EVALUATION OF EMPIRICAL METHODS TO ESTIMATE REFERENCE EVAPOTRANSPIRATION IN UBERABA, STATE OF MINAS GERAIS, BRAZIL

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ABSTRACT: Evapotranspiration is the process of water loss of vegetated soil due to evaporation and transpiration, and it may be estimated by various empirical methods. This study had the objective to carry out the evaluation of the performance of the following methods: Blaney-Criddle, Jensen-Haise, Linacre, Solar Radiation, Hargreaves-Samani, Makkink, Thornthwaite, Camargo, Priestley-Taylor and Original Penman in the estimation of the potential evapotranspiration when compared to the Penman-Monteith standard method (FAO56) to the climatic conditions of Uberaba, state of Minas Gerais, Brazil. A set of 21 years monthly data (1990 to 2010) was used, working with the climatic elements: temperature, relative humidity, wind speed and insolation. The empirical methods to estimate reference evapotranspiration were compared with the standard method using linear regression, simple statistical analysis, Willmott agreement index (d) and performance index (c). The methods Makkink and Camargo showed the best performance, with "c" values of 0.75 and 0.66, respectively. The Hargreaves-Samani method presented a better linear relation with the standard method, with a correlation coefficient (r) of 0.88.

KEYWORDS: climatic elements, empirical equations, FAO Penman-Monteith, irrigation.

AVALIAÇÃO DE MÉTODOS EMPÍRICOS NA ESTIMATIVA DEVAPOTRANSPIRAÇÃO DE REFERÊNCIA PARA UBERABA - MG

RESUMO: A evapotranspiração é o processo de perda de água do solo vegetado devido à evaporação e à transpiração, podendo ser estimada por vários métodos empíricos. Objetivou-se, com o presente trabalho, realizar a avaliação do desempenho dos métodos de Blaney-Criddle, Jensen-Haise, Linacre, Radiação Solar, Hargreaves-Samani, Makkink, Thornthwaite, Camargo, Priestley-Taylor e Penman Original na estimativa da evapotranspiração potencial em comparação com o método-padrão Penman-Monteith (FAO56), para as condições climáticas do município de Uberaba-MG. Utilizou-se um conjunto de dados mensais de 21 anos (1990 a 2010), trabalhando-se com os elementos climáticos temperatura, umidade relativa, velocidade do vento e insolação. Os métodos empíricos para a estimativa da ETo foram comparados com o método-padrão utilizando-se de regressão linear, análise estatística simples, índice de concordância de Willmott (d) e índice de confiança ou desempenho (c). Os métodos de Makkink e de Camargo apresentaram os melhores desempenhos, com valores de “c” de 0,75 e 0,66, respectivamente. O método de Hargreaves-Samani apresentou a melhor relação linear com o método-padrão, com coeficiente de correlação (r) de 0,88.

PALAVRAS-CHAVE: elementos climáticos, equações empíricas, FAO Penman-Monteith, irrigação.

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INTRODUCTION

The growing global concern with the rational use of water requires a more efficient planning for the use and exploitation of water resources, especially in agriculture, whereas the irrigation undoubtedly is the main consumer of water activity (BEZERRA et al., 2010a; MENDONÇA & DANTAS, 2010; OLIVEIRA et al., 2010). FERNANDES et al. (2011) state that one of the key parameters to control an irrigation system is to determine the amount of water required for crops.

The climatic water balance constitutes an important tool to provide data on disability, surplus removal and replacement of water throughout the year, key elements for the planning and implementation of an agricultural activity (CASTRO et al., 2010). The main water balance components are evapotranspiration and precipitation (BORGES & MENDIONDO, 2007), being the estimated evapotranspiration of a culture a vital parameter for sizing and proper management of irrigation systems (CONCEPTION, 2010; ESTEVES et al., 2010; SOUZA et al., 2010).

The evapotranspiration is understood as a process of simultaneous water loss to the atmosphere, whereas the evaporation of water present in the soil and the transpiration from plant tissues (ALENCAR et al., 2011a; PIVETTA et al., 2010). This is a complex phenomenon, opposite to the rain (PEREIRA et al., 2009), which depends on the interaction of the climatic elements, such as solar radiation, wind speed, temperature and air humidity (ZANETTI et al., 2008), and it may be expressed as the equivalent amount of water evaporated per unit of time, generally expressed as water depth per unit of time (mm $days^{-1}$) (VESCOVE & TURCO, 2005).

The term reference evapotranspiration (ETo) is defined as the amount of water used by an extensive vegetated surface with grass, considering losses through evaporation and plant transpiration, of height between 8 and 15cm, actively growing, completely covering the soil surface and without water restriction (SYPERRECK et al., 2008).

According to ALVES SOBRINHO et al. (2011), ETo may be obtained by techniques considered direct and accurate with the use of special equipment such as lysimeters, or may also be estimated using mathematical models, providing satisfactory results. However, the use of weighing lysimeters has high costs (SANTOS et al., 2008), which restricts its use to research institutions, with justifiable application only for regional calibration of indirect methods.

According to CARVALHO et al. (2011), in 1990 experts conducted a review in the ETo estimation methods and they concluded that for various weather conditions the results of ETo, calculated using the Penman-Monteith, showed results closer to those obtained by weighing lysimeters. Since then, among the indirect methods, the FAO (Food and Agriculture Organization) recommends using the Penman-Monteith method as the standard for estimating ETo (BEZERRA, et al., 2010b) and should also be used in the evaluation of other estimation methods. However, this method requires a large number of weather elements, which are not always available, which implies the need to use other simple methods, which use a smaller number of elements (PEREIRA et al. 2009).

To HENRIQUE & DANTAS (2007), both critics and authors recognize the limitations of empirical methods, but while following the search for better solutions, these methods can provide data for use in water balance and, in some cases, values almost as accurate as those obtained through direct methods. In the absence of elements that allow the use of more consistent methods, the simplest empirical formulas are commonly used. To obtain information on water demand through an empirical method, even the simplest one, is better than having no information at all.

Given the above, this study aimed to evaluate ten empirical methods to estimate reference evapotranspiration (ETo) compared to the Penman-Monteith method (FAO 56) for the region of Uberaba, State of Minas Gerais, Brazil.

MATERIAL AND METHODS

For calculations of potential evapotranspiration, it was used data obtained from the 5th District of Meteorology of INMET, collected at the conventional surface weather station (No. 83577), located in the city of Uberaba-MG, whose latitude is 19°43'48" S, longitude is 47º57'00" W, and altitude of 737 m.

It was used monthly data of the following weather elements: mean, maximum and minimum temperature; mean, maximum and minimum relative humidity; insolation; and wind speed (the station measured the wind speed at 2 m high). The data correspond to the period of January 1990 to December 2010, totaling 21 years of data.

It was evaluated the mean monthly reference evapotranspiration (ETo) obtained through the following empirical methods: Blaney-Criddle, Jensen-Haise, Linacre, Solar Radiation, Hargreaves-Samani, Makkink, Thornthwaite, Camargo, Priestley-Taylor and Original Penman. The results were compared and evaluated using as reference the Penman-Monteith method, adopted by FAO. The methods used to estimate ETo are presented below with their corresponding equations.

Penman-Monteith

This method considers that the ETo is derived from energy and aerodynamic terms, these being controlled by the resistance to vapor transport from the surface to the atmosphere (FERNANDES et al., 2011). For the calculation of ETo, it was used the Penman-Monteith equation (FAO) parameterized by ALLEN et al. (1998):

$$ETo_{PM} = \frac{0.408\ \Delta\ (Rn - G) + \left[\dfrac{\gamma\ 900\ U_2\ (e_s - e_a)}{T_m + 273}\right]}{\Delta + \gamma\ (1 + 0,34\ U_2)} \qquad (1)$$

In which: ETo_{PM} is the reference evapotranspiration (mm d^{-1}); Δ is the slope of the vapor pressure curve in the air temperature, (kPa $ºC^{-1}$); Rn is the total daily liquid solar radiation or the net radiation (MJ m^{-2} d^{-1}); G is the heat flow in soil (MJ m^{-2} d^{-1}); γ is the psychometric constant (kPa $ºC^{-1}$); U_2 is the wind speed at 2 m high (m s^{-1}); e_s is the saturation pressure of water vapor (kPa); e_a is the current water vapor pressure (kPa), and T_m is the mean air temperature (ºC). For the reflection coefficient for surface with lawn, it was adopted r = 0.25.

The daily total heat flow in soil (G) for monthly estimates, assuming the temperature variation to a depth of 1m to effect of heat storage in the soil, was obtained using the equation:

$$G = 0.14(T_m - T_{-m}) \qquad (2)$$

In which: T_m is the mean air temperature of the month (ºC), and T_{-m} is the mean air temperature of the previous month, (ºC).

The total daily liquid solar radiation (Rn) is also called net radiation. This net radiation was estimated for lawn by the following equation:

$$Rn = BOC + BOL \qquad (3)$$

In which: BOC is the short wave balance (MJ m^{-2} d^{-1}); BOL is the long wave balance (MJ m^{-2} d^{-1}), and the first may be obtained by:

$$BOC = Rs\ (1 - r) \qquad (4)$$

In which: Rs is the daily global solar radiation (MJ m^{-2} d^{-1}).

For the estimation of daily global solar radiation (Rs), GLOVER & MCCULLOCH (1958) proposed the following approach:

$$Rs = Ro\left[\left(0.29\ \cos\Phi\right)+\left(0.52\ \frac{n}{N}\right)\right] \quad (5)$$

In which: Ro is the total daily incident solar radiation on a horizontal surface (MJ m^{-2} d^{-1}); Φ is the latitude (degrees); n is the total insolation (hours), and N is the photoperiod (hours).

To calculate the total daily incident solar radiation on a horizontal surface, parallel to the plane of the horizon, it was used the equation:

$$Ro = 37.6\ dr\left[\left(\frac{\pi}{180}\right)\left(hn\ sen\ \Phi\ sen\ \delta\right)+\left(\cos\Phi\ \cos\delta\ sen\ hn\right)\right] \quad (6)$$

$$dr = \left[1+0.033\ \cos\left(NDY\ \frac{360}{365}\right)\right] \quad (7)$$

$$\delta = 23.43\ sen\left[\frac{360}{365}\left(284+N\right)\right] \quad (8)$$

$$hn = \ \arccos\ -\left(\tan\Phi\ \tan\delta\right) \quad (9)$$

$$N = \frac{2}{15}\ hn \quad (10)$$

In which: NDY is the number of the day of the year; hn is the hour angle of sunrise (degrees), and δ is the solar declination (degrees).

The long wave balance (BOL) for wet weather may be obtained by:

$$BOL = -\left[4.903\times10^{-9}\ T_{ar}{}^{4}\ \left(0.56-0.25\ \sqrt{e_a}\right)\left(0.1+0.9\ \frac{n}{N}\right)\right] \quad (11)$$

In which: T_{ar} is the mean air temperature (Kelvin).

Blaney-Criddle

The BLANEY & CRIDDLE method (1950) was developed for a semiarid region of the states of New Mexico and Texas located in the western United States. DOORENBOS & PRUITT (1984) proposed the application of a correction factor, using the variable of humidity, wind speed and insolation, for the application of the method to various climatic conditions. To facilitate the calculation and avoid interpolations and monograms, FREVERT et al. (1983) proposed the following modification to the equation of Blaney-Criddle method of FAO-24:

$$ETo_{BC} = a + b\ p\ \left(0.46T_m + 8.13\right) \quad (12)$$

The coefficients "a" and "b" may be obtained from the following equations:

$$a = 0.0043\ RH_{mín} - \frac{n}{N} - 1.41 \quad (13)$$

$$b = a_0 + a_1RH_{mín} + a_2\frac{n}{N} + a_3U_2 + a_4RH_{mín}\frac{n}{N} + a_5RH_{mín}U_2 \quad (14)$$

In which: $RH_{mín}$ is the monthly minimum relative humidity (%); p is the percentage of the monthly mean photoperiod total (ºC) over the anual photoperiod total, obtained in Table 1; n is the total insolation (h); N is the photoperiod (h). Coefficients: a_0 = 0.81917, a_1 = -0.0040922, a_2 = 1.0705, a_3 = 0.065649, a_4 = -0.0059684 and a_5 = -0.0005967.

TABLE 1. Factor p as a function of latitude and time of year.

Month	Latitute South		
	15º	19.73º	20º
January	0.29	0.299	0.30
February	0.28	0.289	0.29
March	0.28	0.280	0.28
April	0.27	0.261	0.26
May	0.26	0.251	0.25
June	0.25	0.250	0.25
July	0.26	0.251	0.25
August	0.26	0.260	0.26
September	0.27	0.270	0.27
October	0.28	0.280	0.28
November	0.29	0.290	0.29
December	0.29	0.299	0.30

Source: DOORENBOS & PRUITT (1984)

Jensen-Haise

This method was developed by JENSEN & HAISE (1963) for arid and semiarid regions, using data of air temperature and solar radiation. The ETo may be obtained using the equation:

$$ETo_{JH} = Rs(0.0252T_m + 0.078) \quad (15)$$

In which: Rs is the solar radiation at ground level (mm d^{-1}).

Linacre

Originally tested for the climatic conditions of Australia, it is a method based on simplification of the Penman-Monteith method, using data from temperature and air relative humidity as a function of latitude and longitude (LINACRE, 1977). The ETo values may be obtained using the equation:

$$ETo_{Lin} = \frac{\dfrac{J(T_m + 0.006h)}{100 - |\Phi|} + 15(T_m - T_0)}{80 - T_m} \quad (16)$$

$$(T_m - T_0) = 0.023h + 0.37T_m + 0.53(T_{máx} - T_{mín}) + 0.35R - 10.9 \quad (17)$$

In which: J is a constant equal to 500, in the case of vegetation (albedo = 0.25); Φ is the local latitude in degrees; Tmax is the monthly maximum temperature (ºC); Tmin is the monthly minimum temperature (ºC); T_0 is the monthly mean temperature at dew point (ºC); R is the difference between the mean temperatures of the hottest and coldest months, and h is the local altitude (m).

Makkink

Popularly known in Western Europe, this method is based on the Penman and uses data of solar radiation at the surface level. It was developed in the Netherlands by MAKKINK (1957), who proposed the following equation:

$$ETo_{Mak} = 0.61\ W\ Rs - 0.12 \quad (18)$$

$$W = \frac{\Delta}{\Delta + \gamma} \quad (19)$$

In which: W is the weighting factor, which represents the fraction of Rs used in evapotranspiration, for different values of temperature and altitude.

Solar radiation

The method used is an adaptation made by DOORENBOS & PRUITT (1984) to the FAO-24 method of solar radiation proposed by MAKKINK (1957), previously developed for the humid conditions of the Netherlands. The ETo may be estimated by the equation:

$$ETo_{RS} = c_0 + c_1 \; W \; Rs \quad (20)$$

The value of coefficient c_1 may be obtained from the equation:

$$c_1 = a_0 + a_1 RH + a_2 U_2 + a_3 RH \; U_2 + a_4 RH^2 + a_5 U_2{}^2 \quad (21)$$

In which: c_0 is the Constant equal to -0.3 (mm d^{-1}). Coefficients: a_0 = 1.0656, a_1 = -0.0012795, a_2 = 0.044953, a_3 = -0.00020033, a_4 = -0.000031508 and a_5 = -0.0011026.

Hargreaves-Samani

HARGREAVES & SAMANI (1985), using data from Davis lysimeter in the lawn of California in semi-arid climate, proposed the following equation for estimating the ETo:

$$ETo_{HS} = 0.0023 \; Qo \; (Tmax - Tmin)^{0.5} (T + 17.8) \quad (22)$$

In which: Qo is the é a total daily incident solar radiation on a horizontal surface (MJ m^{-2} d^{-1}).

Thornthwaite

This method was proposed by THORNTHWAITE (1948) based on the water balance of watersheds and of lysimeters measures, using only air temperature as an independent variable. The monthly mean potential evapotranspiration (ETP) for lawns may be obtained from the equation:

$$ETP = 16 \left(10 \frac{T_m}{I} \right)^a \qquad T_m > 0°C \quad (23)$$

$$a = 6.75 \; 10^{-7} I^3 - 7.71 \; 10^{-5} I^2 + 0.01791 \; I + 0.49239 \quad (24)$$

$$I = \sum_{i=1}^{12} (0{,}2T_m)^{1.514} \qquad T_m > 0°C \quad (25)$$

In which: I is the region heat index.

Thornthwaite's formula estimates the ETP to a standard condition of 12 hours of sunlight and a 30-day month. The corrected monthly ETo is obtained by the equation:

$$ETo_{Th} = ETP \frac{N}{12} \frac{ND}{30} \quad (26)$$

In which: ND is the number of days of the month.

Camargo

Based on the results obtained by THORNTHWAITE (1948), CAMARGO (1971) proposed a simpler method, but with similar efficiency to THORNTHWAITE. This method uses only data of air temperature and extraterrestrial solar radiation. In this method, ETo is given by the equation:

$$ETo_{Cam} = F\ Qo\ T_m\ ND \tag{27}$$

In which: F is the adjustment factor that varies with the mean annual temperature (T_a < 23.5 ºC, F = 0.01).

Priestley-Taylor

PRIESTLEY & TAYLOR (1972) proposed an approach to the Penman method through simplification of Penman equation, leaving only the solar radiation net corrected by an empirical coefficient, known as Priestley and Taylor parameter, which incorporates additional energy to process evapotranspiration due to the aerodynamic term. Thus, ETo may be estimated by the equation:

$$ETo_{PT} = \frac{\alpha\ W(Rn - G)}{\lambda} \tag{28}$$

In which: α is the Priestley and Taylor parameter (α = 1.26); λ is the latent heat of vaporization (λ = 2.45 MJ kg^{-1}).

Penman

The original PENMAM method (1948) is one of the most used, and its equation is derived by assuming proportionality between the water evaporation and evapotranspiration of under irrigated grass. The estimation of ETo is obtained by the equation:

$$ETo_{PE} = \frac{W\ Rn}{\lambda} + (1 - W)\ E_a \tag{29}$$

In which: E_a is the air evaporative power (MJ m^{-2} d^{-1}).

Methods Analysis

The performance evaluation of the models was conducted considering the full year, comparing the values obtained by empirical ETo to the standard Penman-Monteith method (FAO 56), using simple regression analysis and statistical series proposed by WILLMOTT et al. (1985).

The average bias (AB) of the evaluated methods was calculated according to the equation:

$$AB = N^{-1} \sum_{i=1}^{N} (P_i - O_i) \tag{30}$$

In which: O_i is the ETo estimated by the standard method (mm d^{-1}); P_i is the ETo estimated by the considered method (mm d^{-1}), and N is the number of observations.

The errors of the evaluated methods were calculated by root mean square error (RMSE) and by mean absolute error (MAE), as equations:

$$RMSE = \sqrt{\left(N^{-1} \sum_{i=1}^{N} (P_i - O_i)^2\right)} \qquad MAE = N^{-1} \sum_{i=1}^{N} |P_i - O_i| \tag{31}$$

The estimated standard error (ESE) was calculated according to the equation:

$$ESE = \sqrt{\frac{\sum_{i=1}^{N}(O_i - P_i)^2}{N-1}} \quad (32)$$

The accuracy of the methods was given by the coefficient of determination (R^2), correlation coefficient (r) and index of agreement (d) proposed by WILLMOTT et al. (1985), calculated using equation:

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O| - |O_i - O|)^2}\right] \quad (33)$$

In which: O is the mean of the observed values (mm d^{-1}).

The concordance index is a measure of the effectiveness with which the method estimates the observed values of ETo, considering the dispersion of the data relative to the 1:1 line. To analyze the reliability of each method, it was considered the index of confidence (c) proposed by CAMARGO & SENTELHAS (1997), being the product of r and d (c = r x d).

Criteria used to interpret the performance of the methods by confidence index (c) are presented in Table 2.

TABLE 2. Classification of confidence index (c).

"c" value	Performance
> 0.85	Excellent
0.76 a 0.85	Very Good
0.66 a 0.75	Good
0.61 a 0.65	Medium
0.51 a 0.60	Tolerable
0.41 a 0.50	Bad
< 0.41	Terrible

Source: CAMARGO & SENTELHAS (1997)

RESULTS AND DISCUSSION

Changes in average monthly values of climatic elements of Uberaba for the period 1990 to 2010 used to calculate the reference evapotranspiration are shown in Figure 1. The maximum temperature occurs in September, knowing that August and September are the driest months and with the strongest winds. August is the month with the highest insolation. The mean annual rainfall for the period was 1,657 mm.

The statistical analysis of empirical methods is described in Table 3. It was observed by the results of the average bias (AB) that the Thornthwaite and Camargo methods tended to underestimate ETo, considering the global mean of the values of the analyzed period, considering that Makkink and Priestley-Taylor methods were the ones which came closer to the standard method. In general, the methods that underestimated ETo showed lower errors, according to results of the root mean square error (RMSE), mean absolute error (MAE) and estimated standard error (ESE) of the Makkink, Priestley-Taylor, Camargo and Thornthwaite methods.

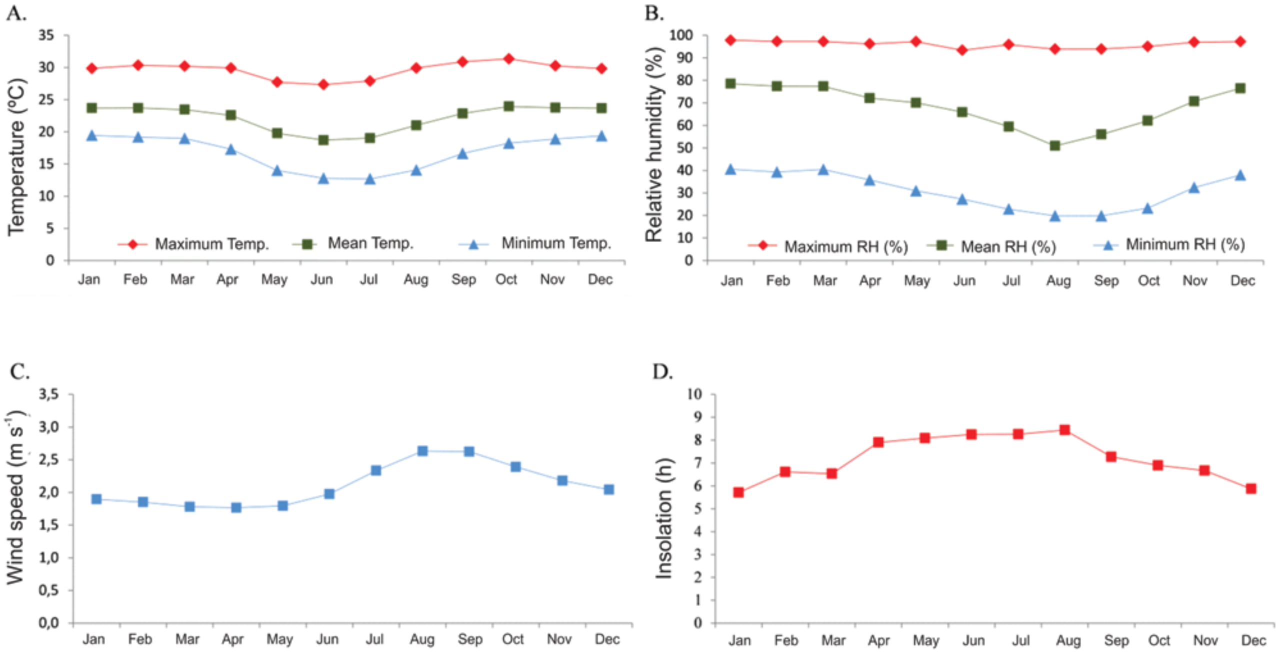

FIGURE 1. Monthly mean values of climatic elements in Uberaba from 1990 to 2010; (A) maximum, mean and minimum temperature; (B) maximum, mean and minimum relative humidity; (C) wind speed and (D) insolation.

TABLE 3. Statistical evaluation of methods.

Methods	Parameters			
	AB (mm d^{-1})	RMSE (mm d^{-1})	MAE (mm d^{-1})	ESE (mm d^{-1})
Blaney-Criddle	1.12	1.25	1.12	1.25
Jensen-Haise	1.58	1.67	1.59	1.67
Linacre	1.34	1.45	1.34	1.45
Solar Radiation	1.33	1.40	1.33	1.41
Hargreaves-Samani	0.96	1.04	0.96	1.04
Makkink	-0.14	0.47	0.36	0.47
Thornthwaite	-0.65	0.82	0.67	0.82
Camargo	-0.46	0.70	0.54	0.70
Priestley-Taylor	-0.09	0.77	0.63	0.77
Original Penman	2.38	2.52	2.38	2.53

AB - average bias; RMSE - root mean square error; MAE - mean absolute error, and ESE - estimated standard error.

The Blaney-Criddle, Jensen-Haise, Linacre, Solar Radiation, Hargreaves-Samani and Penman Original methods showed the highest values of AB, overestimating ETo. They were also the methods that showed the highest values of RMSE, MAE and ESE.

VESCOVE & TURCO (2005), evaluating different methods for estimating ETo for Araraquara, State of São Paulo, Brazil, considering the periods summer-autumn and winter-spring, observed that the Makkink method underestimates the ETo compared to the standard method in both periods.

BARRETO et al. (2009) used empirical methods to estimate ETo of Ribeirão da Onça Basin, in the region of Brotas, State of São Paulo, Brazil, and found that the methods of Thornthwaite and Makkink underestimated evapotranspiration throughout the year of 2005 compared to the Penman-Monteith.

ALENCAR et al. (2011b) compared the Blaney-Criddle, Solar Radiation and Hargreaves-Samani methods for estimating ETo for Uberaba, State of Minas Gerais, Brazil, for the period of 1996 to 2005, and they found through AB that all methods tend to overestimate ETo, considering the global mean. However, they observed that the Blaney-Criddle method underestimates the standard method for the months from November to February, considering the monthly means.

It is observed, in Figure 2, the graphs representing the linear regression analysis of ten empirical methods evaluated in relation to the standard Penman-Monteith method (FAO 56), considering all the results of the period studied (21 years).

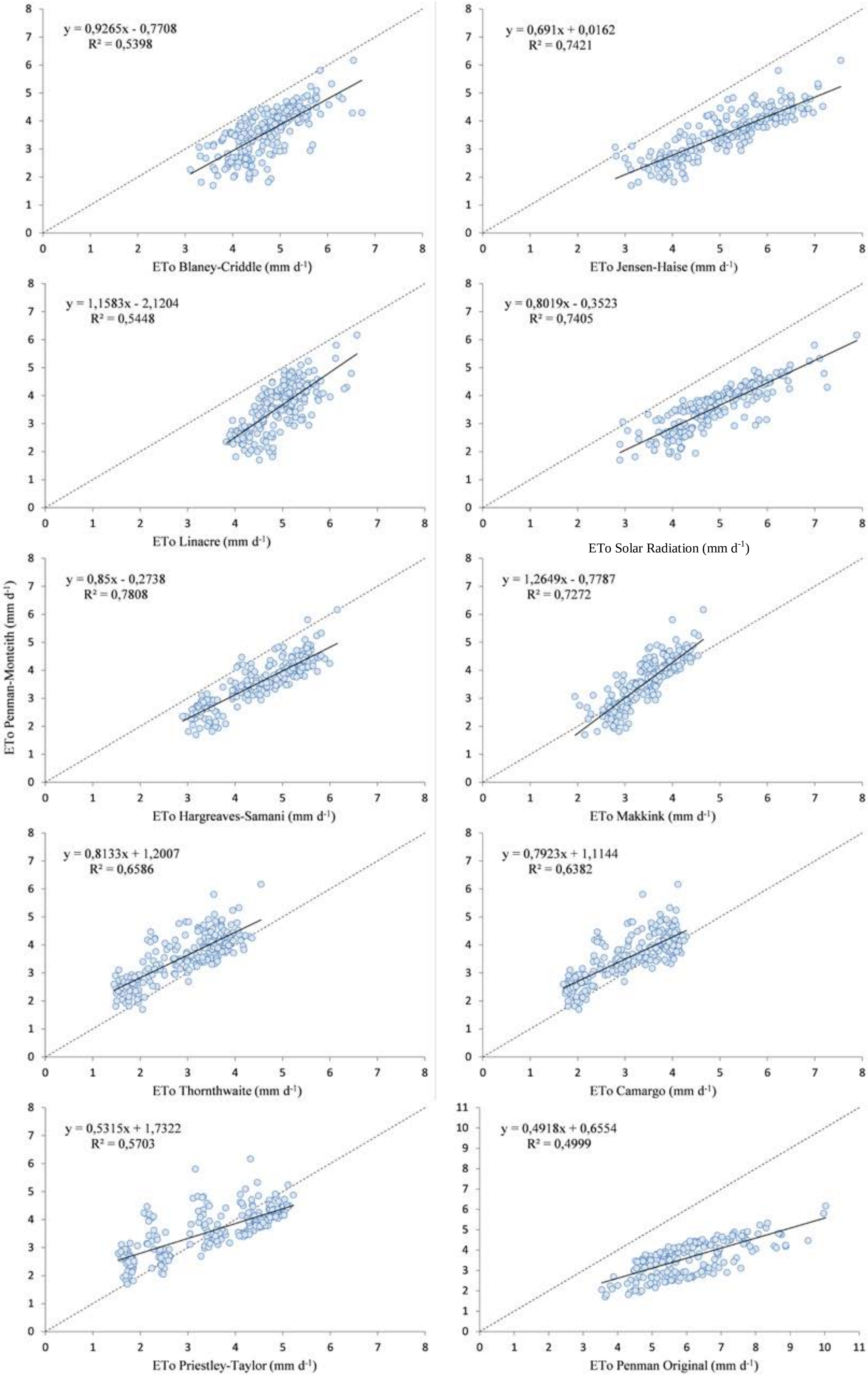

FIGURE 2. Monthly values of ETo (FAO56 Penman-Monteith versus empirical methods) compared by linear regression. The dashed line indicates the 1:1 line.

The values of the parameters of the linear regression equation (a and b) were highly significant (P <0.01) for all cases.

By regression analysis, it is possible to show that the Hargreaves-Samani method was the one that had the best coefficient of determination, with a value of R^2 = 0.7808. The Jensen-Haise and Solar Radiation methods also showed similar coefficients of determination, with values of "R^2" of 0.7421 and 0.7405, respectively. The performance evaluation of methods, as proposed by CAMARGO & SENTELHAS (1997), is presented in Table 4.

TABLE 4. Performance evaluation of methods.

Method	r	d	c	Performance
Blaney-Criddle	0.73	0.61	0.44	Bad
Jensen-Haise	0.86	0.56	0.48	Bad
Linacre	0.74	0.53	0.39	Terrible
Solar Radiation	0.86	0.62	0.53	Tolerable
Hargreaves-Samani	0.88	0.71	0.63	Medium
Makkink	0.85	0.88	0.75	Good
Thornthwaite	0.81	0.78	0.63	Medium
Camargo	0.80	0.83	0.66	Good
Priestley-Taylor	0.76	0.84	0.63	Medium
Original Penman	0.71	0.43	0.30	Terrible

r - correlation coefficient; d - concordance index, and c - performance index.

It is observed that the Hargreaves-Samani method showed the best correlation coefficient, but not the best performance, being classified as "medium". ALENCAR et al. (2011b) used data from the same weather station of Uberaba, but from a 10-year period (1996 to 2005), and achieved the same result when evaluating the Hargreaves-Samani method, considering the full year. However, better results were obtained for the Blaney-Criddle and Solar Radiation methods, with performance rated as "excellent" and "very good", respectively.

The Jensen-Haise method, despite having one of the best correlation coefficients, obtained a low concordance index, and its performance was rated as "bad". Conversely, PEREIRA et al. (2009), to assess the performance of methods for the region of Serra da Mantiqueira, in Minas Gerais, Brazil, concluded that in the monthly scale, the Jensen-Haise method showed the best adjustment to the standard Penman-Monteith method (FAO 56).

The performance of the Priestley-Taylor method was rated as "medium". Better results were obtained by BRAGANÇA et al. (2010), in evaluating this method to three locations in the state of Espírito Santo, considering the rainy season and a smaller time scale (daily, three, five and seven days). The method has been rated as "excellent" for the three regions at all time scales evaluated.

It was observed that the original Penman showed the worst concordance index and the worst correlation between the methods evaluated; consequently its performance was rated as "terrible". The Linacre method also obtained the same classification. Similar results were presented by LEITÃO et al. (2007) compared to the original Penman method, noting that this method had the lowest performance index for the cities of Boqueirão and Patos, in the state of Paraíba, Brazil. Moreover, the Linacre method, despite a systematic error, was rated as "very good" for the city of Boqueirão, and as "good" for the city of Patos.

It was observed that the Camargo method, which is a simplification of the equation of Thornthwaite, presented a performance rated as "good", better than the method that gave rise to it, which was rated as "medium". Similar behavior was reported by BORGES & MENDIONDO (2007), when comparing empirical methods for Jacupiranga river basin in the state of São Paulo, Brazil, where the Camargo method showed a level of performance as "excellent", also higher than the Thornthwaite method, classified as "very good."

It has been found that the Makkink method showed the best performance index, followed by the Camargo method, both classified as "good". OLIVEIRA et al. (2010), comparing the different methods for the northern region of the State of Bahia, Brazil, also achieved the same rating for the Makkink method.

CONCLUSIONS

Blaney-Criddle and Solar Radiation methods have lost performance when the analyzed period increased from 10 to 21 years.

Hargreaves-Samani method showed the best correlation with the Penman-Monteith method (FAO 56), constituting itself as a good alternative in case of having just the climatic elements minimum temperature, mean temperature, maximum temperature and extraterrestrial solar radiation.

The Makkink, Camargo, Priestley-Taylor, Hargreaves-Samani and Thornthwaite methods, using only the climatic elements such as temperature and solar radiation as input variables, showed better performance when compared to methods using higher number of variables.

Due to the better performance index, it was recommend the use of the Makkink method to estimate evapotranspiration in the region of Uberaba for periods exceeding 10 years.

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