PERFORMANCE OF REFERENCE EVAPOTRANSPIRATION MODELS USING TEMPERATURE DATA

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SUMMARY: The use of reference evapotranspiration (ET_o) models that require a lower number of meteorological variables are simpler, more operational and lower cost alternatives for farmers. This work evaluated the performance of ET_o estimated from the maximum and minimum air temperature data using the Hargreaves and reduced-set FAO Penman-Monteith (FAO-PM) equations on the daily scale and with annual and seasonal adjustment for 5 meteorological stations of the Jequitinhonha River Valley. The values obtained were compared with the full set FAO-PM standard method. The correlation (r), determination (R^2) and efficiency (E) coefficients; the agreement (d) and performance (c) indexes; and the standard error of estimate (SEE). The results showed that both models, Hargreaves and reduced-set FAO-PM, even without adjustment, may be a viable recommendation for irrigation management. The seasonal adjustment provided an improvement in the performance of the Hargreaves method and the annual adjustment provided an improvement in the FAO Penman-Monteith method with missing data.

KEYWORDS: Jequitinhonha, reduced set, seasonality

DESEMPENHO DE MÉTODOS DE ESTIMATIVA DE EVAPOTRANSPIRAÇÃO DE REFERÊNCIA UTILIZANDO APENAS DADOS DE TEMPERATURA

RESUMO: O uso de modelos de estimativa da evapotranspiração de referência (ET_o) que demandem um menor número de variáveis meteorológicas é uma alternativa mais simples, operacional e de menor custo para os agricultores. Este trabalho avaliou o desempenho de estimativas da ET_o a partir de dados de temperatura máxima e mínima, utilizando a metodologia de Hargreaves e Penman-Monteith FAO com dados faltantes na escala diária e com ajuste anual e trimestral para 5 estações meteorológicas do Vale do Rio Jequitinhonha. Compararam-se os valores obtidos com o método padrão de Penman-Monteith FAO. Para avaliação do

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desempenho dos modelos, foram considerados os coeficientes de correlação (r), determinação (R^2) e de eficiência (E); os índices de concordância (d) e de desempenho (c); e o erro padrão de estimativa (SEE). Os resultados encontrados mostraram que ambos os modelos, Hargreaves e Penman-Monteith FAO com dados faltantes, mesmo sem ajuste, podem ser uma recomendação viável para o manejo da irrigação. O ajuste trimestral propiciou melhoria no desempenho do método de Hargreaves e o ajuste anual propiciou melhoria no método de Penman-Monteith FAO com dados faltantes.

PALAVRAS-CHAVES: Jequitinhonha, dados faltantes, sazonalidade

INTRODUCTION

The reference evapotranspiration (ET_o) is a basic parameter with high importance for the definition of the crop water requirements. There are lots of equipment, methodologies and agrometeorological models used to estimate ET_o, but some models require significant amounts of climatic elements, such as Penman-Monteith (Ortega-Farias et al., 2009).

The FAO Penman-Monteith (FAO-PM) standard method (Allen et al., 1998) is recommended to determine ET_o at different sites and climates. To use this method, the following meteorological data are required: solar radiation (sunshine), air temperature, wind speed and air humidity.

In Brazil, the availability of meteorological information is reduced, mainly for the small and medium agricultural producers, which is caused by the reduced number of weather stations in the national network and by the high cost of individual automatic stations for rural properties. The lack of local data needed to calculate ET_o is a limitation to use the FAO-PM standard method for estimating reference evapotranspiration.

Air temperature based methods have been frequently used and recommended (Jahanbani & El-Shafie, 2010; Trajkocic & Kolakovic, 2009) because of the simplicity of the calculations and because they require very little input data and easy collection of these data. However, such methods must be calibrated to specific sites in order to provide more reliable results (Mohawesh, 2010).

Allen et al. (1998) propose procedures, due to the lack of data on solar radiation, wind speed, and air humidity, for the estimation of these elements when there is no measurement or there are failures in the climatic data series. It also reports basically two modes of procedures: importing data from a station under the same climatic conditions or estimating from maximum and minimum air temperature data, such as the Hargreaves method and the FAO-PM with missing data set.

These latter methods should be verified in each region compared to the estimates by the FAO-PM method with full data set for meteorological stations where the radiation, air temperature, relative air humidity and wind speed are measured. When necessary, estimates from simplified data should be calibrated on a monthly or annual basis, with empirical adjustment coefficients being determined (Allen et al., 1998), using regression analysis. The seasonality of this calibration, monthly, quarterly or annual, aims to give greater precision to the ET_o estimation by simplified methods compared to the standard method.

Considering these points, this work aimed to evaluate the performance of ET_o estimates based on temperature data, using the Hargreaves and FAO Penman-Monteith reduced set methodologies, both with annual and quarterly adjustment for the Jequitinhonha Valley in Minas Gerais State, Brazil.

MATERIAL AND METHODS

The sites of interest of this work are presented in Table 1, as well as the geographic coordinates, altitude, and the number of years os observation of the climatic data.

The estimates of the reference evapotranspiration (ET_o) was performed by the Irriplus application (Mantovani et al. 2009) using a series of daily climatic data from the conventional weather station, located on each site, provided by the National Institute of Meteorology (INMET) in the software climate database. It was selected the weather stations that served the climatic characteristics of the Jequitinhonha River Basin in Minas Gerais State and the minimum data series of five years.

The daily climatic data available for the estimation of ET_o were maximum, minimum and average air temperatures, sunshine duration hours, relative air humidity and average wind speed.

The daily values of ET_o were calculated from a historical series of meteorological data, presenting the average results for the period of one year. The models used to estimate ET_o values were Hargreaves (HG) (Hargreaves & Allen, 2003) and reduced-set FAO Penman-Monteith ($FAO\text{-}PM_{rs}$) (Allen et al., 1998).

The comparison was made between the HG and FAO 56 PM_{rs} models with the full set FAO Penman-Monteith standard method ($FAO\text{-}PM_{fs}$). The ET_o values were analyzed in average daily values, where the regression equations were adjusted by an electronic spreadsheet.

The procedures established in FAO Bulletin Nº. 56 for the estimation of the other parameters were used when using the FAO-PM_{rs}, i.e., considering only the maximum and maximum air temperature data available.

The actual vapour pressure was obtained by the minimum air temperature, replacing the temperature of the dew point. For the calculation of solar radiation, it was used the methodology proposed by Hargreaves & Samani (1985), which estimates the global solar radiation by the difference of daily air temperature and extraterrestrial radiation.

Allen et al. (1998) suggest mean values of wind speed when it is not available. Thus, the wind velocity of 2 m s^{-1} was used to estimate ET_o.

Linear regression was used for the seasonal calibration of the simplified models. The adjustment parameters were obtained on a quarterly basis (FAO-$PM_{rs\ saj}$ and HG_{saj}) and annual (FAO-$PM_{rs\ aaj}$ and HG_{aaj}), in order to evaluate the effect of seasonality on the quality of this adjustment.

It was used the criteria proposed by Jensen et al. (1990), followed by procedures used by França Neto et al. (2011) to evaluate the goodness-to-fit of the models that involved the Pearson correlation coefficient (r), the coefficient of determination (R^2), the coefficient of efficiency (E), the agreement index (d) and the performance index (c), the standard error of estimation (SEE) and the standard deviation (σ).

The Pearson correlation coefficient (r) was given by the Equation 1.

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad \text{Eq. 1}$$

where: x = ET_o estimation by the standard method; y = ET_o estimation by the model.

The coefficient of determination (R^2) was given by the square of the Pearson correlation coefficient. The Nash-Sutcliffe efficiency coefficient (E) (Nash & Sutcliffe, 1970) was given by the Equation 2.

$$E = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad \text{Eq. 2}$$

The Wilmott concordance index (d) (Wilmott, 1984), is presented in Equation 3.

$$d = 1 - \frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(|y_i - \bar{x}| + |x_i - \bar{x}|)^2} \qquad \text{Eq. 3}$$

It was used the classification criteria based on the performance index proposed by Camargo & Sentelhas (1997), which is the result of the product between the Pearson correlation coefficient (r) and the Willmott concordance index (d), whose interpretation criteria are shown in Table 2.

The standard error of the estimation (SEE) was given by the following Equation 4.

$$SEE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n-1}} \qquad \text{Eq. 4}$$

RESULTS AND DISCUSSION

The daily mean ET_o, estimated by the Hargreaves (HG), reduced-set FAO Penman-Monteith (FAO-PM_{rs}) models and the full-set FAO Penman-Monteith (FAO-PM_{fs}) standard method for the studied sites are shown in Figure 1. The highest monthly mean ETo was estimated by the HG model, 6.04 mm d^{-1}, for the city of Salinas in January and the lowest monthly mean ET_o was 2.21 mm d^{-1}, estimated by the FAO-PM_{fs} model, in June, in Itamarandiba. The maximum evapotranspiration peaks in the study sites were observed in the period from September to April and the lowest, between May and August, coinciding with the periods of higher and lower monthly average temperatures, respectively.

Table 3 shows the daily mean values of ET_o estimated by each model and the performance parameters evaluated. The HG model overestimated on average 13% the evapotranspiration obtained by the standard method, a fact also observed by other authors (França Neto et al., 2011, Trajkovic & Kolakovic, 2009, Vicente et al. 2015), though Pedra Azul estimates have overestimated by 3% only.

On average, the FAO-PM_{rs}, overestimated by 10% the FAO-PM_{fs} standard method, similar results were presented by Carvalho et al. (2013). The localities of Diamantina and Pedra Azul presented a small underestimate (1%), this fact was also found by Costa et al. (2015), who observed that the FAO-PM_{rs}, for several regions studied, underestimated ET_o values when compared to the standard method.

It was also observed the existence of a good correlation between the values estimated by the all the models, which can be proved by the coefficient of determination (R^2). The HG method presented values of the linear coefficient (a) closer to zero and the angular coefficient (b) closer to the unit of the adjusted regression equations, as shown in Table 3, indicating a close agreement between the values estimated by this model and those estimated by the standard method.

The lower values of the Nash-Sutcliffe (E) efficiency coefficient was found in the estimates of HG and FAO-PM_{rs} in Araçuaí. It is observed that, after the adjustments, most of the time, there was an improvement of the values of E, with a tendency to the unity, which indicates the goodness-to-fit.

The standard error of estimation (SEE) ranged from 0.33 to 0.95 mm d_{-1} for the HG model and from 0.28 to 0.98 mm d_{-1} for the FAO-56 PMrs one. On average, the SEE values for FAO-PM_{rs} were lower, resulting from the lower overestimation of ET_o. When comparing the SEE values for HG and FAO-PM_{rs} before and after the adjustments obtained on a quarterly (FAO-$PM_{rs\ saj}$ and HG_{saj}) and annual basis (FAO-$PM_{rs\ aaj}$ and HG_{aaj}), it was observed that, in most cases, there is a decrease in the deviations with the adjustment made by the regression, indicating improvement in ET_o estimation by the local adjustment method. Comparatively, the quarterly adjustments provided smaller standard errors of estimation than the annual adjustments. There was an improvement of 0.01 mm d_{-1} for the HG and 0.16 mm d-1 for FAO-PM_{rs}, which demonstrates the potential of the seasonal adjustment in the ET_o estimates using these two models.

When analyzing only the evaluated models without adjustment, regarding the performance classifications, they obtained the classification varying from "good" to "very good". Only in Araçuaí, there was a difference in the classification, being the HG model the best-ranked one. Diamantina and Pedra Azul methods, regardless of fit, were classified as “excellent”.

There was an improvement in the classification, after adjustments, for the HG model, regardless of annual or quarterly basis, for Araçuaí and Itamarandiba. In Salinas, there was no improvement in the classification. For the FAO-PM_{rs} model, in Salinas and Araçuaí, only the annual basis adjustment provided an improvement in the performance index classification. In Itamarandiba, both the seasonal adjustments led to an improvement.

CONCLUSIONS

The results showed that both models, Hargreaves and reduced-set FAO Penman-Monteith, even without adjustment, may be a viable recommendation for irrigation management when only maximum and minimum temperature data are available.

The quarterly adjustment provided an improvement in the performance of the Hargreaves method when compared to the annual adjustment in all locations (exception in Salinas). For reduced-set FAO Penman-Monteith, the annual adjustment was higher than the quarterly.

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Table 1. Location, latitude, longitude, altitude and years of observation

Location	Latitude (south)	Longitude (west)	Altitude (m)	Years of observation
Araçuaí	16°50’59”	42°17’25”	307	17
Itamarandiba	17°51’26”	42°51’32”	910	17
Diamantina	18°14’58”	43°36’01”	1113	9
Pedra Azul	16°00’19’	41°17’50”	617	7
Salinas	16°10’13”	42°17’25”	471	6

Table 2. Performance index classification of the estimation models, proposed by Camargo & Sentelhas (1997)

Performance index (c)	Classification
>0.85	Excellent
0.76 a 0.85	Very good
0.66 a 0.75	Good
0.61 a 0.65	Reasonable
0.51 a 0.60	Bad
0.41 a 0.50	Very bad
≤0.40	Unacceptable

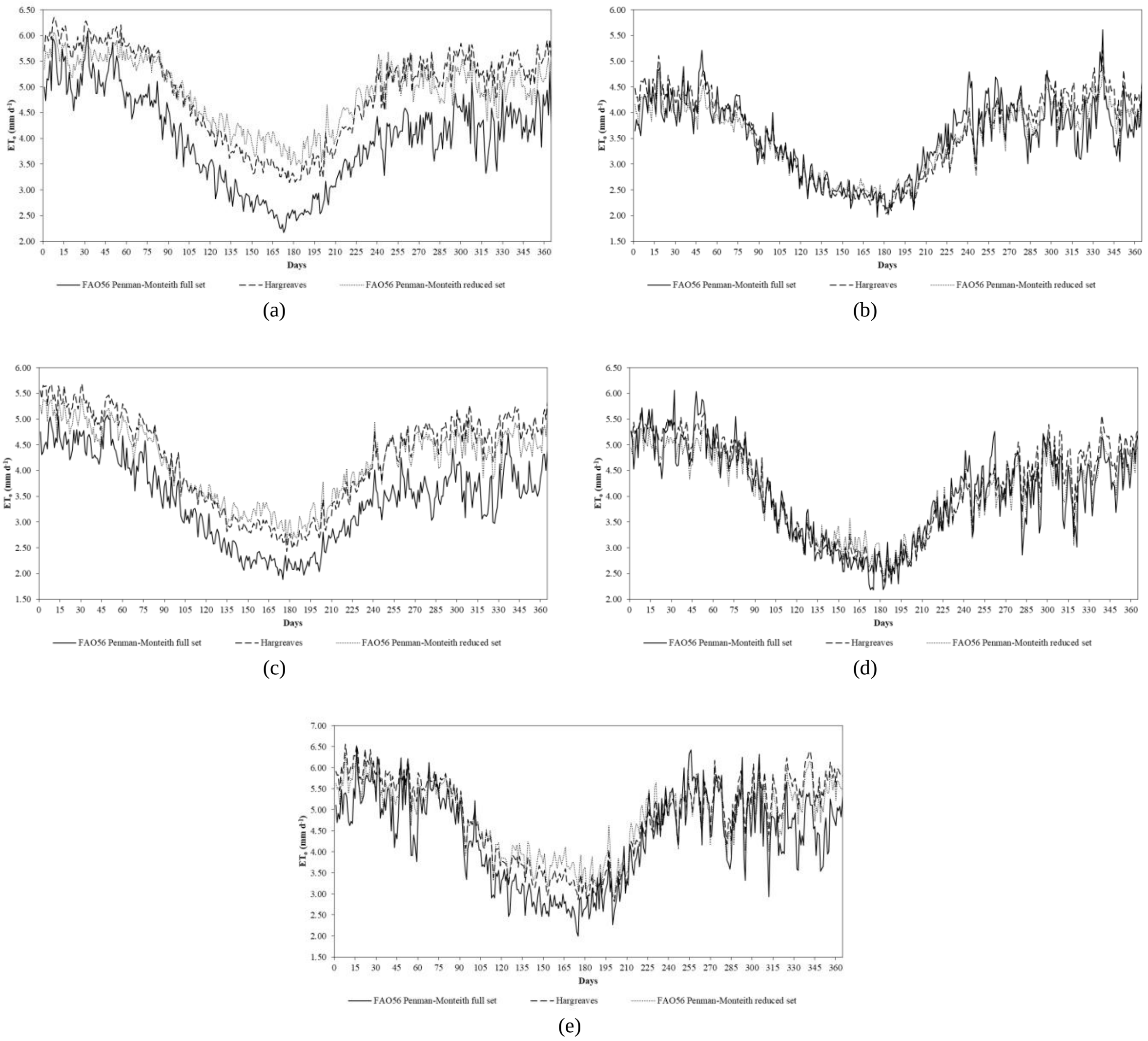

Figure 1. Mean daily ET_o values (mm d^{-1}) estimated by HG, $FAO\text{-}PM_{rs}$ e $FAO\text{-}PM_{fs}$ models to Araçuaí (a), Diamantina (b), Itamarandiba (c), Pedra Azul (d) and Salinas (e).

Table 3. Mean daily ET_o values; standard deviation (σ), standard error of estimation (SEE); Pearson correlation coefficient (r), coefficient of determination (R^2) and coefficient of efficiency (E); the adjustment parameters of the regression equation (a and b); the agreement index (d) and performance index (c) with its classification according to Camargo & Sentelhas (1997)

Model	ET_o (mm d^{-1})	σ (mm)	SEE (mm)	r	R^2	b	a	E	d	c	Classification
					Araçuaí						
FAO-PM$_{fs}$	3.99	0.89	-	-	-	-	-	-	-	-	-
HG	4.91	0.90	0.95	0.96	0.92	0.9705	1.0342	-0.1319	0.7829	0.7527	Very good
HG$_{aj}$	3.99	0.93	0.26	0.96	0.92	1.0001	-0.0005	0.9180	0.9800	0.9422	Excellent
HG$_{saj}$	3.99	0.93	0.24	0.97	0.93	1.0000	0.0003	0.9267	0.9821	0.9479	Excellent
FAO-PM$_{rs}$	4.88	0.65	0.98	0.91	0.84	0.6602	2.2449	-0.1933	0.7156	0.6543	Good
FAO-PM$_{rs\ aj}$	3.99	0.98	0.40	0.91	0.84	1.0000	0.0001	0.8041	0.9539	0.8723	Excellent
FAO-PM$_{rs\ saj}$	3.99	1.09	0.63	0.82	0.67	0.9999	0.0002	0.5107	0.8942	0.7327	Good
					Diamantina						
FAO-PM$_{fs}$	3.54	0.73	-	-	-	-	-	-	-	-	-
HG	3.61	0.82	0.35	0.91	0.82	1.0219	-0.0046	0.7632	0.9459	0.8575	Excellent
HG$_{aj}$	3.54	0.80	0.34	0.91	0.82	1.0004	-0.0015	0.7832	0.9492	0.8605	Excellent
HG$_{saj}$	3.54	0.78	0.28	0.93	0.87	1.0009	-0.0035	0.8487	0.9638	0.8983	Excellent
FAO-PM$_{rs}$	3.49	0.66	0.28	0.93	0.86	0.8399	0.5214	0.8574	0.9595	0.8908	Excellent
FAO-PM$_{rs\ aj}$	3.54	0.78	0.29	0.93	0.86	0.9997	0.0010	0.8396	0.9617	0.8927	Excellent
FAO-PM$_{rs\ saj}$	3.54	0.77	0.26	0.94	0.88	0.9997	0.0017	0.8693	0.9685	0.9107	Excellent
					Itamarandiba						
FAO-PM$_{fs}$	3.43	0.81	-	-	-	-	-	-	-	-	-
HG	4.22	0.91	0.85	0.95	0.90	0.5441	0.7606	-0.1002	0.8013	0.7606	Very good
HG$_{aj}$	3.43	0.85	0.27	0.95	0.90	-0.0002	0.9239	0.8899	0.9734	0.9239	Excellent
HG$_{saj}$	3.43	0.85	0.26	0.95	0.91	0.0004	0.9278	0.8962	0.9748	0.9278	Excellent
FAO-PM$_{rs}$	4.14	0.71	0.76	0.95	0.90	1.2732	0.7575	0.1069	0.7975	0.7575	Very good
FAO-PM$_{rs\ aj}$	3.43	0.85	0.27	0.95	0.90	-0.0003	0.9250	0.8917	0.9738	0.9250	Excellent
FAO-PM$_{rs\ saj}$	3.43	0.86	0.29	0.94	0.89	-0.0007	0.9144	0.8750	0.9699	0.9144	Excellent
					Pedra Azul						
FAO-PM$_{fs}$	4.05	0.91	-	-	-	-	-	-	-	-	-
HG	4.17	0.93	0.33	0.94	0.89	0.9644	0.2543	0.8647	0.9664	0.9097	Excellent
HG$_{aj}$	4.05	0.96	0.33	0.94	0.89	0.9998	0.0007	0.8714	0.9690	0.9121	Excellent
HG$_{saj}$	4.05	0.96	0.31	0.95	0.90	0.9998	0.0008	0.8851	0.9722	0.9208	Excellent
FAO-PM$_{rs}$	4.02	0.76	0.31	0.95	0.90	0.7956	0.8004	0.8867	0.9658	0.9160	Excellent
FAO-PM$_{rs\ aj}$	4.05	0.96	0.30	0.95	0.90	1.0002	-0.0008	0.8885	0.9730	0.9229	Excellent
FAO-PM$_{rs\ saj}$	4.05	0.96	0.32	0.94	0.89	1.0001	-0.0007	0.8739	0.9696	0.9137	Excellent
					Salinas						
FAO-PM$_{fs}$	4.34	1.07	-	-	-	-	-	-	-	-	-
HG	4.84	1.02	0.70	0.90	0.80	0.8514	1.1479	0.5759	0.8920	0.7989	Very good
HG$_{aj}$	4.34	1.19	0.53	0.90	0.80	1.0000	-0.0002	0.7532	0.9426	0.8442	Very good
HG$_{saj}$	4.34	1.21	0.58	0.88	0.77	0.9998	0.0009	0.7052	0.9323	0.8193	Very good
FAO-PM$_{rs}$	4.80	0.83	0.66	0.91	0.82	0.7013	1.7594	0.6127	0.8814	0.7979	Very good
FAO-PM$_{rs\ aj}$	4.34	1.18	0.50	0.91	0.82	1.0003	-0.0014	0.7798	0.9483	0.8585	Excellent
FAO-PM$_{rs\ saj}$	4.34	1.21	0.57	0.88	0.78	1.0000	-0.0001	0.7172	0.9348	0.8254	Very good