

Reference evapotranspiration based on temperature in Minas Gerais state, Brazil

Evapotranspiração de referência com base em temperatura no estado de Minas Gerais, Brasil

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ABSTRACT

In the last decades, the areas of irrigated crops in the state of Minas Gerais have grown considerably, contributing to increase agricultural production in the country. Among the techniques of irrigation management, the determination of the water consumption by the plants is based on the reference evapotranspiration (ET₀), the objective of this work was to evaluate and calibrate the Hargreaves-Samani (HS) method and a Proposed Method (MP) against the standard Penman-Monteith-FAO method (PM-FAO) for the state of Minas Gerais. For that, data from 52 conventional meteorological stations of the National Institute of Meteorology (INMET) were used. ET₀ was estimated by the methods cited including the Hargreaves-Samani calibrated method (HScal) based on the mean absolute error (MAE). The analysis of the methods was carried out using the following statistical indicators: root mean square error (RMSE), systematic root mean square error (RMSEs), unsystematic root mean square error (RMSEun), the proportions of systematic and unsystematic mean square error, Willmott's concordance index (d), confidence index (C) and Pearson correlation coefficient (r). It was verified that after the calibration, the HScal method obtained a superior performance to the original HS method in all the studied stations. It was also observed a superior MP performance with respect to the HScal method, in all stations studied.

Index Terms: Penman-Monteith-FAO; Water resources management; Hargreaves-Samani; Mean Absolute Error.

RESUMO

Nas últimas décadas, as áreas de cultivos irrigados no estado de Minas Gerais vêm crescendo bastante, contribuindo assim para aumento da produção agrícola no País. Dentre as técnicas de manejo da irrigação, tem-se a determinação do consumo de água pelas plantas tomando por base a evapotranspiração de referência (ET₀), diante disso, objetivou-se com este trabalho, avaliar e calibrar o método Hargreaves-Samani (HS) e um Método Proposto (MP) frente ao método padrão Penman-Monteith-FAO (PM-FAO) para o estado de Minas Gerais. Para tanto, foram utilizados dados de 52 estações meteorológicas convencionais do Instituto Nacional de Meteorologia (INMET). Estimou-se a ET₀ pelos métodos citados incluindo o método Hargreaves-Samani calibrado (HScal), com base no erro absoluto médio (EAM). A análise dos métodos foi conduzida mediante aos seguintes indicadores estatísticos: raiz quadrada do erro quadrático médio (REQM), raiz quadrada do erro quadrático médio sistemático (REQMs), raiz quadrada do erro quadrático médio não sistemático (REQMns), proporções do erro quadrático médio sistemático e não sistemático, índice de concordância de Willmott (d), índice de confiança (C) e coeficiente de correlação (r). Constatou-se que após calibração, o método HScal obteve um desempenho superior ao método HS original em todas as estações estudadas. Observou-se também um desempenho superior do MP com relação ao método HScal, em todas as estações estudadas.

Termos para Indexação: Penman-Monteith-FAO; Manejo dos recursos hídricos; Hargreaves-Samani; Erro Absoluto Médio.

INTRODUCTION

Brazil has about 6.95 million hectares (ha) of irrigated area according to data from 2017 of the National Water Agency - ANA. The State of Minas Gerais contributes

significantly to the production of grains in Brazil, mainly through irrigated agriculture. Data from the National Water Agency-ANA (ANA, 2017) reported the existence in 2015, in Minas Gerais, of 1082.373 hectares irrigated which are distributed by different forms of irrigation.

Evapotranspiration is the basis of water management and is commonly the largest and most important component in the water balance in agricultural systems. His knowledge is essential for the design of irrigation projects, establishment of irrigation management and planning in agricultural systems. The importance of evapotranspiration is verified in several studies, not only in the field of Agricultural Sciences, but also in Meteorology, Geography, Hydrology and Ecology.

By definition, the reference evapotranspiration, ET_0 , is the evapotranspiration rate of a reference surface, covered by a hypothetical crop, with a height of 0.12 m, a surface aerodynamic resistance of 70 s m^{-1} and albedo of 0.23, with no soil moisture restriction, actively growing and completely covering the soil surface (Allen et al., 1998).

The FAO Penman-Monteith method (FAO-PM) is considered the standard for calculating ET_0 (Pereira et al., 2015), since it physically models evapotranspiration. The application of this method requires a set of data, as minimum and maximum air temperature, relative humidity, wind speed, pressure atmospheric, sunshine duration and, or radiation balance. The application of a large database is the main obstacle to the application of the standard method, mainly in climatology studies since it is common the occurrence of failures in historical series of meteorological elements. In this sense, it is observed that meteorological stations to obtain the meteorological data required by the FAO-PM method have, in general, a high financial cost, which prevents a considerable portion of agricultural producers to use this kind of data.

The Hargreaves-Samani (HS) method employs only maximum and minimum air temperature data to estimate ET_0 (Hargreaves; Samani, 1985; Paredes et al., 2017; Valiantzas 2013; Valipour, 2015). This empirical method is notable for its wide use and is suggested by Allen et al. (1998) and Pereira et al. (2015) as an alternative to FAO-PM when only air temperature data are available. Due to the empirical nature of this method, there is a need for local calibration against the standard method with a view to gaining accuracy, even using machine learning techniques (Borges Júnior et al., 2017, Shiri et al., 2014, Shiri et al., 2015).

The development of equations for estimation of ET_0 with only temperature data can contribute to a better monitoring of the water requirement by the crops and can be used by producers with low purchasing power, since simple meteorological stations are required for data collection. These methods are also options for filling in historical ET_0 data failures, such data needed for irrigation project design, planning and risk analysis (Borges Júnior et al., 2008a, 2008b).

This study had the objective to evaluate HS and calibrate HScal methods and a Proposed Method (MP)

against the FAO-PM method to estimate the reference evapotranspiration, considering historical series of daily meteorological data from stations in Minas Gerais and some adjacent to this state.

MATERIAL AND METHODS

Study area

The study region is composed by the state of Minas Gerais with some adjacent stations to this state (Figure 1).

For this work, we selected 52 conventional weather stations of the National Institute of Meteorology - INMET, Brazil, with series provided by Bank of Meteorological Data for Teaching and Research - BDMEP (Table 1). Due to the proximity, some stations adjacent to the state of Minas Gerais were chosen, favoring a better characterization of the region of the study.

Estimation of reference evapotranspiration ET_0

Daily ET_0 calculations were performed using the FAO-PM method, according to Allen et al., 1998.

$$ET_{0PM} = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T_{med} + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)}$$

Where, ET_{0PM} is the reference evapotranspiration calculated by the FAO-PM method (mm d^{-1}), R_n is the net radiation at the crop surface ($\text{MJ m}^{-2} \text{d}^{-1}$), G is the soil heat flux density ($\text{MJ m}^{-2} \text{d}^{-1}$), T_{med} is the mean daily air temperature at 2 m height ($^{\circ}\text{C}$), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa), Δ is the slope vapour pressure curve ($\text{kPa } ^{\circ}\text{C}^{-1}$) and γ is the psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$).

The following equation was used to calculate ET_0 by the HS method (Hargreaves e Samani, 1985):

$$ET_{0HS} = A_{HS} R_a (T_{max} - T_{min})^{C_{HS}} (T_{med} + B_{HS})$$

Where, ET_{0HS} is the reference evapotranspiration estimated by the HS method (mm d^{-1}), R_a is the radiation at the "top" of the atmosphere in equivalent evaporation (mm d^{-1}), T_{max} is the maximum air temperature ($^{\circ}\text{C}$), T_{min} is the minimum air temperature ($^{\circ}\text{C}$) and A_{HS} , B_{HS} e C_{HS} is the parameters of the model, originally equal 0.0023, 17.8 and 0.5, respectively.

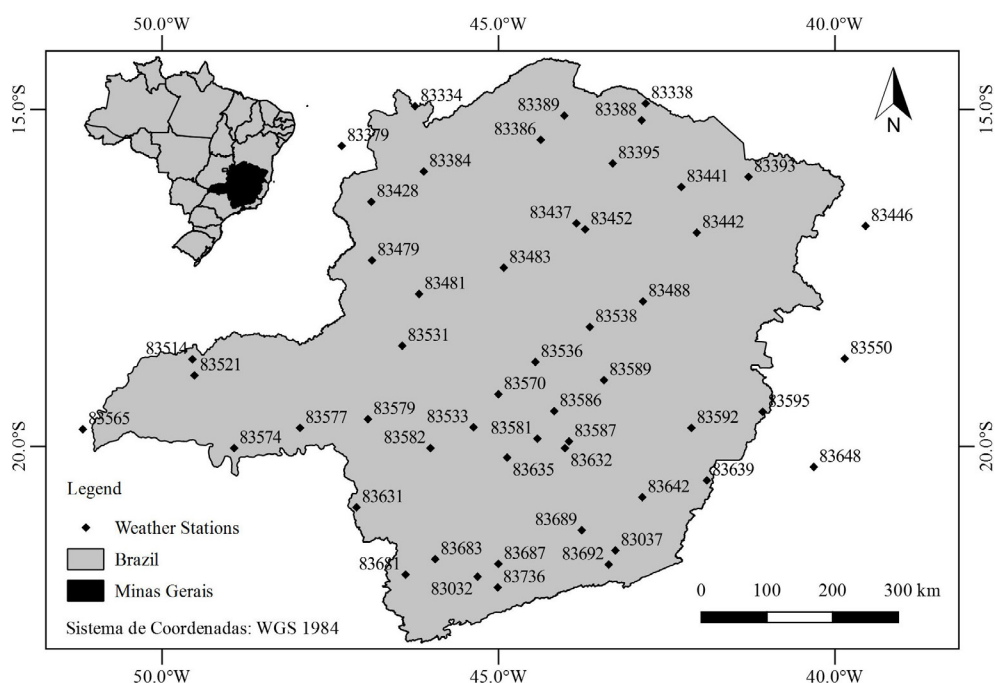


Figure 1: Characterization of the study region.

Table 1: Location of conventional weather stations used.

Station	OMM Code	Latitude	Longitude	Altitude (m)
Aimorés - MG	83595	-19.49°	-41.07 °	82.74
Araçuaí - MG	83442	-16.83 °	-42.05 °	289.00
Araxá - MG	83579	-19.60 °	-46.94 °	1023.61
Arinos - MG	83384	-15.91 °	-46.10 °	519.00
Bambuí - MG	83582	-20.03 °	-46.00 °	661.27
Barbacena - MG	83689	-21.25 °	-43.76 °	1126.00
Belo Horizonte - MG	83587	-19.93 °	-43.95 °	915.00
Bom Despacho - MG	83533	-19.71 °	-45.36 °	695.00
C. do Mato Dentro - MG	83589	-19.02 °	-43.43 °	652.00
Caparaó - MG	83639	-20.51 °	-41.90 °	843.18
Capinópolis - MG	83514	-18.71 °	-49.55 °	620.60
Caratinga - MG	83592	-19.73 °	-42.13 °	609.65
Coronel Pacheco - MG	83037	-21.55 °	-43.26 °	435.00
Curvelo - MG	83536	-18.74 °	-44.45 °	672.00
Diamantina - MG	83538	-18.23 °	-43.64 °	1296.12
Divinópolis - MG	83635	-20.17 °	-44.87 °	788.35
Espinosa - MG	83338	-14.91 °	-42.80 °	569.64
Florestal - MG	83581	-19.88 °	-44.41 °	760.00

Continue...

Table 1: Continuation.

Station	OMM Code	Latitude	Longitude	Altitude (m)
Formosa - GO	83379	-15.54 °	-47.33 °	935.19
Formoso - MG	83334	-14.94 °	-46.23 °	840.00
Frutal - MG	83574	-20.03 °	-48.93 °	543.67
Guaratinga - BA	83446	-16.73 °	-39.54 °	194.67
Ibirité - MG	83632	-20.03 °	-44.01 °	814.54
Itamarandiba - MG	83488	-17.85 °	-42.85 °	914.00
Ituiutaba - MG	83521	-18.95 °	-49.52 °	560.00
Janaúba - MG	83395	-15.80 °	-43.29 °	516.00
Januária - MG	83386	-15.44 °	-44.36 °	473.71
João Pinheiro - MG	83481	-17.74 °	-46.17 °	760.36
Juiz de Fora - MG	83692	-21.76 °	-43.36 °	939.96
Juramento - MG	83452	-16.78 °	-43.71 °	648.00
Lambari - MG	83032	-21.94 °	-45.31 °	878.45
Lavras - MG	83687	-21.75 °	-45.00 °	918.84
Machado - MG	83683	-21.68 °	-45.94 °	873.35
Mocambinho - MG	83389	-15.08 °	-44.01 °	452.00
Monte Azul - MG	83388	-15.16 °	-42.86 °	625.00
Montes Claros - MG	83437	-16.68 °	-43.84 °	652.00
Paracatu - MG	83479	-17.24 °	-46.88 °	712.00
Paranaíba - MS	83565	-19.75 °	-51.18 °	331.25
Patos de Minas - MG	83531	-18.51 °	-46.43 °	940.28
Pedra Azul - MG	83393	-16.00 °	-41.28 °	648.91
Pirapora - MG	83483	-17.34 °	-44.92 °	505.24
Poços de Caldas - MG	83681	-21.91 °	-46.38 °	1150.00
Pompéu - MG	83570	-19.22 °	-45.00 °	690.91
Salinas - MG	83441	-16.15 °	-42.28 °	471.32
São Lourenço - MG	83736	-22.10 °	-45.01 °	953.20
São Mateus - ES	83550	-18.70 °	-39.85 °	25.04
São S. do Paraíso - MG	83631	-20.91 °	-47.11 °	820.00
Sete Lagoas - MG	83586	-19.48 °	-44.17 °	732.00
Uberaba - MG	83577	-19.73 °	-47.95 °	737.00
Unai - MG	83428	-16.36 °	-46.88 °	460.00
Viçosa - MG	83642	-20.76 °	-42.86 °	712.20
Vitória - ES	83648	-20.31 °	-40.31 °	36.20

Daily data search was performed between 1961 and 2015, maximum (T_{max} , °C) and minimum (T_{min} , °C) air temperature, daily sunshine hours (n , h), average daily wind speed at ten meters high (U_{10} , $m\ s^{-1}$) and relative humidity average of the daily (UR, %). The mean temperature (T_{med} , °C) was calculated from T_{max} and T_{min} . Inconsistencies were previously verified in the series, being excluded when identified, registering the increase in the number of data failures.

The work also involved the application of a new proposed method (MP), in which air temperature data are used, taking into consideration, in addition to the average temperature, the thermal amplitude and proportionality between the maximum and minimum local temperature. As in the HS method, radiation is also required at the “top” of the atmosphere, whose variation is defined based on the day of the year and latitude. In the conception of method, it was taken as the basis Borges Junior model for calculation of solar radiation, proposed in Steidle Neto et al. (2015), adapting to obtain the ET_0 , having the following general equation:

$$ET_{0MP} = A_{MP} T_{max} R_a \left[B_{MP} (T_{max} - T_{min})^3 + C_{MP} \left(\frac{T_{min}}{T_{max}} \right)^2 + D_{MP} T_{med} + E_{MP} \right]^2$$

Where, ET_{0MP} is the reference evapotranspiration calculated by the MP method ($mm\ d^{-1}$), R_a is the radiation at the “top” of the atmosphere in equivalent evaporation ($mm\ d^{-1}$), T_{max} is the maximum air temperature ($^{\circ}C$), T_{min} is the minimum air temperature ($^{\circ}C$) and A_{MP} , B_{MP} , C_{MP} , D_{MP} e E_{MP} is the local model adjustment parameters.

Calibration of methods based on temperature

The calibration of the parameters of the HS and MP methods was performed to modify the A_{HS} and C_{HS} coefficients and the B_{HS} exponent of the HS method and the A_{MP} , B_{MP} , C_{MP} , D_{MP} and E_{MP} coefficients of the new MP seeking to minimize the mean absolute error (MAE) (Willmott, et al., 2012). As initial values for the calibration procedure, the original values of the HS method were used and for the MP the coefficients were equal to 0.5.

This process was performed using the Solver tool of the Microsoft Office Excel® 2016 spreadsheet, configuring it for application of the non-linear GRG solution method and convergence of 0.000001; in the field “Derivatives” the marker was applied in “Forward” and in the “Multi-initialization” field the “Required Limits in Variables” option was selected.

Test statistics models

The methods were evaluated based on the mean absolute error (MAE), root mean square error (RMSE), systematic root mean square error (RMSEs), unsystematic root mean square error (RMSEun), the proportions of systematic and unsystematic mean square error, Willmott’s concordance index (d), Pearson correlation coefficient (r), besides the means, standard deviations (sd), coefficient of variation (cv) and maximum and minimum.

$$MAE = N_o^{-1} \sum_{i=1}^N |P_i - O_i|$$

$$RMSE = MSE^{0.5} = \left[N_o^{-1} \sum_{i=1}^N (P_i - O_i)^2 \right]^{0.5}$$

$$RMSEs = MSEs^{0.5} = \left[N_o^{-1} \sum_{i=1}^N (\hat{P}_i - O_i)^2 \right]^{0.5}$$

$$RMSEun = MSEun^{0.5} = \left[N_o^{-1} \sum_{i=1}^N (\hat{P}_i - P_i)^2 \right]^{0.5}$$

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

Where, \hat{P}_i is the P_i estimator based on the linear regression model ($mm\ d^{-1}$), N_o is the number of observations, P_i is the estimated values of ET ($mm\ d^{-1}$), O_i is the ET_0 values calculated by the FAO-PM method ($mm\ d^{-1}$) and O is the mean of the ET_0 values obtained by the standard method ($mm\ d^{-1}$).

RESULTS AND DISCUSSION

The coefficients of the HScal and MP equations are listed in Tables 2 and 3. For purposes of precision in the presentation of the results, the coefficients and exponents of the HScal method were rounded to 6, 3 and 4 decimal places for A_{HS} , B_{HS} and C_{HS} , respectively; for the MP were rounded to 6 decimal places for all coefficients. With the rounding procedure, the variation in the mean absolute error (MAE) was less than $10^{-5}\ mm\ d^{-1}$.

The A_{HS} coefficient values ranged from 0.00067 to 0.004116; the B_{HS} and C_{HS} coefficients ranged from -6.546 to 36.812 and from 0.3431 to 0.8061, respectively.

Feng et al. (2017), studying the calibration of the HS model to estimate ET_0 for the basin of Sichuan in southwest China through the Bayesian theory, using 19 weather stations from 1961 to 2014, found the coefficient values ranging from 0.00213 to 0.00218, 16.19 to 16.58, and 0.40 to 0.46 for A_{HS} , B_{HS} and C_{HS} , respectively. Evaluating stations in the state of Minas Gerais, Ferreira et al. (2018), found when the parameters A_{HS} , B_{HS} and C_{HS}

was simultaneously calibrated, the values of parameters A_{HS} , B_{HS} and C_{HS} ranged from 0.0011 to 0.0023, 1.1669 to 15.5731 and 0.6128 to 0.8312, respectively.

The variations of the A_{MP} , B_{MP} , C_{MP} , D_{MP} and E_{MP} coefficients were, respectively, 0.000616 to 0.086037,

-0.000359 to 0.000129, -3.841521 and 2.929596, -0.043671 to 0.064424 and -2.532777 to 4.474882. This range value occurs due to the calibration site specific for each station studied; the smallest errors occurred with these coefficients for each station.

Table 2: A_{HS} , B_{HS} coefficients and C_{HS} exponent of the Hargreaves-Samani equation calibrated locally for each conventional weather station.

Stations	Coefficients		
	A_{HS}	B_{HS}	C_{HS}
Aimorés	0.002381	-4.844	0.6938
Araçuaí	0.003050	-2.048	0.5306
Araxá	0.001318	8.476	0.7836
Arinos	0.002234	2.923	0.5760
BambuÍ	0.001687	3.819	0.6473
Barbacena	0.001443	10.771	0.6639
Belo Horizonte	0.002551	8.465	0.5275
Bom Despacho	0.002363	0.000	0.5787
C. do Mato Dentro	0.002493	2.725	0.5316
Caparaó	0.002871	-0.338	0.5607
Capinópolis	0.001558	8.591	0.6860
Caratinga	0.002676	-2.590	0.6449
Cel. Pacheco	0.002371	-1.150	0.6135
Curvelo	0.001139	3.938	0.7882
Diamantina	0.001101	20.608	0.7364
Divinópolis	0.001358	6.469	0.7588
Espinosa	0.002613	8.834	0.5499
Florestal	0.002104	4.942	0.5689
Formosa	0.001516	12.949	0.6646
Formoso	0.000670	30.758	0.8061
Frutal	0.002083	6.000	0.5892
Guaratinga	0.002295	0.089	0.6787
Ibirité	0.002396	5.031	0.5198
Itamarandiba	0.001972	10.616	0.5398
Ituiutaba	0.002297	1.657	0.5779
Janaúba	0.002080	36.812	0.3431
Januária	0.001951	4.722	0.6615
João Pinheiro	0.002119	3.334	0.6584
Juiz de Fora	0.001647	10.842	0.6442
Juramento	0.002397	6.001	0.5367

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Table 2: Continuation.

Stations	Coefficients		
	A_{HS}	B_{HS}	C_{HS}
Lambari	0.001283	4.519	0.6760
Lavras	0.001286	10.970	0.7358
Machado	0.001909	4.913	0.6070
Mocambinho	0.001764	7.970	0.6372
Monte Azul	0.002014	18.054	0.5537
Montes Claros	0.001739	7.825	0.6748
P. de Caldas	0.002430	5.131	0.5197
Patos de Minas	0.001000	18.636	0.7575
Paracatu	0.001898	-1.406	0.7647
Paranaíba	0.002683	-0.699	0.5776
Pedra Azul	0.002959	1.671	0.5396
Pirapora	0.002551	0.000	0.6070
Pompéu	0.002267	0.000	0.6282
Salinas	0.002423	-1.557	0.6335
São Lourenço	0.002296	1.152	0.5986
São Mateus	0.003282	-6.546	0.6451
São S. do Paraíso	0.002077	7.586	0.5590
Sete Lagoas	0.001661	9.071	0.6484
Uberaba	0.001707	5.357	0.6875
Unaí	0.002176	0.000	0.6307
Viçosa	0.002325	1.232	0.6154
Vitória	0.004116	-2.534	0.5511

Table 3: Coefficients A_{MP} , B_{MP} , C_{MP} , D_{MP} and E_{MP} of the Proposed Method calibrated locally for each conventional weather station.

Stations	Coefficients				
	A_{MP}	B_{MP}	C_{MP}	D_{MP}	E_{MP}
Aimorés	0.001163	-0.000064	-2.677941	0.057457	2.432574
Araçuaí	0.000838	-0.000062	-2.408044	0.04904	2.987566
Araxá	0.000935	-0.000089	-3.363896	0.046952	3.519001
Arinos	0.086037	-0.000007	-0.234781	0.003001	0.229938
Bambuí	0.055791	0.000002	0.186176	-0.001757	-0.222880
Barbacena	0.001	-0.000056	-2.447916	0.033057	3.155007
Belo Horizonte	0.033999	-0.000021	-0.339693	0.004366	0.406494
Bom Despacho	0.024520	-0.000003	-0.263188	0.005971	0.320664
C. do Mato Dentro	0.000837	-0.000021	-1.743834	0.037337	2.927549

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Table 3: Continuation.

Stations	Coefficients				
	A_{MP}	B_{MP}	C_{MP}	D_{MP}	E_{MP}
Caparaó	0.000892	-0.000027	-1.875859	0.050593	2.719342
Capinópolis	0.000921	-0.000112	-3.71363	0.047824	3.615388
Caratinga	0.001106	-0.000045	-2.231497	0.058567	2.414097
Cel. Pacheco	0.001239	-0.000019	-1.696852	0.044582	2.164268
Curvelo	0.085881	-0.000003	-0.219276	0.003433	0.192770
Diamantina	0.00069	-0.000141	-3.717841	0.039875	4.474882
Divinópolis	0.073683	0.000003	0.217847	-0.00303	-0.236334
Espinosa	0.079055	0.000017	0.337120	-0.003476	-0.316328
Florestal	0.031936	-0.000004	-0.239533	0.003769	0.330556
Formosa	0.000744	-0.000149	-3.841521	0.043265	4.259608
Formoso	0.005430	0.000023	1.022224	-0.008010	-1.054547
Frutal	0.000946	-0.0001	-3.084723	0.042207	3.402767
Guaratinga	0.001314	-0.000079	-2.488216	0.045826	2.694635
Ibirité	0.049390	0.000004	0.186176	-0.002915	-0.270576
Itamarandiba	0.000823	-0.000056	-2.196894	0.024777	3.567307
Ituiutaba	0.000616	-0.000066	-3.057873	0.049521	3.729945
Janaúba	0.023533	0.000018	0.435228	-0.001071	-0.587648
Januária	0.002142	0.000035	1.461719	-0.018785	-1.520345
João Pinheiro	0.000788	0.000129	2.929596	-0.043671	-2.532777
Juiz de Fora	0.001048	-0.000093	-2.581779	0.031906	3.347468
Juramento	0.004038	0.000019	0.781409	-0.012007	-0.993004
Lambari	0.001064	0.000004	-1.370662	0.030071	2.245665
Lavras	0.001148	-0.00006	-2.791125	0.037883	3.075116
Machado	0.000921	-0.000051	-2.336182	0.040775	2.976226
Mocambinho	0.004427	0.000030	1.074686	-0.012658	-1.073795
Monte Azul	0.002709	0.000108	1.764537	-0.016490	-1.754594
Montes Claros	0.029163	0.000011	0.392075	-0.005391	-0.407911
P. de Caldas	0.001027	-0.000033	-1.721197	0.02871	2.893956
Patos de Minas	0.002008	-0.000068	-2.355955	0.023742	2.57359
Paracatu	0.004868	0.000031	1.104948	-0.018926	-0.906715
Paranaíba	0.00082	-0.000115	-3.412543	0.061931	3.257013
Pedra Azul	0.00067	-0.000123	-3.224657	0.054946	3.898238
Pirapora	0.007477	0.000018	0.692383	-0.011974	-0.712772
Pompéu	0.000987	-0.000047	-1.757979	0.033381	1.825659
Salinas	0.001202	-0.000022	-1.936631	0.044653	2.366196
São Lourenço	0.000882	-0.000027	-2.127842	0.049072	2.757288

Continue...

Table 3: Continuation.

Stations	Coefficients				
	A_{MP}	B_{MP}	C_{MP}	D_{MP}	E_{MP}
São Mateus	0.00127	-0.000137	-2.886563	0.064424	2.47882
São S. do Paraíso	0.001062	-0.00006	-2.358875	0.033185	3.059147
Sete Lagoas	0.003052	-0.000036	-1.211879	0.015275	1.257290
Uberaba	0.000695	-0.000091	-3.817426	0.052157	3.962464
Unaí	0.027208	-0.000010	-0.382626	0.006760	0.352244
Viçosa	0.000918	-0.000031	-2.054849	0.046971	2.811409
Vitória	0.001058	-0.000359	-3.462278	0.060349	3.602808

Analysis of descriptive statistics

Tables 4 and 5 show the maximum, minimum and mean ET_0 values and respective standard deviation values and coefficients of variation for each conventional weather station for FAO-PM, original HS, HScal and MP methods.

It can be observed that for the FAO-PM method, the upper and lower limits of the ET_0 were 10.82 mm d⁻¹ in Espinosa and 5.83 mm d⁻¹ in Poços de Caldas for maximum values and 1.45 mm d⁻¹ in Monte Azul and 0.61 mm d⁻¹ in Juiz de for minimum values. For the HS method, the upper and lower limits of the ET_0 were 8.57 mm d⁻¹ in Arinos and 6.76 mm d⁻¹ in Diamantina for maximum values and 2.09 mm d⁻¹ in Juramento and 0.51 mm d⁻¹ in Juiz de for minimum values. In relation to the mean values, the extremes were 4.85 mm d⁻¹ in Espinosa and 2.81 mm d⁻¹ in Lambari, for the FAO-PM method, and 5.14 mm d⁻¹ in Mocambinho and 3.70 mm d⁻¹ in Vitória-ES for the HS method.

The overestimation bias of the ET_0 by the HS method was highlighted in 49 of the 52 stations studied, being the exception verified for Espinosa-MG, Monte Azul-MG and Vitória-ES stations. This result can be explained by the location of the stations in a region subject to high wind speed values.

Some authors have found overestimation of ET_0 by HS in humid environments and underestimation in very windy conditions compared to the standard FAO-PM method (Allen et al., 1998; Djaman et al., 2015; Droogers; Allen, 2002).

In Table 5, for the HScal method, it is observed that the limit values of the maximum ET_0 were 9.13 mm d⁻¹ for Vitória-ES and 5.44 mm d⁻¹ for Poços de Caldas. For the minimum ET_0 , the limits were 2.15 mm d⁻¹ for Janaúba and 0.23 mm d⁻¹ for Juiz de Fora. For MP, the extremes of ET_0 maximum were 7.71 mm d⁻¹ for Aimorés and 5.35 mm d⁻¹ for Poços de Caldas and extreme values

of minimum ET_0 were 0.03 mm d⁻¹ for João Pinheiro and 1.27 mm d⁻¹ for Juramento.

In view of this, it was verified the local calibrations of the HS and MP methods considerably approached the ET_0 averages to the FAO-PM standard method for all stations studied.

Statistical measures and indices relating to performance analysis of alternative methods are presented in Tables 6 and 7. After analysis of the mean absolute error (MAE) present in Table 6, it was verified that, for all the conventional stations studied, the MP performance was superior to the other two methods.

The MAE variation for the HS and HScal methods was from 0.59 mm d⁻¹ (Diamantina) to 2.01 mm d⁻¹ (Lambari) and from 0.34 mm d⁻¹ (São Lourenço) to 0.88 mm d⁻¹ (Monte Azul), respectively, evidencing a large reduction in the MAE value after the local calibration of the HS method. For most stations studied, more than 50% reduction in mean absolute error values was obtained.

Pandey et al. (2014) verified that the parametric calibration of the HS equation provided a reduction in the MAE between 0.442 to 0.621 mm d⁻¹ for the wet region in India. Zhao et al. (2015) adjusted the HS equation on a monthly basis by means of linear regression for the North, Northeast and Northwest regions of China, and obtained a reduction in the MAE of 9.3, 9.6 and 10.8 mm month⁻¹, respectively.

Martí et al. (2015a), modeling ET_0 at two stations in Spain between 2007 and 2012, observed improvements of 0.476 mm d⁻¹ in the MAE after the local calibration of the HS method. Likewise, Martí et al. (2015b) analyzed the performance of calibrated and non-calibrated HS equations at 30 stations in Eastern Spain at daily, weekly, fortnightly and monthly scales. The MAE values decreased for locally calibrated models for all stations in the study.

Table 4: Descriptive statistics with maximum (Max) and minimum (Min) values, mean (med), standard deviation (sd), in mm d⁻¹, and coefficients of variation (cv, %), of the FAO Penman-Monteith (FAO-PM) and original Hargreaves-Samani (HS) methods.

Stations	ET ₀ FAO-PM					ET ₀ HS				
	Max	Min	Med	sd	cv	Max	Min	Med	sd	cv
Aimorés	7.86	1.13	3.84	1.32	34.25	8.35	1.45	4.77	1.187	24.89
Araçuaí	7.74	1.15	3.79	1.19	31.45	8.37	1.42	4.85	1.171	24.15
Araxá	7.92	0.82	3.62	1.14	31.44	7.00	0.98	4.14	1.019	24.62
Arinos	7.97	1.37	3.97	1.09	27.58	8.57	1.85	5.05	1.05	20.75
BambuÍ	6.55	1.05	3.28	1.10	33.39	8.02	1.30	4.67	1.11	23.74
Barbacena	6.27	0.71	2.94	1.09	37.05	6.91	0.71	3.87	1.129	29.18
Belo Horizonte	7.70	1.03	3.66	1.13	30.90	6.94	1.04	4.01	1.03	25.74
Bom Despacho	6.56	1.19	3.58	1.11	31.01	8.23	1.43	5.05	1.18	23.32
C.do Mato Dentro	7.16	1.08	3.33	1.13	33.85	8.12	1.03	4.49	1.197	26.66
Caparaó	7.13	1.04	3.23	1.17	36.25	7.49	1.11	4.18	1.123	26.86
Capinópolis	9.45	0.87	4.05	1.20	29.56	8.01	1.26	4.76	1.074	22.55
Caratinga	8.02	1.05	3.42	1.23	35.89	7.68	1.30	4.19	1.059	25.28
Cel. Pacheco	6.87	0.94	3.18	1.18	37.05	8.07	1.11	4.38	1.201	27.41
Curvelo	7.98	1.10	3.46	1.17	33.93	7.82	1.54	4.90	1.10	22.43
Diamantina	7.11	1.05	3.28	1.08	32.91	6.76	1.21	3.71	0.957	25.77
Divinópolis	7.95	1.04	3.88	1.27	32.70	7.55	1.32	4.62	1.13	24.34
Espinosa	10.82	1.37	4.85	1.43	29.48	7.59	1.78	4.68	0.99	21.06
Florestal	6.99	1.10	3.41	1.03	30.15	7.72	1.25	4.63	1.10	23.80
Formosa	7.62	1.29	3.75	1.02	27.07	7.90	1.36	4.32	0.890	20.58
Formoso	7.33	1.38	3.97	1.09	27.46	7.89	1.71	4.82	0.98	20.27
Frutal	7.86	1.04	3.90	1.16	29.79	7.84	1.04	4.75	1.139	23.97
Guaratinga	7.35	1.22	3.69	1.27	34.51	7.31	1.38	4.25	1.136	26.71
Ibirité	6.95	1.11	3.33	1.09	32.68	7.70	1.39	4.48	1.08	24.21
Itamarandiba	6.12	1.05	3.18	1.03	32.27	7.13	1.18	4.09	1.098	26.85
Ituiutaba	8.38	1.18	3.81	1.09	28.59	8.09	1.06	4.96	1.091	22.00
Janaúba	10.62	1.29	4.42	1.18	26.73	8.25	1.86	4.96	1.12	22.68
Januária	9.75	1.35	4.48	1.25	27.91	8.04	1.84	4.99	1.01	20.15
João Pinheiro	7.76	0.87	4.00	1.12	27.91	8.29	1.23	4.53	0.98	21.60
Juiz de Fora	7.94	0.61	3.09	1.25	40.29	7.24	0.51	3.73	1.204	32.31
Juramento	8.15	1.24	3.88	1.09	28.15	8.07	2.09	4.75	1.03	21.72
Lambari	5.99	0.93	2.81	1.02	36.39	8.23	1.46	4.82	1.283	26.63
Lavras	7.20	0.90	3.53	1.21	34.30	7.35	1.15	4.23	1.154	27.24
Machado	7.24	0.89	3.13	1.07	34.06	7.76	0.97	4.28	1.143	26.70
Mocambinho	8.65	1.31	4.36	1.15	26.36	8.13	1.12	5.14	1.02	19.92
Monte Azul	10.65	1.45	4.70	1.36	28.96	7.41	1.48	4.59	1.01	21.96

Continue...

Table 4: Continuation.

Stations	ET ₀ FAO-PM					ET ₀ HS				
	Max	Min	Med	sd	cv	Max	Min	Med	sd	cv
Montes Claros	8.48	1.38	4.16	1.23	29.60	7.81	1.57	4.64	1.00	21.65
P. de Caldas	5.83	0.88	2.95	0.98	33.30	7.03	0.89	4.01	1.052	26.25
Patos de Minas	8.36	1.14	3.72	1.11	29.84	8.09	1.29	4.37	0.983	22.48
Paracatu	7.57	1.03	3.61	1.12	30.94	6.94	1.04	4.06	1.02	25.20
Paranaíba	7.87	0.92	3.84	1.22	31.79	8.01	1.23	4.75	1.119	23.55
Pedra Azul	8.12	1.25	3.69	1.21	32.87	7.53	1.55	4.31	1.107	25.68
Pirapora	8.90	1.15	4.15	1.22	29.44	8.13	1.40	4.84	1.01	20.79
Pompéu	7.11	1.07	3.55	1.11	31.18	7.78	1.47	4.61	1.05	22.76
Salinas	8.10	1.32	3.86	1.28	33.22	8.05	1.43	4.78	1.163	24.33
São Lourenço	6.78	0.91	3.23	1.16	35.95	8.20	1.07	4.40	1.199	27.27
São Mateus	7.07	1.14	3.50	1.21	34.45	7.22	1.53	4.20	0.959	22.84
São S. do Paraíso	6.76	1.00	3.46	1.10	31.71	7.55	1.03	4.44	1.109	24.98
Sete Lagoas	8.72	1.16	3.72	1.14	30.68	7.71	1.22	4.50	1.06	23.63
Uberaba	9.58	0.83	3.93	1.22	31.03	8.18	0.96	4.63	1.069	23.06
Unaí	8.94	1.27	3.83	1.10	28.84	8.17	1.42	4.94	1.00	20.23
Viçosa	6.97	0.97	3.17	1.17	37.03	7.83	0.84	4.09	1.152	28.15
Vitória	8.55	1.08	3.87	1.43	36.85	7.56	1.10	3.70	1.085	29.32

Table 5: Descriptive statistics with maximum (Max) and minimum values (Min), mean (med), standard deviation (sd), in mm d⁻¹, and coefficients of variation (cv, %), of the Hargreaves-Samani calibrated (HScal) and Proposed Method (MP).

Stations	ET ₀ HScal					ET ₀ MP				
	Max	Min	Med	sd	cv	Max	Min	Med	sd	cv
Aimorés	8.49	0.67	3.85	1.24	32.26	7.71	0.54	3.86	1.25	32.37
Araçuaí	7.12	0.91	3.78	1.07	28.34	6.88	0.80	3.79	1.08	28.59
Araxá	7.13	0.46	3.57	1.05	29.44	6.45	0.34	3.57	1.04	29.14
Arinos	7.09	1.22	3.93	0.94	23.92	6.28	0.45	3.95	0.96	24.17
Bambuí	6.45	0.64	3.27	0.92	28.03	6.05	0.57	3.27	0.93	28.34
Barbacena	5.77	0.35	2.92	0.96	32.99	5.53	0.27	2.93	0.97	33.18
Belo Horizonte	6.64	0.82	3.64	1.00	27.49	6.64	0.82	3.64	1.03	28.17
Bom Despacho	6.58	0.77	3.59	1.01	28.05	6.59	0.63	3.57	1.02	28.43
C. do Mato Dentro	6.57	0.66	3.28	0.99	30.31	6.49	0.74	3.28	0.99	30.32
Caparaó	6.73	0.67	3.20	1.05	32.90	6.52	0.64	3.21	1.06	32.94
Capinópolis	7.62	0.72	4.02	1.04	25.92	6.91	0.41	4.02	1.05	25.92
Caratinga	7.55	0.71	3.40	1.10	32.32	7.15	0.62	3.40	1.11	32.51
Cel. Pacheco	6.86	0.53	3.17	1.08	34.00	6.73	0.49	3.18	1.09	34.18
Curvelo	6.46	0.66	3.46	0.96	27.59	6.25	0.46	3.51	0.98	28.02
Diamantina	7.00	0.60	3.26	0.95	29.18	5.76	0.64	3.27	0.95	29.17

Continue...

Table 5: Continuation.

Stations	ET ₀ HScal					ET ₀ MP				
	Max	Min	Med	sd	cv	Max	Min	Med	sd	cv
Divinópolis	7.35	0.66	3.83	1.11	29.09	6.82	0.53	3.83	1.10	28.75
Espinosa	8.08	1.59	4.76	1.08	22.75	7.23	0.11	4.74	1.16	24.47
Florestal	6.18	0.74	3.41	0.92	27.12	5.93	0.62	3.40	0.93	27.27
Formosa	7.59	0.87	3.71	0.88	23.65	6.10	0.64	3.71	0.87	23.65
Formoso	8.25	0.78	3.97	0.97	24.36	6.44	0.48	3.98	0.97	24.40
Frutal	6.99	0.66	3.91	1.05	26.71	6.73	0.46	3.90	1.07	27.28
Guaratinga	7.47	0.86	3.72	1.23	33.14	7.12	0.81	3.73	1.24	33.36
Ibirité	5.95	0.91	3.31	0.89	26.96	5.66	0.78	3.34	0.90	26.98
Itamarandiba	5.73	0.81	3.14	0.90	28.71	5.46	0.72	3.15	0.91	28.78
Ituiutaba	6.78	0.61	3.78	0.96	25.46	6.37	0.51	3.77	0.95	25.33
Janaúba	6.45	2.15	4.34	0.84	19.37	5.88	0.04	4.30	0.92	21.36
Januária	8.02	1.16	4.46	1.08	24.21	7.38	0.85	4.46	1.08	24.22
João Pinheiro	8.32	0.74	4.02	1.02	25.40	6.71	0.03	4.02	1.03	25.52
Juiz de Fora	6.57	0.23	3.03	1.11	36.59	6.13	0.36	3.04	1.11	36.57
Juramento	7.02	1.55	3.88	0.93	23.86	6.43	1.27	3.87	0.94	24.31
Lambari	5.54	0.61	2.85	0.90	31.50	5.59	0.65	2.85	0.89	31.36
Lavras	6.88	0.62	3.51	1.10	31.26	6.41	0.48	3.51	1.10	31.45
Machado	6.31	0.50	3.11	0.95	30.66	5.81	0.40	3.10	0.96	30.84
Mocambinho	7.72	2.14	4.45	0.89	19.95	6.66	0.37	4.33	1.00	23.16
Monte Azul	7.62	1.30	4.59	1.05	22.77	6.82	0.57	4.58	1.10	23.96
Montes Claros	7.76	0.91	4.12	1.05	25.46	6.98	0.72	4.12	1.07	25.89
P. de Caldas	5.44	0.54	2.92	0.86	29.47	5.35	0.48	2.94	0.86	29.34
Patos de Minas	7.83	0.72	3.64	0.93	25.62	6.19	0.54	3.65	0.93	25.56
Paracatu	6.58	0.82	3.68	0.99	26.95	6.10	0.52	3.68	1.01	27.52
Paranaíba	7.36	0.58	3.83	1.08	28.09	7.03	0.42	3.83	1.10	28.69
Pedra Azul	7.08	1.15	3.70	1.09	29.35	6.54	0.94	3.71	1.10	29.66
Pirapora	7.86	0.81	4.10	1.04	25.29	7.37	0.26	4.09	1.06	25.80
Pompéu	6.92	0.79	3.55	0.98	27.70	6.16	0.62	3.57	0.99	27.80
Salinas	7.54	0.82	3.82	1.16	30.38	7.39	0.89	3.82	1.16	30.31
São Lourenço	6.98	0.55	3.21	1.06	33.02	6.75	0.47	3.22	1.07	33.16
São Mateus	7.59	0.89	3.57	1.04	29.25	7.15	0.73	3.57	1.05	29.34
São S. do Paraíso	6.25	0.67	3.45	0.94	27.31	5.92	0.52	3.46	0.95	27.61
Sete Lagoas	7.04	0.73	3.70	0.99	26.63	6.38	0.45	3.71	1.00	26.97
Uberaba	8.04	0.41	3.86	1.04	26.95	6.87	0.44	3.85	1.03	26.79
Unaí	7.11	0.79	3.80	0.94	24.86	6.78	0.49	3.79	0.97	25.46
Viçosa	6.94	0.41	3.15	1.07	34.05	6.47	0.39	3.16	1.07	33.94
Vitória	9.13	0.86	3.89	1.34	34.51	7.42	0.66	3.90	1.36	34.86

Table 6: Mean absolute error (MAE, mm d⁻¹), root mean square error (RMSE, mm d⁻¹), systematic root mean square error (RMSEs, mm d⁻¹) and unsystematic (RMSEun, mm d⁻¹) for the original Hargreaves-Samani (HS) and calibrated (HScal) and Proposed (MP) estimation methods.

Stations	EAM			RMSE			RMSEs			RMSEns		
	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP
Aimorés	0.95	0.42	0.41	1.10	0.54	0.53	0.96	0.18	0.17	0.53	0.51	0.50
Araçuaí	1.07	0.43	0.42	1.21	0.56	0.55	1.07	0.25	0.23	0.56	0.51	0.50
Araxá	0.73	0.54	0.53	0.91	0.69	0.68	0.63	0.30	0.30	0.65	0.62	0.61
Arinos	1.13	0.53	0.48	1.30	0.68	0.64	1.12	0.36	0.32	0.66	0.58	0.56
Bambuí	1.39	0.44	0.43	1.52	0.59	0.58	1.40	0.32	0.31	0.60	0.49	0.49
Barbacena	0.95	0.41	0.40	1.09	0.53	0.52	0.94	0.25	0.24	0.56	0.47	0.47
Belo Horizonte	0.61	0.53	0.51	0.77	0.68	0.66	0.46	0.33	0.29	0.62	0.59	0.59
Bom Despacho	1.47	0.35	0.34	1.56	0.47	0.46	1.47	0.20	0.19	0.51	0.43	0.42
C. do Mato Dentro	1.18	0.41	0.41	1.30	0.55	0.55	1.16	0.27	0.26	0.59	0.49	0.48
Caparaó	0.99	0.44	0.43	1.13	0.59	0.58	0.97	0.26	0.25	0.58	0.53	0.53
Capinópolis	0.86	0.59	0.56	1.07	0.75	0.74	0.81	0.38	0.37	0.70	0.65	0.64
Caratinga	0.83	0.44	0.43	0.97	0.58	0.57	0.82	0.26	0.25	0.51	0.51	0.51
Cel. Pacheco	1.21	0.41	0.40	1.33	0.54	0.53	1.21	0.22	0.21	0.57	0.49	0.49
Curvelo	1.46	0.57	0.56	1.64	0.74	0.80	1.48	0.43	0.46	0.71	0.60	0.65
Diamantina	0.59	0.45	0.44	0.75	0.58	0.57	0.52	0.27	0.27	0.53	0.51	0.50
Divinópolis	0.84	0.50	0.49	1.01	0.65	0.63	0.81	0.31	0.32	0.61	0.57	0.55
Espinosa	0.87	0.87	0.80	1.09	1.07	1.02	0.80	0.71	0.61	0.74	0.80	0.81
Florestal	1.22	0.38	0.36	1.33	0.50	0.49	1.22	0.22	0.21	0.53	0.45	0.44
Formosa	0.73	0.51	0.49	0.90	0.66	0.64	0.67	0.35	0.33	0.59	0.57	0.54
Formoso	0.91	0.52	0.50	1.11	0.67	0.64	0.91	0.32	0.30	0.63	0.59	0.56
Frutal	0.89	0.47	0.45	1.06	0.60	0.59	0.87	0.27	0.24	0.60	0.54	0.54
Guaratinga	0.66	0.46	0.46	0.85	0.61	0.61	0.63	0.19	0.18	0.56	0.58	0.58
Ibirité	1.19	0.52	0.50	1.37	0.69	0.68	1.18	0.40	0.38	0.69	0.56	0.56
Itamarandiba	0.93	0.41	0.40	1.07	0.52	0.51	0.91	0.25	0.24	0.56	0.46	0.45
Ituiutaba	1.18	0.46	0.44	1.32	0.61	0.60	1.17	0.29	0.29	0.62	0.53	0.52
Janaúba	0.97	0.77	0.72	1.15	0.97	0.93	0.73	0.69	0.60	0.89	0.68	0.70
Januária	0.70	0.54	0.50	0.88	0.69	0.66	0.66	0.35	0.33	0.57	0.60	0.57
João Pinheiro	0.71	0.57	0.53	0.93	0.72	0.70	0.66	0.33	0.31	0.65	0.64	0.63
Juiz de Fora	0.80	0.55	0.53	0.98	0.71	0.70	0.69	0.34	0.32	0.70	0.63	0.62
Juramento	0.93	0.48	0.45	1.09	0.63	0.61	0.91	0.34	0.31	0.60	0.53	0.53
Lambari	2.01	0.43	0.43	2.13	0.58	0.58	2.01	0.28	0.29	0.73	0.51	0.50
Lavras	0.78	0.47	0.46	0.95	0.59	0.58	0.74	0.26	0.24	0.60	0.54	0.53
Machado	1.16	0.36	0.35	1.26	0.48	0.47	1.15	0.22	0.21	0.52	0.43	0.42
Mocambinho	0.86	0.61	0.46	1.03	0.78	0.62	0.84	0.50	0.30	0.59	0.60	0.54
Monte Azul	0.88	0.88	0.83	1.07	1.07	1.04	0.74	0.71	0.64	0.78	0.81	0.82

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Table 6: Continuation.

Stations	EAM			RMSE			RMSEs			RMSEns		
	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP
Montes Claros	0.68	0.52	0.50	0.84	0.67	0.65	0.62	0.36	0.33	0.57	0.57	0.56
P. de Caldas	1.07	0.37	0.36	1.18	0.49	0.48	1.06	0.24	0.23	0.53	0.43	0.42
Patos de Minas	0.81	0.52	0.51	0.98	0.68	0.67	0.74	0.38	0.37	0.63	0.57	0.55
Paracatu	0.66	0.52	0.50	0.82	0.67	0.66	0.54	0.33	0.30	0.61	0.59	0.59
Paranaíba	0.95	0.48	0.46	1.11	0.62	0.60	0.95	0.29	0.26	0.58	0.54	0.54
Pedra Azul	0.72	0.49	0.47	0.89	0.62	0.61	0.67	0.28	0.26	0.58	0.56	0.55
Pirapora	0.82	0.51	0.48	0.97	0.68	0.65	0.79	0.36	0.33	0.56	0.57	0.56
Pompéu	1.08	0.44	0.42	1.22	0.59	0.57	1.08	0.27	0.26	0.57	0.52	0.51
Salinas	0.98	0.49	0.48	1.13	0.63	0.63	0.96	0.27	0.28	0.59	0.57	0.57
São Lourenço	1.17	0.34	0.33	1.26	0.45	0.44	1.17	0.19	0.18	0.47	0.41	0.41
São Mateus	0.83	0.59	0.58	1.06	0.79	0.78	0.85	0.41	0.40	0.63	0.67	0.66
São S. do Paraíso	1.00	0.45	0.44	1.16	0.59	0.58	0.99	0.30	0.29	0.60	0.51	0.50
Sete Lagoas	0.84	0.48	0.45	1.00	0.61	0.57	0.82	0.31	0.28	0.58	0.52	0.50
Uberaba	0.87	0.56	0.54	1.04	0.73	0.72	0.80	0.39	0.39	0.66	0.62	0.60
Unai	1.15	0.51	0.48	1.31	0.67	0.64	1.15	0.35	0.32	0.62	0.57	0.56
Viçosa	0.94	0.39	0.38	1.07	0.51	0.51	0.94	0.21	0.21	0.51	0.47	0.46
Vitória	0.70	0.65	0.64	0.88	0.85	0.84	0.58	0.33	0.31	0.65	0.78	0.78

Borges Júnior et al. (2017) evaluated the HS and HS method calibrated at different time scales (annual, semi-annual, quarterly, and monthly) for the city of Sete Lagoas-MG, and verified that at any time basis, the calibration of the equation significantly reduced the MAE values, making the method more accurate. In a study carried out in Uberaba-MG by Melo and Fernandes (2012), different estimation methods of ET_0 were evaluated, comparing with the FAO-PM method, and it was observed that the HS method in its original form reached a value of MAE of 0.96 mm d^{-1} , considered high by the authors.

Also, in Table 6, it was verified that for the regionally calibrated MP for each conventional meteorological station, a performance similar to that achieved with the HScal method was obtained. The mean absolute error variation for the MP was 0.33 to 0.83 mm d^{-1} for the Monte Azul and São Lourenço stations, respectively. When compared to HScal, the maximum reduction of MP was 0.07 mm d^{-1} ; for some stations, there was no reduction in MAE values.

It is observed that RMSE extremes (Table 6) are 0.75 (Diamantina) and 2.13 mm d^{-1} (Lambari) for the HS method and 0.45 (São Lourenço) and 1.07 mm d^{-1} (Monte Azul and Espinosa) for the HScal method. Calibration of the HS method reduced RMSE values in most stations

studied. It was verified that RMSE overestimates the magnitude of the mean error when compared to the MAE, as emphasized by Willmott and Matsuura (2005).

For calibrated HS method (one parameter calibrated), Mallikarjuna et al. (2014) obtained RMSE values between 0.64 and 1.07 mm day^{-1} for five stations in a semiarid climate in India. Berti et al. (2014) worked with the HS method in northwest Italy, calibrating only the A_{HS} coefficient to verify its importance in the equation. The authors found that RMSE values were reduced on average about 30% when compared to the values obtained with the original HS method.

Maestre-Valero et al. (2013), working with 66 modern automatic weather stations in south-eastern Spain, used Hargreaves equation calibrated in two different ways to verify the best fit to the region. They concluded that the regionally calibrated version of the Hargreaves equation clearly improved the performance, reducing the RMSE values for all stations.

When the analysis occurs for the MP, it is verified that the RMSE ranged from 0.44 to 1.04 mm d^{-1} for the São Lourenço and Monte Azul stations, respectively. As observed for the MAE, the reduction relative to the RMSE was maximum of 0.07 mm d^{-1} for the stations studied, when MP is compared with HScal.

In order to represent the main trends or patterns in the observed values, that is, in the values estimated with the FAO-PM method, the RMSEs should be close to zero, while the RMSEun should be close to RMSE, according to an expected pattern for a “good” model, according to Willmott et al. (2012). It is observed in Table 6 that there were the aforementioned approximations, especially with the calibration of the equations. This fact shows that the values of the estimated equations approached the values calculated by the FAO-PM method.

The correlation coefficients (r) are recorded in Table 7 and express the intensity of the linear association between the studied variables, and the closer to 1, the association will be more perfect. The values found for the HS, HScal and MP methods ranged from 0.61 to 0.92; 0.59 to 0.92 and 0.64 to 0.92 (Janaúba and São Lourenço), respectively.

In the index of agreement (d), a considerable increase is observed with the calibration of the HS method. The values are between 0.56 (Lambari) to 0.88 (Guaratinga-BA) for the HS method and 0.74 (Janaúba) to 0.96 (São Lourenço) for

the HScal method. Regarding MP, the extreme values of d are equal to the HScal method, with a slight increase for the stations in general (maximum of 8.33% in Mocambinho). The index of agreement averages were 0.80 for the HS method and 0.92 for the HScal and MP methods.

Silva et al. (2012) verified that the performance of the HS method without calibration presented satisfactory results in the 1, 3 and 10-day scale for the northern region of the city of Recife-PE, and for the daily scale they obtained values of r , d , and C equal to 0.83, 0.99, 0.83, classifying the method as “very good”. Similarly, Ferreira et al. (2018) evaluating the confidence index (C) and Willmott’s index of agreement (d) observed that all calibrations under study promoted an increasing in the indexes, with exception only for Paracatu with calibration of coefficient A_{HS} . The better performances in the estimation of ETo were found by Arraes et al. (2016) after promote the calibration. For meteorological stations in Poland, Bogawski and Bednorz (2014) obtained d values from 0.80 to 0.93 in testing different configurations for the HS model.

Table 7: Correlation coefficient (r), agreement index (d), confidence index (C) for the original Hargreaves-Samani (HS) and calibrated (HScal) and Proposed Method (MP).

Stations	r			d			C		
	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP
Aimorés	0.90	0.91	0.91	0.83	0.95	0.96	0.75	0.87	0.87
Araçuaí	0.88	0.88	0.89	0.79	0.94	0.94	0.69	0.82	0.83
Araxá	0.77	0.80	0.81	0.82	0.89	0.89	0.63	0.72	0.72
Arinos	0.78	0.79	0.81	0.72	0.88	0.89	0.56	0.69	0.73
BambuÍ	0.84	0.84	0.85	0.69	0.91	0.91	0.58	0.76	0.77
Barbacena	0.87	0.87	0.88	0.80	0.93	0.93	0.69	0.81	0.82
Belo Horizonte	0.80	0.81	0.82	0.87	0.89	0.90	0.69	0.72	0.74
Bom Despacho	0.90	0.91	0.91	0.70	0.95	0.95	0.63	0.86	0.86
C.do Mato Dentro	0.87	0.87	0.87	0.75	0.93	0.93	0.66	0.81	0.81
Caparaó	0.86	0.87	0.87	0.80	0.93	0.93	0.68	0.80	0.81
Capinópolis	0.76	0.78	0.79	0.79	0.88	0.88	0.60	0.69	0.70
Caratinga	0.88	0.88	0.89	0.84	0.94	0.94	0.74	0.83	0.83
Cel. Pacheco	0.88	0.89	0.89	0.76	0.94	0.94	0.67	0.84	0.84
Curvelo	0.76	0.78	0.74	0.66	0.87	0.85	0.51	0.68	0.63
Diamantina	0.83	0.85	0.85	0.87	0.91	0.92	0.72	0.77	0.78
Divinópolis	0.84	0.86	0.87	0.83	0.92	0.92	0.70	0.79	0.80
Espinosa	0.66	0.67	0.71	0.77	0.79	0.83	0.51	0.53	0.59
Florestal	0.87	0.88	0.88	0.72	0.93	0.94	0.63	0.82	0.82

Continue...

Table 7: Continuation.

Stations	r			d			C		
	HS	HScal	MP	HS	HScal	MP	HS	HScal	MP
Formosa	0.75	0.76	0.78	0.79	0.87	0.88	0.59	0.66	0.69
Formoso	0.76	0.80	0.81	0.76	0.89	0.90	0.58	0.71	0.73
Frutal	0.85	0.86	0.86	0.81	0.92	0.93	0.69	0.79	0.80
Guaratinga	0.87	0.88	0.88	0.88	0.94	0.94	0.76	0.83	0.83
Ibirité	0.77	0.78	0.78	0.70	0.87	0.88	0.54	0.68	0.69
Itamarandiba	0.86	0.86	0.87	0.79	0.92	0.93	0.68	0.80	0.80
Ituiutaba	0.83	0.83	0.84	0.73	0.91	0.91	0.60	0.76	0.76
Janaúba	0.61	0.59	0.64	0.74	0.74	0.78	0.45	0.43	0.50
Januária	0.82	0.83	0.85	0.85	0.91	0.92	0.70	0.76	0.78
João Pinheiro	0.75	0.77	0.79	0.81	0.88	0.88	0.60	0.68	0.70
Juiz de Fora	0.81	0.83	0.83	0.84	0.90	0.91	0.69	0.75	0.75
Juramento	0.81	0.82	0.83	0.78	0.90	0.90	0.63	0.73	0.75
Lambari	0.82	0.83	0.83	0.56	0.90	0.90	0.46	0.75	0.75
Lavras	0.85	0.87	0.88	0.85	0.93	0.93	0.73	0.81	0.82
Machado	0.89	0.89	0.90	0.75	0.94	0.94	0.67	0.84	0.85
Mocambinho	0.81	0.74	0.84	0.80	0.84	0.91	0.65	0.62	0.77
Monte Azul	0.63	0.64	0.67	0.77	0.78	0.80	0.48	0.49	0.54
Montes Claros	0.83	0.84	0.85	0.86	0.91	0.92	0.71	0.76	0.78
P. de Caldas	0.86	0.87	0.87	0.74	0.93	0.93	0.64	0.80	0.81
Patos de Minas	0.76	0.80	0.80	0.80	0.88	0.89	0.61	0.70	0.71
Paracatu	0.80	0.81	0.82	0.85	0.89	0.90	0.68	0.72	0.73
Paranaíba	0.86	0.86	0.87	0.81	0.92	0.93	0.69	0.80	0.81
Pedra Azul	0.85	0.86	0.86	0.86	0.92	0.93	0.73	0.79	0.80
Pirapora	0.83	0.83	0.85	0.82	0.90	0.91	0.68	0.75	0.78
Pompéu	0.84	0.85	0.86	0.75	0.92	0.92	0.63	0.78	0.79
Salinas	0.86	0.87	0.87	0.82	0.93	0.93	0.70	0.81	0.81
São Lourenço	0.92	0.92	0.92	0.78	0.96	0.96	0.72	0.88	0.89
São Mateus	0.75	0.76	0.77	0.78	0.87	0.87	0.59	0.66	0.68
São S. do Paraíso	0.84	0.84	0.85	0.77	0.91	0.92	0.65	0.77	0.78
Sete Lagoas	0.84	0.85	0.86	0.82	0.91	0.92	0.69	0.77	0.80
Uberaba	0.78	0.80	0.81	0.81	0.89	0.89	0.63	0.71	0.72
Unaí	0.78	0.80	0.82	0.71	0.89	0.90	0.56	0.71	0.73
Viçosa	0.90	0.90	0.90	0.82	0.95	0.95	0.74	0.85	0.85
Vitória	0.80	0.81	0.82	0.87	0.90	0.90	0.70	0.73	0.74

Borges Júnior et al. (2017), evaluating the HS and HS method calibrated at different time scales for the city of Sete Lagoas-MG, verified that after calibration there were high concentrations of deviations between -1 and 1 mm referring to the standard method, being 64.0%, 90.8%, 91.1%, 91.4% and 91.7%, respectively, for the original HS method and with annual, semester, quarterly and monthly calibration. In the present study, intervals of deviations between -1 and 1 mm from 3.35% (Lambari-MG) to 87.82% (Paracatu-MG) were found for the HS method, 75.68% (Espinosa-MG) and 99.99% (BambuÍ-MG) for the HScal method and 79.11% (Vitória-ES) and 99.99% (BambuÍ-MG) for the MP.

CONCLUSIONS

It was found that the calibration of the HS method provided a significant improvement in 50 of 52 of the studied stations when compared to the standard FAO-PM method. In relation to MP, a similar performance to that observed for the HScal method was observed for all the stations studied, with a slight decrease in the MAE and RMSE values and a slight increase for the Pearson correlation coefficient (r) and agreement index of Willmott (d), when compared with the HScal method. The HScal and MP methods are appropriate alternatives for estimation of ET_0 in all climatic regions of Minas Gerais State, particularly for the very remote stations having only minimum and maximum temperature records.

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