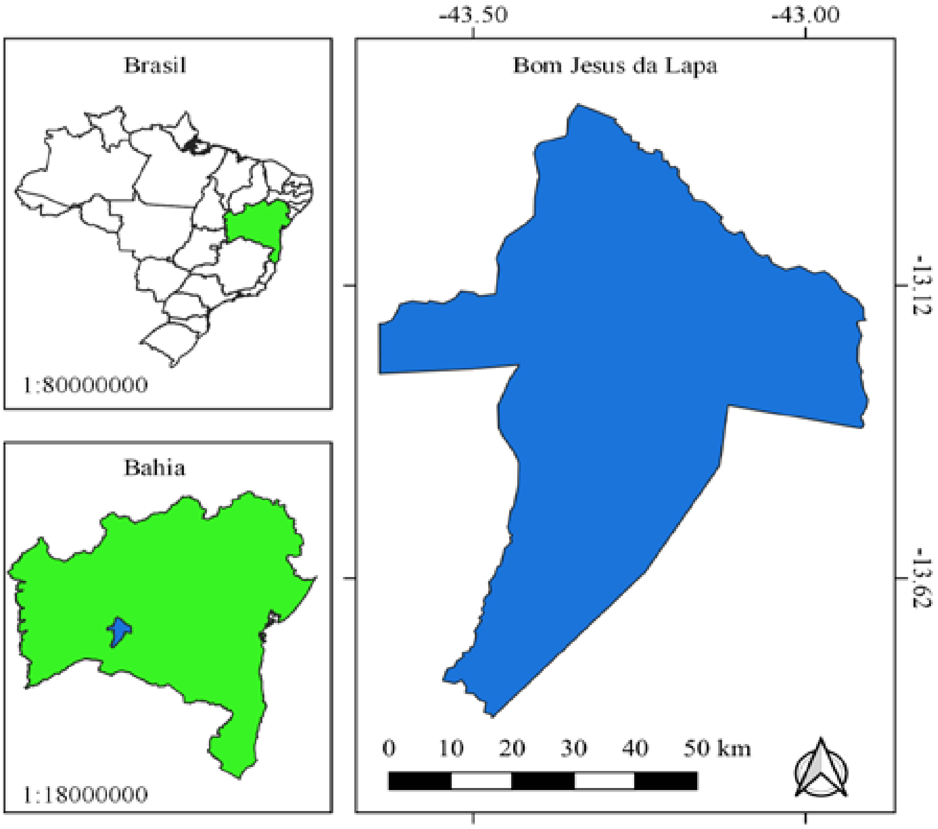

Figure 1. Geographical location of the municipality of Bom Jesus da Lapa, Bahia.

Prior to the calculations of ETo, an analysis was carried out to verify the quality of the data and to exclude possible measurement errors in the field. Based on the methodology proposed by Sales et al. (2018b), data inconsistent with the following parameters were excluded: minimum temperature below 0°C, maximum temperature above 39°C, maximum temperature less than the minimum temperature for the same day, global solar radiation equal to zero and global solar radiation greater than extraterrestrial solar radiation. Consequently, after these analyses, 2,633 days remained with consistent measurements, corresponding to 90.17% of the data.

Then, the equations used to calculate ETo for the different estimation methods are shown.

Penman Monteith (PM FAO-56)

For ETo estimate, using the Penman-Monteith method, Equation 1 was used, according to FAO Bulletin 56 (Allen *et al.*, 1998).

$$ETo PM = \frac{0.408\,\Delta\,(R_n - G) + \gamma\left(\frac{900U_2}{T_{med} + 273}\right)(e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

In which,

Δ = slope of the saturation water vapor pressure curve, kPa °C^{-1};

R_n = net radiation, MJ m^{-2} d^{-1};

G = soil heat flux density, MJ m^{2} d^{-1};

γ = psychometric constant, kPa °C^{-1};

U_2 = Wind speed (daily average) at 2 m above soil surface;

e_s = vapor saturation pressure, kPa;

e_a = vapor real pressure, kPa, and

T_{med} = average temperature, °C.

Camargo (CM)

The Method of Camargo (1971) is a simplification of the Thornthwaite method. The main advantage of this method is the use of only the daily average air temperature data and the extraterrestrial solar radiation, which can be easily estimated from equations or obtained from specific tables (Equation 2).

$$ETo CM = \frac{0.011 \text{ x Ra}}{2.45} \text{ x } T_{average} \quad (2)$$

In which,
Ra = extraterrestrial solar radiation, MJ m^{-2} d^{-1}, and
$T_{average}$ = air average temperature, ºC.

Benevides and Lopes (BL)

It can be seen in Equation 3 the method developed by Benevides and Lopez (1970), which is based on data of average temperature and relative humidity of the air.

$$ETo BL = 1.21 \text{ x } 10^{\left(\frac{7.5 x T_{average}}{237.3 + T_{average}}\right)} \text{ x } (1 - 0.01 \text{ x RH}) + 0.21 \text{ x } T_{average} - 2.30 \quad (3)$$

In which,
$T_{average}$ = average air temperature, ºC, and
RH = air relative humidity, %.

Hargreaves and Samani (HS)

The model proposed by Hargreaves and Samani (1985) is an alternative to estimate ETo in places where data on solar radiation, relative humidity and wind speed are not available (Equation 4).

$$ETo HS = 0.0023 \text{ x } \frac{Ra}{2.45} (T_{max} - T_{min})^{0.5} (T_{average} + 17.8) \quad (4)$$

In which,
Ra = extraterrestrial solar radiation, MJ m^{-2} d^{-1};
T_{max} = maximum day temperature, ºC;
T_{min} = minimum day temperature, ºC; and
$T_{average}$ = average day temperature, ºC.

Priestley and Taylor (PT)

The Priestley and Taylor Method (1972) is a simplification of the Penman and Penman-Monteith method. Thus, this model has the advantage of requiring less climatological data (Equation 5).

$$ETo PT = 1.26 \text{ x } \left(\frac{\Delta}{\Delta + \gamma}\right) \left(\frac{(R_n - G)}{2.45}\right) \quad (5)$$

In which,
γ = psychrometric constant, kPa ºC^{-1};
Δ = slope of the water vapor saturation curve, kPa °C^{-1};
R_n = net radiation, MJ m^{-2} d^{-1}; and
G = soil heat flux density, MJ m^2 d^{-1}.

For comparative analysis and indication of the best ETo estimation methods for the municipality of Bom Jesus da Lapa, the following statistical indices were used: Willmott's "d" agreement index (WILLMOTT *et al.*, 1985), root of the mean square error (RMSE in mm d^{-1}), systematic error (BIAS in mm d^{-1}), determination coefficient R^2, "r" correlation coefficient and confidence coefficient or performance "c", in addition to the classification of the confidence coefficient (Equations 6, 7, 8, 9, 10).

$$RMSE = \left[\frac{\sum_{i=1}^{n} (E_i - O_i)^2}{N}\right]^{1/2} \quad (6)$$

$$d = 1 - \frac{\sum_i^n (O_i - E_i)^2}{\sum_{i=1}^n (|E_i - \overline{O}| + |O_i - \overline{O}|)^2} \quad (7)$$

$$BIAS = \frac{\sum_{i=1}^{n} (E_i - O_i)}{N} \quad (8)$$

$$R^2 = \left[\frac{\sum_{i=1}^n (E_i - \overline{E})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^n (E_i - \overline{E})^2} \sqrt{\sum_{i=1}^n (O_i - \overline{O})^2}}\right]^2 \quad (9)$$

$$r = \frac{\sum_{i=1}^n (E_i - \overline{E})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^n (E_i - \overline{E})^2} \sqrt{\sum_{i=1}^n (O_i - \overline{O})^2}} \quad (10)$$

In which,
E_i = value obtained by means of the alternative methods (mm d^{-1});
O_i = value estimated through the Penman-Monteith standard method (mm d^{-1});
$\overline{E}$ = mean of the estimated by means of the alternative methods (mm d^{-1}); and
$\overline{O}$ = means of the estimated by means of the Penman-Monteith standard method (mm d^{-1}); and
N = number of values.

The "d" values may range from 0 to any agreement, to 1, for a perfect concordance.

Table 1 shows the confidence coefficient, proposed by CAMARGO & SENTELHAS (1997), which is obtained by the product between the correlation coefficient (r) and the Willmott index (d).

Table 1. Classification of the performance of methods for estimating ETo according to the “c” confidence index

Value of “c” performance index	Classification
>0.85	Excellent
0.76 – 0.85	Very good
0.66 – 0.76	Good
0.61 – 0.65	Medium
0.51 – 0.60	Tolerable
0.41 – 0.51	Bad
≤ 0.40	Terrible

Source: Camargo and Sentelhas (1997).

For all statistical calculations, it was used the Microsoft Office Excel® software in order to assist in the organization of data and also the R open source software (*R core team*, 2016).

RESULTS AND DISCUSSION

The statistical indicators RMSE, BIAS and R^2 for the estimation of daily ETo are shown in Figure 2. The analysis of coefficient of determination R^2 allowed to observe that it varied from 0.34 to 0.66, where the PT method indicated the highest value. However, analyzing R^2 as the sole criterion for selecting the ETo model is not convenient, as this parameter does not indicate the range of differences between a standard value (PM FAO-56) and a value predicted by the alternative models (BARROS *et al.* , 2009).

One of the reasons PT had shown the highest R^2 among the methods under study is because this model uses solar radiation as a predictor variable as this meteorological element is one of the most important in ETo estimate (PANDEY *et al*., 2016). According to Allen *et al*. (1998), the evapotranspiration process is conditioned to the amount of energy available for water evaporation. Also, according to the authors, solar radiation is the most important energy source of the plant and influences the physical processes of water, transforming liquid water into vapor.

Based on the root of the mean square error (RMSE), the methods were ranked in the following order: HS <PT <CM <BL. The HS method obtained an RMSE value of 0.66 mm d^{-1}, while the BL showed an RMSE of 2.98 mm d^{-1}, which is very high in comparison to the others. Such result may be linked to the environmental conditions of the study area, since HS was developed in semi-arid California, with conditions similar to those found in the municipality under study.

The BIAS systematic error shows the under- or overestimation of a model, thus it is possible to observe that HS and BL overestimated, being more accentuated for BL with a systematic error of 2.68 mm d^{-1} while the PT and CM methods underestimated it (Figure 2). These results are in agreement with Santos *et al*. (2017), as when studying ETo in Feira de Santana, state of Bahia, found values for HS overestimating PM FAO-56 in all the months. The authors Borges Júnior *et al*. (2017), when estimating the daily ETo for Sete Lagoas, state of Minas Gerais, found that the original HS has an overestimate tendency.

It is evident that the BL had the greatest overestimation of the standard method PM FAO-56 (Figure 2), in addition to presenting R^2 of 0.44. The trend line of this model is further away from the line 1:1, together with the CM. Therefore, it was evident that BL and CM showed the worst adjustments for the municipality of Bom Jesus da Lapa, State of Bahia.

Table 2 shows the correlations between the ETo estimated through PM FAO-56 and the ETo estimated by means of the other models for Bom Jesus da Lapa, Bahia. Smaller dispersions were found for the HS and PT models, and worse correlations for the estimates obtained using CM and BL models, with respective values of 0.58 and 0.65. The low correlation found for CM and BL was followed by a lower agreement between the data, thus impairing their performance, since it is a product between the correlation and the concordance.

These results are in agreement with those found by Borges Júnior *et al*. (2012), when estimating the daily ETo using different methods in Garanhuns, Pernambuco state, in which a poor performance was observed for CM. It should be highlighted that the method of Camargo was initially proposed to determine ETo for periods from seven days onwards, and for regions with temperate and humid climates, which contributed to its low accuracy (PAZ & THEBALDI, 2018).

According to Araújo *et al*. (2010), when working with ETo in the city of Crateús, state of Ceará, found unsatisfactory results for the BL method, which showed a poor performance. This result was also found in this study, and can be explained by the semiarid climate in the municipalities.

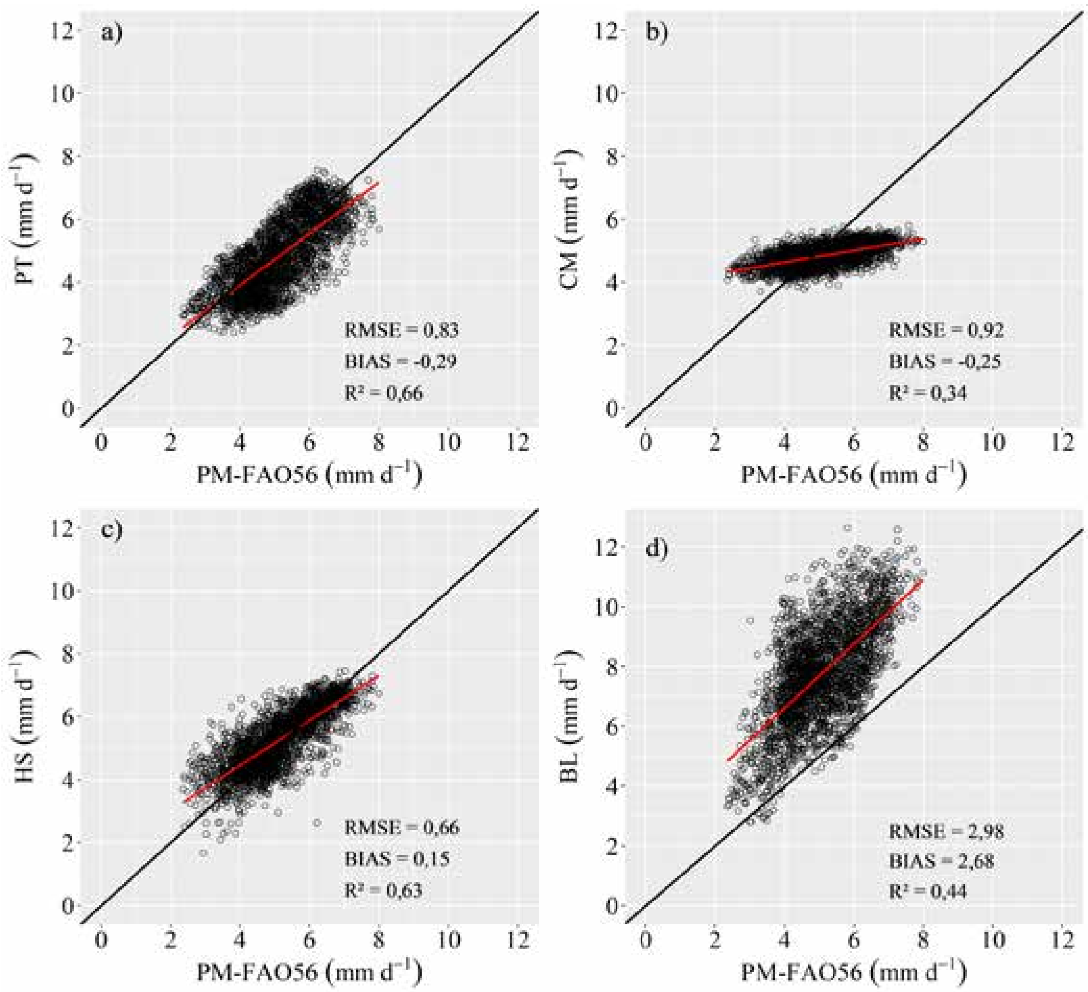

Figure 2. Correlations between the daily reference evapotranspiration (ETo) estimated by means of the Penman-Monteith method (FAO) and the simplified models (PT, CM, HS and BL) over 2010-2017 period, in Bom Jesus da Lapa, Bahia.

Table 2. Evaluation of ETo (mm d^{-1}) estimates obtained through different methods in relation to the standard method, PM FAO-56.

ETo methods	r	d	c	"classification
Penman Monteith (PM FAO56)				
Priestley and Taylor (PT)	0.79	0.84	0.66	Good
Hargreaves and Samani (HS)	0.75	0.88	0.66	Good
Camargo (CM)	0.58	0.53	0.31	Terrible
Benevides and Lopes (BL)	0.65	0.52	0.34	Terrible

Coefficient of correlation (r); Willmott "d" concordance index; "c" confidence coefficient; Confidence coefficient classification.

The correlation and concordance values found through HS and PT are close to those obtained by Tagliaferre *et al*. (2012) by evaluating ETo on a daily scale in the municipality of Piatã, state of Bahia, with a correlation of 0.70 and 0.86 respectively, and with concordance between the data of 0.82 for HS and 0.87 for PT. Studies conducted by Oliveira *et al*. (2010), for the region of Juazeiro, BA showed that the HS method had a performance considered Good.

It is possible to observe in Figure 3 the annual accumulated ETo estimate among the different methods analyzed in the study. The annual sum of ETo estimates by means of BL was 2,889.70 mm

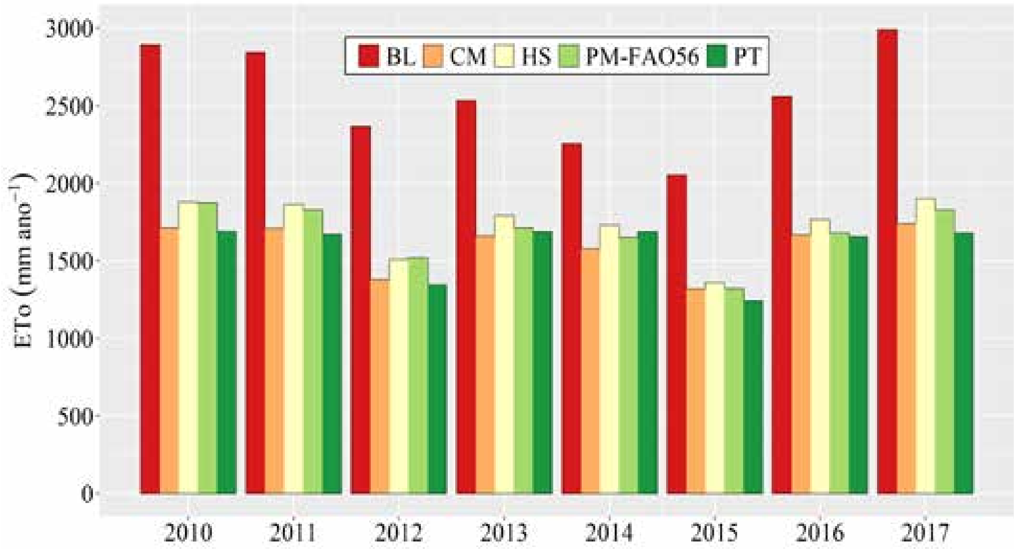

Figure 3. Total annual estimates of ETo (mm $year^{-1}$) provided by the different methods in the 2010-2017 period, in Bom Jesus da Lapa, state of Bahia.

$year^{-1}$ in 2010 to 2,987.23 mm $year^{-1}$ in 2017, while the PM FAO-56 standard showed the value of 1,869.22 mm $year^{-1}$ in 2010 and 1,824.76 mm $year^{-1}$ in 2017. In all the years evaluated, it is observed that the greatest accumulation of ETo always occurred for BL, considered the worst result, in which it is visible through the dispersion graph and the annual accumulated (Figure 2, 3), being much higher than the PM-FAO56 standard method during the eight analyzed years.

When observing the HS model, it can be seen that ETo has always approached the PM-FAO56. However, although CM has presented values closer to that of PM-FAO56 when accumulated annually, their statistics show that it cannot be recommended for the region (Figure 2). This is due to the lower concordance and correlation between the data, thus showing greater variability between them, that is, on specific days, it overestimated very much and on others, it underestimated.

CONCLUSION

- According to the adopted statistical criteria, the methods of Hargreaves and Samani and Priestley and Taylor showed the best performance for daily estimation of ETo, when compared to the PM FAO-56, being recommended to be used in the region under study.
- The methods of Benevides and Lopez and Hargreaves and Samani overestimated reference evapotranspiration.
- Camargo and Benevides and Lopes models are methodologies not recommended for calculating ETo in Bom Jesus da Lapa, Bahia, and require regional calibration of their coefficients so to be used.

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