Reference Evapotranspiration (ETo) in North Fluminense, Rio de Janeiro, Brazil: A Review of Methodologies of the Calibration for Different Periods of Analysis

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1. Introduction

Water is the essential element for life on Earth planet, where currently different regions suffer from shortages due to the large population growth and depletion of natural sources. The agricultural sector is the human activity that consumes the most water in the world (about 70% of drinking water sources) and one of the main problems of irrigated agriculture is the correct quantification of crop water requirements. In this sense, there is a constant search to implement sustainable practices for the management of water resources, one of the more efficient determination of evapotranspiration (ET), which is the term used to describe the amount of water effectively ceded the land surface to atmosphere and an important component of the hydrological cycle and used for quantifying the calculation of water balance in soil, detection of water stress conditions and use as input for quantitative models of harvesting or other applications (Ferreira et al., 2011.)

With the objective to standardize the definition of evapotranspiration given by various authors, as Penman (1948) and Thornthwaite (1948), it became necessary to define the reference evapotranspiration (ETo), which according to Allen et al. (1998) can be defined as the rate of evapotranspiration from a hypothetical crop with an assumed height of 0.12 m, with a surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evaporation from an extensive surface of green grass of uniform height, actively growing and adequately watered.

Several researchers have developed methods for estimating and measuring evapotranspiration. Burman et al. (1983) did a review of these methods in different parts of the world and commented that many methods have been proposed and the methods may be broadly classified as those based on combination theory, humidity data, radiation data, temperature data, and miscellaneous methods which usually involve multiple correlations of ET and various climate data. Usually the reference evapotranspiration methods are classified in Combination methods, Radiation method, Temperature methods, pan evapotranspiration, etc.

Allen et al. (1998) mentioning that evapotranspiration is not easy to measure. Specific devices and accurate measurements of various physical parameters or the soil water balance in lysimeters are required to determine evapotranspiration. The methods are often expensive, demanding in terms of accuracy of measurement and can only be fully exploited by well-trained research personnel. Although the methods are inappropriate for routine measurements, they remain important for the evaluation of ET estimates obtained by more indirect methods.

Since the 1930s there are several methods for estimating ETo. However, whatever the method is detailed and rigorous, there will always be the needs of local or regional calibrations if you are being adopted outside the region where it was developed. Burman et al (1983) argue that several equations to estimate reference evapotranspiration developed around the world use the grass and alfalfa as a standard surface. This situation creates difficulties as the proposal for an empirical equation bears a strong dependence on the standard surface, causing undesirable and significant errors in estimation. Based on these discussions is that the Penman-Monteith equation was parameterized by Allen et al. (1998).

The surface resistance is defined as the resistance of water vapor through the openings of stomata and drag as that of the upper plant, involving the friction of the air flow over the surface vegetated. The aerodynamic resistance is a parameter dependent on the local weather and its demonstration of layers depends on the roughness governing the processes of transport of momentum and heat, and the offset and zero plane. This displacement of the zero plane refers to the height to which the speed is zero. Thereafter the profile starts log wind speed. However, the aerodynamic resistance scheme used in the formulation Penman-Monteith (FAO, 56) is restricted to the condition parameter neutral atmosphere, ie when the air temperature, atmospheric pressure and wind speed field close to the adiabatic condition. One can also be noted that the displacement of the zero plane and the layers of roughness, the processes that govern the amount of heat transport is correlated with the height of culture and as regards the parameter of surface resistance, it is directly proportional stomatal resistance and inversely proportional to the active leaf area index, stomatal resistance being directly affected by atmospheric conditions and the availability of water for the crop.

Allen et al. (1998) clain that the Penman-Monteith(FAO-56) for estimating reference evapotranspiration does not allow controversy and provides consistent and reliable information in different weather conditions and location is recommended by the FAO, the lack of lysimeters as calibration standard in the world.

Zanetti et al. (2007) tested an artificial neural network (ANN) for estimating the reference evepotranspiration (ETo) as a function of the maximum and minimum air temperatures in the Campos dos Goytacazes, Rio de Janeiro State. The data used in the network training were obtained from a historical series (September 1996 to August 2002) of daily climatic data collected in Campos dos Goytacazes. When testing the artificial neural network, two historical series were used (September 2002 to August 2003) relative to Campos dos Goytacazes, Rio de Janeiro and Viçosa, Minas Gerais State. The ANNs (multilayer perceptron type) were trained to estimate ETo as a function of the maximum and minimum air temperatures, extraterrestrial radiation, and the daylight hours; and the last two were previously calculated as a function of either the local latitude or the Julian date. According to the results obtained in this ANN testing phase, it is concluded that when taking into account just the maximum and minimum air temperatures, it is possible to estimate ETo in Campos dos Goytacazes, RJ.

One work was performed with the aim of proposing an artificial neural network (ANN) to estimate the reference evapotranspiration (ETo) as a function of geographic position coordinates and air temperature in the State of Rio de Janeiro (Zanetti et al., 2008). Data used for the network training were collected from 17 historical time series of climatic elements located in the State of Rio de Janeiro. The daily ETo calculated by Penman-Monteith (FAO-56) method was used as a reference for network training. ANNs of multilayer perceptron type were trained to estimate ETo as a function of latitude, longitude, altitude, mean air temperature, thermal daily amplitude and day of the year. After training with different network configurations, the one showing best performance was selected, and was composed by only one intermediary layer (with twenty neurons and sigmoid logistic activation function) and one output layer (with one neuron and linear activation function). According to the results obtained it can be concluded that, considering only geographical positioning coordinates and air temperature, it is possible to estimate daily ETo in 17 places of Rio de Janeiro State by using an ANN.

Another method of estimating the ETo are evaporimeters, which measure the evaporation of water, the most common Class "A" Pan developed by the U.S. Weather Service (USWB) and widespread use. According to Pereira et al. (1997) Class "A" Pan (TCA) is influenced by solar radiation, wind speed, temperature and relative humidity and thus, different researchers have questioned the methodology of choice of the pan coefficient (Kt) and should be determined by results of scientific research estimates that there are no wrong.

It is observed that the choice of methodology to be adopted should be based on the availability of climate data, the necessary precision, convenience and cost. In irrigation projects are required for short periods, ranging from daily to a maximum of fortnightly research is needed to evaluate the efficiency of the methodologies in these conditions. Using a series of ten years of daily average data collected at Evapotranspirometric Station of Universidade Estadual do Norte Fluminense Darcy Ribeiro, this study aimed to evaluate the performance of indirect methods for estimating reference evapotranspiration (ETo) proposed by Hargreaves-Samani (1985), FAO-24 Radiation Solar (1977), Jensen-Haise (1963), Linacre (1977), Makkink

(1957), Penman Simplified (2006) and Pan Class "A" estimated using four equations for determining the coefficient of the Pan - Kt: Allen (1998), Bernardo et al. (1996), Cuenca (1989) and Snyder (1992) for periods of 1, 5 and 10 days, with the Penman-Monteith FAO-parameterized, in the North Fluminense, Rio de Janeiro, Brazil.

2. Materials and methods

2.1. Study area

The city of Campos dos Goytacazes located in the North Fluminense occupies an area of 4.027 km². The downtown area is located in the following geographical coordinates: 21° 45″ 23′ south latitude, 41° 19″ 40′ west longitude and 14 m above sea level. In Figure 1 is presented the study area contained in the North Fluminense, in reference to the state of Rio de Janeiro and Brazil. According Köeppen climate, this region’s clime is classified as Aw, that is, tropical humid, with rainy summer, dry winter and the temperature average above 18°C during the coolest months. The annual average temperature stands at around 24 º C and the small temperature range; The climatological normal rainfall is 1055.3 mm (Ramos et al., 2009).

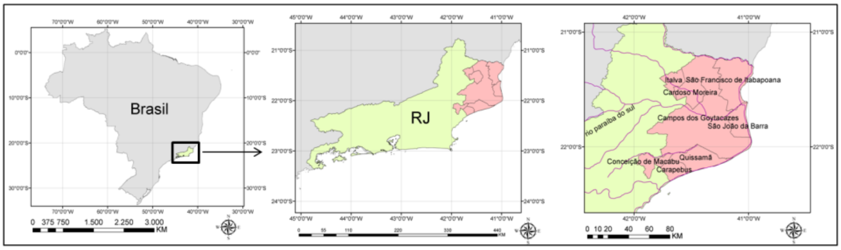

Figure 1. Study area localization in reference to the Rio de Janeiro State and Brazil.

In this study were used weather data daily, a period of 10 years (1996-2006), collected by an automatic station, model Thies Clima, installed at the Experimental Station of Pesagro-Rio (geographical coordinates: 21°18'47" south; 41º18'24" west and altitude of 11 meters).

The Thies automatic weather station is equipped with sensors for measuring meteorological data the following:

- Wind Speed: a sensor to detect the wind speed in the range 0.3 to 50 m / s;
- Atmospheric Pressure: A barometer can measure values in the range 946 to 1053 hPa;
- Temperature and Relative Humidity: A thermo-hygrometer allows register values of relative humidity in the range 1-100% and a temperature range of -35 to + 70 °C;

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- Global Solar Radiation: A pyranometer can measure values in the range 0 to 1400 W/m2;
- Precipitation: A rain gauge measuring rainfall intensity of up to 7 mm/min.

All sensors are connected to a datalogger model DL-15 - V. 2:00 – Thies Clima, with total capacity of 256 Kbytes of memory storage, recording daily averages between 24-h. The sensor values recorded every minute, and a stored mean value every 6 minutes

Observations the conventional meteorological station (Class A pan and weighing lysimeter) for such work were performed at 9 h.

The lysimeter tank with dimensions of 3.0 x 2.0 x 1.5 m, made of sheet metal had their weight carried by a set of four load cells manufactured by J-Star Electronics, Wisconsin, and installed at the tank base, and determining the lysimeter blade evapotranspired obtained by variation in weight observed in the period divided by evaporating surface area (6 m2).The station area is covered with grass Batatais (Paspalum notatun Fluegge).

2.2. Methods for obtaining the reference evapotranspiration (ETo)

2.2.1. FAO Penman-Monteith method (FAO-PM - 1998)

The Penman-Monteith parameterized by Allen et al.(1998) was selected as a benchmark method for comparation can be derived (Equation 1).

$$ETo = \frac{0,408\,\Delta\left(Rn - G\right) + \gamma \frac{900}{T + 273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0,34\,u_2\right)} \quad (1)$$

Where:

ETo is the reference evapotranspiration, in mm/day;

Rn - net radiation at crop surface, in MJ m^{-2}/day;

G -soil heat flux density, in MJ/m^2/day;

T - air temperature at 2 m height, in °C;

γ- psychrometric constant, kPa/C;

Δ -slope vapor pressure curve, in kPa;

u_2 - wind speed at 2 m height, in m/s;

e_s - saturation vapor pressure, in kPa;

e_a - actual vapor pressure, kPa;

e_s - e_a-the saturation vapor pressure deficit, in kPa.

2.2.2. FAO – 24 Radiation method (1977)

The estimate ETo by the FAO - 24 Radiation method was described for Doorenbos and Pruitt (1977) andcan be derived (equation 02)

$$ETo = c_o + cL \ W\,Rs \tag{2}$$

Where

C_0 =-0,3; a0 = 1,0656 ; a1 = -0,0012795 ; a2 = 0,044953 ; a3 = -0,00020033 ; a4 = -0,000031508 ; a5 = -0,0011026

cL =- a0 + a1 UR + a2 Vd + a3 UR Vd+ a4 UR^2 + a5 Vd^2

UR = Relative Humidity (%);

Vd = Average wind speed during the day to 2 m in height, in m/s (considered to Vd = 70% of the average wind speed within 24 h);

Rs - Radiation at the surface, expressed as equivalent evaporation (Rs, mm/day);

W - Weight factor dependent on the temperature (Tair).

The weighting factor (W) can be obtained by the following equations:

$$W = 0,407 + 0,0145T_{air} \ if \ 0 < T_{air} < 16^{\circ}C \tag{3}$$

$$W = 0,483 + 0,01T_{air} \ if \ 16,1 < T_{air} < 32^{\circ}C \tag{4}$$

Where T_u is the average daily temperature of air, to take $T_u = T_{ar}$.

2.2.3. Hargreaves –Samani method (1985)

The Hargreaves - Samani method data requires only air temperature and extraterrestrial radiation to estimate ETo. For applicationused thefollowing equation:

$$ETo = 0,0023\,Ra\left(Tmáx - T\min\right)^{0,5}\left(T + 17,8\right) \tag{5}$$

Where: Ra extraterrestrial radiation, in mm day^{-1}, T max is the maximum temperature in °C;Tmin is the minimum temperature, in °C.

2.2.4. Jansen-Haise method (1963)

For the estimation of ETo by Jensen-Haise method used the equation 06:

$$ETo = Rs\,(0{,}0252\,T + 0{,}078) \tag{6}$$

2.2.5. Makkink method (1957)

For the estimation of ETo by the Makkink method used the equation 07:

$$ETo = Rs\,(\frac{\Delta}{\Delta + \gamma}) + 0{,}12 \tag{7}$$

Where

Rs - Radiation at the surface, expressed as equivalent evaporation (Rs, mm/day);

Δ -slope vapor pressure curve, in kPa/°C;
γ- psychrometric constant, kPa/°C.

2.2.6. Linacre method (1977)

For the estimation of ETo by the Linacre method used the equation 08:

$$ETo = \frac{\frac{J\left(T + 0{,}006\ h\right)}{100 - \varphi} + 15\left(T - T_{dew}\right)}{80 - T} \tag{8}$$

Where J is a dimensionless constant equal to 700; h is the local altitude in meters; ϕ is the local latitude degrees and T_o is the temperature of dew point. The dew point temperature (T_{dew}) can be estimated by equation 09:

$$T_{dew} = \frac{237{,}3\log\left(e_a\right) - 156{,}8}{8{,}16 - \log\left(e_a\right)} \tag{9}$$

Where ea is the vapor pressure of water in kPa, determined by equation 10:

$$e_a = e_s\left(T\right)0{,}01\,RU(\%) \tag{10}$$

Where RU (%) - relative humidity and e_s - saturation vapour pressure, inkPa/°C.

2.2.7. Simplified Penman's Method (2006)

A simplified estimation method to calculate the potential evapotranspiration was developed to Villa Nova et al. (2006) based on the Penman approach, considering only the diurnal values of evapotranspiration rates thatare more representative of the water vapor transfer process to the atmosphere for a givenagricultural ecosystem. In addition, the classical expression of the Bowen ratio (b) was modifiedherein by considering the sensible heat flux (H) emergent from the evaporative surface inconjunction with the air turbulent flux, which transports also latent heat flux (LE). Such procedureresults in a similarity between the aerodynamic resistances of sensible heat and latent heat fluxes soas to allow for a considerable simplification without impairing the estimates.

ETo estimated by the SPM proposed by Villa Nova et al. (2006) was obtained from equation 11:

$$ETo = 0,408\ \frac{(Rn - G)}{(2 - W)} \tag{11}$$

Where:

ETo - Evapotranspiration from the wet surface (mm/day) during the sunshine period;

G - heat flux in the soil (MJ/m^2 /day) during the diurnal period;

Rn - diurnal net radiation at a vegetated surface (MJ/m^2 /day), and

W - tangent of water the vapor saturation pressure curve at the point of diurnal daily mean airtemperature (Tair).

2.2.8. Class A Pan Method (TCA)

The ETo is estimated by the Class "A" Pan by using the following equation:

$$ETo^{TCA} = EV\,.\,Kt \tag{12}$$

Where: Ev - Evaporation of Class A Pan, in mm dia^{-1} and Kt, the Pan coefficient (dimensionless).

2.2.8.1. Methods to estimate the Pan coefficient – Kt

To estimate the Pan coefficient - Kt method used in the Class "A" Pan were evaluated four methodologies are described below:

2.2.8.1.1. Methodology proposed by Cuenca (1989)

$$\begin{aligned} Kt = {} & 0,475 - 2,4.10^{-4}\,U_2 + 5,16.10^{-3}.\,H + 1,8.10^{-3}.\;F - 1,6.10^{-5}.\,RU^2 \\ & -1,01.10^{-6}.\,F^2 - 8,0.10^{-9}\,RU^2.\,U_2 - 1,0.10^{-8}.\,RU^2.\,F \end{aligned} \tag{13}$$

2.2.8.1.2. Methodology proposed by Snyder (1992)

$$Kt = 0,482 + 0,024 \ln(F) - 0,000376\, U_2 + 0,0045\, RU \tag{14}$$

2.2.8.1.3. Methodology proposed by Bernardo et al. (1996)

$$Kt = 0,69 \tag{15}$$

2.2.8.1.4. Methodology proposed byAllen et al. (1998)

$$Kt = 0,108 - 0,0286\, U_2 + 0,0422 \ln(F) + 1434 \ln(RU) - 0,000631 \left[\ln(F)\right]^2 \ln(RU) \tag{16}$$

Where U_2 is the wind speed at 2 m height in km/day, RU is the average relative humidity (%), and F is the boundary of the green crop area, considered in this study equal to 15 m.

2.3. Evaluation of methods

To evaluate the performance of the methods we proceeded to linear regression analysis, considering the linear model y = bx (regression through the origin), in which the independent variable was the Penman-Monteith (ETo_{PM}), and the dependent variable, the other methods. Was also used the Index of agreement of Willmott (D) (Willmott, 1981), the mean absolute error (MAE), the maximum error (EMAX) and the efficiency of the method (EF), based on the equations 17, 18, 19 and 20:

$$D = 1 - \frac{\sum_i^n (Pi - Oi)^2}{\sum_i^n (|\, Pi - \overline{O}\,| + (Oi - \overline{O}\,|)^2} \tag{17}$$

$$MAE = \frac{1}{n} \sum_i^n (Oi - Pi) \tag{18}$$

$$EMAX = MAX(\left|Oi - Pi\right|)_{in}^{n} \tag{19}$$

$$EF = \frac{\sum (O - \overline{O})^2 + \sum (O - Pi)^2}{\sum (O - \overline{O})^2} \tag{20}$$

Where: O = estimated values by ETo_{PM}, Pi = estimated by other methods; $\overline{O}$ = mean value ETo_{PM}.

3. Results and discussion

3.1. Comparison of Penman-Monteith with other methods

Table 1 shows the monthly averages of air temperature, the relative humidity, wind speed and solar radiation for the ten years of data analyzed.

Months	Tair (ºC)	RU (%)	U_2 ($m\ s^{-1}$)	Rs ($W\ m^{-2}$)
January	26.47	74.35	2.36	305
February	26.54	73.55	2.12	296
March	25.69	75.75	1.73	247
April	24.41	76.70	1.54	207
May	21.85	75.16	1.50	176
June	20.98	77.41	1.51	159
July	20.28	76.35	1.68	160
August	21.60	75.90	2.24	194
September	22.16	75.80	2.43	209
October	23.07	75.90	2.31	227
November	24,29	76,19	2,34	251
December	25,79	75,99	2,21	281

Table 1. Average monthly values of air temperature (Tar), relative humidity (RU), wind speed at 2m (U_2) and solar radiation (Rs) for 1996 to 2006 period.

These meteorological variables are required as input data to the standard method and estimation of other variables, as well as entries for the other methods tested. Evapotranspiration is a complex phenomenon and non-linear, because it is dependent on the interaction between various climatological elements (Kumar et al, 2002).

Table 2 shows the parameters for statistical analysis: correlation coefficient (r^2), index of agreement of Wilmott (D), mean absolute error (MAE), efficiency of the method (EF), maximum error (EMAX) and the slope (b) comparing the parameterized Penman-Monteith method (FAO PM) with other methodologies and Figure 2, the graphs of correlation in respect to the line 1:1.

Periods (days)	**Methods**	R^2	**D**	MAE (mm d^{-1})	EF (mm d^{-1})	EMAX (mm d^{-1})	**b**
1	H-S	0.84	0.95	0.46	0.83	2.18	1.02
5	H-S	0.91	0.97	0.29	0.90	1.42	1.02
10	H-S	0.93	0.80	0.24	0.93	1.24	1.02
1	RS-FAO	0.92	0.98	0.38	0.89	1.56	0.94
5	RS-FAO	0.95	0.99	0.26	0.93	1.06	0.95
10	RS-FAO	0.96	0.99	0.22	0.95	0.90	0.96
1	MAK	0.93	0.89	0.82	0.60	2.37	1.23
5	MAK	0.96	0.87	0.82	0.51	1.81	1.23
10	MAK	0.97	0.87	0.82	0.48	1.59	1.24
1	J-H	0.92	0.89	1.00	0.34	2.80	0.80
5	J-H	0.94	0.88	0.95	0.23	2.39	0.81
10	J-H	0.95	0.87	0.95	0.19	2.28	0.81
1	LIN	0.54	0,78	0,84	0,51	3,08	0.95
5	LIN	0.64	0,83	0,68	0,60	2,05	0.94
10	LIN	0.67	0,85	0,63	0,62	1,79	0.94
1	MSP	0.89	0.93	0.66	0.72	2.45	1.16
5	MSP	0.91	0.93	0.66	0.68	1.85	1.16
10	MSP	0.92	0.93	0.66	0.67	1.45	1.16

Table 2. Analysis of statistical methods for estimating evapotranspiration for averaging periods of 1, 5 and 10 days.

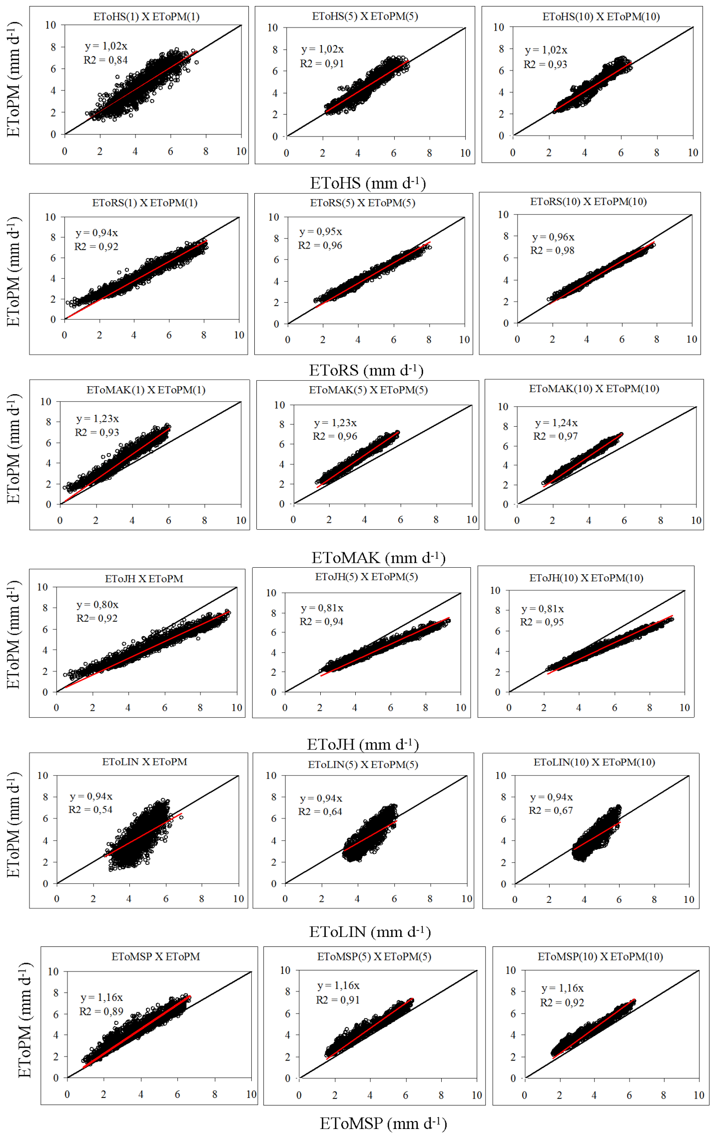

Figure 2. Graphs of correction in respect to the line 1:1.

Observing the values in Table 2 and Figure 2, it appears that all methods were evaluated value of the correction coefficient (r^2) larger than 0.80, with the exception of the method of Linacre, where r^2 values to the two periods varied from 0.54 (for 1 day) to 0.67 (for 10 days). This adjustment increased r^2, a measure that increased the periods studied was common to all methods. This finding agrees with Mendonça (2001, 2003) justified by smoothing the averages of the sampled values. Another observation concerning the increment of the remaining days is that on the Hargreaves-Samani, Solar Radiation-FAO and Linacre, the mean absolute error (MAE) suffered a decrement. For the method of Hargreaves-Samani, this range was 0.46 mm d^{-1} (for the period of 1 day) going to 0.24 mm dia^{-1} (for 10 days). For the FAO-24 solar radiation method, the variation was of 0.38 mm d^{-1} (within 1 day) to 0.22 mm d^{-1} at 10 days. To Linacre method, the same variation was from 0.84 to 0.63 mm d^{-1}.

Makkink method and Simplified Penman method showed no variation in the mean absolute error, keeping them constant in d-1 0.82 mm and 0.66 mm d^{-1} for all periods, respectively. Since the Jensen-Haise method presented the MAE of 1.00, 0.96 and 0.95 mm d^{-1}, respectively, for periods of 1, 5 and 10 days.

Analyzing the slopes of the methods evaluated was observed that Makkink and Simplified Penman Method showed values above 1 for all periods, with the group of methods overestimated ETo-PM. These results agree with those observed by Mendonça (2001; 2003) and Fernandes (2006), assessments in the same area of study.

In the group of methods that are underestimated ETo FAO-24 Radiation, Jensen-Haise and Linacre. Observing Table 2, can be seen that the maximum error (EMAX) obtained similar behavior to EMA, decreasing as you increase the periods analyzed. The greater EMAX observed for a period of 1 day was the method of Linacre, equal 3.08 mm d^{-1}. Also for this method was the largest decrease in EMAX, when will the period 1 to10 days, with 1.79 mm d^{-1} for this period.

As for efficiency, it is clear that the methods of Hargreaves-Samaniand FAO-24 Radiation remained throughout the period evaluated with EF greater than 0.82. These methods also showed the best adjustment of the index of agreement ofWilmontt, and FAO-24 Radiation coming to D index of 0.99, for periods of 5 and 10 days.

The Simplified Penman method received a satisfactory performance for the estimation of ETo in the study region, for the daily period, with r^2 of 0.89, showing a small dispersion compared ETo_{PM}, a situation similar to that found by Villa Nova et al. (2006). The rate of agreement Wilmontt observed for this method was greater than 0.90 (D = 0.93).

The Simplified Penman and Makkink methods decreased efficiency over the period analyzed. EF were their best for the period of 1 day (0.72 to 0.60 mm d^{-1}, respectively) was lower for 10 days (0.66 and 0.47 mm d^{-1}, respectively.) as for the concordance index Wilmontt(D), Makkink values decreased from 0.89 (for the 1 day period) going to 0.86 for the period of 10 days. Simplified Penman method showed D constant for periods of 1, 5 and 10 days (0.93) Linacre was efficient and index D increased with the increase of the periods analyzed, as can be seen in table 1. Jensen-Haise showed EF decreasing with the increase of the evaluation period, with the worst rates of EF methods (ranging from 0.34 for 1 day, to 0.17 in 10 days). The index D remained above 0.86, D being its highest rate for the period of 1 day (0.89).

3.2. Comparison of methods for estimating the Kt

Table 3 shows the results of statistical analysis of different methodologies for determining the coefficient of the Pan (Kt) used in the Class "A" Pan method and Figure 3, the graphs of correlation in respect to the line 1:1

Periods (days)	Methods (TCA)	r^2	D	MAE (mm d^{-1})	EF (mm d^{-1})	EMAX (mm d^{-1})	b
1	Allen	0.81	0.95	0.53	0.77	2.14	0.94
5	Allen	0.95	0.98	0.31	0.90	1.36	0.95
10	Allen	0.95	0.98	0.27	0.92	1.17	0.95
1	Bernardo	0.80	0.95	0.53	0.79	1.78	1.03
5	Bernardo	0.92	0.97	0.33	0.89	1.31	1.05
10	Bernardo	0.94	0.98	0.30	0.91	1.07	1.05
1	Cuenca	0.81	0.95	0.50	0.81	1.83	0.97
5	Cuenca	0.91	0.98	0.26	0.93	1.08	0.98
10	Cuenca	0.95	0.99	0.22	0.95	0.90	0.99
1	Synder	0.81	0,92	0,69	0,63	2,68	0.88
5	Synder	0.93	0,94	0,53	0,74	1,78	0.89
10	Synder	0.95	0,95	0,51	0,75	1,62	0.89

Table 3. Analysis of statistical methods of different methodologies for determining the coefficient of the Pan (Kt) for estimating evapotranspiration for averaging periods of 1, 5 and 10 days.

Looking at Table 3 and Figure 3 can see an increase in the coefficient of correlation (r^2) as it increases the evaluation period and all the methods used to determine the coefficient of the Pan (Kt) present good adjustment r^2, were above 0.80 in all periods. These results agree with those found by Conceição (2002; 2005) who compared the monthly ETo estimated by the Class "A" Pan with the Penman-Monteith-FAO and Mendonça et al. (2006) who compared the daily ETo estimated.

It is observed that the best method for determining Kt on a daily, and subsequent conversion of EV with ETO was proposed by Cuenca with EF = 0.81, followed by Bernardo, EF = 0.79. However, for the same period of 1 day, the index of agreement of Wilmontt of the two methods presented the same amount (D = 0.95).

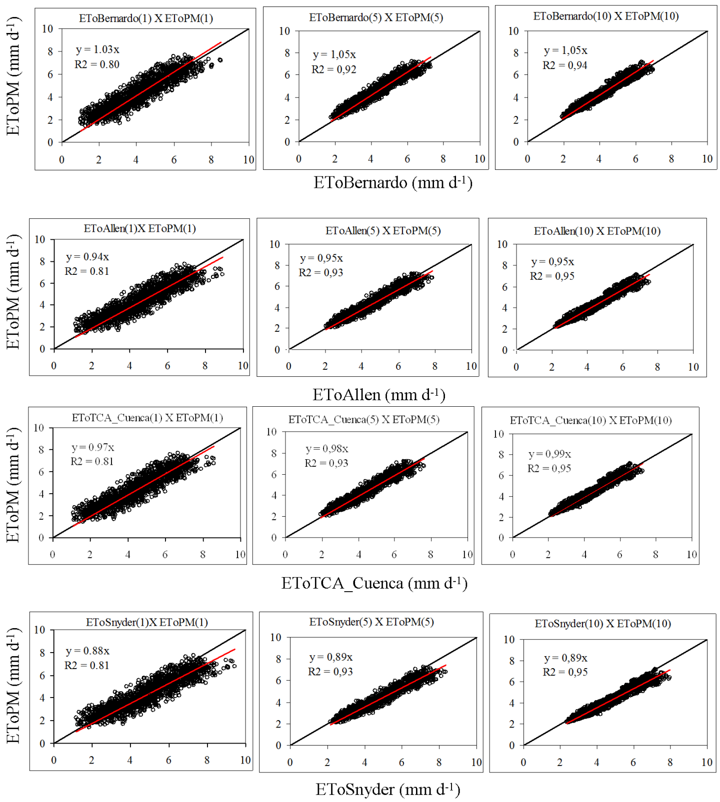

Figure 3. Graphs of correlation in respect to the line 1:1.

It was also found that all methods showed an increase in the value of efficiency (EF) as it increased the period and those proposed by Allen, Snyder and Cuenca, overestimated ETo-PM at all times. The methodology presented Allen, from 5 days a slope (b) constant at 0.95, as does the method of Snyder (b = 0.89).

The mean absolute error (MAE) of all methods decreased as the periods analyzed increased, and the method of Cuenca presented the lowest MAE (0.22 mm d^{-1}) for the period of 10 days. Methodologies for determining the assessed value of Kt, the worst results were obtained by the method of Snyder, the value of its efficiency (EF) 0.63, 0.74 and 0.75, respectively stop for a period of about 1, 5 and 10 days, while other methods reached levels higher than EF 0.90. This same method was maximum error (EMAX) decrease as you increased the periods analyzed, however, persisted for 10 days at 1.62 mm d^{-1}, while for the same period the methodology proposed by Allen reached 1.17 mm. d^{-1}, Bernardo et al., 1.07 mm d^{-1} and Cuenca, 0.90 mm d^{-1}.

4. Conclusions

Based on the results obtained in this work can be concluded that all indirect methods assessed showed improvements in their statistical indices as they increased the periods of analysis. It can be concluded that the methods of Makkink, Jansen-Haise, Linacre and Class "A" Pan using the methodology proposed by Snyder for obtaining Kt did not achieve satisfactory levels and should not be adopted for the estimation of reference evapotranspiration (ETo) in the study area. Otherwise, the methods of Hargreaves-Samani, FAO-24Solar Radiation, Simplified Penman Method and Class "A" Pan using the methodology proposed by Cuenca for obtaining Kt presented the best adjustment for the evaluation period and can be used satisfactorily for the estimation of ETo in the North Fluminense, Rio de Janeiro, Brazil.

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