Original Article

REFERENCE EVAPOTRANSPIRATION ESTIMATES BY MEANS OF HARGREAVES-SAMANI AND PENMAN-MONTEITH FAO METHODS WITH MISSING DATA IN THE NORTHWESTERN MATO GROSSO DO SUL

ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA PELOS MÉTODOS HARGREAVES-SAMANI E PENMAN-MONTEITH FAO COM DADOS FALTOSOS NO NOROESTE SUL-MATO-GROSSENSE

Fernando França da CUNHA[1]; Luan Peroni VENANCIO[1]; Flávio Bastos CAMPOS[1]; Gilberto Chohaku SEDIYAMA[1]

1. Departamento de Engenharia Agrícola da Universidade Federal de Viçosa, Viçosa, MG, Brasil. fernando.cunha@ufv.br

ABSTRACT: We aimed to assess the performance of different methodologies to estimate the reference evapotranspiration (ET0) in different seasons for at 1, 3, 6 and 10 days for the Northwestern Mato Grosso do Sul. We used a set of daily data obtained from the networks of the Brazilian National Institute of Meteorology for Água Clara, Cassilândia, Chapadão do Sul, Paranaíba and Três Lagoas locations. The meteorological data used were: maximum and minimum air temperatures, wind speed, solar radiation, and relative humidity. The methodologies used for the ET0 estimation were Hargreaves-Samani and Penman-Monteith (PM-FAO) using all the meteorological data needed and missing data on relative humidity, solar radiation and wind speed. To compare ET0 values estimated by means of equations tested against the PM-FAO method we analyzed the parameters of linear regression equation "β_0" and "β_1", coefficient of determination (r^2), standard-error of estimate (SEE) and coefficient of performance (c). The PM-FAO method with missing data (relative humidity and wind speed) were the best alternatives to estimate ET0, followed by the PM-FAO method with missing solar radiation data in all timescales during fall and winter seasons. The Hargreaves-Samani method is not recommended to be used in its original form to estimate ET0 in the Northwestern Mato Grosso do Sul, in none of the timescales and seasons.

KEYWORDS: Agrometeorology. Timescale. ET0. Seasons.

INTRODUCTION

The reference evapotranspiration (ET0) is widely used for irrigation engineering to define the crop water needs and to manage the water distribution in existing systems (DROOGERS; ALLEN; 2002).

The Penman-Monteith FAO method (PM-FAO) is widely used to estimate ET0. This method is based on physical aspects of the evaporation and transpiration processes with respect to hypothetical grass reference (ALLEN et al., 1998), and it has been used worldwide (CUNHA et al., 2013). However, an important disadvantage of this method is the relative large number of input meteorological variables (DROOGERS; ALLEN, 2002; BORGES JÚNIOR et al., 2012), and then its use may become unreliable due to non-availability and low quality information at certain localities (PALARETTI et al., 2014).

In order to find alternatives when facing this situation, many researchers have been proposed estimating ET0 with methods that demand less input data (ALENCAR et al., 2011; FANAYA JUNIOR et al., 2012; CHAGAS et al., 2013; PALARETTI et al., 2014; CARVALHO et al., 2015). Among those methods, Hargreaves-Samani (HARGREAVES; SAMANI, 1985), with only minimum and maximum temperature data, is considered the simplest one to estimate the reference evapotranspiration (ALENCAR et al., 2015) and it can be used for irrigation management (NÓIA et al., 2014).

In addition, using methods that employ a small variables number is useful when there is a broken sensor in the meteorological station and/or a reading error (ALENCAR, et al., 2015; CARVALHO et al., 2015; COSTA et al., 2015; MORAIS et al., 2015). Allen et al. (1998) described alternative equations to estimate the missing data of relative air humidity, solar radiation and winds to be used in the PM-FAO equation. Sentelhas et al. (2010), when evaluating ET0 estimation with missing data in southern Ontario, Canada, found out that the PM-FAO method provided good estimates for ET0 with missing relative humidity and wind speed data. With missing solar radiation data PM-FAO method did not perform well and when only air temperature data were available, adjusted Hargreaves and modified Thornthwaite performed better.

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The behavior that has been verified in Canada will not necessarily occur in other regions. Then, before indicating any method to estimate the ET0, its performance must be previously known in different locations and years, since there is great variability in weather conditions. Thus, a method may have an unsatisfactory performance in winter but it could have a good performance in summer and so it could be recommended.

The state of Mato Grosso do Sul has a great importance for agriculture in the Brazil, since it is the second largest producer of cotton, corn, soybeans and sorghum (CONAB, 2016). These crops are generally irrigated, and so farmers depend on the estimated ET0 for a correct irrigation water management. Then, the choice of methods for such a purpose will contribute to strengthen the irrigated agricultural activity. In addition, the generated information can be used by extension workers, consultants, irrigation companies, educational institutions, and others.

The objective of this paper was to evaluate the performance of the Penman-Monteith (PM-FAO) with missing data and Hargreaves-Samani methods to estimate the ET0, for five locations in the Northwestern region of Mato Grosso do Sul.

MATERIAL AND METHODS

The meteorological data required for carrying out this study were obtained from the Brazilian National Institute of Meteorology (INMET) networks, from five meteorological stations in the northwestern of the state of Mato Grosso do Sul (Table 1 and Figure 1).

Table 1. Information regarding the meteorological stations of Mato Grosso do Sul used for estimating the reference evapotranspiration

Code	Location	Latitude	Longitude	Altitude (m)	Data period	Type climate*
OMM: 86812	Água Clara	-20.4444º	-52.8758º	324	Aug/2010 - Dec/2012	Aw
OMM: 86791	Cassilândia	-19.1225º	-51.7207º	495	Mar/2008 - May/2012	Aw
OMM: 86772	Chapadão do Sul	-18.8022º	-52.6026º	821	Jan/2008 - Dec/2013	Aw
OMM: 86792	Paranaíba	-19.6955º	-51.1818º	408	Mar/2008 - Dec/2013	Aw
OMM: 86813	Três Lagoas	-20.7900º	-51.7122º	329	Jan/2008 - Dec/2013	Aw

* Climate type according to Köppen classification (KOTTEK et al., 2006).

Figura 1. The locations of the meteorological stations used in this research: Água Clara (AC), Cassilândia (Ca), Chapadão do Sul (CS), Paranaíba (Pa) and Três Lagoas (TL).

The meteorological data used were: average, maximum and minimum temperatures (ºC); average, maximum and minimum relative air humidities (%); average, maximum and minimum dew point temperatures (ºC); average, maximum and minimum atmospheric pressures (kPa); wind speed at 10 m height (m s^{-1}) and solar radiation (kJ m^{-2} d^{-1}). The data were obtained from an automatic weather station that consists of the equipment WAWS 301 of the brand VAISALA, 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 verifications were carried out and, subsequently, all information considered discrepant or inconsistent were eliminated, aiming to obtain more representative data set. In order to be considered inconsistent the data should present a minimum temperature greater than maximum, negative or greater than 16 h of insolation, negative or greater than 100% of relative humidity or negative or greater than 20 m s^{-1} for wind speed (10 m high). Proceeding this way 1.92% of the data were discarded.

The methodologies used in the research for the daily reference evapotranspiration estimation (ET0) were:

- a) (default) - Penman-Monteith (PM-FAO) using all the needed meteorological data. It is expressed as Allen et al. (1998):

$$ET0 = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{t+273}\,U_2\,(e_S - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \quad (1)$$

where: ET0 - reference evapotranspiration (mm d^{-1}); Δ - temperature pressure curve slope (kPa °C^{-1}); Rn - net radiation (MJ m^{-2} d^{-1}); G - soil heat flux (MJ m^{-2} d^{-1}); γ - psychrometric constant (kPa °C^{-1}); t - average temperature (°C); U_2 - wind speed (m s^{-1}); e_S - saturation vapor pressure (kPa) and e_a - actual vapor pressure (kPa).

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

$$U_2 = \frac{4.868}{\ln(67.75\,z - 5.42)}\,U_z \quad (2)$$

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:

$$Rn = Rns - Rnl \quad (3)$$

$$Rns = R_S\,(1 - r) \quad (4)$$

$$Rnl = 4.903\,10^{-9}\left[\frac{T_{max}^4 + T_{min}^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\,\frac{R_S}{(0.75 + 2\,10^{-5}\,z)R_a} - 0.35\right) \quad (5)$$

where, Rn - net radiation (MJ m^{-2} d^{-1}); Rns - net solar or shortwave radiation (MJ m^{-2} d^{-1}); Rnl - net outgoing longwave radiation (MJ m^{-2} d^{-1}); R_S - solar or shortwave radiation (MJ m^{-2} d^{-1}); r - albedo or canopy reflection coefficient (dimensionless); T_{max} - maximum absolute temperature during the 24/hour period (K = °C + 273.16); T_{min} - minimum absolute temperature during the 24/hour period (K = °C + 273.16); e_a - actual vapour pressure (kPa); z - station elevation above sea level (m) and R_a - extraterrestrial radiation (MJ m^{-2} d^{-1}).

- b) PM-FAO using the methodology with missing data (relative humidity). The relative humidity was obtained by means of the relation between the current and saturation vapor pressures. In order to calculate the saturation vapor pressure, the maximum air temperature was used and for the current vapor pressure the minimum temperature was considered as the temperature of the dew point, according to Equation 6:

$$e_a = 0.611\,\exp\left(\frac{17.27\,T_{min}}{T_{min} + 237.3}\right) \quad (6)$$

where: e_a - actual vapor pressure (kPa) and T_{min} - minimum air temperature (°C).

- c) PM-FAO with missing data (solar radiation). In this methodology, solar radiation data from the nearest station were used, thus, for Chapadão do Sul, Cassilândia's data were used and vice versa; And for Águas Claras, Três Lagoas' data were used and vice versa. For Paranaíba, which has a distance of over 50 km in the north-south position, Equation 7 was applied with Cassilândia's data.

$$R_S = \frac{R_{S,reg}}{R_{a,reg}}\,R_a \quad (7)$$

where: R_S - solar or shortwave radiation at Paranaíba's station (MJ m^{-2} d^{-1}); $R_{S,reg}$ - solar or shortwave radiation at Cassilândia's station (MJ m^{-2} d^{-1}); $R_{a,reg}$ - extraterrestrial radiation at Cassilândia's station (MJ m^{-2} d^{-1}) and R_a - extraterrestrial radiation at Paranaíba's station (MJ m^{-2} d^{-1}).

- d) PM-FAO with missing data (solar radiation) and replacing with estimated data by the air temperature. In order to do that Equation 8 was applied.

$$R_S = 0.16\,(T_{max} - T_{min})^{0.5}\,R_0 \quad (8)$$

R_S - solar or shortwave radiation (MJ m^{-2} d^{-1}); T_{max} - maximum air temperature (°C) and T_{min} - minimum air temperature (°C).

- e) PM-FAO with missing data (wind speed). For this method, using the meteorological data (Table 1), the average wind speed values at 2 m height were calculated for each location. The average speed values used to estimate the ET0 for Águas Claras, Cassilândia, Chapadão do Sul, Paranaíba and Três Lagoas stations were 1.34, 1.08, 1.54, 1.23 and 1.15 m s^{-1}, respectively.
- f) Hargreaves-Samani. The original equation (Equation 9) was used, according to Hargreaves and Samani (1985).

$$ET0 = 0.0023\,(T + 17.8)(T_{max} - T_{min})^{0.5}\,R_a \quad (9)$$

where: ET0 - reference evapotranspiration (mm d^{-1}); T - average air temperature (°C); T_{max} - maximum air temperature (°C); T_{min} - minimum air temperature (°C) and R_a - extraterrestrial solar radiation (mm d^{-1}).

The ET0 data obtained through different methodologies were confronted with the data obtained by the Penman-Monteith FAO method at intervals of one, three, six and ten days. Irrigation frequencies higher than one day are used. Therefore, the use of larger scales was chosen in order to improve the ET0 estimates due to the unsystematic effect. ET0 estimates were compared just within the same season (winter, fall, summer and spring), since they show distinct behavior among different seasons.

After the data verification, a regression analysis that correlated ET0 estimated values, the Penman-Monteith equation was performed. The coefficients "β_0" and "β_1" of the respective linear regressions and the coefficient of determination (r^2) were considered. The best alternative was the one that showed regression coefficient "β_0" near zero, coefficient "β_1" near unit and higher coefficient of determination, larger 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 variance. The methods accuracy was also analyzed by means of linear regression coefficients with near zero values for β_0 and β_1 near unit.

The methodology adopted for results comparison was proposed by Allen et al. (1989), and it is based on the standard-error of estimate (SEE), calculated by Equation 10. The best method to estimate ET0 was the one that presented the lowest SEE.

$$SEE = \left[\frac{\sum_{i=1}^{n}(X_i - Y_1)^2}{n-1}\right]^{0,5} \quad (10)$$

where: SEE - standard-error of estimate (mm d^{-1}); X_i - reference evapotranspiration estimated by the standard method (mm d^{-1}); Y_i - reference evapotranspiration obtained by the tested method (mm d^{-1}); and n - number of observations.

The approximation of ET0 values estimated by the studied method, in relation to the values obtained using the standard method, was obtained by an index called Willmott agreement index, represented by the letter "d" where its values range from zero, where there is no agreement, to 1, for the perfect agreement (WILLMOTT et al., 1985). The agreement index (d) was calculated using the Equation 11. To validate the model, it was also obtained the Pearson's correlation coefficient (r) through Equation 12 and, consequently, the reliable coefficient or performance (c) through Equation 13.

$$d = 1 - \frac{\sum_{i=1}^{n}(X_i - Y_1)^2}{\sum_{i=1}^{n}[(|X_i - \bar{X}|) + (|Y_i - \bar{X}|)]^2} \quad (11)$$

$$r = \frac{\sum_{i=1}^{n}(|X_i - \bar{X}|)\,(|Y_i - \bar{Y}|)}{\sqrt{\sum_{i=1}^{n}(|X_i - \bar{X}|)^2}\sqrt{\sum_{i=1}^{n}(|Y_i - \bar{Y}|)^2}} \quad (12)$$

$$c = r\,d \quad (13)$$

where: d - Willmott's agreement index; X_i - reference evapotranspiration estimated by the standard method (mm d^{-1}); Y_i - reference evapotranspiration obtained by the tested method (mm d^{-1}); $\bar{Y}$ - average values of reference evapotranspiration obtained by the tested method (mm d^{-1}); $\bar{X}$ - average values of reference evapotranspiration obtained by standard method (mm d^{-1}); n - number of observations; r - Pearson's correlation coefficient; and c - reliable coefficient or performance.

The reliable coefficient or performance, proposed by Camargo e Sentelhas (1997), is interpreted in accordance with the 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

Results of linear regressions with different missing data on daily reference evapotranspiration (ET0) and by Hargreaves-Samani method, along the seasons of the year are presented in Figure 2. High coefficients of determination were observed (r^2 > 0.92), regardless the season, when estimating ET0 for missing relative air humidity and wind speed data. This result is attributed to the average value that satisfactorily represented the wind speed in each annual season, due to the low temporal variability presented by this factor; and due to a good correlation between dew point humidity and minimum humidity, which was used to estimate the air relative humidity. These data corroborate with Morais et al. (2015) researches in the sub-mid region of Vale do São Francisco and also with Alencar et al. (2015) to several cities in the State of Minas Gerais. Sentelhas et al. (2010), in a similar study in the southern part of Ontario province, Canada, found that the Penman-Monteith method, in the absence of relative humidity or wind speed data, is a good choice for ET0 estimates.

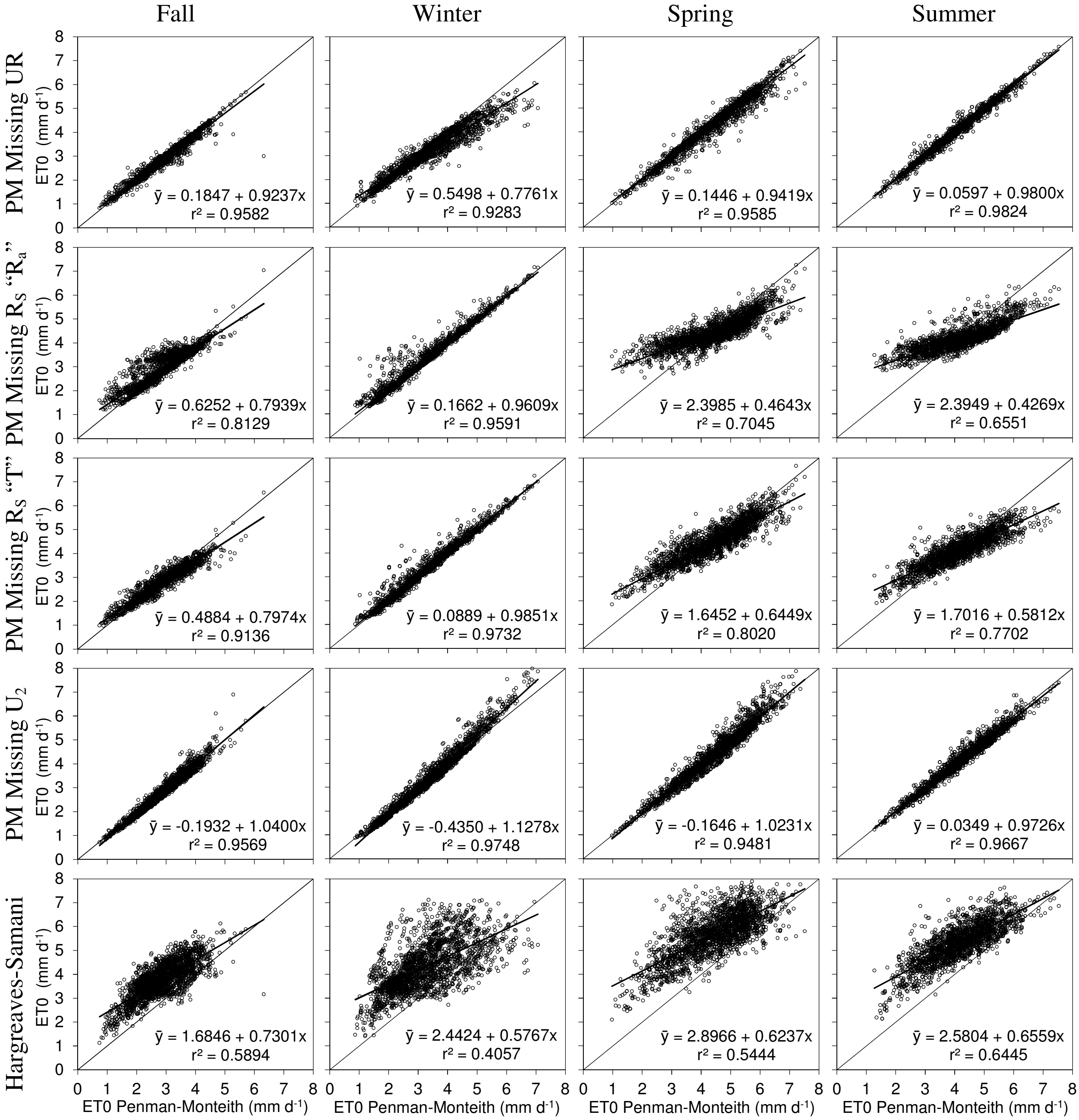

Figure 2. Reference evapotranspiration (ET0) values obtained by the Penman-Monteith FAO method compared with the ET0 values obtained by the Penman-Monteith FAO method calculated with missing data and from Hargreaves-Samani in daily timescale for different seasons.

The performance of the method with missing solar radiation data presented the best performance during winter season, with higher value for r², and the coefficients β_0 and β_1 close to a line type 1:1. The worst fitting was obtained during spring and summer months, in addition to the great tendency to overestimate when ET0 shows values below 4.3 mm d^{-1} and to underestimate above this value. This good performance during colder months, especially winter, is due to the relative humidity and the wind speed, which are the main ET0 conditioning elements. Unlike during hotter periods when the radiation is the most responsible element for the ET0 estimation, then its absence leads to worse estimates. Similar behavior is observed for missing solar radiation and replaced with estimated data by air temperature (PM-FAO missing R_S "T"). However, there is a performance gain in all seasons on the basis of the r², mainly in summer time. This behavior can also be attributed to the absence of clouds during the winter, favoring the estimation of the shortwave radiation balance.

Silva et al. (2011) found that the most sensitive variable in determining ET0 by Penman-

Monteith method is the net solar radiation followed by relative humidity, wind speed and the average air temperature. Similarly, Langensiepen et al. (2009) found that the radiation is the most sensitive variable of this method. Westerhoff (2015) found the following order: air temperature, solar radiation and relative humidity. Thus, this work also shows lower efficiency of the PM-FAO methods with missing solar radiation data.

The Figure 2 also shows, from the standard line (1:1), that the Hargreaves-Samani method overestimates the ET0 practically throughout the year, especially when the Penman-Monteith FAO method shows estimates below 5.8 mm d^{-1}, which can also be seen by the high values of the "β_0" coefficient. The worst fitting was observed in winter (r^2 = 0.4057). These results can be explained based on the climate of the studied localities (Table 1) which are of type Aw (tropical hot and humid), with a rainy weather in summer and a dry weather in winter, according to the Köppen classification (KOTTEK et al., 2006), unlike the semi-arid conditions in which the Hargreaves-Samani method was derived. Tanaka et al. (2016), working with data from 28 locations in the State of Mato Grosso found the worst statistical indicators to estimate ET0 at daily scale using Hargreaves-Samani method. They do not recommend its use. Several other papers show the ET0 overestimations using this method, in daily scale, for humid or subhumid climate regions (YODER et al., 2005; LIMA et al., 2013; ALENCAR et al., 2011; ALENCAR et al., 2015).

Table 2 shows ET0 estimates for the scales of three, six and ten days for different seasons of the year, aiming to identify the performance of methods in a larger timescale. Pereira et al. (2009) highlighted that before applying a method to a particular location or region, it is necessary to check its performance in relation to the standard method, in different timescales and, when necessary, to make calibrations in order to minimize estimation errors. It turns out that, for the PM-FAO method with missing relative humidity or wind speed data, there was an excellent independent fitting for 3, 6 or 10 days timescales according to r^2, where all of them were greater than or equal to 0.92. Moreover, the coefficient "β_0" tended to zero and "β_1" near unit, showing an efficient ET0 estimate, regardless the timescale and the time of year.

Table 2. The coefficients of linear regression "β_0" and "β_1" values, coefficient of determination (r^2) for the regression between the reference evapotranspiration (ET0) obtained by the Penman-Monteith FAO method compared with ET0 values obtained by Penman-Monteith FAO method calculated with missing data and for the Hargreaves-Samani method on scales of three, six and ten days in different seasons

	Method	Fall			Winter			Spring			Summer		
		β_0	β_1	r^2	β_0	β_1	r^2	β_0	β_1	r^2	β_0	β_1	r^2
3 days	PM Missing UR	0.17	0.93	0.97	0.54	0.78	0.94	0.19	0.93	0.96	0.08	0.97	0.98
	PM Missing R_S 'R_a'	0.46	0.85	0.85	0.08	0.99	0.97	2.21	0.51	0.72	2.13	0.49	0.69
	PM Missing R_S 'T'	0.42	0.82	0.93	0.04	1.00	0.98	1.58	0.66	0.81	1.55	0.62	0.78
	PM Missing U_2	-0.17	1.03	0.96	-0.43	1.12	0.98	-0.15	1.02	0.94	0.11	0.96	0.97
	Hargreaves-Samani	1.62	0.75	0.63	2.41	0.59	0.42	2.88	0.63	0.54	2.36	0.71	0.69
6 days	PM Missing UR	0.15	0.94	0.98	0.53	0.78	0.95	0.23	0.92	0.95	0.10	0.97	0.98
	PM Missing R_S 'R_a'	0.34	0.89	0.87	0.04	0.99	0.98	2.06	0.54	0.73	1.90	0.54	0.70
	PM Missing R_S 'T'	0.38	0.83	0.94	0.02	1.01	0.98	1.57	0.66	0.79	1.52	0.63	0.76
	PM Missing U_2	-0.16	1.03	0.96	-0.44	1.13	0.98	-0.16	1.02	0.93	0.16	0.94	0.97
	Hargreaves-Samani	1.59	0.76	0.65	2.44	0.58	0.40	2.95	0.61	0.51	2.27	0.73	0.70
10 days	PM Missing UR	0.13	0.94	0.98	0.53	0.78	0.95	0.23	0.92	0.95	0.11	0.97	0.98
	PM Missing R_S 'R_a'	0.25	0.92	0.90	0.02	1.00	0.98	1.93	0.57	0.73	1.70	0.59	0.72
	PM Missing R_S 'T'	0.36	0.84	0.95	0.02	1.01	0.99	1.60	0.66	0.77	1.55	0.62	0.72
	PM Missing U_2	-0.16	1.03	0.97	-0.46	1.14	0.98	-0.17	1.02	0.92	0.17	0.94	0.97
	Hargreaves-Samani	1.60	0.76	0.65	2.45	0.56	0.39	3.03	0.59	0.47	2.29	0.73	0.68

The calculated ET0 for PM-FAO with missing R_S "R_a", as noted in the daily scale, had a better performance in winter with a value of r^2 above 0.97 and coefficients "β_0" and "β_1" tending to the 1:1 line, for all periods. Fall also showed a good fitting, having a higher value for the r^2 in the 10 days scale. For spring and summer we had the worst fitting. We can see by the r^2 and by the regression coefficients that ET0 estimates by PM-FAO with missing R_S "T" presented better settings in relation to the PM-FAO missing R_S "R_a" methodology. However, the trends were the same and we observed better performances for winter, fall, spring and summer, respectively.

The timescale increase has favored almost every ET0 estimation method with missing data, based only the r², except for PM-FAO with missing R_S "T", for spring and summer time; and PM-FAO with missing wind speed data for spring time, considered 6 and 10 days, which showed a slight decrease compared to the daily scale. Bragança et al. (2010) studied several methods in different timescales in the rainy weather for the localities Venda Nova do Imigrante, Sooretama and Cachoeiro de Itapemirim in the State of Espírito Santo, and they found higher values for the coefficient of determination (r^2), coefficient of correlation (r), the Willmott agreement index (d) and the confidence index or performance (c) for the three timescales of three, five and seven days, compared to the daily timescale.

The Hargreaves-Samani method, as well as daily scale, adjusted itself poorly based on r² for all the tested time scales. By analyzing the coefficients, especially the "β_0" (positively far from zero), there was a tendency to keep the overestimates as samples in the daily scale (Figure 2). However, summer and fall seasons showed higher r² for all timescales, in relation to the daily scale. Pilau et al. (2012) tested the Hargreaves-Samani method for the localities of Frederico Westphalen and Palmeira das Missões, in Rio Grande do Sul State, in different timescales (5, 10, 15 and 30 days) and verified better coefficients of correlation, accuracy and performance for the tested scales in relation to the daily scale. In similar work, Mendonça et al. (2003) tested the Hargreaves-Samani method for the location of Campos de Goytacazes, in Rio de Janeiro State, which has similar climatic conditions to the studied regions for this paper and found that this method offers better results for ET0 estimated values collected in 7 and 10 days.

It is worth to show that the mere adoption of the r^2 as the only rule for defining the quality of methods is not suitable, since this method does not establish the type and magnitude of the differences between a default value and a value predicted by models estimate or other mechanisms of different measure (BARROS et al., 2009). Then, we used the criteria listed in Table 3 to assist in interpreting the results which presented the standard-error of estimate (SEE) and the Camargo and Sentelhas performance (c), obtained from the correlations between ET0 values by the Penman-Monteith FAO method and those obtained by the studied methods.

Table 3. The standard-error of estimate (SEE) and the Camargo and Sentelhas performance coefficient (c) obtained from correlations between the values of reference evapotranspiration by Penman-Monteith FAO method with the tested methods in different scales and seasons

	Method	Fall		Winter		Spring		Summer	
		SEE	c	SEE	c	SEE	c	SEE	c
Daily	PM Missing UR	0.1623	Great	0.3888	Great	0.2562	Great	0.1359	Great
	PM Missing R_S "R_a"	0.3346	Great	0.2302	Great	0.6906	Good	0.6560	Good
	PM Missing R_S "T"	0.2590	Great	0.1886	Great	0.5417	Very good	0.5312	Very good
	PM Missing U_2	0.1895	Great	0.2495	Great	0.2772	Great	0.2004	Great
	Hargreaves-Samani	1.0510	Badly	1.4127	Not good	1.4455	Badly	1.2924	Badly
3 days	PM Missing UR	0.1279	Great	0.3477	Great	0.2135	Great	0.1126	Great
	PM Missing R_S "R_a"	0.2714	Great	0.1787	Great	0.5039	Good	0.5059	Good
	PM Missing R_S "T"	0.2117	Great	0.1517	Great	0.4083	Very good	0.4233	Very good
	PM Missing U_2	0.1656	Great	0.2182	Great	0.2330	Great	0.1691	Great
	Hargreaves-Samani	1.0136	Badly	1.3579	Not good	1.3589	Not good	1.2341	Badly
6 days	PM Missing UR	0.1051	Great	0.3253	Great	0.1925	Great	0.1008	Great
	PM Missing R_S "R_a"	0.2281	Great	0.1486	Great	0.3938	Very good	0.4080	Good
	PM Missing R_S "T"	0.1867	Great	0.1323	Great	0.3388	Very good	0.3683	Very good
	PM Missing U_2	0.1490	Great	0.2032	Great	0.2089	Great	0.1501	Great
	Hargreaves-Samani	0.9948	Badly	1.3311	Not good	1.3206	Not good	1.2095	Badly
10 days	PM Missing UR	0.0894	Great	0.3092	Great	0.1795	Great	0.0923	Great
	PM Missing R_S "R_a"	0.1935	Great	0.1291	Great	0.3320	Very good	0.3386	Very good
	PM Missing R_S "T"	0.1709	Great	0.1183	Great	0.3039	Very good	0.3357	Very good
	PM Missing U_2	0.1396	Great	0.1941	Great	0.1942	Great	0.1389	Great
	Hargreaves-Samani	0.9844	Not good	1.2872	Not good	1.3033	Terrible	1.1973	Not good

It was observed that the best methods for estimating the ET0 in Northwestern Mato Grosso do Sul were the PM-FAO with missing relative humidity and wind speed data, for all timescales and seasons. The methodologies for ET0 estimates with missing solar radiation data, regardless the timescale, have also presented optimal performance according to "c" classification (CAMARGO; SENTELHAS, 1997) for fall and winter showing low SEE values, ranging from 0.0894 to 0.3888.

The second best performance category is seen for the PM-FAO (missing R_S "T") when applied during spring and summer in all timescales and for PM-FAO (missing R_S "R_a") in spring (timescales of 6 and 10 days) and in summer (10 days). It showed very good performance according to Camargo and Sentelhas (1997) index and SEE of 0.3; 0.4 and 0.5. The PM-FAO missing R_S "R_a" method received the rating "good". These results allow classifying the PM with missing relative humidity or wind speed data as the best options among the proposed models, followed by PM-FAO (missing R_S "T") and PM-FAO (missing R_S "R_a"), respectively. These results corroborate with those obtained by Alencar et al. (2015) for 20 locations in the State of Minas Gerais, Morais et al. (2015) in the sub-mid region of Vale do São Francisco and Carvalho et al. (2015) in the States of Espírito Santo and Rio de Janeiro, also studied with the Penman-Monteith FAO method with missing data.

The Hargreaves-Samani method presented the worst performance by varying from the classifications of bad, terrible to poor in the "c" classification proposed by Camargo and Sentelhas (1997). From the SEE it presented higher values ranging from 0.9844 to 1.4127, mainly in winter and spring. Thus, the Hargreaves-Samani method should not be used in the Northwest region of Mato Grosso do Sul in its original form for the studied timescales. Several authors have tested this method in many locations in Brazil and they have not found good results either, like Reis et al. (2007) for Venda Nova, in Espírito Santo, Rigoni et al. (2013) for Aquidauana, in Mato Grosso do Sul, Alencar et al. (2015) for 20 locations in Minas Gerais and Morais et al. (2015) in the Sub-mid region of São Francisco Valley. However, the method needs only maximum and minimum temperature data, and that presented a reasonable value of r^2 in summer and fall. Another fact is that the method can easily be used by producers for irrigation management (NÓIA et al., 2014).

CONCLUSIONS

The Penman-Monteith FAO method with missing relative humidity and wind speed data is the best alternative to estimate the reference evapotranspiration, followed by the methods of Penman-Monteith FAO with missing solar radiation data in all timescales for fall and winter.

The Hargreaves-Samani method is not recommended to be used in its original form to estimate the reference evapotranspiration in the Northwest region of Mato Grosso do Sul, for none of the timescales and periods of the year.

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RESUMO: Objetivou-se avaliar o desempenho de diferentes metodologias na estimativa da evapotranspiração de referência (ET0) nas distintas estações anuais e considerando as escalas de 1, 3, 6 e 10 dias para a região noroeste sul-mato-grossense. Foi utilizado um conjunto de dados diários adquiridos de estações automáticas da rede do Instituto Nacional de Meteorologia das localidades de Água Clara, Cassilândia, Chapadão do Sul, Paranaíba e Três Lagoas. Os dados meteorológicos utilizados foram: temperaturas máximas e mínimas do ar, velocidade do vento, radiação solar e umidade relativa do ar. As metodologias utilizadas para a estimativa da ET0 foram: Hargreaves-Samani e Penman-Monteith FAO (PM-FAO) utilizando todos os dados meteorológicos necessários e com dados faltantes de umidade relativa do ar, radiação solar e velocidade do vento. Para comparar os valores de ET0 estimados por meio das equações testadas com os do método PM-FAO foram considerados os parâmetros da equação de regressão "β_0" e "β_1", coeficiente de determinação (r^2), erro padrão de estimativa (EPE) e coeficiente de desempenho (c). Os métodos de PM-FAO com dados faltosos de umidade relativa e velocidade do vento são as melhores alternativas para a estimativa de ET0, seguido dos métodos de PM-FAO com dados faltosos de radiação solar em todas as escalas de tempo e para as estações outono e inverno. O método de Hargreaves-Samani não é recomendado para ser utilizado em sua forma original nas estimativas de ET0 na região noroeste sul-mato-grossense, em nenhuma das escalas de tempo e estações anuais.

PALAVRAS-CHAVE: Agrometeorologia. Escala temporal. ET0. Estações anuais.

REFERENCES

ALENCAR, L. P.; DELGADO, R. C.; ALMEIDA, T. S.; WANDERLEY, H. S. Comparação de diferentes métodos de estimativa diária da evapotranspiração de referência para a região de Uberaba. **Revista Brasileira de Ciências Agrárias**, v. 6, n. 2, p. 337-343, 2011. https://doi.org/10.5039/agraria.v6i2a1124

ALENCAR, L. P.; SEDIYAMA, G. C.; MANTOVANI, E. C. Estimativa da evapotranspiração (ET0 padrão FAO), para Minas Gerais, na ausência de alguns dados climáticos. **Revista Engenharia Agrícola**, v. 35, n. 1, p. 39-50, 2015. https://doi.org/10.1590/1809-4430-Eng.Agric.v35n1p39-50/2015

ALLEN, R. G.; JENSEN, M. E.; WRIGHT, J.; BURMAN, R. D. Operational estimates of reference evapotranspiration. **Agronomy Journal**, v. 81, n. 4, p. 650-662, 1989. https://doi.org/10.2134/agronj1989.00021962008100040019x

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop evapotranspiration: guidelines for computing crop water requirements**. Rome: FAO, 1998. 300 p. (Irrigation and Drainage Paper, 56).

BARROS, V. R.; SOUZA, A. P.; FONSECA, D. C.; SILVA, L. B. D. Avaliação da evapotranspiração de referência na região de Seropédica, Rio de Janeiro, utilizando lisímetro de pesagem e modelos matemáticos. **Revista Brasileira de Ciências Agrárias**, v. 4, n. 2, p. 198-203, 2009. https://doi.org/10.5039/agraria.v4i2a13

BORGES JÚNIOR, J. C. F.; ANJOS, R. J.; SILVA, T. J. A.; LIMA, J. R. S.; ANDRADE, C. L. T. Métodos de estimativa da evapotranspiração de referência diária para a microrregião de Garanhuns-PE. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 16, n. 4, p. 380-390, 2012. https://doi.org/10.1590/S1415-43662012000400008

BRAGANÇA, R.; REIS, E. F.; GARCIA, G. O.; PEZZOPANE, J. E. M. Estudo comparativo da estimativa da evapotranspiração de referência no período chuvoso para três localidades no estado do Espírito Santo. **Idesia**, v. 28, n. 2, p. 21-29, 2010. https://doi.org/10.4067/S0718-34292010000200003

CAMARGO, A. P.; SENTELHAS, P. C. Avaliação do desempenho de diferentes métodos de estimativa da evapotranspiração potencial no estado de São Paulo. **Revista Brasileira de Agrometeorologia**, v. 5, n. 1, p. 89-97, 1997.

CARVALHO, D. F.; ROCHA, H. S.; BONOMO, R.; SOUZA, A. P. Estimativa da evapotranspiração de referência a partir de dados meteorológicos limitados. **Pesquisa Agropecuária Brasileira**, v. 50, n. 1, p. 1-11, 2015. https://doi.org/10.1590/S0100-204X2015000100001

CHAGAS, R. M.; FACCIOLI, G. G.; NETTO, A. O. A.; SOUZA, I. F.; VASCO, A. N.; SILVA, M. G. Comparação entre métodos de estimativa da evapotranspiração de referência (ET0) no município de Rio Real-BA. **Irriga**, v. 18, n. 1, p. 351-363, 2013.

CONAB - COMPANHIA NACIONAL DE ABASTECIMENTO. **Planilhas eletrônicas: (1) Algodão-Brasil; (2) Milho total (1ª E 2ª safra)-Brasil; (3) Soja-Brasil; (3) Sorgo-Brasil.** Disponível: <http://www.conab.gov.br/conteudos.php?a=1252&t=2>. Acesso em 10 agosto 2016.

COSTA, M. S.; MANTOVANI, E. C.; SEDIYAMA, G. C. Comportamento dos diferentes métodos de determinação da evapotranspiração de referência nas cinco regiões brasileiras. **Revista Brasileira de Agricultura Irrigada**, v. 9, n. 5, p. 310-319, 2015. https://doi.org/10.7127/rbai.v9n500320

CUNHA, F. F.; MAGALHÃES, F. F.; CASTRO, M. A. Métodos para estimativa da evapotranspiração de referência para Chapadão do Sul - MS. **Engenharia na Agricultura**, v. 21, n. 2, p. 159-172, 2013. https://doi.org/10.13083/1414-3984.v21n02a06

DROOGERS, P.; ALLEN, R. G. Estimating reference evapotranspiration under inaccurate data conditions. **Irrigation Drainage System**, v. 16, n. 1, p. 33-45, 2002. https://doi.org/10.1023/A:1015508322413

FANAYA JÚNIOR, E. D.; LOPES, A. S.; OLIVEIRA, G. Q.; JUNG, L. H. Métodos empíricos para estimativa da evapotranspiração de referência para Aquidauana, MS. **Irriga**, v. 17, n. 4, p. 418-434, 2012. https://doi.org/10.15809/irriga.2012v17n4p418

HARGREAVES, G. H.; SAMANI, Z. A. Reference crop evapotranspiration from temperature. **Journal of Applied Engineering in Agriculture**, v. 1, n. 2, p. 96-99, 1985. https://doi.org/10.13031/2013.26773

KOTTEK, M.; GRIESER, J.; BECK, C.; RUDOLF, B.; RUBEL, F. 2006. World Map of the Köppen-Geiger climate classification updated. **Meteorologische Zeitschrift**, v. 15, n. 3, p. 259-263, 2006. https://doi.org/10.1127/0941-2948/2006/0130

LANGENSIEPEN, M.; FUCHS, M., BERGAMASCHI, H.; MORESHET, S.; COHEN Y.; WOLFF, P.; JUTZI, S. C.; COHEN, S.; ROSA, L. M. G.; LI, Y.; FRICKE, T. Quantifying the uncertainties of transpiration calculations with the Penman-Monteith equation under different climate and optimum water supply conditions. **Agricultural and Forest Meteorology**, v. 149, n. 6, p. 1063-1072, 2009. https://doi.org/10.1016/j.agrformet.2009.01.001

LIMA, J. R. S.; ANTONINO, A. C. D.; SOUZA, E. S.; HAMMECKER, C.; MONTENEGRO, S. M. G. L.; LIRA, C. A. B. O. Calibration of Hargreaves-Samani equation for estimating reference evapotranspiration in sub-humid region of Brazil. **Journal of Water Resource and Protection**, v. 5, n. 12, p. 1-5, 2013. https://doi.org/10.4236/jwarp.2013.512A001

MENDONÇA, J. C. SOUSA, E. F.; BERNARDO, S.; DIAS, G. P.; GRIPPA, S. Comparação entre métodos de estimativa da evapotranspiração de referência (ET0) na região Norte Fluminense, RJ. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 7, n. 2, p. 275-279, 2003. https://doi.org/10.1590/S1415-43662003000200015

MORAIS, J. E. F.; SILVA, T. G. F.; SOUZA, L. S. B.; MOURA, M. S. B.; DINIZ, W. J. S.; SOUZA, C. A. A. Avaliação do método de Penman-Monteith FAO 56 com dados faltosos e de métodos alternativos na estimativa da evapotranspiração de referência no Submédio Vale do São Francisco. **Revista Brasileira de Geografia Física**, v. 8, n. 6, p. 1644-1660, 2015. https://doi.org/10.5935/1984-2295.20150093

NOIA, C. P. Z.; PEREIRA, S. B.; ROSA, D. R. Q.; ALMEIDA, R. A. Evapotranspiração de referência estimada pelos métodos Penman-Monteith-FAO (56) e Hargreaves & Samani para o município de Dourados, MS. **Revista Agrarian**, v. 7, n. 24, p. 300-308, 2014.

PALARETTI, L. F.; MANTOVANI, E. C.; SEDIYAMA, G. C. Comparação entre métodos de estimativa da evapotranspiração de referência (ET0) em regiões citrícolas paulistas. **Engenharia Agrícola**, v. 34, n. 1, p. 38-47, 2014. https://doi.org/10.1590/S0100-69162014000100005

PEREIRA, D. R.; YANAGI, S. N. M.; MELLO, C. R.; SILVA, A. M.; SILVA, L. A. S. Desempenho de métodos de estimativa da evapotranspiração de referência para a região da Serra da Mantiqueira-MG. **Ciência Rural**, v. 39, n. 9, p. 2.488-2.493, 2009.

PILAU, F. G.; BATTISTI, R.; SOMAVILLA, L.; RIGHI, E. Z. Desempenho de métodos de estimativa da evapotranspiração de referência nas localidades de Frederico Westphalen e Palmeira das Missões, RS. Desempenho de métodos de estimativa. **Ciência Rural**, v. 42, n. 2, p. 283-290, 2012. https://doi.org/10.1590/S0103-84782012000200016

REIS, E. F.; BRAGANÇA, R.; GARCIA, G. O. Estudo comparativo da estimativa da evapotranspiração de referência para três localidades do Estado do Espírito Santo no período seco. **Idesia**, v. 25, n. 3, p. 75-7854, 2007.

RIGONI, E. R.; OLIVEIRA, G. Q.; BISCARO, G. A.; QUEIRÓZ, M. V. B. M.; LOPES, A. S. Desempenho sazonal da evapotranspiração de referência em Aquidauana, MS. **Engenharia na Agricultura**, v. 21, n. 6, p. 547-562, 2013. https://doi.org/10.13083/1414-3984.v21n06a03

SENTELHAS, P. C.; GILLESPIE, T. J.; SANTOS, E. A. Evaluation of FAO Penman-Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada. **Agricultural Water Management**, v. 97, n. 5, p. 635-644, 2010. https://doi.org/10.1016/j.agwat.2009.12.001

SILVA, B. K. N.; SILVA, V. P. R.; AZEVEDO, P. V.; FARIAS, C. H. A. Análise de sensibilidade dos métodos de estimativa da evapotranspiração de referência e razão de Bowen em cultura da cana-de-açúcar. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, n. 10, p. 1046-1053, 2011. https://doi.org/10.1590/S1415-43662011001000008

TANAKA, A. A.; SOUZA, A. P.; KLAR, A. E.; SILVA, A. C.; GOMES, A. W. A. Evapotranspiração de referência estimada por modelos simplificados para o Estado do Mato Grosso. **Pesquisa Agropecuária Brasileira**, v. 51, n. 2, p. 91-104, 2016. https://doi.org/10.1590/S0100-204X2016000200001

WESTERHOFF, R. S. Using uncertainty of Penman and Penman-Monteith methods in combined satellite and ground-based evapotranspiration estimates. **Remote Sensing of Environment**, v. 169, n. 11, p. 102-112, 2015. https://doi.org/10.1016/j.rse.2015.07.021

WILLMOTT, C. J.; ACKLESON, S. G.; DAVIS, R. E.; FEDDEMA, J. J.; KLINK, K. M.; LEGATES, D. R.; O'DONNELL, J.; ROWE, C. M. Statistics for the evaluation and comparison of models. **Journal of Geophysical Research**, v. 90, n. 5, p. 8995-9005, 1985. https://doi.org/10.1029/JC090iC05p08995

YODER, R. E.; ODHIAMBO, L. O.; WRIGHT, W. C. Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the humid southeast united states. **Applied Engineering in Agriculture**, v. 21, n. 2, p. 197-202, 2005. https://doi.org/10.13031/2013.18153