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PERFORMANCE OF ESTIMATIVE MODELS FOR DAILY REFERENCE EVAPOTRANSPIRATION IN THE CITY OF CASSILÂNDIA, BRAZIL

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ABSTRACT: Before choosing the method of the estimate of reference evapotranspiraton (ET0) in a region, it is important to evaluate the degree of precision of the model. The present research aimed to evaluate the performance of 30 methods for daily ET0 estimate in the Cassilândia city, Brazil. The meteorological data had been obtained from the National Institute of Meteorology in the period of four years (from April, 2008 to March, 2012). As standard method it was chosen the Penman-Monteith-FAO56, and the comparison of the results was by means of the estimated standard error (ESE), the determination coefficient (R^2), the coefficients “a” and “b” of the linear regressions, Willmott's index of agreement (d), Pearson's correlation coefficient (r) and the reliable coefficient (c). The best methods for estimate the daily ET0 had been: Penman-Original, Stephens-Stewart, Abtew, Thornthwaite-Modified, Priestley-Taylor, Penman-FAO 24, Hicks-Hess, Liquid-Radiation, Turc, Hamon, Camargo, Temperature-Radiation, Global-Radiation and the Original Hargreaves. When it has been given only temperature data, the Camargo method is the more recommended. The methods Blaney-Criddle-FAO 24, Radiation-FAO 24, Makkink, Hargreaves-Samani, Jensen-Haise, Linacre, Ivanov, Kharrufa, Garcia-Lopez, Blaney-Morin, McCloud, McGuiness-Bordne, Romanenko, Lungeon, Tanner-Pelton and Thornthwaite should not be used to estimate the daily ET0.

KEYWORDS: agrometeorology, ET0, evaporation, irrigation, Penman-Monteith-FAO 56 method.

INTRODUCTION

Evapotranspiration is the simultaneous process of water loss to the atmosphere through evaporation of the soil and plant transpiration, and it is a fundamental climatological component corresponding to the opposite rain process. Evapotranspiration is controlled by the energy balance, by the atmospheric demand, by the supply of water from the soil to the plants and by the physiological characteristics of the plants. However, to avoid conflicts, the concept of reference evapotranspiration (ET0) was introduced, which definition is linked to the process of water loss to the atmosphere considering a large area covered by grass with height between 0.08 and 0.15m in active growth, covering completely the soil and without water disabilities (PEREIRA et al., 2009).

ET0 is a parameter used in agricultural water balance and in climatological and hydrological modeling processes, in order to estimate irrigation requirements, crop forecasting, assessment of water resource availability, agroclimatic zoning and characterization of climate (BACK, 2008).

According to PEREIRA et al. (2009), the ET0 can be determined by means of estimation methods (indirect), which are less costly than the direct methods, since its application is based on meteorological parameters measured at appropriate stations. According GRISMER et al. (2002), there are approximately, fifty methods for estimate ET0, which require distinct meteorological information, and therefore often produce inconsistent results. The Penman-Monteith method (ALLEN et al., 1998) has been recommended by the FAO as standard to calculate the ET0 and has been used worldwide. This method requires several input parameters such as air temperature, relative humidity, solar radiation and wind speed. However, there is a limited number of meteorological stations to monitor these weather variables. This lack of meteorological data leads to

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the development of simpler approaches to estimate ET0 that require only a few input parameters. In this context, several methods have been reported in the literature for estimating ET0.

Despite the existence of several different models to estimate ET0, these, however, are used in agronomic and climatic conditions very different from those that they were initially designed for, and therefore, it is extremely important to evaluate the degree of accuracy of those models before using them to new condition. There are also methods designed for different timescales (schedule, daily, decennial, fortnightly and monthly). Most methods for estimate ET0 existing in the literature are for the daily intervals. For monthly intervals, according to FERNANDES et al. (2010), we highlight the following methodologies: Camargo, Linacre, Hamon, Romanenko, Lungeon, Thornthwaite and Thornthwaite-Modified. Several studies comparing various methods for estimating ET0 are found in the literature for different regions (BACK, 2008; BARROS et al., 2009; KISI, 2009; PEREIRA et al., 2009; CAVALCANTE JR. et al., 2011; ARAÚJO et al., 2012; KISI et al., 2012; MAGALHÃES & CUNHA, 2012; SAHOO et al., 2012; CHAGAS et al., 2013; CUNHA et al., 2013).

As such, the aim of this study was to evaluate the performance of 30 methods for estimating daily ET0, comparing them with the Penman-Monteith-FAO 56 standard method, in the city of Cassilândia, Mato Grosso do Sul, Brazil.

MATERIAL AND METHODS

The meteorological data required for execution of this study were taken from the National Institute of Meteorology (INMET) for the automatic meteorological station in the city of Cassilândia, state of Mato Grosso do Sul (Latitude 19º 07' 21"S, Longitude 51º 43' 15" W, Altitude 516m) for four years, from April 2008 to March 2012.

The meteorological data used in the research were: average temperature, maximum and minimum (ºC); average relative humidity, maximum and minimum (%); average dew point temperature, maximum and minimum (ºC); average pressure, maximum and minimum (hPa) wind speed at 10 m height (m s^{-1}) and global radiation (kJ m^{-2}). Data were obtained from a meteorological station that consists of the equipment WAWS 301 (Automatic Weather Station) of the Brand VAISALA, whose composition is described as follows: (1) Pyranometer CM6B; (2) Pressure Sensor PMT16A; (3) Thermometer QMH102; (4) Hygrometer QMH102; (5) Pluviometer QMR102 and (6) Anemometer WAA151. The hourly meteorological data were converted to daily data. In order to make the meteorological variables data more homogeneous, verification was made and, subsequently, the information considered discrepant or inconsistent was eliminated, aiming to obtain more representative data groupings. The methodologies used in this research to estimate the daily reference evapotranspiration (ET0) are presented in Table 1.

TABLE 1. Methodologies and their respective equations to estimate the daily reference evapotranspiration (ET0) used in the research.

Methodology	Equation
Penman-Monteith-FAO56	$ET0 = \frac{0{,}408\ s\ (Rn - G) + \gamma\ \frac{900}{t+273}\ U_2\ \frac{(e_S - e)}{10}}{s + \gamma\ (1 + 0{,}34\ U_2)}$
Penman-Original	$ET0 = \frac{s}{s+\gamma} 0{,}408\ (Rn - G) + \frac{\gamma}{s+\gamma}\ 0{,}26\ \left(1 + \frac{U_2}{160}\right)(e_S - e)$
Penman-FAO24	$ET0 = c\left[\frac{s}{s+\gamma} 0{,}408\, Rn + \frac{\gamma}{s+\gamma} 0{,}27(1 + 0{,}864 U_2)(e_S - e)\right]$
Blaney-Criddle-FAO24	$ET0 = k\ \ p\ (0{,}457\ t + 8{,}13)$
Radiation-FAO24	$ET0 = -0{,}3 + k\ \left(\frac{s}{s+\gamma}\ R_{GE}\right)$

Makkink	$ET0 = R_{GE} \left(\frac{s}{s+\gamma}\right) + 0{,}12$
Hargreaves-Samani	$ET0 = 0{,}0023\ R_{0E}\ (t_{max} - t_{min})^{0{,}5}\ (t + 17{,}8)$
Hargreaves-Original	$ET0 = 0{,}135\ \frac{R_G}{\lambda}\ (t + 17{,}8)$
Priestley-Taylor	$ET0 = 0{,}5143\ \frac{s}{s+\gamma}\ (Rn - G)$
Jensen-Haise	$ET0 = R_{GE}\ (0{,}025\ t + 0{,}08)$
Camargo*	$ET0 = 0{,}01\ R_{0E}\ t$
Linacre*	$ET0 = \frac{500\ (t + 0{,}006z)}{100 - \phi} + 15\ (t - t_d) \Big/ (80 - t)$
Hamon*	$ET0 = 0{,}55 \left(\frac{N}{12}\right)^2 \left(\frac{4{,}95\ \exp^{0{,}062\,t}}{100}\right) 25{,}4$
Ivanov	$ET0 = 0{,}006\ (25 + t)^2\ \left(1 - \frac{f}{100}\right)$
Kharrufa	$ET0 = 0{,}34\ p\ t^{1{,}3}$
Garcia-Lopez	$ET0 = 1{,}21\ 10^{\left(\frac{7{,}45\,t}{243{,}7 + t}\right)}\ (1 - 0{,}01\ f) + 0{,}21\ t - 2{,}30$
Blaney-Morin	$ET0 = p\ (0{,}457\ t + 8{,}13)\ (1{,}14 - 0{,}01\ f)$
Turc	$ET0 = \frac{0{,}013\ t}{t + 15} (23{,}9\ R_G + 50)$
McCloud	$ET0 = 0{,}254\ \ 1{,}07^{(1{,}8\,t)}$
McGuiness-Bordne	$ET0 = \frac{R_0}{\lambda}\ \frac{t + 5}{68}$
Romanenko*	$ET0 = 4{,}5 \left(1 + \frac{t}{25}\right)^2 \left(1 - \frac{e}{e_S}\right)$
Lungeon*	$ET0 = 0{,}2985\ (e_S - e) \left(\frac{273 + t}{273}\right) \left(\frac{760}{P - e_S}\right)$
Abtew	$ET0 = \frac{0{,}53}{\lambda}\ R_G\ (1 - r)$
Hicks-Hess	$ET0 = \frac{1}{\lambda} \left(\frac{s}{0{,}90\ s + 0{,}63\ \gamma}\right) Rn$
Global-Radiation	$ET0 = 0{,}9 + 0{,}115\ R_G$
Liquid-Radiation	$ET0 = 0{,}86\ \frac{Rn}{\lambda}$
Temperature-Radiation	$ET0 = \frac{1}{\lambda} \left(\frac{R_G\ t_{max}}{56}\right)$
Stephens-Stewart	$ET0 = 0{,}4047\ R_G\ [(0{,}01476\ t) + 0{,}0724]$
Tanner-Pelton	$ET0 = 0{,}457\ Rn - 0{,}11$
Thornthwaite-Modified*	$ET0 = \frac{16}{30} \left(10 \frac{0{,}36\ (3\ t_{max} - t_{min})}{I}\right)^a \frac{N}{12}$
Thornthwaite*	$ET0 = \frac{16}{30} \left(10 \frac{t_i}{I}\right)^a \frac{N}{12}$

ET0 = reference evapotranspiration (mm day^{-1}); s = slope of the pressure curve (kPa °C^{-1}); Rn = net radiation (MJ m^{-2} day^{-1}); G = heat flux (MJ m^{-2} day^{-1}); γ = psychrometric constant (kPa °C^{-1}); t = average temperature (°C); U_2 = wind speed (m s^{-1}); $_S$ = saturation vapor pressure (hPa); e = vapor pressure (hPa); c = adjustment coefficient (adm); k = local coefficient (adm); p = annual percentage of light (%); f = relative humidity (%), R_{GE} = global radiation (mm day^{-1}); R_{0E} = extraterrestrial radiation (mm day^{-1}); t_{max} = maximum temperature (°C); t_{min} = minimum temperature (°C); λ = latent heat of vaporization (MJ kg^{-1}); z = local altitude (m); φ = local latitude (degrees); t_d = dew point temperature (°C); N = photoperiod (h); R_G = global radiation (MJ m^{-2} day^{-1}); R_0 = extraterrestrial radiation (MJ m^{-2} day^{-1}); P = atmospheric pressure (hPa); a = local constant (adm); I = annual heat index (adm); and t_i = monthly temperature (°C). * Indicated for monthly intervals.

The wind speed was corrected to a height of 2 m (equation 1).

$$U_2 = \frac{4{,}868}{\ln\left(67{,}75\ z - 5{,}42\right)} U_z \quad (1)$$

where,

U_2 - wind speed at 2 m above ground surface, m s^{-1};

U_z - measured wind speed at “z” m above ground surface, m s^{-1}, and

z - height of measurement above ground surface, m.

The net radiation was estimated according to the following equations:

$$Rn = Rns + Rnl \quad (2)$$

$$Rns = R_G\ (1 - r) \quad (3)$$

$$Rnl = 4{,}8989\ 10^{-9}\ T^4\ \left(0{,}09\ \sqrt{0{,}75\ e} - 0{,}56\right)\left(1{,}35 \frac{R_G}{(a+b)\ R_0} - 0{,}35\right) \quad (4)$$

where,

Rn - net radiation, MJ m^{-2} day^{-1};

Rns - net solar or shortwave radiation, MJ m^{-2} day^{-1};

Rnl - net outgoing longwave radiation, MJ m^{-2} day^{-1};

R_G - solar or shortwave radiation, MJ m^{-2} day^{-1};

r - albedo or canopy reflection coefficient, dimensionless;

T - average daily temperature of the air, K [K = °C + 273.16];

e - actual vapour pressure, kPa;

a e b - fraction of extraterrestrial radiation reaching the earth on clear days, dimensionless, and

R_0 - extraterrestrial radiation, MJ m^{-2} day^{-1}.

After obtaining the daily ET0 through different methodologies it was conducted a regression analysis that correlated the ET0 values estimated by empirical equations with the Penman-Monteith method-FAO 56 (ALLEN et al., 1998). It was considered the coefficients "a" and "b" of the respective linear regressions and the coefficient of determination (R^2). The best alternative was the one that showed regression coefficient "a" near to zero, coefficient "b" near the unity and higher coefficient of determination, more than 0.60. The precision was measured through the coefficient of determination, which indicates the degree to which the regression explains the sum of the total squared (TAGLIAFERRE et al., 2012a).

The models performance analysis was performed by comparing the daily ET0 values obtained by empirical methods such as the Penman-Monteith-FAO 56 (ALLEN et al., 1998). The methodology adopted for comparison of results was proposed by ALLEN et al. (1989), and is based on the standard error of the estimate (ESE), calculated by [eq. (5)]. The best method to estimate ET0 was the one that presented the lowest ESE.

$$ESE = \left[\frac{\sum_{i=1}^{n}\left(X_i - Y_i\right)^2}{n}\right]^{1/2} \quad (5)$$

where,

ESE - standard error of estimate, mm day^{-1};

X_i - reference evapotranspiration estimated by the standard method, mm day^{-1};

Y_i - reference evapotranspiration obtained through the tested method, mm day^{-1}, and

n - number of observations.

The approximation of ET0 values estimated by the method studied, in relation to the values obtained using the standard method, was obtained by an index called concordance, represented by the letter "d" where its values range from zero, where there is no concordance, to 1, for the perfect concordance. The concordance index (d) was calculated using the [eq. (6)]. To validate the model, it was also obtained the Pearson's correlation coefficient (r) through [eq. (7)] and the reliable coefficient or performance (c) through [eq. (8)].

$$d = 1 - \frac{\sum_{i=1}^{n}\left(X_i - Y_i\right)^2}{\sum_{i=1}^{n}\left[\left(\left|X_i - \overline{Y}\right|\right) + \left(\left|Y_i - \overline{Y}\right|\right)\right]^2} \quad (6)$$

$$r = \frac{\sum_{i=1}^{n}\left(\left|Y_i - \overline{Y}\right|\right)\left(\left|X_i - \overline{X}\right|\right)}{\sqrt{\sum_{i=1}^{n}\left(Y_i - \overline{Y}\right)^2}\sqrt{\sum_{i=1}^{n}\left(X_i - \overline{X}\right)^2}} \quad (7)$$

$$c = r\ d \quad (8)$$

where,

d - Willmott’s concordance index;

X_i - reference evapotranspiration estimated through the standard method, mm day^{-1};

Y_i - reference evapotranspiration obtained through the method tested, mm day^{-1};

$\overline{Y}$ - average values of reference evapotranspiration obtained through the method tested, mm day^{-1};

$\overline{X}$ - average values of reference evapotranspiration obtained through standard method, mm day^{-1};

n - number of observations;

r - Pearson's correlation coefficient, and

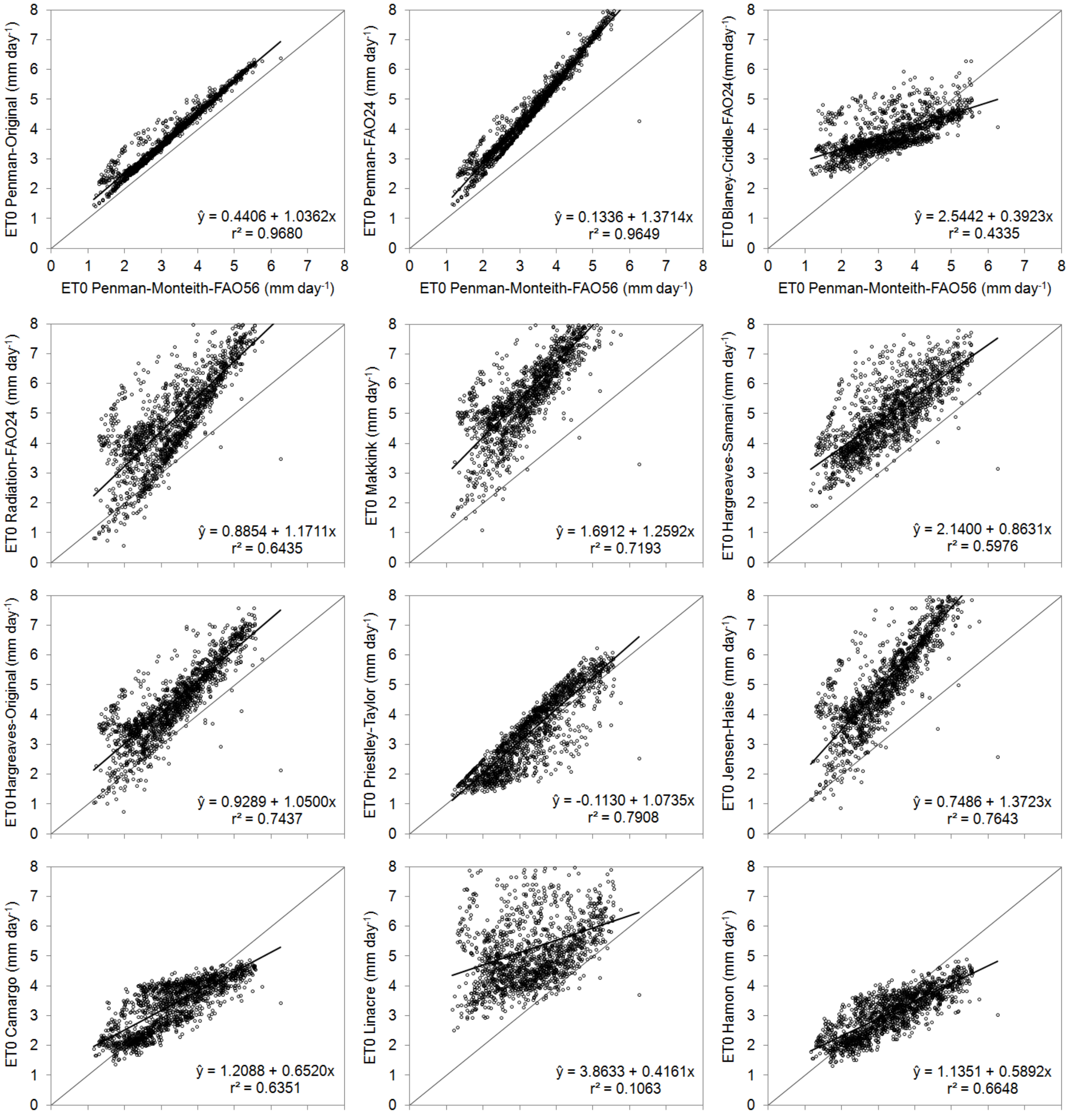
c - reliable coefficient or performance.

The correlation coefficient (r) can be classified as: "very low" ($r < 0.1$), "low" ($0.1 < r < 0.3$), "moderate" ($0.3 < r < 0.5$); "high" ($0.5 < r < 0.7$); "very high" ($0.7 < r < 0.9$); and "almost perfect" ($r > 0.9$).

The coefficient "c", proposed by CAMARGO & SENTELHAS (1997), is interpreted in accordance with authors such as: "great" ($c > 0.85$); "very good" ($0.76 < c < 0.85$); "good" ($0.66 < c < 0.75$), "average" ($0.61 < c < 0.65$), "badly" ($0.51 < c < 0.60$), "not good" ($0.41 < c < 0.50$) and "terrible" ($c < 0.40$).

RESULTS AND DISCUSSION

It is observed that the Blaney-Morin method underestimated ET0 values only when the Penman-Monteith-FAO 56 method showed estimates above 2.0 mm day^{-1}. The methods Abtew, Hamon, Global-Radiation and Stephens-Stewart underestimated ET0 when the Penman-Monteith-FAO 56 values showed estimates above 3.0 mm day^{-1}, the Camargo method above 3.5 mm days^{-1}, the Lungeon and Thornthwaite-Modified method above 4.0 mmday^{-1}, and Blaney-Criddle-FAO 24 above 4.5 mm day^{-1}. The other methods stood out for the high regression coefficients "a" and "b", i.e., independent of the evapotranspirometric demand, these methods overestimated the ET0 values in relation to the standard method (Figures 1 and 2).



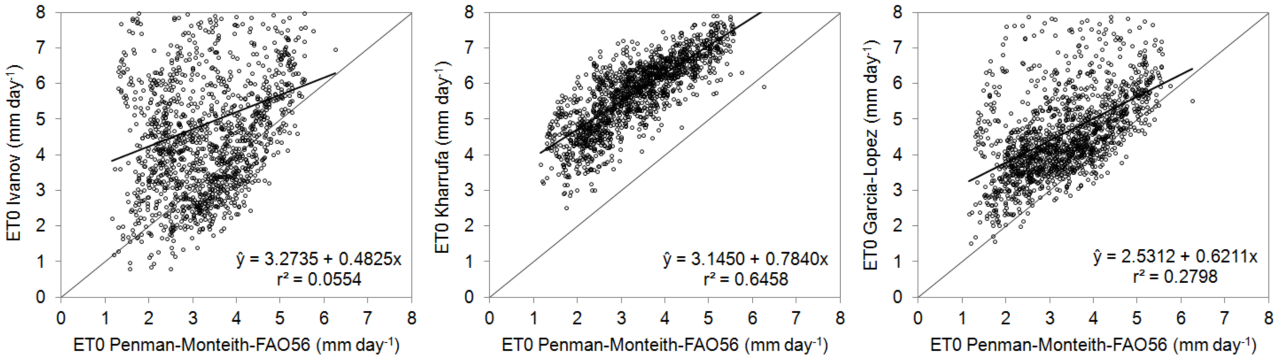
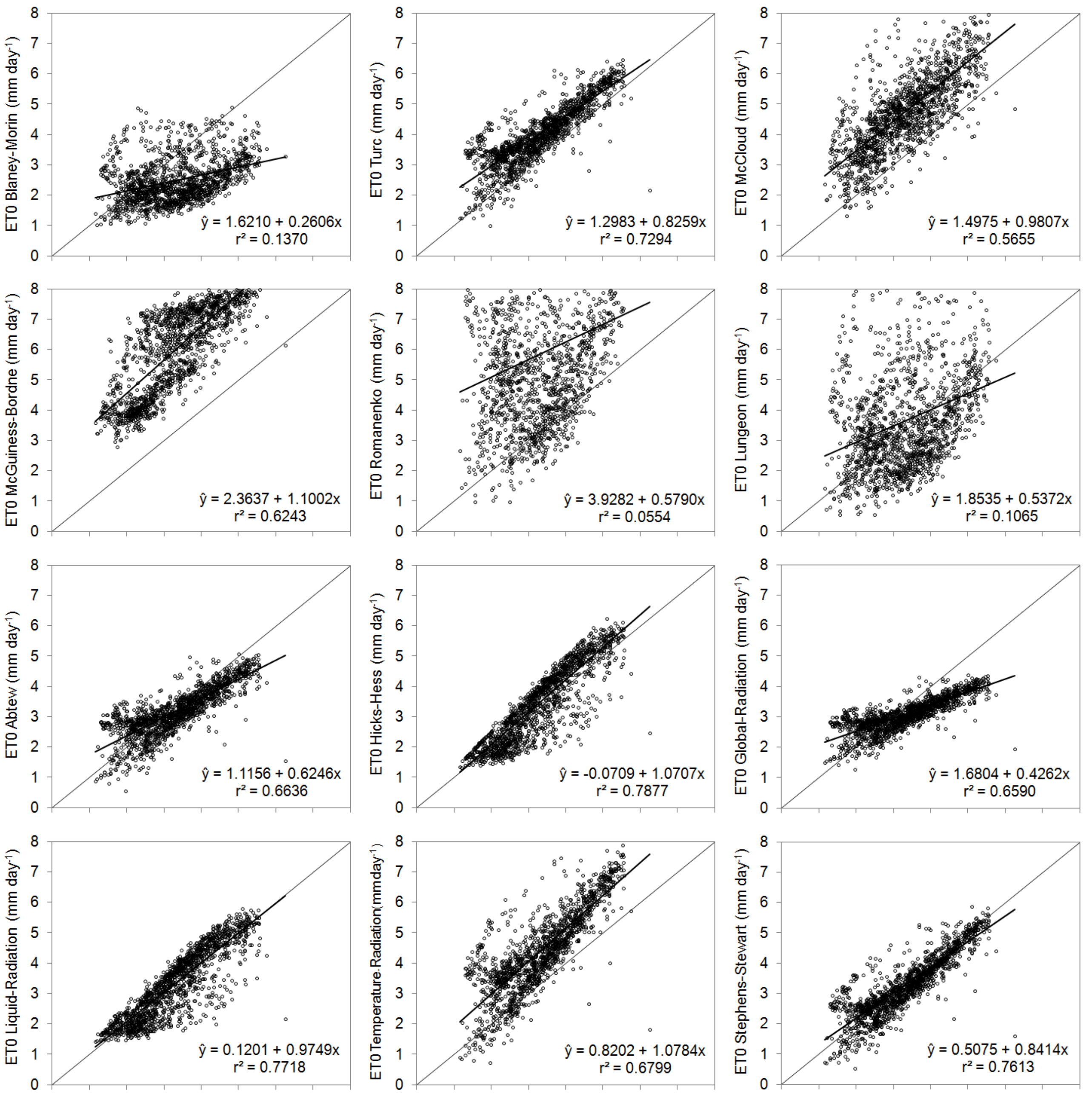


FIGURE 1. Values of reference evapotranspiration (ET0) obtained through Penman-Monteith-FAO 56 compared with ET0 values obtained through the methods studied.



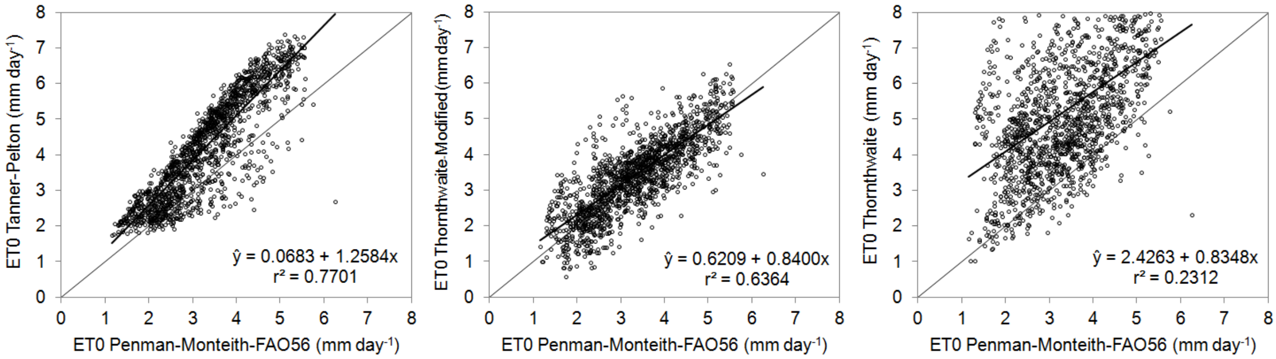


FIGURE 2. Values of reference evapotranspiration (ET0) obtained through Penman-Monteith-FAO 56 compared with ET0 values obtained through the methods studied.

It is also observed in Figures 1 and 2 that the methods that showed the best result, according to the coefficient of determination (R^2) were the methods Penman-Original (R^2 = 0.9680) and Penman-FAO 24 (R^2 = 0.9649). This result was due to the standard method of Penman-Monteith-FAO 56 have originated these methods, and before that, using the same input parameters. The methods Penman-Original and Penman-FAO 24 also presented the regression coefficient "a" closer to zero and the coefficient "b" closer of the unit, confirming their superiority among other methods to estimate ET0 in climatic conditions in Cassilândia city.

Other methods that presented lines near to the ideal ratio of 1:1 were Priestley-Taylor, Hicks-Hess, Liquid-Radiation, and Tanner-Pelton, but they showed adjustments (R^2) between 0.7701 and 0.7908. The worst adjustments of equations for determining ET0, according to R^2, were for the methods Linacre, Ivanov, Garcia-Lopez, Blaney-Morin, Romanenko, Lungeon and Thornthwaite. This result was due these methodologies where was designed only to estimate monthly of the ET0 (FERNANDES et al., 2010; SCUDERI, 2010; CARVALHO et al., 2011). Among these, many are characterized by their simplicity of equations by the reduced number of input parameters. Despite these advantages, the mentioned methods should not be used to estimate daily ET0 in the Cassilândia city. Some equations, when presenting their simplicity in calculations and input parameters are easy to acquire, they receive calibrations to be used in a particular region. However, in the last mentioned equations, they could not receive such calibration due to the high dispersion of their values with respect to the lines 1:1 presented in Figures 1 and 2.

Table 2 presents the estimates of standard error (ESE), Willmott's concordances (d), Pearson's correlations (r), reliable coefficients (c) and Camargo and Sentelhas performances, obtained from the correlations between the ET0 values through Penman-Monteith-FAO 56 method with those obtained by the studied methods. It is observed that the best model for estimating ET0 in Cassilândia, according to ESE and Camargo and Sentelhas performance, was the Penman-Original method corroborating with PEREIRA et al. (2009) in Minas Gerais, CAVALCANTE JR. et al. (2011) in Brazil's Northeast semi-arid and KISI et al. (2012) in the United States. Although the Penman-FAO24 method has presented satisfactory R^2, its Willmott's concordance value has not achieved the same success, making its performance (CAMARGO & SENTELHAS, 1997) rated only as "good". This result can be explained by the fact that the values estimated by Penman-FAO 24 have significantly overestimated the ET0 compared to the standard method in high evapotranspirometric rate moments (Figure 1), therefore, during the comparison between these punctual values of ET0, there was a concordance index value reduction.

TABLE 2. Estimation of standard error (ESE) Willmott's concordance (d), Pearson's correlation (r), reliable coefficient (c) and Camargo and Sentelhas performance, obtained from the correlations between the reference evapotranspiration values estimated by the studied methods, with values estimated by Penman-Monteith FAO 56 method in Cassilândia city, Brazil.

Method	ET0	ESE	d	R	c	Performance
Penman-Monteith-FAO56	3,307					
Penman-Original	3,868	0,594	0,925	0,990	0,916	Great
Penman-FAO24	4,670	1,439	0,743	0,979	0,728	Good
Blaney-Criddle-FAO24	3,842	0,938	0,700	0,851	0,595	Badly
Radiation-FAO24	4,759	1,711	0,669	0,915	0,612	Average
Makkink	5,856	2,685	0,509	0,870	0,443	Not good
Hargreaves-Samani	4,995	1,841	0,591	0,839	0,496	Not good
Original Hargreaves	4,402	1,263	0,754	0,885	0,668	Good
Priestley-Taylor	3,438	0,583	0,930	0,786	0,731	Good
Jensen-Haise	5,287	2,161	0,599	0,897	0,537	Badly
Camargo	3,365	0,620	0,882	0,786	0,693	Good
Linacre	5,240	2,368	0,441	0,788	0,348	Terrible
Hamon	3,084	0,639	0,862	0,809	0,698	Good
Ivanov	4,869	2,618	0,406	0,775	0,315	Terrible
Kharrufa	5,738	2,511	0,479	0,814	0,390	Terrible
Garcia-Lopez	4,585	1,679	0,584	0,833	0,487	Not good
Blaney-Morin	2,483	1,302	0,548	0,816	0,447	Not good
Turc	4,030	0,904	0,821	0,880	0,722	Good
McCloud	4,741	1,681	0,640	0,833	0,534	Badly
McGuiness-Bordne	6,002	2,834	0,460	0,781	0,359	Terrible
Romanenko	5,843	3,546	0,338	0,775	0,262	Terrible
Lungeon	3,630	1,688	0,549	0,782	0,430	Not good
Abtew	3,181	0,607	0,878	0,849	0,746	Good
Hicks-Hess	3,470	0,595	0,928	0,784	0,728	Good
Global-Radiation	3,090	0,699	0,790	0,848	0,670	Good
Liquid-Radiation	3,344	0,543	0,934	0,776	0,724	Good
Temperature-Radiation	4,387	1,320	0,746	0,902	0,673	Good
Stephens-Stewart	3,290	0,508	0,933	0,895	0,835	Very good
Tanner-Pelton	4,230	1,189	0,794	0,775	0,615	Average
Thornthwaite-Modified	3,399	0,675	0,889	0,836	0,744	Good
Thornthwaite	5,187	2,445	0,488	0,842	0,411	Not good

The Stephens-Stewart method had a "very good" performance because it reconciled high values of Willmott's concordance and Pearson's correlation. Furthermore, this method has showed low ESE value, confirming its satisfactory performance. However, this method requires, in addition to temperature, global radiation data or number of hours of sunshine as input parameters, making it difficult to use in relation to methods that require only extraterrestrial radiation data, temperature and relative humidity. It is worth mentioning that the extraterrestrial radiation can be only obtained with date and latitude of the local, without the need, therefore, of devices for its measurement. Some authors also found satisfactory estimates of ET0 using the Stephens-Stewart method (KISI, 2009; KISI et al., 2012; SAHOO et al., 2012).

The methods Original Hargreaves, Turc, Abtew, Hicks-Hess, Global-Radiation, Liquid-Radiation, Temperature-Radiation received "good" performance, according to CAMARGO & SENTELHAS (1997). These methods can be used to estimate ET0 in Cassilândia, Mato Grosso do Sul State, but have the drawback dependence of global radiation for their calculation, as previously reported for the Stephens-Stewart method.

The methods of Priestley-Taylor, Camargo, Hamon and Thornthwaite-Modified also received "good" performance, according to CAMARGO & SENTELHAS (1997). The Priestley-Taylor method was developed to estimate the evaporation of saturated surfaces in a non-saturated atmosphere, which is the nature's normal condition (BARROS et al., 2009; CAVALCANTE JR. et al., 2011) and its performance confirmed with what was observed by MOURA et al. (2010); MAGALHÃES & CUNHA (2012) and TAGLIAFERRE et al. (2012b). The Camargo method is derived from the Thornthwaite method, and it works effectively in tropical climate and equatorial humid regions (CAVALCANTE JR. et al., 2011). BACK (2008) also observed good daily ET0 estimates through the Camargo method in Urussanga city, Santa Catarina State, Brazil. By being fairly simple, requiring only average temperature data, it is expected that the Camargo method is used by those who lack complete meteorological stations. The Hamon method, despite the complexity of presenting many coefficients, requires only one parameter measured, average air temperature, making it a method with potential to be used in Cassilândia. The Thornthwaite-Modified method can be used in the study area. However, the constants "a" and "I", necessary for estimating ET0, were taken of only four years of the series, because the Cassilândia's meteorological station has not present yet climatologic regular of 30 years, which would be recommended. Among all methods studied in this research, the equations Thornthwaite-Modified along with Thornthwaite, which received "not good" performance, are the only physical equations. Some researchers have found good performance in these methods in Brazil (BACK, 2008; SILVA et al., 2011; PILAU et al., 2012), except ARAÚJO et al. (2012) for the Thornthwaite method in the State of Roraima, Brazil.

The other methods were "badly", "not good" or "terrible" and should not be used in Cassilândia. The Hargreaves-Samani method is widely used to estimate ET0 in the country, but it was rated as "not good", and it is not, therefore, recommended to the study area, corroborating with BACK (2008) in Urussanga city, Santa Catarina State, BARROS et al. (2009) in Seropédica city, Rio de Janeiro State, PEREIRA et al. (2009) in Serra da Mantiqueira city, Minas Gerais State and ARAÚJO et al. (2012) in Boa Vista city, Roraima State. The Makkink method was developed for climatic conditions in Wageningem, the Netherlands, and probably this was the reason for its performance. Other researchers also observed the same behavior in their research (BARROS et al., 2009; CAVALCANTE JR. et al., 2011; ARAÚJO et al., 2012; MAGALHÃES & CUNHA, 2012). The Linacre method is derived from Penman, estimating evapotranspiration through geographic data (latitude and altitude) and temperature, however, possibly denying of radiation and wind speed have turn it into unsatisfactory performance, corroborating PEREIRA et al. (2009) and MAGALHÃES & CUNHA (2012). The Ivanov method is simple and was developed to estimate ET0 for periods of at least a month. DORFMAN (1977) adapted the equation for calculating daily ET0 and, as verified, did not presented satisfactory performance in Cassilândia, supporting research the BACK (2008). The Kharrufa method has the same parameters as the Blaney-Criddle method-FAO 24, and both had poor performance, mainly due to low Willmott's concordance, corroborating the results of BACK (2008) and PEREIRA et al. (2009). The methods Lungeon, Tanner-Pelton and Makkink also present coefficients obtained in other countries, and possibly, this is the explanation of low performance. The Tanner-Pelton method is based on net radiation, and their constants were obtained for the conditions of Wisconsin, United States.

CONCLUSIONS

In order, the best methods for estimating the daily reference evapotranspiration in the city of Cassilândia, Mato Grosso do Sul are: Penman-Original, Stephens-Stewart, Abtew, Thornthwaite-Modified, Priestley-Taylor, Penman-FAO 24, Hicks-Hess, Liquid-Radiation, Turc, Hamon, Camargo, Temperature-Radiation, Global-Radiation and Original Hargreaves.

The methods of Blaney-Criddle-FAO 24, Radiation-FAO 24, Makkink, Hargreaves-Samani, Jensen-Haise, Linacre, Ivanov, Kharrufa, Garcia-Lopez, Blaney-Morin, McCloud, McGuiness-Bordne, Romanenko, Lungeon, Tanner-Pelton and Thornthwaite should not be used to estimate the daily reference evapotranspiration in the Cassilândia city.

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