Scientia Agraria Paranaensis

Scientia Agraria Paranaensis – Sci. Agrar. Parana.
ISSN: 1983-1471 – Online
DOI: https://doi.org/10.18188/sap.v20i1.25409

COMPARISON OF REFERENCE EVAPOTRANSPIRATION ESTIMATION METHODS, ON DAYS WITH AND WITHOUT PRECIPITATION

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SAP 25409 Received: 17/07/2020 Accepted: 18/01/2021
Sci. Agrar. Parana., Marechal Cândido Rondon, v. 20, n. 1, jan./mar., p. 52-61, 2021

ABSTRACT - Water is gradually becoming scarcer and more expensive. Therefore, any means that aims at a more efficient use of this substance in the most diverse sectors, becomes essential. In this context, the accurate estimation of evapotranspiration is of fundamental importance. With this in mind, the objective of this work was to compare the performance of different methodologies for estimating reference evapotranspiration in relation to the FAO Penman-Monteith method on days with and without precipitation in the region of Cambará do Sul/RS. To achieve this goal, daily data on maximum air temperature (°C), minimum temperature (°C), relative air humidity (%), dew point temperature (°C), wind speed at 2 m high (m s^{-1}), atmospheric pressure (hPa) and global solar radiation (MJ m^{-2} d^{-1}), were acquired from the automatic weather station located in Cambará do Sul/RS and divided into two sets (days with and without precipitation). The comparison between the different methodologies and the standard method, for each period mentioned above, took place through a simple linear regression analysis to obtain the regression coefficients a and b and the determination coefficient. Subsequently, Pearson's correlation coefficient, root of the mean square of the error, Willmott index and the Camargo and Sentelhas index were calculated . For the municipality of Cambará do Sul/RS to replace the Penman-Monteith method, we recommend the use of the Penman and Makkink methods, which presented satisfactory performance in all periods analyzed.
Keywords: water use efficiency, water scarcity, irrigation.

COMPARAÇÃO DE MÉTODOS DE ESTIMATIVA DA EVAPOTRANSPIRAÇÃO DE REFERÊNCIA, EM DIAS COM E SEM PRECIPITAÇÃO

RESUMO - A água está se tornando gradativamente mais escassa e cara. Portanto, qualquer meio que vise um uso mais eficiente dessa substância nos mais diversos setores, torna-se essencial. Nesse contexto, a estimativa precisa da evapotranspiração assume fundamental importância. Pensando nisso, objetivou-se com esse trabalho, comparar o desempenho de diferentes metodologias de estimativa da evapotranspiração de referência em relação ao método FAO Penman-Monteith em dias com e sem precipitação na região de Cambará do Sul/RS. Para atingir tal objetido, dados diários de temperatura máxima do ar (°C), temperatura mínima (°C), umidade relativa do ar (%), temperatura do ponto de orvalho (°C), velocidade do vento a 2 m de altura (m s^{-1}), pressão atmosférica (hPa) e radiação solar global (MJ m^{-2} d^{-1}), foram adquiridos da estação meteorológica automática localizada em Cambará do Sul/RS e divididos em dois conjuntos (dias com e sem precipitação). A comparação entre as diferentes metodologias e o método padrão, para cada período mencionado anteriormente, se deu através de uma análise de regressão linear simples, para obtenção dos coeficientes a e b da regressão e do coeficiente de determinação (R^2). Posteriormente, calculou-se o coeficiente de correlação de Pearson (r), raiz do quadrado médio do erro, índice de Willmottd e índice de Camargo e Sentelhas. Para o município de Cambará do Sul/RS em substituição ao método de Penman-Monteith, recomenda-se o uso dos métodos de Penman e Makkink.
Palavras-chave: eficiência do uso da água, escassez de água, irrigação.

INTRODUCTION

Future scenarios have pointed out that global warming will influence the definition of water management strategies, since the use of irrigation has been more and more frequent. Therefore, it is of great importance to know the water requirement of the crops (ASSAD and PINTO, 2008). Therefore, techniques are needed to maximize control and minimize water use without compromising agricultural production (CHAGAS et al., 2013; ARAÚJO et al, 2010). In this sense, the study of evapotranspiration assumes fundamental importance.

Evapotranspiration can be defined as the loss of water to the atmosphere due to the process of evaporation from surfaces and the transpiration of plants (DJAMAN et al., 2015; PACHECO et al., 2014). It is considered the most active variable in the hydrological cycle and the main water consuming process in agricultural systems. It presents a high variation due to the influence of weather and climate

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(ROCHA et al., 2015) and, therefore, its determination is crucial for a more efficient use of water in the most diverse regions of the world.

Over the years, several empirical methods have emerged to estimate evapotranspiration. However, these methods are only necessary in climatic conditions adjusted for each model, generating large errors when tested in climatic conditions different from those that were originally calibrated, and may cause waste of water resources in activities that require this hydrological variable. To minimize errors in the use of evapotranspiration estimation methods, the FAO (Food and Agriculture Organization) sought to obtain a standard method adapted to different climates and locations, thus creating the FAO methodology Penman-Monteith (PM), a method originally derived from de Penman (ALLEN et al., 1998).

However, although the Penman-Monteith methodology is considered the standard for estimating reference evapotranspiration (ETo), this method requires meteorological variables that are most often not measured at certain weather stations and, for this reason, research has been carried out. developed to evaluate methods that use fewer meteorological variables and perform better compared to the method recommended by FAO (HALLAL et al., 2017).

In this sense, several studies found in the literature have evaluated methods that require less need for meteorological information monitored in meteorological monitoring stations, some presenting good estimates in different locations. However, it is worth emphasizing that the values of the parameters of these methods vary in each condition of climate and location, and this affects the accuracy of the methods used. As an example, the work of Ribeiro et al. (2016), who, estimating the evapotranspiration in the dry and rainy period, obtained a better result with the Jensen-Haise methodology in the two evaluated periods, while the methodologies of Hargreaves-Samani and Priestley and Taylor changed the performance from poor and very good in the dry season, to medium in the rainy season. The objective of this work was to compare the performance of reference evapotranspiration estimation methodologies in relation to the standard FAO Penman-Monteith method, in conditions with and without precipitation, in Cambará do Sul / RS.

MATERIAL AND METHODS

Characterization of the study site and data collection stations

The determination of the reference evapotranspiration (ETo) was performed using meteorological data from the automatic meteorological station of Cambará do Sul located in the geographical coordinates -29.04915ºS and -50.149636ºW with an altitude of 1017 m. The present study covered the period from 10/16/2018 to 3/14/2019, totaling 150 days.

Input meteorological variables, such as maximum air temperature (°C), minimum temperature (°C), average air temperature (°C), maximum and minimum relative humidity (%), dew point temperature (°C), average wind speed at 2 m high (m s^{-1}), atmospheric pressure (hPa), saturation pressure of water vapor in the air (hPa), partial pressure of water vapor in the air (hPa), global solar radiation (MJ m^{-2} d^{-1}) and heat stroke (h), used to determine potential daily evapotranspiration (ETo), using different empirical methods, referring to the Penman-Monteith method as a standard comparative to the other methods, were divided into two periods (days with and without precipitation).

Estimation of Reference Evapotranspiration (ETo)

The methods used to estimate the reference evapotranspiration were: Penman-Monteith, Penman, Jensen-Haise, Hargreaves-Samani, Camargo, Benevides-Lopes, Turc, Linacre, Priestley and Taylor, Tanner and Pelton and Makkink (Table 1).

TABLE 1 - Reference evapotranspiration estimation methods and their equations.

Methodologies	Equations
Penman-Monteith-FAO56 (ALLEN et al., 1998)	$\mathrm{ETo} = \frac{\left[0{,}408.\Delta.(\mathrm{Rn}-\mathrm{G}) + \left(900.\mathrm{U}_2/_{\mathrm{T}+273}\right).(\mathrm{es}-\mathrm{ea})\right]}{\Delta + \gamma.(1 + 0{,}34.\mathrm{U2})}$
Penman (1948)	$ETo = \frac{\frac{\Delta}{\gamma}\frac{Rn}{2{,}45} + (0{,}2625 + 1{,}38.U_2).(\mathrm{es}-\mathrm{ea})}{\frac{\Delta}{\gamma}+1}$
Hagreves e Samani, (1985)	$\mathrm{ETo} = 0{,}408.0{,}0023.(\mathrm{T} + 17{,}8).(\mathrm{T_{max}} - \mathrm{T_{min}})^{0{,}5}.\mathrm{R}_{\mathrm{a}_{\mathrm{mm\ dia}^{-1}}}$
Makkink (1957)	$\mathrm{ETo} = 0{,}61.\mathrm{R}_{\mathrm{S}_{\mathrm{mm\ dia}^{-1}}}.\left(\frac{\Delta}{\Delta+\gamma}\right) - 0{,}12$
Camargo (1971)	$\mathrm{ETo} = 0{,}01.\mathrm{R}_{\mathrm{a}_{\mathrm{mm\ dia}^{-1}}}.\mathrm{T}$
Tanner e Pelton (1960)	$ETo = 1{,}12.\frac{Rn}{2{,}45} - 0{,}11$
Turc (1961)	$\mathrm{ETo} = 0{,}013.[T_{max.}(Tmax + 15)^{-1}.(50 + 23{,}88Rg)$
Jensen-Haise (1963)	$\mathrm{ETo} = \mathrm{R}_{\mathrm{S}_{\mathrm{mm\ dia}^{-1}}}(0{,}025.\mathrm{T} + 0{,}078)$
Benevides-Lopes (1970)	$\mathrm{ETo} = 1{,}21.10\hat{}\left(\frac{7{,}45.\mathrm{T}}{234{,}7.\mathrm{T}}\right).(1 - 0{,}01\mathrm{UR_m}) + 0{,}21.\mathrm{T} - 2{,}30$

Continuation of Table 1 - Reference evapotranspiration…

Linacre (1977)	$$ETo = \frac{500\left(\frac{T + 0{,}006 \times h}{100 - \varphi}\right) + 15\,(T - T_{po})}{(80 - T)}$$
Priestley-Taylor (1972)	$$ETo = 0{,}5143.\frac{\Delta}{\Delta + \gamma}.(R_n - G)$$

ETo = reference evapotranspiration (mm day^{-1}); Δ = pressure curve slope (kPa $°C^{-1}$); Rn = radiation balance (MJ m^{-2} day^{-1}); G = heat flow (MJ m^{-2} day^{-1}); γ = psychrometric constant (MJ kg^{-1}); T = average temperature (ºC); U_2 = wind speed (m s^{-1}); es = vapor saturation pressure (kPa); ea = steam pressure (kPa); Tmax = maximum temperature (ºC); Tmin = minimum temperature (ºC); $Ra_{mm.day}{}^{-1}$ = extraterrestrial radiation (mm day^{-1}); $Rs_{mm.day}{}^{-1}$ = global radiation (mm day^{-1}); λ = latent heat of vaporization (MJ mm^{-1}); URm = average relative humidity (%); h = location altitude (m); φ = latitude in module (degree); Tpo = dew point temperature (ºC).

Evaluation of methods

The evaluations were carried out using the daily values of the variables for the periods with and without precipitation. The comparison between the methods and the standard, for each period previously mentioned, was done through a simple linear regression analysis (Yi = a + bŶi) to obtain the regression coefficients a and b and the determination coefficient (R^2). Subsequently, Pearson's correlation coefficient (r), the root of the mean square of the error (RQME), the Willmott index (d) (WILLMOTT, 1982) and the Camargo and Sentelhas index (c) (1997) were calculated.), obtained according to Table 2. The values of the correlation coefficients (r) and the performance or confidence indices (c) found were classified following the classification proposed by Cohen (1988) and Camargo and Sentelhas (1997), respectively (Table 3).

TABLE 2 - Statistical performance indicators of methods and RQME.

Statistical indicators	Equations
Pearson's correlation coefficient	$$r = \frac{\sum_{i=1}^{N}(Oi - O).(Pi - P)}{\sqrt{\sum_{i=1}^{N}(Oi - O)^2}.\sqrt{\sum_{i=1}^{N}(Pi - P)^2}}$$
Root of the mean square of the error	$$RQME = \sqrt{\frac{\sum_{i=1}^{n}(Oi - Pi)^2}{n}}$$
Agreement coefficient	$$d = 1 - \left[\frac{\sum(Pi - Oi)^2}{\sum(\lvert Pi - O\rvert + \lvert Oi - O\rvert)^2}\right]$$
Confidence index	$$c = r.d$$

Pi = evapotranspiration estimated by the tested method (mm d^{-1}); P = evapotranspiration average of the tested method (mm d-¹); Oi = evapotranspiration estimated by the standard method (mm d^{-1}); O = average of the values observed by the standard method (mm d^{-1}) and n is the number of days comprised in the period.

TABLE 3 - Classification of the correlation coefficient (r) according to Cohen (1988) and the performance index (c), proposed by Camargo and Sentelhas (1997).

r	Correlation	c	Performance
> 0.9	Almost perfect	> 0.85	Excellent
0.7 – 0.9	Very tall	0.76 a 0.85	Very good
0.5 – 0.7	High	0.66 a 0.75	Good
0.3 – 0.5	Moderate	0.61 a 0.65	Median
0.1 – 0.3	Low	0.51 a 0.60	Sufferable
0.0 – 0.1	Very low	0.41 a 0.50	Bad
-	-	≤ 0.40	Terrible

Source: Cohen (1988); Camargo and Sentelhas (1997).

RESULTS AND DISCUSSION

Figure 1 shows the variation of the main meteorological elements used as input data for the ETo estimate during the study period. the variation of the average daily data of air temperature, relative humidity of the air, wind speed and solar radiation, between the months of October 2018 to March 2019, obtained from the automatic meteorological station of Cambará do Sul / RS. In the period from October to March, the average monthly wind speed varied very little, with a minimum value of 1.34 m s^{-1} (02/26/2019) and a maximum of 4.29 m s^{-1} (07 / 01/2019). The daily average air temperature varied between 11.42 to 24.21ºC for the days 08/12 and 01/30, respectively. The lowest value of relative air humidity was observed for 11/12 (59.5%) and the highest for 3/9 (96.35%). In turn, solar radiation showed its minimum value on 10/28 (0,46 MJ m^{-2} day^{-1}) and maximum on 12/4 (34,18 MJ m^{-2} day^{-1}).

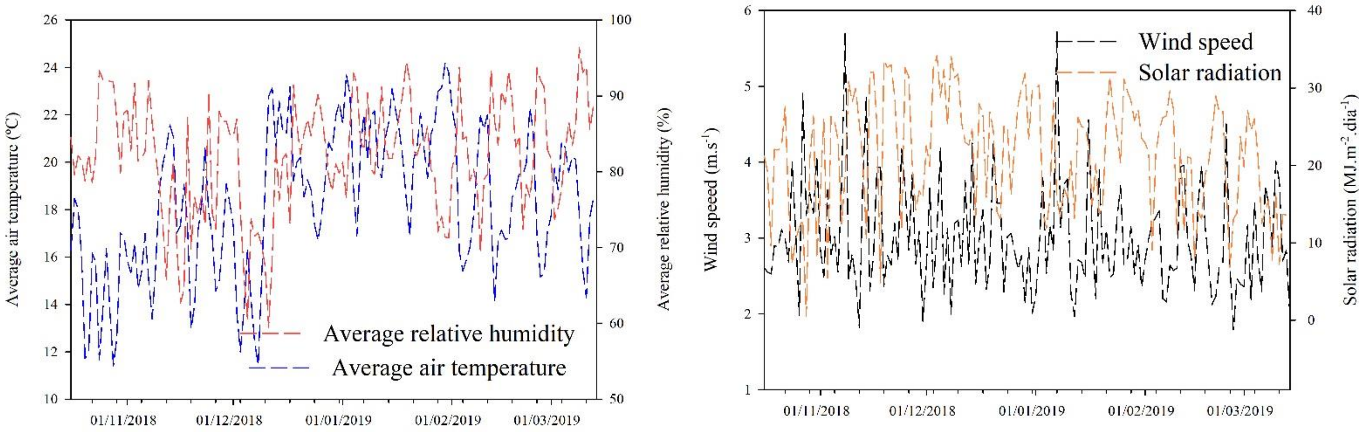

FIGURE 1 - Daily variation of average temperature (ºC), relative humidity (%), global radiation (MJ m^{-2} day^{-1}) and wind speed (m s^{-1}) in the period from 10/16 to 3/14 in Cambará do Sul, RS.

REFERENCE EVAPOTRANSPIRATION FOR DAYS WITHOUT PRECIPITATION

Figure 2 shows the graphs and the model resulting from the linear regression and the angular (a) and linear (b) coefficients, as well as the determination (R^2) obtained between the FAO standard methodology and the other methodologies. It can be seen that only the methodologies of Hagreaves-Smani, Camargo, Benevides-Lopes and Linacre tended to underestimate the ETo values obtained with the Penman-Monteith methodology, with angular coefficients (a) below 1.

It is also observed that the ETo estimation methodologies of Penman, Jensen-Heise, Priestley and Taylor, Hargreaves-Samani, Turc, Makkink, Linacre and Tanner and Pelton were the ones that best fit the standard method based on the value of R^2, which was also observed in relation to the correlation coefficient (r). In general, the best fit among the tested methods was observed with the Penman methodology (R^2 = 0.98). This is justified by the fact that this method uses the same input data as the standard method.

On the other hand, the methodologies with the worst adjustment based on R^2 were: Camargo and Benevides-Lopes with values of R^2 = 0.56 and 0.57, respectively. In addition, these two methods tended to underestimate ETo, although they had the lowest RQME values (0.62 and 1.29 mm day^{-1}, respectively) (Table 4). These two methods are mainly characterized by their simplicity, especially because they require few meteorological elements to estimate ETo, however, they should not be used to estimate ETo in Cambará do Sul/RS.

Table 4 shows the correlation coefficient (r), agreement (d), performance (c) and the root of the mean square of error (RQME) in the daily scales considering the period without precipitation for Cambará do Sul/RS.

In the period without precipitation, the methods that showed the best performance among those studied were Penman's with good performance (c = 0.70; d = 0.71; r = 0.99 and RQME = 1.14 mm day^{-1}) and Makkink, who also performed well (c = 0.67; d = 0.79; r = 0.85 and RQME = 0.88 mm day^{-1}). It is likely that the results found here are due to the fact that these methods present in their equations the balance of radiation and global solar radiation, respectively, as main elements, not being directly affected by other elements, with radiation being considered the main source of energy for the evapotranspiration process. Results different from those found here were obtained by Santana et al. (2019), who, when estimating evapotranspiration by different methodologies in the period considered without precipitation for Balsas/MA, observed that the Makkink methodology presented a median performance.

The Priestley and Taylor, Camargo and Turc methods showed poor performance with a "c" value ranging from 0.56 (Turc) to 0.60 (Camargo). The poor performance found here by the Priestley and Taylor method can be attributed to the fact that this method was created to estimate ETo in humid climatic locations, which is why it tends to overestimate the ETo obtained by the standard method when used in periods of lower humidity, resulting in a high RQME (1.34 mm day^{-1}). Results different from those found here were obtained by Ribeiro et al. (2016), who in their work comparing ETo estimation methodologies for the dry and rainy season in Piripiri/PI, observed a median performance for the Priestley and Taylor methodology in the period considered without precipitation.

For the Turc methodology, the poor performance found in the rainless period is probably due to the fact that this method requires temperature data in its formulation, and as the temperature has a wide range of variation throughout the day, it may end up causing very low values or very high ETo leading to large discrepancies (RQME = 1.43 mm day^{-1}) with the Penman-Monteith method. In Sorriso/MT, Santana et al. (2019) obtained a poor performance with the use of the Turc methodology in the period without precipitation with a value of c = 0.29, r = 0.45 and d = 0.64.

The Jensen-Heise method, in turn, had the second highest RQME value = 2.32 mm day^{-1}, with low values for the agreement index (d = 0.50) and confidence (c = 0.47) , thus being classified as poor performance, although it showed a high correlation with the standard method (r = 0.93). The poor performance found here for the Jensen-Haise methodology may be linked to the fact that this method was created for locations that present arid and semi-arid climates, with a tendency to overestimate ETo when used in cold regions. Passos et al. (2017) also observed this same trend of overestimation of ETo by the Jensen method, this method being the one with the highest RQME value in their work (2.5117 mm day^{-1}) also classified as poor performance.

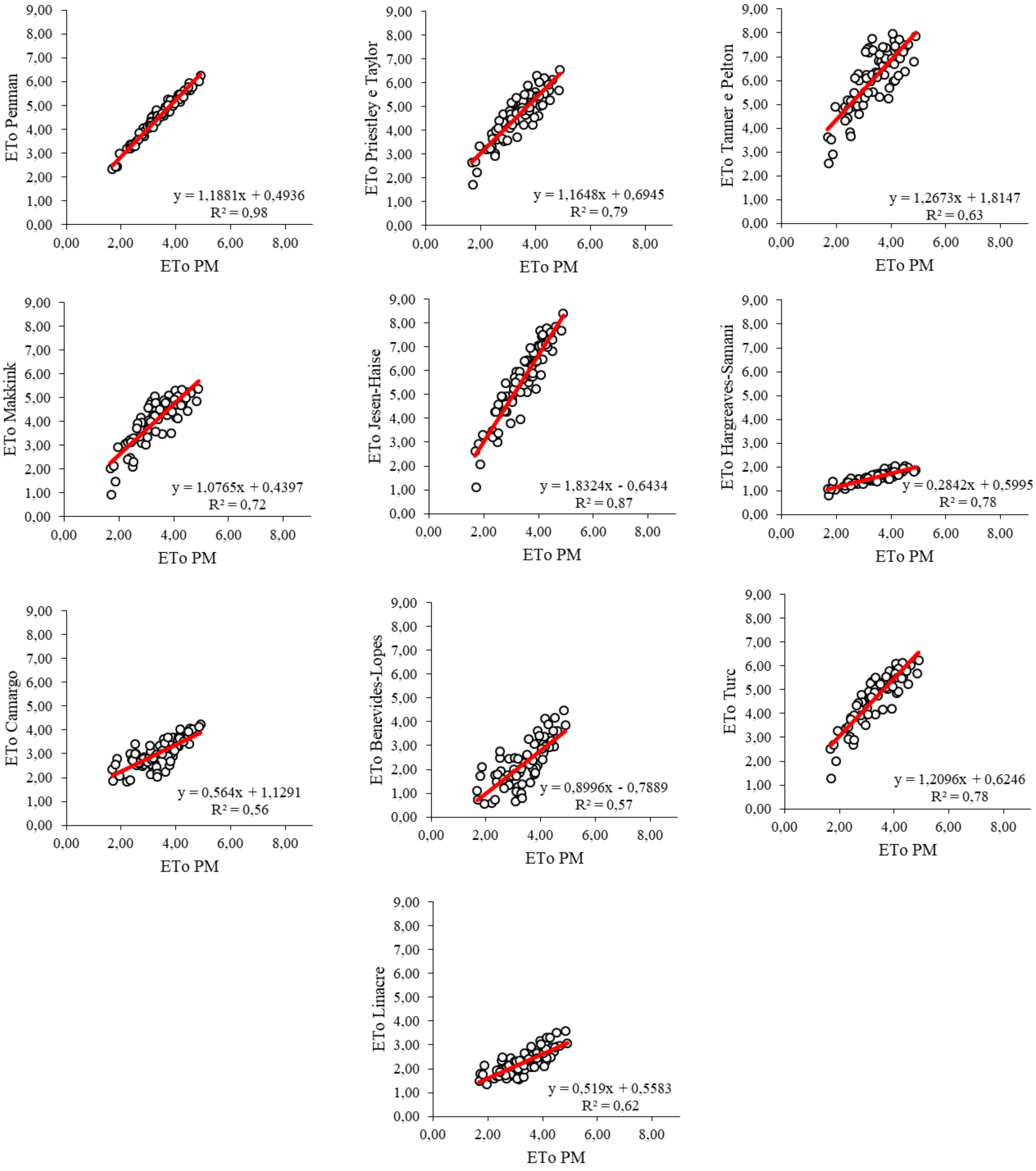

FIGURE 2 - Linear regression obtained between the reference evapotranspiration (ETo mm day^{-1}) estimated with the Penman-Monteith FAO (PM) method and that obtained by the other methods for days without precipitation in Cambará do Sul/RS.

TABLE 4 - Performance of daily ETo estimation methods for days without precipitation in Cambará do Sul/RS.

Coeficientes	Métodos de estimativa da ETo									
	PM	PT	TP	MK	JH	HS	CM	BL	TC	LN
d	0.71	0.65	0.38	0.79	0.50	0.44	0.80	0.62	0.63	0.60
r	0.99	0.89	0.79	0.85	0.93	0.88	0.75	0.76	0.88	0.78
c	0.70	0.58	0.30	0.67	0.47	0.39	0.60	0.47	0.56	0.47
R^2	0.98	0.79	0.63	0.72	0.87	0.78	0.56	0.57	0.78	0.62
RQME	1.14	1.34	2.83	0.88	2.32	1.89	0.62	1.29	1.43	1.17
Performance	B	SO	PE	B	M	PE	SO	M	SO	M

PM – Penmam, PT – Priestley e Taylor, TP – Tanner e Pelton, Mk – Makkink, JH – Jesen-Haise, HS – Hargreaves-Samani, CM – Camargo, BL – Benevides Lopes, TC – Turc, LN – Linacre, MB – Very good, B – Good, ME – Median, SO – Sufferable, M – Bad, PE – Terrible.

Another method that presented a poor performance (c = 0.47) for the days without precipitation was that of Benevides-Lopes. This method presents only humidity and temperature data as input data for estimating ETo. As these variables show constant variation throughout the day and in an inverse way, this may have been the reason for the poor performance found here. Jung et al. (2016), in their work estimating the reference evapotranspiration in the Upper Pantanal region, obtained a poor performance with the Benevides-Lopes method, with a value of c = 0.56, d = 0.70, r = 0.80 and a standard error of the estimate of 1.56 mm day^{-1}.

In turn, the Linacre method, as well as the Jensen-Heise and Benevides-Lopes methods, performed poorly (c = 0.47, d = 0.60, r = 0.78 and RQME = 1.17). This behavior is due to the fact that the Linacre model uses only air temperature and dew point and altitude as the location variable, limiting the representativeness of climatic conditions for the purpose of estimating ETo. Jung et al. (2016) and Santana et al. (2019) found poor performance using the Linacre methodology to estimate ETo in periods of less precipitation (dry period) with values of c = 0.55 and 0.41, respectively.

The Hargreaves-Samani method performed poorly in the rainless period (c = 0.39). The results found here can be explained according to Sentelhas et al. (2010), because, originally, the Hargreaves-Samani method was developed for semi-arid climate, and is based only on temperature data, providing in many places values different from those found by the standard method, which here can be easily observed based on in the low agreement index (d = 0.44), indicating a high deviation between the ETo values obtained by this method in relation to the values obtained by the Penman-Monteith method, thus providing a high RQME value = 1.89 mm Day 1. Results different from those found here were obtained by Ribeiro et al. (2016) and by Pereira et al. (2009), who in their work found average and poor performance for this method in the period considered dry.

The Tanner and Pelton methodology, in turn, had the highest RQME in the period without precipitation (RQME = 2.83 mm day^{-1}), thus indicating that this method presented ETo values quite different from those found by Penman-Monteith. In addition to the very high RQME, this method had the lowest performance index (c = 0.30) among the methodologies tested in the period without precipitation. Tanner and Pelton's methodology is based on the radiation balance to estimate ETo. However, according to Cunha et al. (2013), the method constants were obtained for the conditions of the state of Wisconsin, United States, which is the probable reason for the poor performance found here. Different results were obtained by Silva et al. (2018) who, evaluating evapotranspiration estimation methodologies in Jaíba (MG) obtained very good performance with this method.

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Figure 3 shows the graphs and the model resulting from the linear regression and the angular (a) and linear (b) coefficients, as well as the determination (R^2) obtained between the FAO standard methodology and the other methodologies for the period with precipitation . The use of linear regression for days with precipitation, aimed to verify whether the ETo estimation methodologies tested here would behave in the same way as on days without precipitation. What, with the exception of the Camargo methodology, which showed a tendency of underestimation of ETo in the period without precipitation, changing to a tendency of overestimation in the rainy period, occurred for all methods.

As seen in Figure 3, the best adjustments based on R^2 continue to be observed for the methods of Penman, Jensen-Haise, Priestley and Taylor, Makkink, Hargreaves-Samani and Tanner and Pelton. Camargo's method continued to be the method with the lowest R^2 value. The values for the coefficient of determination (R^2), observed here, ranged from 0.57 (Camargo) to 0.98 (Penman), and are higher than those obtained by Cunha et al. (2013), who obtained R^2 values for the methods of Makkink (0.70), Hargreaves-Samani (0.57), Priestley and Taylor (0.36), Jensen-Haise (0.76), Camargo (0 , 37), Linacre (0.40), Turc (0.72) and Tanner and Pelton (0.32).

Table 5 presents the indicators of correlation (r), agreement (d), confidence (c) and the root of the mean square of error (RQME) in the daily scales considering the period with precipitation for Cambará do Sul / RS. In the rainy period, the methodologies that stood out the most in ETo estimation were Penman, Makkink, Priestley and Taylor, Benevides-Lopes and Turc with values of c = 0.81, 0.78, 0.71, 0.68 and 0.73 respectively (Table 5). It is also observed that, for rainy days, Makkink's methodology improved its performance, going from good in the period without precipitation, to very good, in the period with precipitation.

This result is probably linked to the fact that the Makkink method was developed for regions with cold weather, and in the rainy season, in most cases, there is a reduction in temperature, which may have contributed to better estimates of ETo by this method. This same improvement behavior in the rainy season was observed by Santana et al. (2019) in the Balsas / MA region, where Makkink's methodology went from average performance in the rainless season to good in the rainy season.

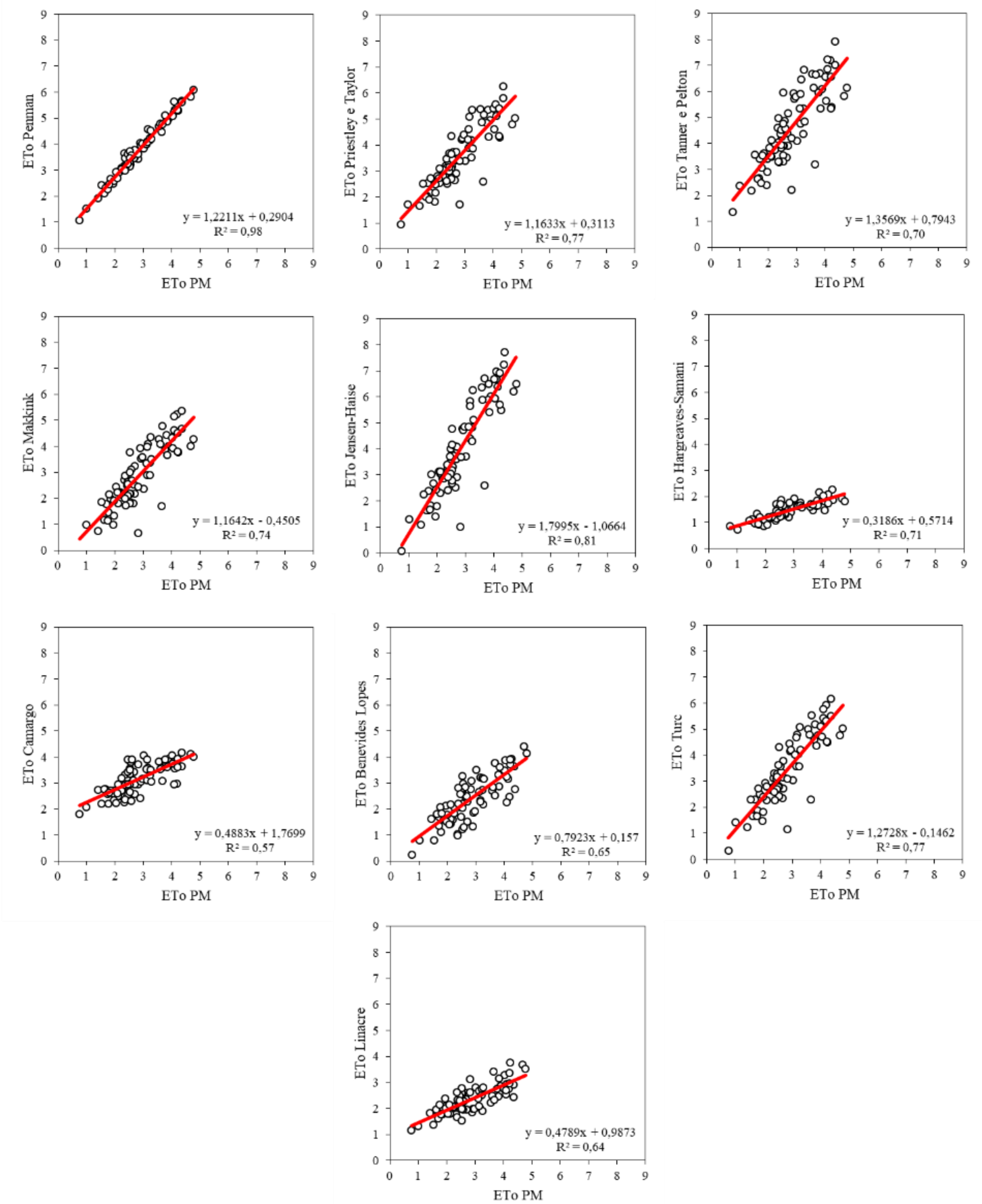

FIGURE 3 - Linear regression obtained between the reference evapotranspiration (ETo mm.dia-1) estimated with the Penman-Monteith method (PM) and that obtained by the other methods for days with precipitation in Cambará do Sul/RS.

The Pryestley and Taylor method also improved its performance in the period with precipitation, going from poor to good (Table 5). In addition, it reduced the RQME from 1.34 mm day^{-1} to 0.97 mm day^{-1}, and also increased Willmott's concordance index, going from 0.65 to 0.81, thus indicating that in the rainy season method estimated ETo with values closer to those obtained by the standard method.

The improvement in the performance of the Priestley and Taylor method can be attributed to the effect of lesser advection, since it is the rainy season. Improvements in the performance of this method were also observed by Ribeiro et al. (2016), where the method went from median performance in the dry period, to very good in the rainy period.

TABLE 5 - Performance of the daily ETo estimation methods, For days with precipitation in Cambará do Sul / RS.

Coeficiente	Métodos de estimativa da ETo									
	PM	PT	TP	MK	JH	HS	CM	BL	TC	LN
d	0.82	0.81	0.57	0.91	0.70	0.53	0.79	0.84	0.83	0.76
r	0.99	0.88	0.84	0.86	0.90	0.84	0.75	0.81	0.88	0.80
c	0.81	0.71	0.48	0.78	0.63	0.44	0.59	0.68	0.73	0.60
R^2	0.98	0.77	0.70	0.74	0.81	0.71	0.57	0.65	0.77	0.64
RQME	0.95	0.97	2.00	0.63	1.59	1.50	0.67	0.70	0.92	0.75
Desempenho	MB	B	M	MB	ME	M	SO	B	B	SO

PM – Penmam, PT – Priestley e Taylor, TP – Tanner e Pelton, Mk – Makkink, JH – Jesen-Haise, HS – Hargreaves-Samani, CM – Camargo, BL – Benevides Lopes, TC – Turc, LN – Linacre, MB – Very good, B – Good, ME – Median, SO – Sufferable, M – Bad, PE – Terrible.

Another method that also improved its performance was Benevides-Lopes, going from bad (c = 0.47) in the dry period, to good (c = 0.68) in the rainy period. It is likely that the improvement in ETo estimates by this method in the rainy season is related to smaller variations in relative humidity and air temperature, which are the only input parameters in the estimation equation of this method.

As with the methods of Penman, Makkink, Priestley and Taylor and Benevides-Lopes, the Turc method also improved its performance, going from poor (c = 0.56) in the rainless period, to good in the rainy period (c = 0.73). This is probably due to the fact that this method was originally created for Western Europe, which has air humidity values generally above 50%. In the rainy season there is an increase in relative humidity, thus improving the performance of the method in this period. This result corroborates with Fanaya Júnior et al. (2012), who also performed well with the Turc method.

The Linacre method also showed a small improvement in its performance, going from bad to poor. Like the Benevides Lopes method, it is likely that the improvement of the Linacre method is related to lower temperature variations in the rainy season, thus making the method improve ETo estimates. JUNG et al. (2016) did not observe an improvement in the method comparing the dry season with the rainy season. On the other hand, Santana et al. (2019) also obtained improvement of the method in the period with precipitation.

For the methods of Tanner and Pelton, Jensen-Haise and Hargreaves-Samani, a change in performance was also observed. However, even with improved performance, these methods should not be used to estimate reference evapotranspiration in Cambará do Sul / RS. Despite having improved its performance, the Tanner and Pelton method continued to show the highest RQME = 2 mm day^{-1} and a low value for the concordance index d = 0.57, although it had a very high correlation r = 0.84.

The performance improvement observed here by the Jensen-Heise method, is probably due to the fact that it was developed for application in irrigated areas. Contrasting results were found by Ribeiro et al. (2016), who, when estimating the reference evapotranspiration for the municipality of Piripiri (PI), in the rainy period, found that the Jensen-Haise method obtained an excellent performance.

Although it changed its performance, going from bad in the dry period (c = 0.39, d = 0.44, r 0.88 and RQME = 1.89 mm.day^{-1}) to Bad in the rainy season (c = 0 , 44, d 0.53, r = 0.84 and RQME = 1.50 mm day^{-1}), the Hargreaves-Samani method is still not satisfactory, as the method has been developed for arid regions, with a reduction in the accuracy of the evapotranspiration estimate when used in humid regions or periods. In the work by SANTANA et al. (2019) the authors also observed a change in performance for the Hargreaves-Samani method, changing from poor performance in the period considered without precipitation (c = 0.30, d = 0.65 and r = 0.46) to median (c = 0.64, d = 0.84 and r = 0.76).

For the Camargo method, there was no improvement in performance, thus being classified as poor both in the period without precipitation and in the period with precipitation. These results can be explained according to Cunha et al. (2013), because the Camargo method is derived from the Thornthwaite method, and works effectively for humid tropical and equatorial regions, unlike the climate of the region where the present study was conducted.

CONCLUSION

For the municipality of Cambará do Sul / RS to replace the Penman-Monteith method, we recommend the use of the Penman and Makkink methods, which presented satisfactory performance in all periods analyzed.

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