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Articles

Daily reference evapotranspiration models in the rice zone of Valle del Cauca, Colombia

Modelos de evapotranspiración de referencia diaria en la zona arrocera del Valle del Cauca, Colombia

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Abstract

The opportune calculations of the daily reference evapotranspiration (ETo) quantify and schedule the use of the water availability and consequently determine a daily consumption, mostly in the conditions where the lack of climatic information interrupts the performance of diverse models to estimate the daily reference evapotranspiration in a certain region. Therefore, the objective of this work is to evaluate the behavior of the equations of Hargreaves-Samani, Priestley and Taylor, García and López, and Linacre in the calculation of daily reference evapotranspiration (ETo) for the equation of FAO Penman-Monteith (PM) using daily information from five stations near the rice production area of Valle del Cauca, Colombia. The daily evapotranspiration of 28 consecutive years was estimated, the results were confirmed by the statistical indicators: Determination Coefficient (R^2); the square root of the mean square of the error (RMSE); Nash-Sutcliffe Efficiency (NSE), and box diagrams. The Priestley-Taylor (PT) and Linacre (LN) models have shown the closest results to the standard model. Bengala and Ciat Quilichao stations are shown as the areas with the best behavior of all the models with the coefficient of determination index (R^2); all the stations presented acceptable results with the square root of the mean square of the error (RMSE) for the different comparisons made but not with the Nash-Sutcliffe Efficiency (Nash-Sutcliffe Efficiency). However, there is limited evidence of the daily use of the Garcia and Lopez model, being this method and that of the Hargreaves-Samani the least ideal for the Independence station.

Keywords: Evapotranspiration models, rice, daily data, reference evapotranspiration.

Resumen

Los cálculos oportunos de la evapotranspiración de referencia diaria (ETo) cuantifican y planifican el uso de la disponibilidad hídrica y, en consecuencia, determinan un consumo diario, más en las condiciones donde la falta de información climática interrumpe el rendimiento de los diversos modelos para estimar la evapotranspiración de referencia diaria en una determinada región. El objetivo de este trabajo es evaluar el comportamiento de las ecuaciones de Hargreaves-Samani, Priestley y Taylor, García y López, y Linacre en el cálculo de la evapotranspiración de referencia diaria (ETo) respecto a la ecuación de FAO Penman-Monteith (PM), utilizando la información diaria de cinco estaciones próximas a la zona productora de arroz del Valle del Cauca, Colombia. Se estimó la evapotranspiración de referencia diaria de 28 años consecutivos; se utilizaron los indicadores estadísticos: coeficiente de determinación (R^2); la raíz cuadrada del cuadrado medio del error (RMSE); eficiencia de Nash-

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Sutcliffe (NSE), y diagramas de cajas para definir la bondad de los modelos utilizados. Los modelos Priestley-Taylor (PT) y Linacre (LN) han exhibido los resultados más afines al modelo estándar. Las estaciones Ing. Bengala y Ciat Quilichao se exhiben como las áreas que mejores comportamientos poseen de todos los modelos con el índice del coeficiente de determinación (R^2); todas las estaciones presentaron resultados aceptables con la raíz cuadrada del cuadrado medio del error (RMSE) para las diversas comparaciones realizadas, no así con la eficiencia de Nash-Sutcliffe. Existe evidencia limitada del uso diario del modelo García y López, siendo este método y el de Hargreaves-Samani los menos ideales para la estación Independencia.

Palabras clave: modelos de evapotranspiración, arroz, datos diarios, evapotranspiración de referencia.

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Introduction

Estimates of reference evapotranspiration (ETo) have been widely studied and used in irrigation engineering fundamentals to define crop water requirements. According to Sánchez (2000), the term reference evapotranspiration (ETo) has been used to describe the total processes of water transfer to the atmosphere from vegetation with well-defined characteristics. In agriculture, ETo is one of the elemental variables to promote more efficient use of water, hence the need to have adequate estimates (Back, 2008); because it plays an essential role in the water balance for watershed management and the estimation of irrigation requirements, irrigation scheduling and climate change studies.

The south of Valle del Cauca-Colombia has two planting seasons at rainfed level with 3750 acres producing rice (Dane & Fedearroz, 2017), and the quantification of the daily ETo for the area at daily level is necessary to improve crop management, know its water needs and make efficient use of water (Martínez & Pérez, 2006), but to estimate such variable there is a lack of daily records to use the Penman-Monteith (PM) model proposed by Allen, Pereira, Raes and Smith (1998). In Colombia there are some works related to the estimation of ETo at different scales: Barco *et al*. (2000) concluded that Penman and Morton are difficult to implement due to the climatic information required; the Cenicafe equation developed by Jaramillo (2006) allows calculating evapotranspiration (ETo) in a simple way; this equation only depends on the elevation above sea level and the ETo estimated for the whole country by Poveda *et al*. (2007)

indicates that the equations presented by Turc and Morton are the most convenient for these evaluations.

The trend in the estimation of this type of meteorological variable has indicated that more results obtained at the scale, annual and monthly are reported; however, some significant reports published in the years 2017 in Taiwan and 2019 in Senegal about the estimation of daily reference evapotranspiration used in the estimation of ET of rice crop have been identified in Scopus. By resorting to the examples, Yao *et al*. (2017) obtained the 10-day average ETo maps from meteorological satellite images compared with the ETo maps from meteorological satellite images compared with the ETo derived from the FAO (Food and Agriculture Organization of the United Nations) PM model (Allen *et al*., 1998), and Djaman, Sall, Sow, Manneh, and Irmak (2019) determine the measured climatic data in the irrigated rice area used in ETo estimation using the Penman-Monteith model under conditions where there are no records from meteorological stations.

The election of a model or calculation method depends on the availability of meteorological data, as well as on the accuracy and precision of the model for a given region (De-Carvalho *et al*., 2013). Therefore, FAO has adopted the Penman-Monteith model mainly for two reasons: a) it is a physical model that applies not only to a specific area and b) the data used can be obtained from meteorological stations, observatories, or measurements through lysimeters (López, Hess, & White, 2009). Because of the above, there is at least one model for the Cauca valley that estimates ETo with a low error at a daily level concerning a standard model. The aim of this work was to evaluate the performance

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of the Hargreaves-Samani, Priestley-Taylor, García and López, and Linacre equations in the calculation of daily reference evapotranspiration (ETo) regarding the FAO Penman-Monteith (PM) equation.

Materials and methods

The rice-growing zone in the south of Valle del Cauca extends approximately between 3°5'0'' and 3°20'0'' north latitude and between 76°10'0'' and 76°50'0'' west longitude. The elevation of the area is approximately 1000 m.a.s.l., a mean temperature of 23°C predominates; with a daily oscillation of 11°C, relative humidity of 73 to 80 %, and sunshine of 138 to 200 hours per month approximately (Valencia, García, & Montero, 2017). According to Köppen, it corresponds to the tropical rainforest climate (Martínez & Mendivelso, 2004: p. 53) (Figure 1).

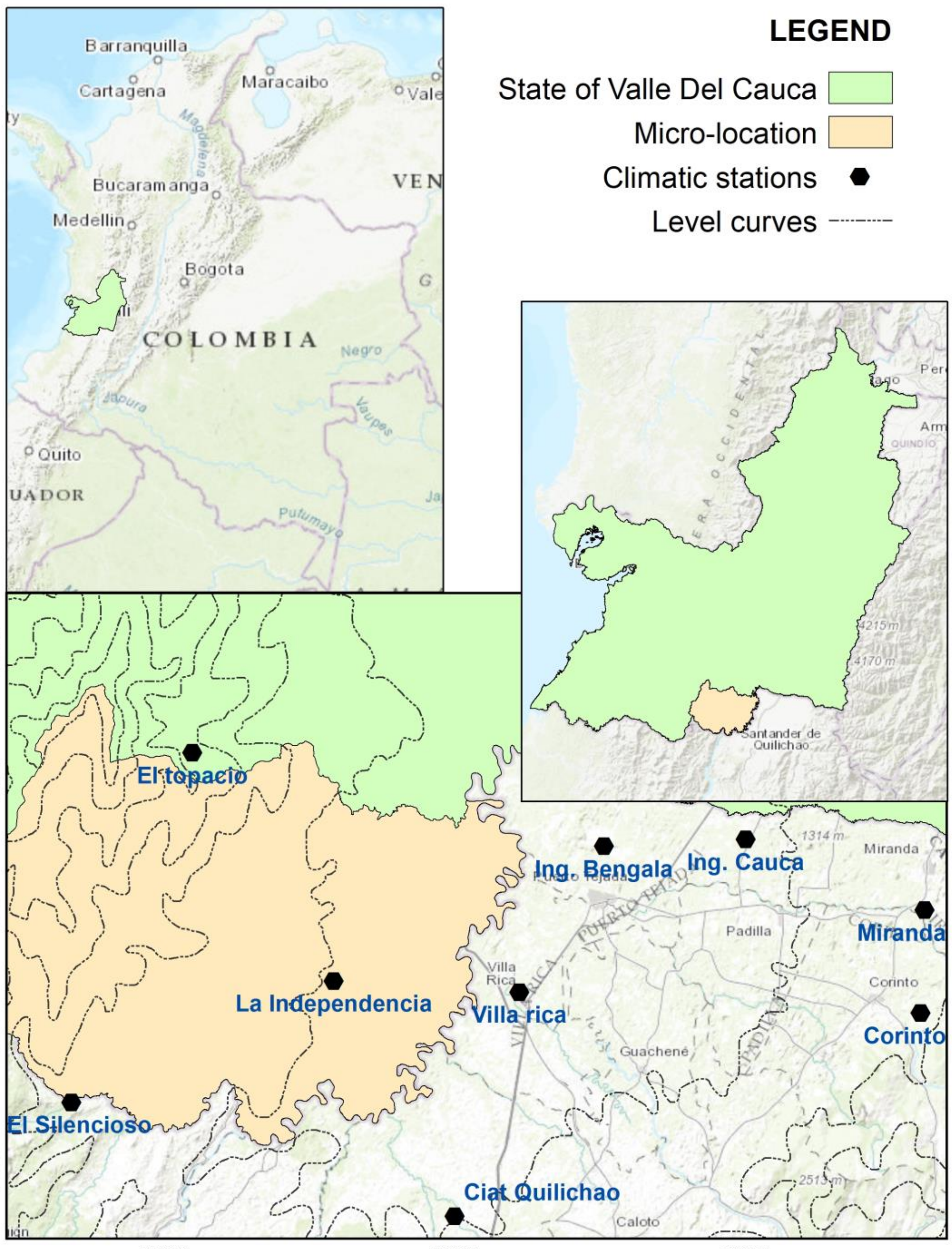

Figure 1. Study area location.

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Daily records of maximum temperature, minimum temperature, relative humidity, and sunshine from five climate stations were used for a study period from 1989 to 2016 (Table 1).

Table 1. Description of the climatic stations.

Station	Altitude (masl)	Latitude (N)	Longitude (W)
Ciat Quilichao	977	03° 03´	76° 30´
Ingenio Bengala	1 000	03° 15´	76° 24´
Ingenio Cauca	1 000	03° 14´	76° 13´
La Independencia	963	03° 11´ 8″	76° 34´ 9″
Ingenio Miranda	1 128	03° 16´	76° 20´

Models for estimating daily reference evapotranspiration (Eto)

Reference evapotranspiration (ETo) was calculated with five recognized models on a daily basis in the Excel program. The models are listed below:

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Penman Monteith Equation (PM)

The Penman-Monteith is considered the standard and most accurate model for estimating ETo (Allen *et al*., 1998). It was developed with the definition of the reference crop which is a hypothetical one of 0.12 m height, with a surface resistance of 70 s m-1 and an albedo of 0.23 and which represents the evapotranspiration of a large area of green grass of uniform height, actively growing and adequately irrigated (Allen, Pereira, Raes, & Smith, 2006):

$$ETo_{PM} = \frac{0.408\triangle\ (Rn-G)+\gamma*\frac{900}{T+\ 273}u_2(e_s-e_a)}{\triangle+\gamma(1+0{,}34u_2)} \quad (1)$$

ETo_{PM}, reference evapotranspiration (mm d^{-1}).

Rn, crop's net radiation (MJ m^{-2} d^{-1}).

G, ground heat flow (MJ m^{-2} d^{-1}).

T, mean air temperature at 2 m altitude (°C).

u_2, wind speed at 2m height (m s^{-1}).

e_s-e_a, Vapor pressure deficit (kPa).

Δ, The slope of the vapor pressure curve at saturation (KPa° C^{-1}).

γ, psychrometric constant (KPa° C^{-1}).

The processing of the data for being taken to daily scale the G=0 value for the reference crop according to Allen *et al*. (2006).

Hargreaves-Samani Equation (HS)

The Hargreaves-Samani model is a simpler model that requires meteorological variables, temperature (mean, maximum, and minimum), incident radiation (Xu & Singh, 2001), and extraterrestrial solar radiation (Ra) to estimate ETo, for a given latitude and day; Ra can be obtained from tables or can be calculated by a set of equations using the temperature:

$$ETo_{HS} = 0.0023(T_{media} + 17.8)(T_{max} - T_{min})^{0.5}R_a \quad (2)$$

Priestley-Taylor Equation (PT)

It is a semi-empirical model that requires fewer parameters for the calculation of evapotranspiration in comparison to the Penman-Monteith model (Cervantes, Arteaga, Vázquez, Ojeda, & Quevedo, 2013). This methodology involves solar radiation and shows fewer errors compared to the standard method (Pereira, 2004). The elements necessary for its calculation are:

Δ, the slope of the saturation vapor curve (KPa° C $^{-1}$)

ɑ, the equivalent empirical coefficient a 1.26

γ, psychrometric constant (KPa° C^{-1})

$R_{n,}$ crop's net radiation (MJ m^{-2} d $^{-1}$)

G, ground heat flux (MJ m^{-2} d $^{-1}$), as the daily scale G=0 value for the reference crop according to Allen *et al*. (2006):

$$ETo_{PT} = \alpha * \left[\frac{\Delta}{\Delta + \gamma}\right] * (Rn - G) \quad (3)$$

Linacre Equation (LN)

This model is derived from Penman, estimating evapotranspiration through geographical data (latitude and altitude) and temperature data. (Carvalho, Rios, Miranda, & Castro, 2011):

$$ETo LN = \frac{\left(\frac{500*Tm}{100-A}\right)+15*(T-TPR)}{80-T} \quad (4)$$

EToLN, in mm day^{-1}.

Tm= T + 0.006*h.

h, the height of the site, en masl.

TPR, dew-point temperature, ºC.

Latitude of the site (Decimal Degrees).

T, mean temperature, ºC.

García and López Equation (GL)

The proposed model is adapted to latitudes from 15º N to 15º S. The variables used are mean temperature in ºC and relative humidity in % (García & López, 1970):

$$EToGL = \left[1.21 * 10^{\frac{7.45*T}{234.7+T}} * (1-0.01*HR)\right] + 0.21*T - 2.3 \quad (5)$$

Linear Regression Model

Five stations were used to define the scatter diagrams and the relationship between the data calculated with the PM model and those estimated with the HS, PT, LN, and GL equations, from which the following linear models are obtained:

$$ETo_{PM-HS} = a + b * EToHS \quad (6)$$

$$ETo_{PM-PT} = a + b * EToPT \quad (7)$$

$$ETo_{PM-LN} = a + b * EToLN \quad (8)$$

$$ETo_{PM-GL} = a + b * EToGL \quad (9)$$

Statistical index

The indicators used to evaluate the goodness-of-fit of the models are as follows:

a) The coefficient of determination (R^2) greater than 0.60 indicates the degree to which the regression explains the sum of the total squared (Tagliaferre *et al*., 2012).

b) The square root of the mean square of the error compares a predicted value and an observed or known value (RMSE) (Caí, Liu, Lei, & Santos, 2007).

c) Nash-Sutcliffe Efficiency (NSE): This coefficient sets the relationship between actual and modeled behavior. The mathematical domain of the NSE coefficient value is from 1, where unity represents a perfect simulation. A perfect fit means that the variance of errors is zero; it is zero when the variance of errors is equal to the observed variance, which means that the model produces estimates of the average of the observations in all intervals. Negative values indicate poor performance of the model (Magana-Hernández, Ba, Guerra-Cobian, & Víctor, 2013).

Box Plots

These plots were used to identify how the mean and standard deviation are distributed and how the data calculated by all models are distributed, for each station.

Results

The performance of the reference evapotranspiration of some representative hydrological years for the production zone evaluated is presented. The year 1999 was chosen as the wettest year (10513 mm yr^{-1} for the zone), 2012 was an intermediate year (7791 mm yr^{-1}), and 1992 was a dry year (5544 mm yr^{-1}).

PT and GL presented similar results in the rainy year, but in the intermediate and dry year, GL presented higher values than PT, but lower than HS. Another considerable observation is that the LN method showed higher estimates in July, August, and September; because the

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temperature is higher at this time of the year and influences the estimation by this method (Figure 2, Figure 3, Figure 4).

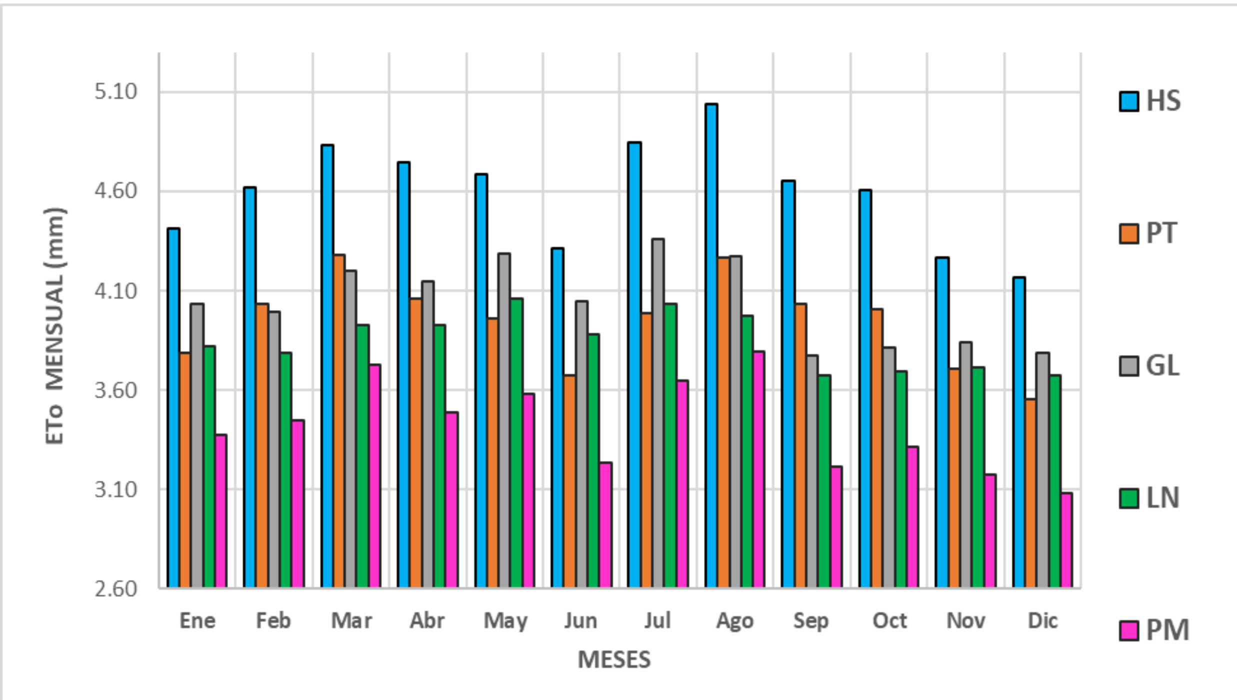

Figure 2. Monthly mean ETo for a rainy year in the rice-growing zone.

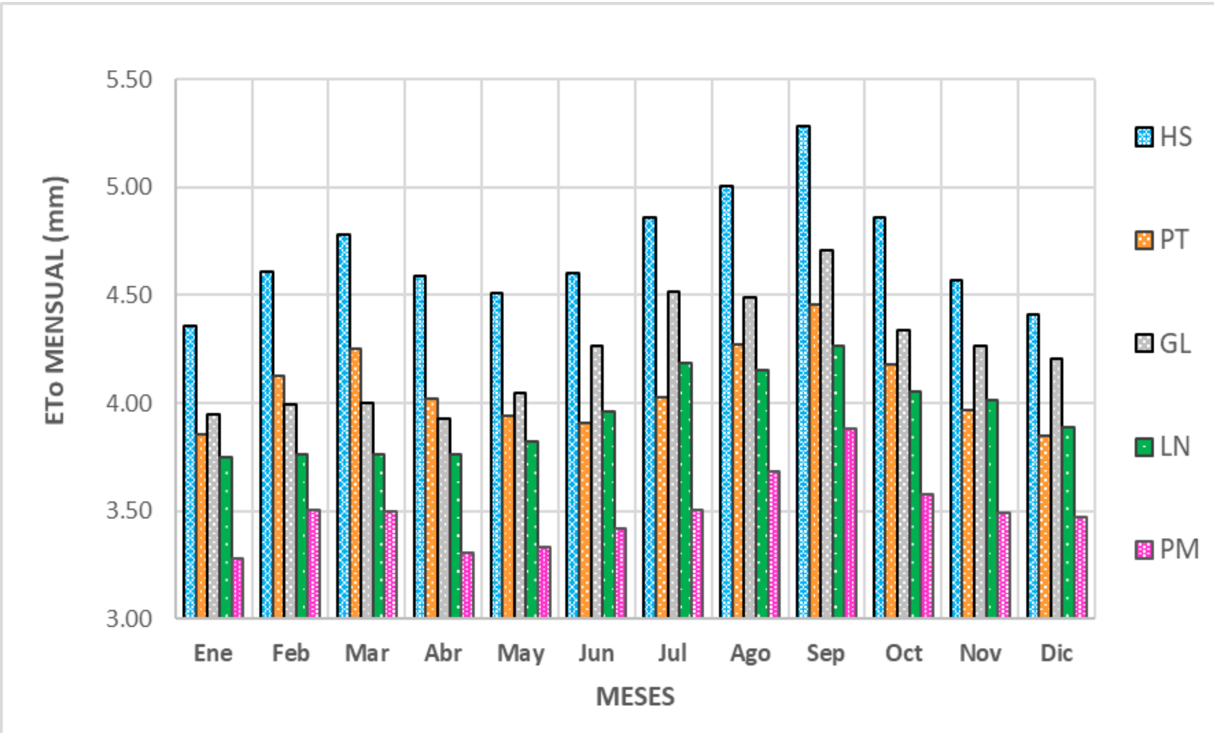

Figure 3. Monthly mean mean ETo for an intermediate year in the rice growing zone.

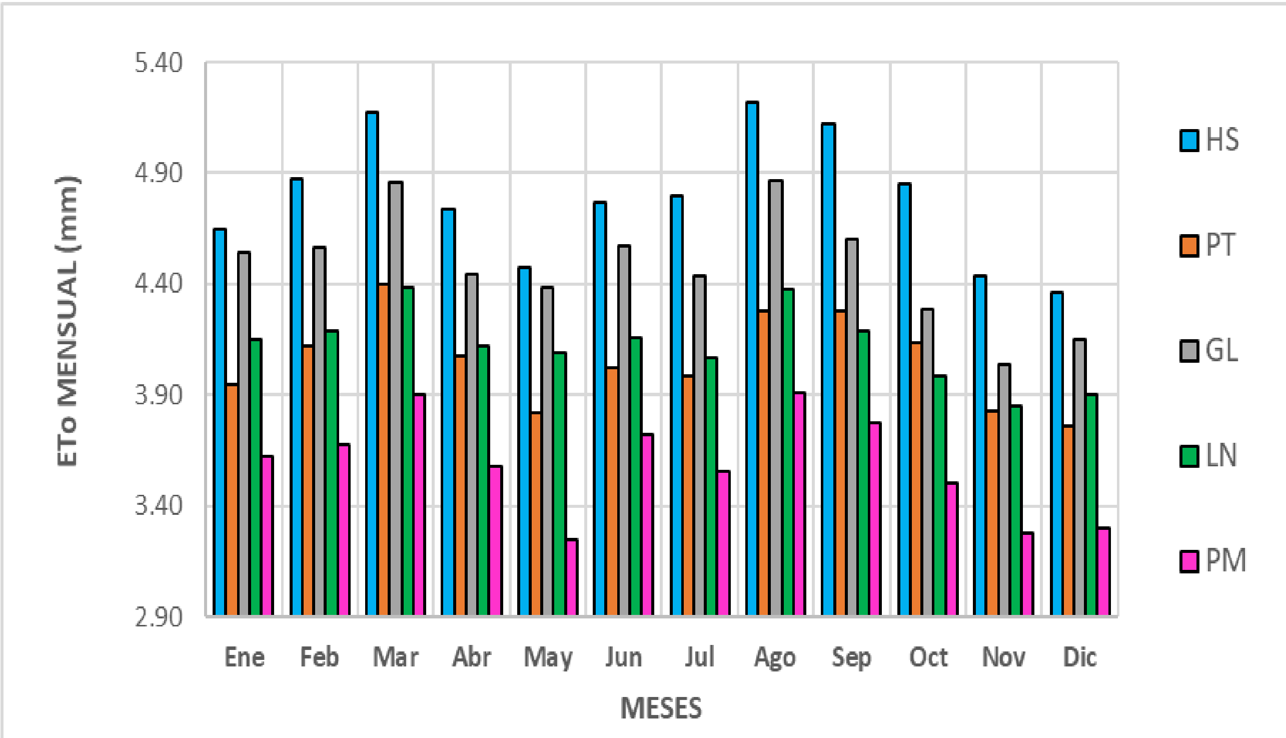

Figure 4. Monthly mean ETo for a dry year in the rice-growing zone.

It was observed that for the Ing. Bengala and Ciat Quilichao stations, estimates higher than 0.5 were obtained for the coefficient of determination in all models. In fact, the estimates between the Penman-Monteith and Priestley-Taylor models presented values of 0.597 of R^2 for Ing. Bengala and 0.834 for Ciat Quilichao (Figure 5) and values lower than 0.35 of R^2 for Ing. Cauca, Independencia, and Ing. Miranda.

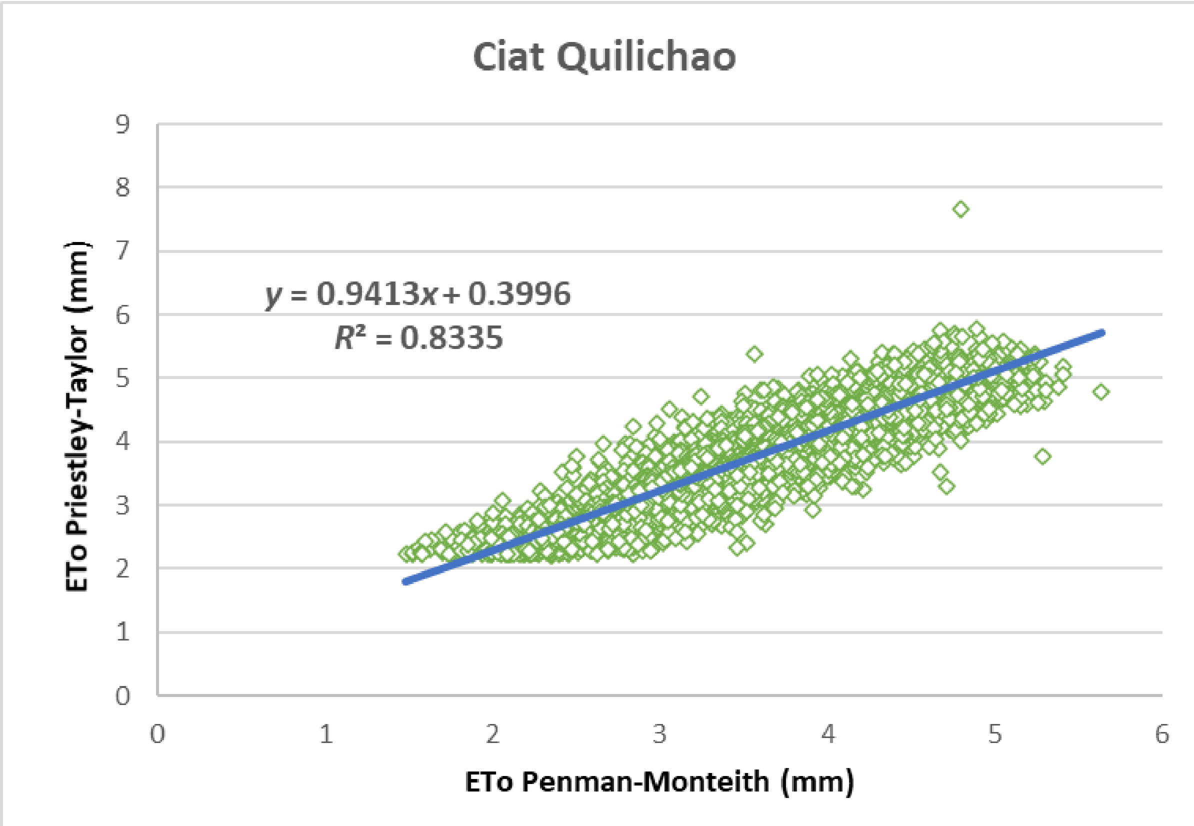

Figure 5. Linear Regression Between PM and PT for the Ciat Quilichao Station.

The HS model exhibited low determination coefficients as follows: R^2 values equal to 0.376, 0.290, and 0.268, for the station's Ing. Cauca, Independencia, and Ing. Miranda, respectively, but not for the station Ing. Bengala where its determination coefficient was 0.8264 (Figure 6). Likewise, the Garcia and Lopez model presented a range of R^2 values between 0.42 and 0.29 for the three stations before mentioned.

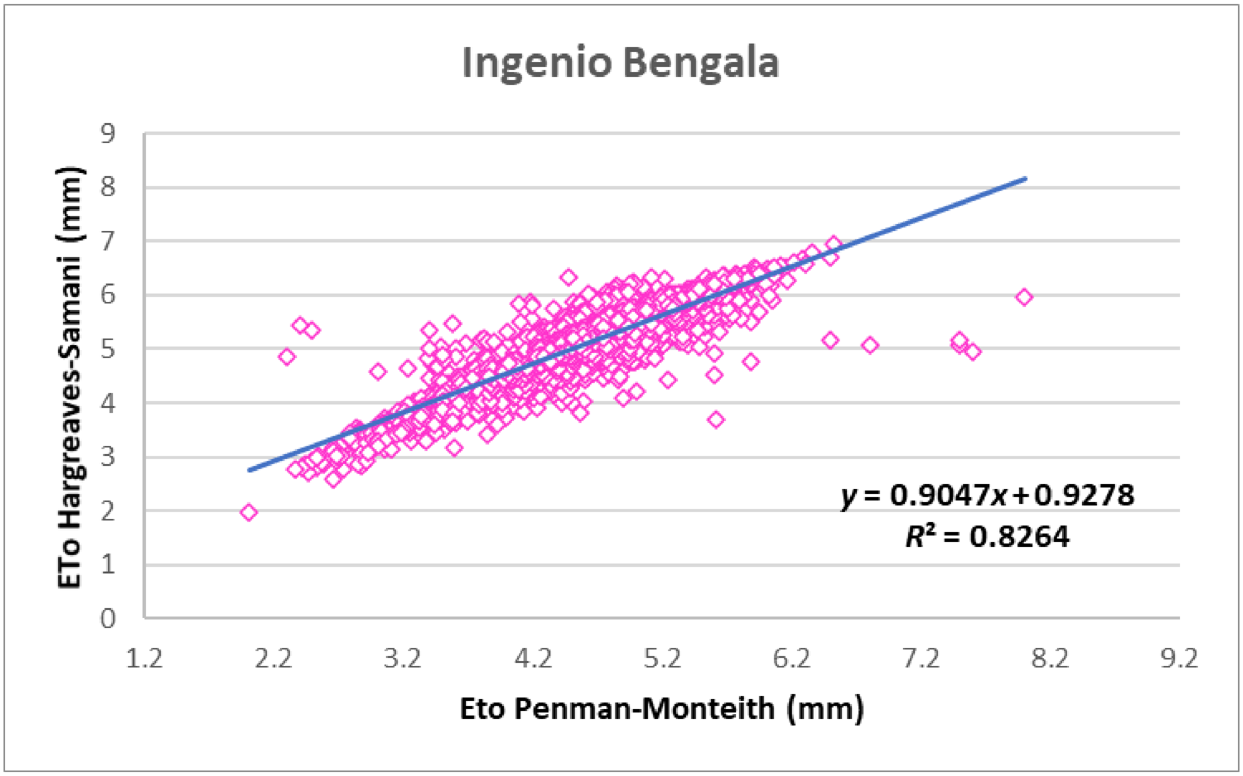

Figure 6. Linear Regression Between PM and HS for Bengal Engineering Station.

Linacre showed the lowest R^2 values for Independencia and Ing. Cauca (Figure 7); whereas for Ing. Miranda it exhibited a value of 0.330 R^2.

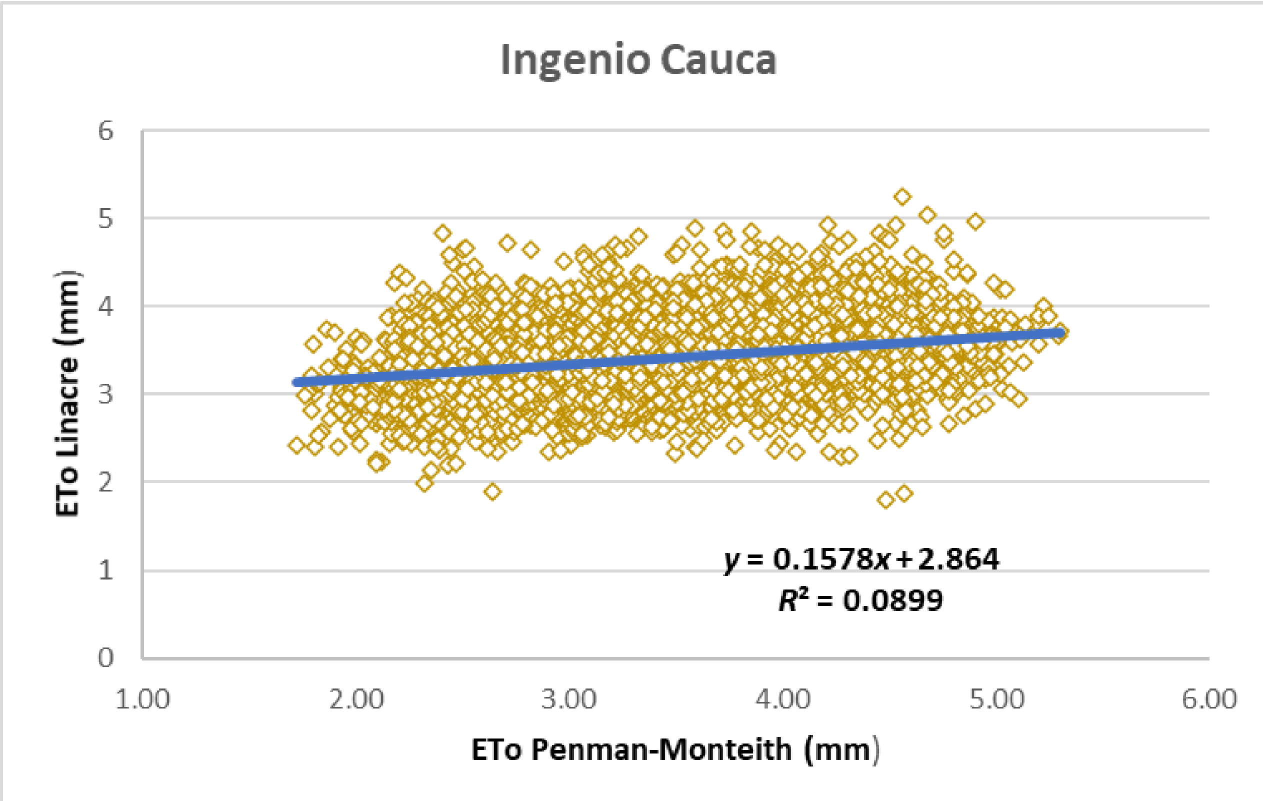

Figure 7. Linear Regression Between PM and LN for Ing. Cauca station.

The confidence intervals in which the coefficients of the linear regressions were estimated are based on a 95 % confidence level (Figure 5, 6, and 7, Table 2) and it can be seen that the values of the intercept "a" and "b" are within the limits allowed for this confidence level.

Table 2. Interval of confidence to 95 %.

Models	Station	intercept a	Slope b	Interval of confidence a		Interval of confidence b	
				Lower limit a	Upper limit a	Lower limit b	Upper limit b
PT-PM	Ciat Quilichao	0.3996	0.9413x	0.371	0.429	0.933	0.949
HS-PM	Ing. Bengala	0.9278	0.9047x	0.892	0.964	0.897	0.913
LN-PM	Ing. Cauca	2.8640	0.1578x	2.829	2.899	0.148	0.168
HS: Hargreaves-Samani Equation							
PT: Priestley-Taylor Equation							
LN: Linacre Equation							
PM: Penman Monteith Equation							

For this study, the average error of the HS model was 1.38 mm day^{-1}, which is acceptable whereas it is the highest average error of all the models concerning PM (Table 3). In turn, this index allows presenting that the Linacre model can be a substitute for the PT method; therefore, its mean RMSE of the five stations for the study area was 0.71 mm day^{-1} (Table 3).

Table 3. Root mean square error (RMSE) of ETo-PM concerning HS, PT, GL, and LN for each station.

Equ	**PM-Ing.Bengala**	**PM-Ing.Cauca**	**PM-Ciat Quilichao**	**PM-Independencia**	**PM-Ing.Miranda**
HS	0.55	1.39	1.30	2.01	1.66
PT	0.35	0.59	0.36	1.13	0.76
GL	0.64	0.66	0.71	2.69	0.73
LN	1.03	0.59	0.60	0.75	0.60
HS: Hargreaves-Samani Equation					
PT: Priestley-Taylor Equation					
GL: García-López Equiation					
LN: Linacre Equation					

Regarding the Nash-Sutcliffe efficiency (NSE), low accuracy in ETo estimation was found in all models by the station. However, two significant positive results were identified: PM-PT for Ciat Quilichao and PM-LN for Ing. Bengala (Table 4); there is no doubt that the PT model at the Ciat Quilichao station is the only model that obtained a positively high-efficiency value and had a lower error (Table 3 and Table 4).

Table 4. Nash-Sutcliffe efficiency (NSE) of ETo-PM concerning HS, PT, GL, and LN for each station.

Ecu	**PM-Ing.Bengala**	**PM-Ing.Cauca**	**PM-Ciat Quilichao**	**PM-Independencia**	**PM-Ing.Miranda**
HS	-0.09	-3.60	-2.38	-8.21	-5.84
PT	-0.70	-2.06	0.74	-3.84	-2.97
GL	-0.46	-0.03	-0.02	-15.52	-0.34
LN	0.42	0.02	-0.88	-0.76	-2.07
HS: Hargreaves-Samani Equation					
PT: Priestley-Taylor Equation					
GL: García-López Equation					
LN: Linacre Equation					

Box Plots

The results obtained from the previous analyses identified that the Priestley-Taylor model is one of the methods that have a high affinity with the standard method, but another relevant feature of the discussion is the distribution of the data set of each model by the station (Figure 8).

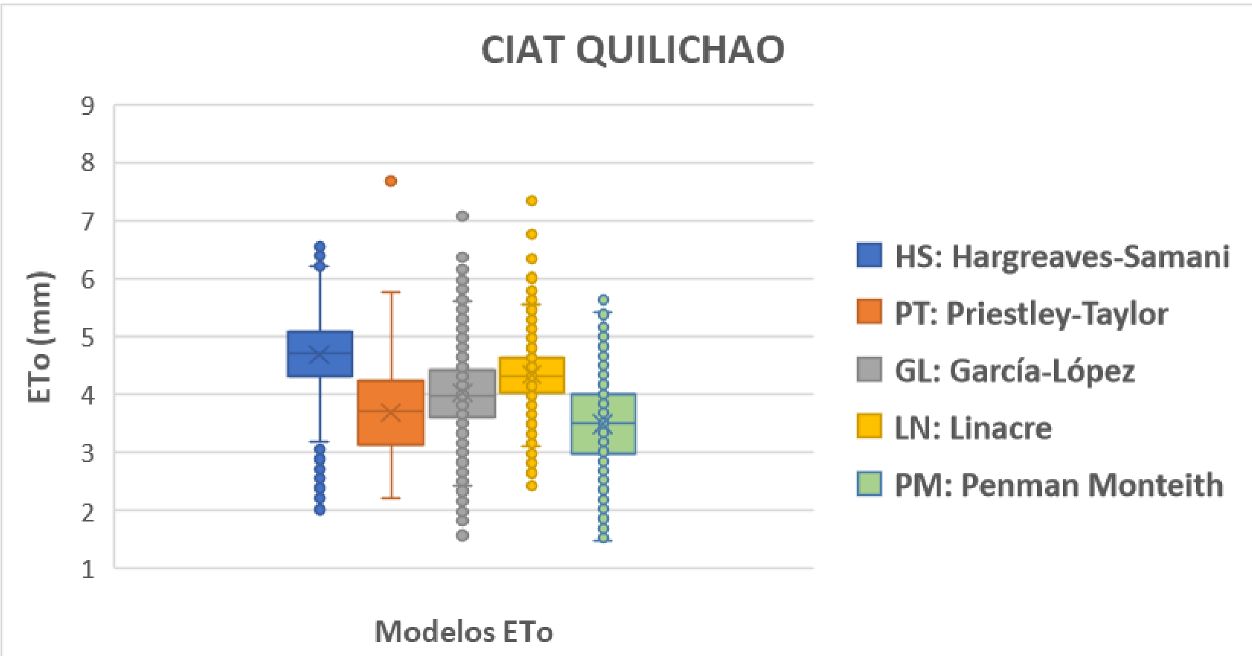

Figure 8. ETo estimations for Ciat Quilichao station.

There is a big variability in the estimates of the daily ETo, so it is notorious the unequal position of the boxes among them and after the estimates of the NSE it was identified that for the independence station the accuracy of the models used against the standard model is not quantitatively described (Figure 9).

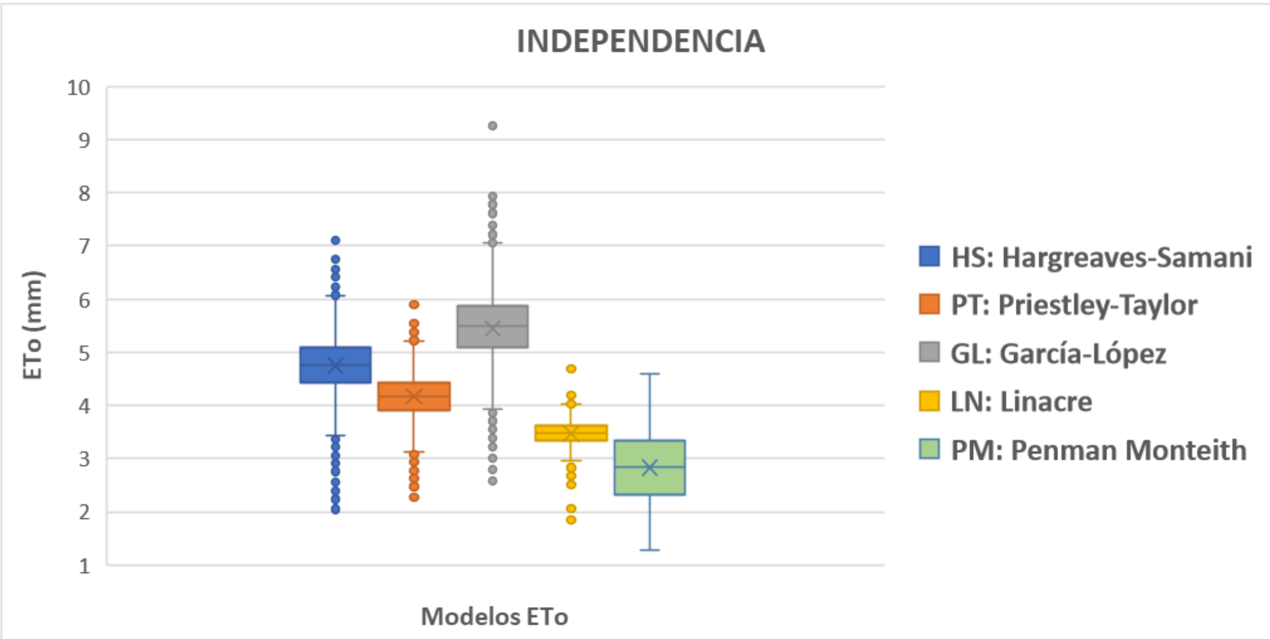

Figure 9. ETo estimations for Independencia station.

At the Ing. Miranda station, the LN and PT models have a variance of 0.12 and similar behavior in their standard deviation of 0.34 and 0.35 mm dia-1; with a data set that coincides with the estimates made by the standard method (Figure 10). The LN-PM model presented better results than the other models for this station (Table 3).

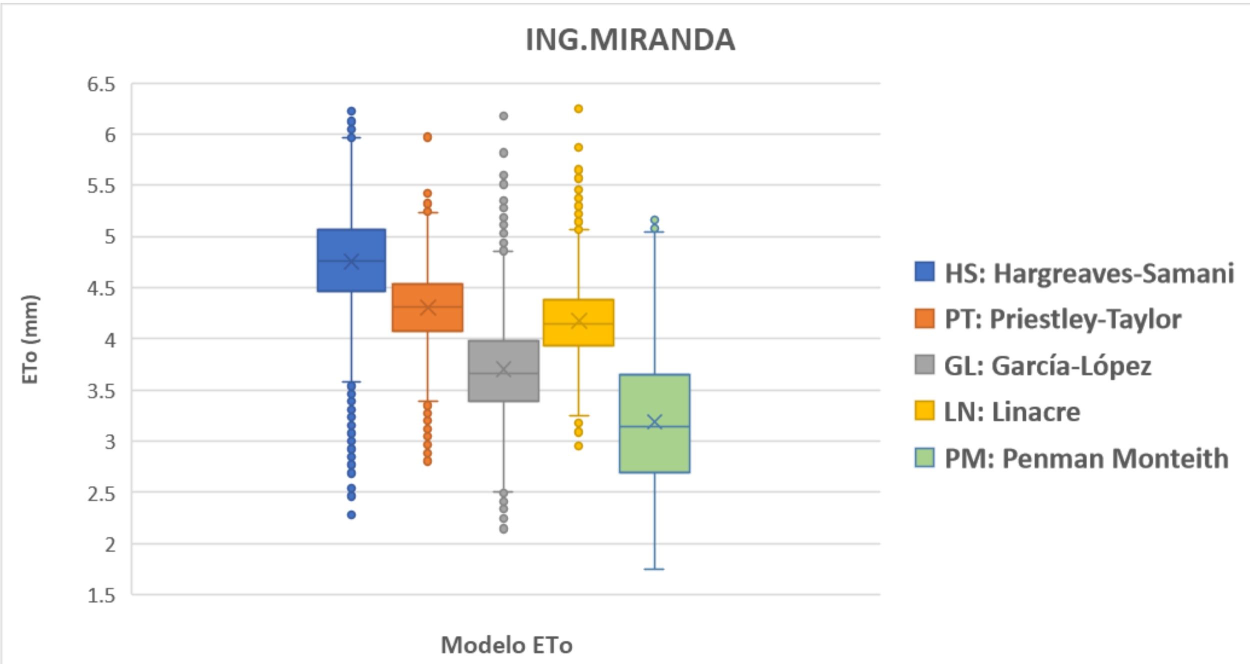

Figure 10. ETo estimations for Ing. Miranda station.

Ing. Bengala station exhibits that the estimates made by the PM and HS model have a variance of 0.281 and 0.278 respectively, and a similar standard deviation of 0.53 mm day^{-1} (Figure 11). However, for this case, it was the same standard method that presented more observations that are unusually far from the rest of the data. On the other hand, the PT, GL, and LN models in their data set were closer to the mean and obtained the lowest errors for this station with the RMSE index.

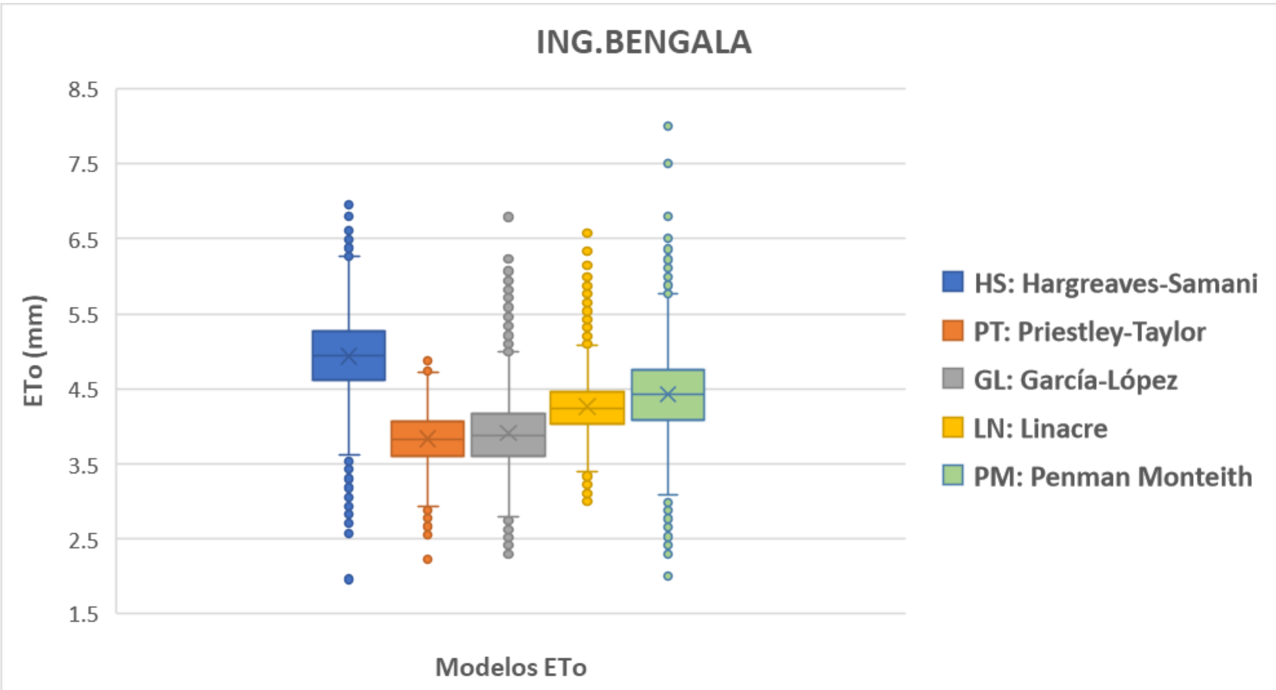

Figure 11. ETo estimations for Ing. Bengala station.

The values obtained for the square root of the mean square of the error for the Ing. Cauca station were less than 1 mm for the PT, GL, and LN models (Figure 12, Table 3), which agree with 95 % of the estimates made with the GL model with the standard model for the Ing. Cauca station. On the other hand, 75 % of the results obtained from the Linacre model agree with 50 % of the values obtained from the PM model. Similarly, Hargreaves-Samani has the highest mean with outliers and extreme values; comparing this with the standard model could indicate that HS is not a suitable method for this station, given that PM considers them within its variance.

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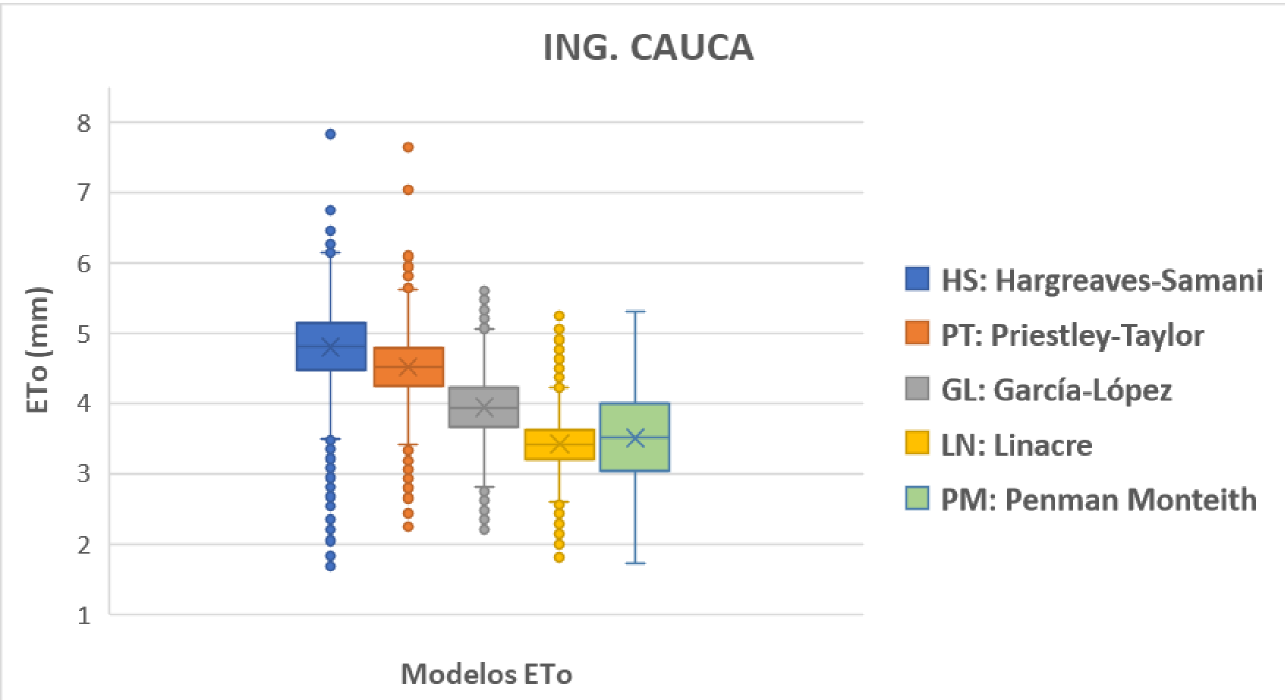

Figure 12. ETo estimations for Ing. Cauca station.

The graphs displayed above show that the models closest to the standard method for the five stations were the PT and LN; they presented identical statistics, better fits, or lower errors.

Discussion

The PM model, on a general level, showed an interval of 3 to 3.8 mm month^{-1} and HS was the method that presented higher monthly averages in all the chosen years. In the rainy year, June and December are the months with the lowest averages in all methods; this is due to the phenomenon of the intertropical convergence zone that influences the bimodal behavior of precipitation for the country (Figure 2).

March and August of the dry year present the highest averages and between methods, the values tend to be similar (Figure 4); according to IDEAM records, August is the month with the highest evaporation recorded in the historical data.

A study was done to compare PM and PT models estimated reference evapotranspiration at a monthly level in tropical countries was performed by Gunston and Batchelor (1983), who acquired an acceptable performance of R^2=0.87 for 126 wet months, R^2=0.90 for 86 months of intermediate rainfall and R^2=0.48 in 148 months of drought. Another example was run by Qiu *et al*. (2019), in Nanjing city, Jiangsu province in China, whose PT model reasonably estimated ETo for the rice production area; with coefficients of determination of 0.92 and 0.96 for two seasons. This model has been successful, after the PM method, because of the net radiation (Rn); which is a meteorological variable that affects the short-term ET-reference in the rice production system. However, when a weather station has a limited data set, temperature, and solar radiation, the best option for that case seems to be the use of PT, which is a simplification of the original Penman-Monteith method (Senthelas, Gillespie, & Santos, 2010).

Regarding the HS model, Awal, Habibi, Fares, and Deb (2020) indicate that the daily ETo estimated with the Hargreaves-Samani model at different stations in West Texas, USA revealed more than 0.7 coefficient of determination between this model and the PM model; that is, there is a high level of agreement between both methods for this area.

Furthermore, the results of the GL model, despite being low, are considered acceptable, since this model has been used in other studies at the monthly and annual levels (Sánchez, 2000); it is an option when other methods cannot be used due to the lack of sunshine records.

In this sense, the results of the LN model corroborate with those found by Issaka *et al*. (2017), who indicated that this model was positioned in last place with a moderate performance of $R^2 = 0.47$ among the evaluation of six models to the standard; whose daily data used were those of the weather station of Doha International Airport, Qatar over 30 years. Another example is that of Araújo, Oliveira, Araújo, Ledo, and Silva (2010), who evaluated the performance of reference evapotranspiration estimation methods in cities in the state of Ceará, finding an acceptable performance for this method of $R^2 = 0.934$. The performance of this model is because it uses only air temperature and altitude data as the site variable, limiting the representativeness of climatic conditions for ETo estimation purposes (Pereira, Yanagi, Mello, Silva, & Silva, 2009).

From the twenty linear developed models, the slope identified value was statistically different from zero; but not greater than one, and therefore the regression is significant. The p-value was similar (< 2e-16) for all regressions; this is less than the critical p-value (0.05).

From the values obtained from the RMSE index between the PM-HS models, similarities are identified as expressed by Amatya, Skaggs, and Gregory (1995), who obtained a range of RMSE errors from 0.87 to 1.37 mm day^{-1}; on the other hand, the average RMSE error between the HS and PM models for twelve stations in Khuzestan, southwest Iran was 1.17 mm day^{-1} (Rahimi, 2008). However, Lavado, Lhomme, Labat, Loup-Guyot, and Boulet (2015), present 0.50 mm day^{-1} as the error of the HS model mean concerning the PM reference model for eight stations in Peru. While it is notorious, the Independencia station exhibited the highest results in this index in the HS, PT, and GL versus PM models; this allows stating that these methods can be recommended for the calculation of ETo in another type of scale for that station (Martínez, Boueri, & Escalona, 2005).

The LN results are similar to those reported by Lavado *et al*. (2015), who show values from 0.42 to 1.05 mm day^{-1} for eight stations in the Andean Amazon basin. This has been possible, thanks to the fact that only the mean temperature (T) and dew point (Td) is required, and it is a useful model in a wide range of climates exposed by Linacre (1977), it is not necessary to measure the dew point if extreme daily temperatures are available, since these allow making an approximate estimation.

For the scope of this investigation, the NSE value obtained for Ciat Quilichao happens to be much higher than that reported by Celestin, Qi, Li, Yu, and Cheng (2020), who evaluated 32 reference evapotranspiration equations against the Penman-Monteith method in the Hexi corridor, in northwest China; they also conclude that the HS model is a good substitute for PM at a monthly scale and for that location. Moreover, no papers on the Linacre model were found that investigated the model's goodness of fit.

Box Plots

The PM model exhibits a range of 3 to 4 mm day^{-1} of ETo estimated for the Ciat Quilichao station, which coincides with 50 % of the results obtained by the PT model. Both models exhibit similar correspondence for this station; since the respective variance values are 0.50 mm² for PM and 0.53 mm² for PT and the standard deviation is 0.71 mm day-1 for PM and 0. 73 mm day-1 for PT; which allows inferring that in the absence of data to estimate this parameter with the PM model, the PT can be used, as corroborated with the Nash-Sutcliffe efficiency index (Table 4 and Figure 8), a similarity also reported by Lu, Sun, McNulty, and Amatya (2005) when comparing six daily models to calculate ETo concerning the PM model in the southeastern United States.

Linacre can be considered as a third model to estimate ETo at the Independencia station; because it has shown a similar range of results to PM. On the other hand, the other models do not coincide with PM; since the variance for GL, PT and HS are 0.60, 0.40, and 0.53 mm², respectively (Figure 9). Comparatively, Vicente-Serrano *et al.* (2014), exhibit that, for the fall season, the Linacre model showed equal and higher ETo values than the PM method; but lower estimated LN values were observed for the summer section concerning the standard method. This is possible because each equation was created for specific climatic conditions that may differ from those presented by each season, so the behavior of each model is very changeable depending on the place and time of the year in which it is used (Sánchez, 2000).

However, at the Ing. Miranda station the PM model presents a data set between 1.7 and 5.1 mm day^{-1}, with few extreme values between 5.2 and 5.5 mm day^{-1}; that indicates that the use of this model for this station exhibits some values far from its mean by more than two units (Figure 10). Similar research conducted in Western Macedonia, Greece by Efthimiou, Alexandris, Karavitis, and Mamassis (2013), presented that the LN and PT models reported 79 and 89 % agreement in the 34-year daily estimates of ETo concerning those of Penman-Monteith.

Both the PM and HS models serve to characterize this variable at the Ing. Bengala station; this is confirmed by the coefficient of determination between both methods which was 0.826 (Figure 6). PM is influenced by several parameters that, according to experiments done by Tyagi, Sharma, and Luthra (2000) there is a probability of 93.4 % that a different model from PM can match with it (Figure 11); but Lang *et al*. (2017), allude that the HS equation can be used more easily than PT to estimate ETo in southwest China; since the former requires fewer parameters to estimate ETo than the latter.

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At the Ing. Cauca station, the PT and GL models are characterized by 0.43 and 0.44 mm dia^{-1} standard deviation, but with a different mean and data set. Gong, Xu, Chen, Halldin, and Chen (2006) state that the climatic variables in the daily ETo measurements between the PM and GL models show that relative humidity is the most sensitive meteorological factor, followed by wind speed, solar radiation, and temperature. In Figure 12 the method that is most similar to PM is LN. The HS model presents the greatest dispersion in the distribution of the data; similar cases are reported by Pérez and Castellví (2002) who state that this model exhibits the greatest outliers in the calculation of ETo in the region of Catalonia in Spain.

In summary, the relationship of the Penman-Monteith and Priestley-Taylor equations shows their validity when the necessary records are available for their application at the daily level. Two important notes, expressed by Vicente-Serrano *et al*. (2014), indicate that temperature-based models such as Hargreaves-Samani often underestimate ETo for several stations at a single location and that some methods may show the best agreement with the PM model; but, could have the poorest agreement at a different station. However, it is important to note that the remaining models are an admissible tool when there is insufficient climatological data or data from reliable sources, as pointed out by Allen *et al*. (1998), who indicate that various methods can be suggested for the calculation of ETo based on the type of climatic information available.

Conclusions

The FAO Penman-Monteith model estimates the daily reference evapotranspiration (ETo) by considering a complete set of meteorological data and, likewise, is the main restriction for its use in places where data is missing; as it happens in the south of the department of Valle del Cauca, and with few meteorological stations, where the lack of data on wind speed, relative humidity, and solar radiation is frequent. There is no previous study that evaluates the performance of the various methods for estimating daily reference evapotranspiration in this region of Colombia.

The Priestley-Taylor model is a good method among those studied; it showed a high similarity to the values obtained for the standard Penman-Monteith model with the Root Mean Square Error (RMSE) index for all stations. The Nash-Sutcliffe Efficiency index only presented a highly acceptable value for the Ciat Quilichao station. Another useful model for estimating daily reference evapotranspiration is the Linacre model; like Priestley-Taylor, both methods are ideal, inasmuch they are modifications of the standard model.

There is evidence that the daily use of the Garcia and Lopez model is limited; despite being an equation adapted for the tropics, whose climatological factors are easy to acquire. The Hargreaves-Samani model is presented as an acceptable method for the Ing. Bengala station; however, this model together with the Garcia y Lopez model is not ideal for the Independence station; since the results obtained by the RMSE and NSE method are not per the expected results in the scope of this work.

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