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Probable reference evapotranspiration for Chapecó, Santa Catarina, Brazil

Evapotranspiração de referência provável para Chapecó, Santa Catarina

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ABSTRACT

Evapotranspiration data are important for water resources management and irrigation design and management. The present work aimed to determine the probable reference evapotranspiration for Chapecó, Santa Catarina. Daily data from 07/01/1973 to 11/30/2016 from the Chapecó meteorological station were used. Daily evapotranspiration was calculated using the Penman-Monteith method and grouped into pentads. The average, maximum and minimum values per pentad as well as average values for dry and rainy days were determined. The Beta probability distribution was adjusted for each pentad and the goodness of fit was evaluated with the Kolmogorov-Smirnov test and determination of the maximum error, mean error, and standard error of the estimate. Probable ETo values were determined for 50, 75, 80, 90, and 95% probability. The average monthly values obtained were 18 to 80% higher than those normally used in the region, with the greatest differences occurring in the winter months. It is observed that the mean values of ETo per pentad vary from 1.60 mm day^{-1} to 4.84 mm day^{-1}. The ETo values of dry days are on average 38% higher than those of rainy days. The ETo with 75% of probability presents values of 10 to 32% superior to the values of ETo with 50% of probability, being the differences bigger in the winter months. For the design of irrigation projects in the Chapecó region, it is recommended to use ETo values with 75% probability.

Palavras-chave:
Irrigação
Demanda hídrica
Penman-Monteith
Distribuição Beta

RESUMO

Os dados de evapotranspiração são importantes para a gestão de recursos hídricos e para o dimensionamento e manejo da irrigação. O presente trabalho teve como objetivo determinar a evapotranspiração de referência provável para Chapecó, Santa Catarina. Foram usados os dados diários do período de 01/07/1973 a 30/11/2016 da estação meteorológica de Chapecó. A evapotranspiração diária foi calculada pelo método de Penman-Monteith e posteriormente agrupadas em pêntadas. Foram determinados os valores médios, máximos e mínimos por pêntada bem como valores médios para os dias secos e dias chuvosos. Foi ajustada a distribuição de probabilidades Beta para cada pêntada e a qualidade do ajuste foi avaliada com o teste de Kolmogorov-Smirnov e determinação do erro máximo, erro médio e erro padrão de estimativa. Foram determinados os valores de ETo provável para 50, 75, 80, 90, e 95% de probabilidade. Os valores médios mensais obtidos foram de 18 a 80% superiores aos normalmente usados na região, sendo que as maiores diferenças ocorrem nos meses de inverno. Observa-se que os valores médios de ETo por pêntada variam de 1,60 mm dia^{-1} a 4,84 mm dia^{-1}. Os valores de ETo dos dias secos apresentam em média 38% superior aos dos dias chuvosos. A ETo com 75% de probabilidade apresenta valores de 10 a 32% superior aos valores de ETo com 50% de probabilidade, sendo as diferenças maiores nos meses de inverno. Para o dimensionamento de projetos de irrigação na região de Chapecó recomenda-se utilizar os valores de ETo com 75% de probabilidade.

INTRODUCTION

The knowledge of evapotranspiration is of great importance for climate characterization, estimation of irrigation needs as well as water resources planning and management (ALLEN et al., 2011; TABARI et al., 2013).

In agrometeorological studies, crop evapotranspiration (ETc) can be obtained through the reference evapotranspiration (ETo) corrected by the crop coefficient (Kc) (SANTOS et al., 2021). As the determination of evapotranspiration is difficult and laborious (CRUZ et al., 2017), and considering that the main factors that act on evapotranspiration are meteorological factors, the common practice adopted is to estimate ETo from climatic variables. In this sense, several methods have been developed to estimate ETo, and the choice of method to be used depends mainly on the availability of the historical series of the study site (SHIRI et al., 2014).

Aiming at standardizing ETo estimates, the Food and Agriculture Organization of the United Nations (FAO) recommends the Penman-Monteith equation (PM-FAO 56) as a standard, as the results indicated that the PM-FAO 56 method presents estimates safer compared to lysimeter data (ALLEN et al., 1998; LIMA et al., 2021).

Evapotranspiration is strongly influenced by meteorological parameters, such as temperature, wind speed, relative humidity, and solar radiation (ASSIS et al., 2021). The daily, seasonal, and annual variability of these parameters implies a great variation in the evapotranspiration values.

In several agronomic applications, daily evapotranspiration data are grouped into periods, generally ranging from five days to monthly. The range of ETo data also depends on the length of time the data is grouped. Back (2007) found that the average ETo values are not statistically different when calculated with intervals of one, five, ten, 15 days, or monthly. However, the ETo with 75% probability, calculated in a daily interval, was on average 17% higher than the values calculated in a monthly interval. This difference decreases as the interval increases, being respectively 8.4% and 4.8% for the intervals of five and ten days.

For the climatic characterization, the average values of evapotranspiration are normally adopted, however, for the purpose of dimensioning the irrigation systems, one must consider the demand in the periods of maximum water demand, with a low risk of being exceeded (ASSIS et al., 2021). Costa et al. (2021) emphasize that the use of average values of ETo can result in errors in the design of agricultural projects, recommending the use of ETo with a certain level of probability. According to Gurski et al. (2021), the probable ETo is defined as the minimum expected value of ETo, in a given period in the year, for a given level of probability. Uliana et al. (2017) highlight that the use of probable ET allows the designer to include a risk factor in irrigation projects, allowing the most appropriate sizing according to the crop and irrigation system.

Determining probable ETo requires frequency analysis of evapotranspiration values (SAAD et al., 2002). Several probability distributions can be used to determine the probable evapotranspiration, highlighting the Normal, Log-normal, Gamma, and Beta distributions (SOUZA et al., 2014; DENSKI; BACK, 2015). Several studies have shown that the reference evapotranspiration frequency distribution fits the Beta distribution (PEREIRA; FRIZZONE, 1994; BLAIN; BRUNINI, 2007; DENSKI; BACK, 2015).

The western region of the state of Santa Catarina is highlighted by the economy based on agriculture and the agribusiness sector. In recent decades, these activities have suffered from the frequent occurrence of droughts (BUFFON; BINDA, 2013). Climate change associated with temperature increase can worsen water scarcity and demand for water resources (SALES FILHO et al., 2021). The management of water resources and irrigation of crops are among the measures aimed at mitigating the damage caused by droughts FREITAS; OLIVEIRA, 2017). In this sense, the objective of this work was to determine the reference evapotranspiration for the region of Chapecó to subsidies studies of water resources management and the design of irrigation systems.

MATERIAL AND METHODS

Daily data on maximum temperature, minimum temperature, insolation, relative humidity, and wind speed from 07/01/1973 to 11/30/2016 from the Chapecó meteorological station were used (Epagri, 2020). The station is located at latitude 27.10°S, longitude 52.64°W, and altitude 654m.

The climate of the region, according to the Köppen climate classification, is of the Cfa type, that is, subtropical, rainy, hot temperate, humid with no defined dry season and mild winter (PANDOLFO et al., 2002).

Reference evapotranspiration (ETo) was calculated using the FAO Penman-Monteith method, following the recommendations of Smith (1991), and Allen et al. (1998) having the following notation.

$$ET_0 = \frac{\delta}{\delta + \gamma^*}(Rn - G)\frac{1}{\lambda_e} + \frac{\gamma}{\delta + \gamma^*}\frac{900}{T+273}U_2(e_s - e_a) \quad (1)$$

On what: ETo = reference evapotranspiration (mm.day^{-1}); Rn = net radiation at de crop surface (MJ.m^{-2}.day^{-1}); G = soil heat flux density (MJ.m^{-2}.day^{-1}); T = mean daily air temperature at 2 m height (ºC); U_2 = wind speed at 2 m height (m.s^{-1}); (e_s – e_a) = saturation vapor pressure deficit (kPa); δ = slope vapour pressure curve (kPa.ºC^{-1}); λ_e = latent heat of evaporation (MJ.kg^{-1}); γ^* = modified psychrometric constant (kPa.ºC^{-1}); γ = psychrometric constant ((kPa.ºC^{-1}).

The saturation of water vapor e_a is given by the equation 2.

$$e_s = 0.6108exp\left(\frac{17.27T}{T+237.3}\right) \quad (2)$$

On what: e_s = vapor saturation pressure (kPa); T = average temperature (°C).

The latent heat of vaporization is given by:

$$\lambda_e = 2.501 - (2.361\ x\ 10^{-3})T \quad (3)$$

The slope of the curve relating saturation pressure to temperature is given by:

$$\delta = \frac{4098e_a}{(T+237.3)^2} \quad (4)$$

The psychrometric constant is calculated by the equation:

$$\gamma = 0.0016286\frac{Pa}{\lambda_e} \quad (5)$$

where P_a is the atmospheric pressure calculated by the equation:

$$P_a = 101.3\left(\frac{(273+T)-0.0065Z}{273+T}\right)^{5.256} \quad (6)$$

where: P_a = atmospheric pressure at altitude z (kPa); z = altitude of the location (m).

The modified psychrometric constant is calculated by the equation:

$$\gamma^* = \gamma(1 + 0.33U_2) \quad (7)$$

To convert the measured wind speed to a height other than 2 meters, the following expression was used:

$$U_2 = 4.868\big(ln(67.75z - 5.42)\big)^{-1}U_{zv} \quad (8)$$

where: U_{zv} = wind speed measured at a height of zv (m.s^{-1}).

The net radiation at the surface is given by the equation:

$$R_n = R_{ns} + R_b \quad (9)$$

where: R_{ns} = shortwave balance (MJ.m^{-2}d^{-1}); R_b = long wave balance in (MJ.m^{-2}d^{-1}).

The shortwave radiation balance is calculated by the following equation:

$$R_{ns} = (1-r)\left(0.25 + 0.50\frac{ina}{N}\right) R_a \quad (10)$$

Where: r = albedo, considered to be 0.23; ins = observed insolation (h); N = theoretical maximum insolation (h); R_a = radiation at the top of the atmosphere ($MJ.m^{-2}day^{-1}$).

The long wave balance was calculated by the equation:

$$R_b = -\left(0.9\frac{ins}{N} + 0.1\right)\left(0.34 - 0.14\sqrt{e_d}\right)\sigma\, 0.5(T_{kx}^4 + T_{kn}^4) \quad (11)$$

Where: σ = Stefan Boltzmann constant (4.903. 10^{-9} MJm^{-2} K^4 day^{-1}); T_{kx} = maximum daily temperature (ºK); T_{kn} = minimum daily temperature in (ºK).

The radiation at the top of the atmosphere is estimated by the equation:

$$R_a = 37.586\, d_r(\varpi_s\, sen\varphi\, sen\psi + cos\varphi\, cos\psi\, sen\omega_s) \quad (12)$$

Where: d_r = relative distance from the earth to the sun (rad.); ω_s = sunset angle (rad.); φ = latitude (rad.); ψ = solar declination (rad).

The relative earth-sun distance is estimated by the equation:

$$d_r = 1 + 0.033\, cos\left(\frac{2\pi}{365}J\right) \quad (13)$$

Where: J = day of the year [0 to 364].

The sunset angle is estimated by the equation:

$$\omega_s = arccos(-tan\varphi\, tan\psi) \quad (14)$$

The solar declination is estimated by the equation:

$$\psi = 0.4093\, sen\left(\frac{2\pi}{365}J - 1.405\right) \quad (15)$$

The theoretical maximum insolation is expressed by the equation:

$$N = \frac{24}{\pi}\omega_s \quad (16)$$

For the estimation of ETo by pentads, the daily values of ETo calculated by the PM-FAO equation were grouped in consecutive periods of 5 days and in the last pentad of the month the values from the 26th to the last day of the month were grouped.

From the daily values, the monthly averages of evapotranspiration were calculated, as well as the averages of the reference evapotranspiration of the days with rain and the days without rain. Since rainfall is recorded as the total rainfall between 9:00 am of one day and 9:00 am of the next day, when observing whether the day was dry or rainy, the precipitation of the following day was considered, considering rainy every day with precipitation equal to or greater than 0.1 mm.

The estimation of ETo values with occurrence probabilities of 50, 75, 80, 90 and 95% was performed using the Beta probability distribution. The probability density function of the Beta distribution for the interval (a, b) is:

$$f(x) = \frac{1}{(b-a)}.\frac{\Gamma(p+q)}{\Gamma(p).\Gamma(q)}.\left(\frac{x-a}{b-a}\right)^{p-1}.\left(1-\frac{x-a}{b-a}\right)^{q-1} \quad (17)$$

Where a ≤ x ≤ b, p > 0, q > 0; where a is the smallest value of the data series; b is the largest value in the data series; p and q are the parameters of the Beta distribution; x is any value of the variable under study included in the interval (a, b).

The estimation of the distribution parameters was performed using the method of moments:

$$p = \frac{m_1\beta}{(1-m_1)} \quad (18)$$

$$q = (1-m_1)\left[\frac{m_1 - m_1{}^2}{m_2} - 1\right] \quad (19)$$

Where m_1 is the 1st order moment for the variable x'; m_2 is the moment of order 2 for the variable x'; transformed by the expression

$$x' = \frac{x-a}{b-a} \quad (20)$$

The adherence of the ETo data to the Beta distribution was evaluated with the Kolmogorov-Smirnov test at a significance level of 5%. To evaluate the fit of the probability distribution, the values of maximum error, mean error and standard error of estimate were calculated. The mean error (EMean) is calculated by:

$$EMean = \frac{\sum_{i=1}^{n}|Po_i - Pe_i|}{n} \quad (21)$$

where: EMean = mean error; P_O = observed empirical probability calculated with the Weibull frequency (BACK, 2013); Pe = probability calculated with the Beta distribution.

The maximum error (EMax) is given by:

$$EMax = Max|Po_i - Pe_i| \quad (22)$$

The standard error of estimate (Sx) was calculated by:

$$Sx = \sqrt{\frac{\sum_{i=1}^{n}(Po_i - Pe_i)^2}{n}} \quad (23)$$

RESULTS AND DISCUSSION

Table 1 shows the monthly average values of the climatic variables used in the ETo calculation. It is observed that the estimated values for ETo are close to the climatic normals presented by Wrege et al. (2012). Monthly ETo ranges from 49.9 mm in July to 146.4 mm in December. When compared with the ETo values of Wrege et al. (2012) and Massignam and Pandolfo (2006), which are normally used in studies of climate characterization of the region, it is observed that the values obtained were 18 to 80% higher. The biggest differences occur in the winter months. These differences are mainly due to the method used to estimate ETo, since both Massignam and Pandolfo (2006) and Wrege et al. (2012) calculated the ETo with the Thornthwaite method, using only the monthly average temperatures and later adjusted a regression equation to estimate ETo based on the coordinates (latitude, longitude, and altitude).

Camargo et al. (1999) emphasize that the Thornthwaite equation works very well in humid regions, giving values close to those obtained by Penman-Monteith. However, for regions with arid climate or during the dry season, the Thornthwaite equation underestimates the ETo values. Varejão-Silva (2005) made some criticisms of this method, specifically related to the Thornthwaite equation (1948), warning that this method only provides an approximation of the order of magnitude that one wants to know, as it does not consider numerous factors intervening in the evapotranspiration process. The main issue related to Thornthwaite's method (1948) lies in the fact that it uses only temperature data. This method may not satisfactorily estimate ETo because it does not consider the aerodynamic term in its formulation, especially in arid and super-humid climates. Another factor that may explain the differences observed is that the Thornthwaite method was developed for monthly estimation, being little sensitive to daily variations. Differences between the Thornthwaite and Penman-Monteith methods were also highlighted by Medeiros (2002) and Back (2008).

Table 1. Mean monthly values of mean air temperature (Tm), relative humidity (RH), wind speed (Vel), insolation (Ins) and Calculated reference evapotranspiration (ETo) and average values used for Chapecó, SC (01/07/1973 to 30/11/2016).

Month	Tm(ºC)	UR (%)	Vel (m s^{-1})	Ins. (h)	ETo (mm)	ETo[1](mm)	ETo[2] (mm)
January	23.4	71.5	2.5	7.3	146.0	122.6	121.7
February	22.9	74.2	2.5	6.9	121.2	102.3	102.5
March	21.9	73.7	2.2	7.0	115.0	97.7	95.0
April	19.3	74.6	2.4	6.4	83.4	68.8	63.4
May	15.7	77.4	2.4	5.8	60.3	45.1	44.4
June	14.4	77.3	2.7	5.1	49.9	34.2	33.1
July	14.3	73.6	2.9	5.6	60.8	35.4	34.0
August	16.2	69.1	2.9	5.8	79.7	46.3	44.5
September	17.1	70.3	2.9	5.6	91.2	55.9	54.9
October	19.6	70.6	2.7	6.3	116.4	65.8	76.0
November	21.2	67.5	2.7	7.5	135.1	93.1	92.0
December	22.8	69.1	2.5	7.3	146.4	117.6	114.3
Total	-	-	-	-	1205.3	884.3	880.2

[1] ETo according to Wrege et al. (2012) [2] ETo according to Massignam and Pandolfo (2006)

The choice of time interval for calculating the ETo depends on the objective and the desired precision, and the time interval used in calculating the averages of the meteorological variable. Jensen et al. (1990) report that the Penman-Monteith equation is more accurate when used on an hourly basis and adding their values to obtain the daily estimate. According to the authors, sample calculations clearly show that, when using daily weather elements, the Penman-Monteith equation can provide accurate estimates of ETo.

For studies of water demand and irrigation needs, it is necessary to obtain ETo values on a daily scale or for short periods, like the irrigation shift. Table 2 shows the average, maximum and minimum values of ETo per pentad. It is observed that the mean values of ETo range from 1.60 mm day^{-1} to 4.84 mm day^{-1}, and the absolute minimum and maximum values were respectively 0.76 mm day^{-1} and 6.93 mm day^{-1}.

One of the uses of ETo data is in serial water balance studies. As precipitation series are usually available longer than the ETo data series, mean ETo values have been used to simulate the water balance. Dufloth and Back (2012) performed the water balance using the reference evapotranspiration calculated for rainy and non-rainy days (dry days) and found gains in precision and performance indices in relation to the calculated water balance daily average evapotranspiration. For Chapecó, it can be observed (Figure 1) that the relationship between ETo on dry days and ETo on rainy days varies from 1.22 to 1.65, with an average of 1.38. Back (2015) analyzing ETo data from Urussanga, obtained this relationship ranging from 1.18 to 1.59. In the pentads corresponding to the autumn and winter months, when there is a lower proportion of rainy days, it is observed that the average ETo is closer to the ETo of dry days.

Table 3 shows the parameters of the Beta distribution and the statistics used to evaluate the fit of the distribution for each pentad. The highest maximum error value was 0.1455, which is lower than the critical value of the Kolmogorov-Smirnov test for the 5% significance level, indicating that the Beta distribution was not rejected for all 72 pentads analyzed. The mean error ranged from 0.0145 to 0.0535 with a mean of 0.0309, showing that the probability estimates of evapotranspiration events with the Beta distribution have a mean error of less than 6%. These results agree with other studies showing that the Beta distribution is suitable for analyzing the frequency of evapotranspiration data (BLAIN et al., 2009).

Table 4 shows the ETo values for the probabilities of 50, 75, 80, 90 and 95%. The criterion for choosing the level of probability must be based on an economic analysis, considering the losses associated with the reduction in the quantity and quality of production, resulting from water deficiency, and the increase in system costs to satisfy higher levels probability (SILVA et al., 1998).

Saad et al. (2002) emphasize that in conditions of typically supplementary irrigation, as seen in the central-south region of Brazil, the economy of irrigation projects hardly justifies choosing levels of probability of occurrence above 90%. Doorenbos and Pruitt (1984) point out that in most irrigated regions these levels vary between 75 and 80%. Higher levels of probability are selected for crops of high economic value and reduced conditions of available water in the soil (PRUITT et al., 1972; JENSEN, 1974).

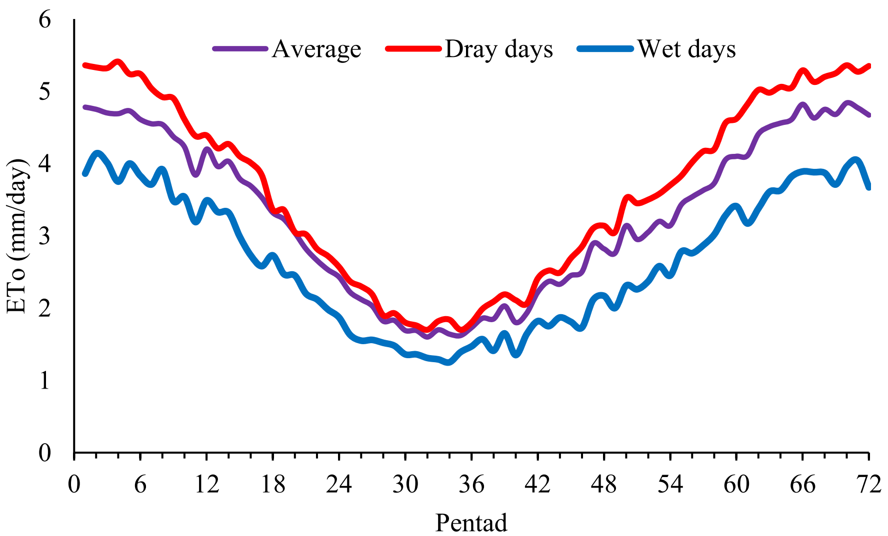

Figure 1. Variation of reference evapotranspiration per pentad for Chapecó, SC (01/071973 to 30/11/2016).

Table 2. Reference evapotranspiration by pentads for Chapecó, SC (01/071973 to 30/11/2016).

	ETo ($mm.day^{-1}$)				ETo ($mm.day^{-1}$)	
Pentad	Average	Maximum	Minimum	N° of pentad	Dray days	Wet days
1	4.78	5.94	2.76	43	5.36	3.86
2	4.75	6.10	3.32	43	5.33	4.14
3	4.70	6.74	2.80	43	5.32	4.01
4	4.69	6.84	3.35	43	5.41	3.75
5	4.73	6.75	2.91	43	5.24	4.00
6	4.61	6.36	2.87	43	5.24	3.83
7	4.55	6.93	2.47	42	5.04	3.71
8	4.54	6.78	3.08	42	4.92	3.92
9	4.37	6.55	3.05	42	4.90	3.48
10	4.23	5.68	3.08	42	4.61	3.54
11	3.84	5.04	2.69	42	4.38	3.19
12	4.20	6.06	2.16	42	4.39	3.49
13	3.96	5.25	2.54	42	4.21	3.33
14	4.03	5.27	2.58	42	4.27	3.32
15	3.79	4.67	2.38	42	4.10	2.99
16	3.69	5.90	2.24	42	4.01	2.73
17	3.53	5.04	2.16	42	3.84	2.58
18	3.32	4.51	2.16	41	3.36	2.73
19	3.23	4.39	2.06	41	3.36	2.47
20	3.04	4.09	2.19	41	3.05	2.45
21	2.82	4.17	1.59	42	3.02	2.20
22	2.66	4.33	1.63	42	2.82	2.12
23	2.53	4.41	1.43	42	2.72	1.98
24	2.43	3.71	1.42	42	2.57	1.87
25	2.22	3.03	1.17	42	2.37	1.63
26	2.12	3.64	1.20	42	2.30	1.55
27	2.03	3.48	1.25	42	2.19	1.56
28	1.82	2.81	1.02	42	1.90	1.52
29	1.83	2.87	1.12	42	1.93	1.48
30	1.69	3.44	0.96	42	1.80	1.36
31	1.69	2.78	0.90	42	1.76	1.36
32	1.60	3.23	0.76	42	1.70	1.31
33	1.70	2.79	0.82	42	1.82	1.29
34	1.64	2.69	0.94	42	1.84	1.25
35	1.62	3.00	0.81	42	1.70	1.39
36	1.73	3.51	0.81	42	1.80	1.47
37	1.86	3.50	0.88	44	1.99	1.57
38	1.85	4.50	0.90	44	2.09	1.41
39	2.03	4.36	1.00	44	2.19	1.65
40	1.80	3.93	0.92	44	2.11	1.35
41	1.93	3.25	0.83	44	2.06	1.64
42	2.22	3.87	1.17	44	2.41	1.82
43	2.37	4.46	0.96	44	2.52	1.75
44	2.33	4.36	1.18	43	2.49	1.87
45	2.45	4.03	1.13	44	2.69	1.81
46	2.50	4.58	1.39	44	2.85	1.73
47	2.89	5.03	1.51	44	3.10	2.11
48	2.82	4.28	1.58	44	3.14	2.17
49	2.76	3.91	1.22	44	3.05	2.00
50	3.14	5.05	1.19	44	3.52	2.31
51	2.95	5.78	1.20	44	3.45	2.26
52	3.05	4.33	1.41	44	3.50	2.37
53	3.20	6.89	1.71	44	3.58	2.58
54	3.14	4.67	1.75	44	3.70	2.45
55	3.43	4.92	1.99	44	3.83	2.78
56	3.54	5.68	2.34	44	4.02	2.76
57	3.63	5.90	2.15	44	4.17	2.87
58	3.73	5.00	2.52	44	4.20	3.02
59	4.05	5.64	2.58	44	4.56	3.28
60	4.10	5.89	2.56	44	4.62	3.41
61	4.11	6.23	2.48	44	4.82	3.17
62	4.41	6.07	2.84	44	5.02	3.38
63	4.51	6.60	2.72	44	4.98	3.61
64	4.56	6.30	3.06	44	5.06	3.63
65	4.61	6.65	2.88	44	5.05	3.82
66	4.82	6.37	2.86	44	5.29	3.89
67	4.63	6.51	2.44	43	5.13	3.88
68	4.75	6.74	2.97	43	5.20	3.87
69	4.68	5.84	2.83	43	5.25	3.71
70	4.84	6.73	3.01	43	5.36	3.96
71	4.77	6.14	2.93	43	5.27	4.04
72	4.67	6.37	3.00	43	5.35	3.67

Table 3. Parameters of the Beta probability distribution and values of maximum error (EMax), mean error (EMean) and standard error of estimate (Sx) for pentad evapotranspiration in Chapecó, SC

	Beta distribution parameters				Evaluation criteria		
Z	p	q	a	b	EMax	EMean	Sx
1	1.83	1.05	2.76	5.94	0.085	0.024	0.030
2	0.99	0.93	3.32	6.10	0.065	0.023	0.028
3	1.86	1.99	2.80	6.74	0.064	0.029	0.034
4	1.08	1.73	3.35	6.84	0.071	0.023	0.029
5	2.87	3.17	2.91	6.75	0.093	0.040	0.049
6	1.56	1.56	2.87	6.36	0.086	0.027	0.034
7	2.42	2.78	2.47	6.93	0.078	0.035	0.041
8	1.51	2.31	3.08	6.78	0.081	0.037	0.043
9	1.67	2.74	3.05	6.55	0.081	0.035	0.042
10	1.05	1.32	3.08	5.68	0.061	0.025	0.030
11	1.31	1.37	2.69	5.04	0.073	0.029	0.035
12	1.97	1.78	2.16	6.06	0.056	0.021	0.025
13	1.89	1.71	2.54	5.25	0.045	0.018	0.021
14	2.48	2.11	2.58	5.27	0.111	0.053	0.062
15	1.81	1.14	2.38	4.67	0.053	0.020	0.024
16	2.06	3.14	2.24	5.90	0.095	0.039	0.046
17	1.52	1.67	2.16	5.04	0.068	0.029	0.036
18	1.55	1.58	2.16	4.51	0.096	0.031	0.040
19	1.59	1.56	2.06	4.39	0.106	0.044	0.052
20	1.28	1.61	2.19	4.09	0.067	0.019	0.024
21	2.04	2.22	1.59	4.17	0.106	0.045	0.055
22	1.27	2.07	1.63	4.33	0.069	0.020	0.026
23	2.08	3.59	1.43	4.41	0.069	0.030	0.035
24	1.58	2.01	1.42	3.71	0.062	0.027	0.032
25	1.51	1.15	1.17	3.03	0.071	0.024	0.029
26	1.54	2.56	1.20	3.64	0.082	0.027	0.035
27	1.08	1.99	1.25	3.48	0.100	0.043	0.049
28	1.22	1.52	1.02	2.81	0.041	0.015	0.018
29	1.10	1.63	1.12	2.87	0.057	0.025	0.029
30	1.38	3.31	0.96	3.44	0.106	0.042	0.049
31	1.14	1.58	0.90	2.78	0.099	0.041	0.049
32	1.41	2.73	0.76	3.23	0.071	0.026	0.032
33	1.31	1.62	0.82	2.79	0.083	0.035	0.041
34	0.82	1.25	0.94	2.69	0.070	0.030	0.035
35	1.13	1.93	0.81	3.00	0.072	0.028	0.035
36	1.49	2.90	0.81	3.51	0.060	0.026	0.030
37	1.33	2.36	0.88	3.50	0.081	0.026	0.033
38	1.19	3.59	0.90	4.50	0.084	0.029	0.036
39	1.30	3.14	1.00	4.36	0.083	0.029	0.034
40	1.27	3.31	0.92	3.93	0.091	0.028	0.036
41	1.84	2.34	0.83	3.25	0.069	0.024	0.031
42	1.34	2.23	1.17	3.87	0.086	0.033	0.039
43	1.74	2.75	0.96	4.46	0.063	0.020	0.025
44	1.51	2.66	1.18	4.36	0.108	0.046	0.052
45	1.57	1.97	1.13	4.03	0.059	0.028	0.033
46	1.40	2.80	1.39	4.58	0.078	0.041	0.045
47	1.28	2.10	1.51	5.03	0.058	0.026	0.030
48	1.71	2.10	1.58	4.28	0.074	0.026	0.032
49	1.66	1.29	1.22	3.91	0.095	0.041	0.048
50	2.10	2.15	1.19	5.05	0.065	0.021	0.027
51	1.97	3.38	1.20	5.78	0.068	0.026	0.032
52	1.91	1.56	1.41	4.33	0.082	0.026	0.031
53	2.39	6.44	1.71	6.89	0.083	0.031	0.038
54	1.40	1.63	1.75	4.67	0.056	0.026	0.029
55	2.35	2.56	1.99	4.92	0.067	0.022	0.027
56	1.99	3.80	2.34	5.68	0.145	0.045	0.062
57	1.63	2.66	2.15	5.90	0.106	0.040	0.050
58	1.62	1.80	2.52	5.00	0.141	0.042	0.055
59	1.86	2.13	2.58	5.64	0.066	0.025	0.031
60	2.06	2.53	2.56	5.89	0.101	0.039	0.048
61	1.95	2.67	2.48	6.23	0.069	0.024	0.030
62	1.99	2.19	2.84	6.07	0.106	0.035	0.045
63	2.04	2.52	2.72	6.60	0.116	0.035	0.045
64	2.05	2.48	3.06	6.30	0.082	0.026	0.033
65	3.47	4.30	2.88	6.65	0.123	0.053	0.062
66	2.13	1.76	2.86	6.37	0.098	0.041	0.050
67	2.68	2.29	2.44	6.51	0.084	0.039	0.046
68	2.14	2.40	2.97	6.74	0.064	0.025	0.030
69	1.70	1.07	2.83	5.84	0.081	0.035	0.040
70	1.99	2.06	3.01	6.73	0.065	0.025	0.029
71	2.16	1.61	2.93	6.14	0.071	0.035	0.039
72	1.80	1.82	3.00	6.37	0.074	0.027	0.034

Table 4. Probable evapotranspiration from Chapecó, SC.

Pentad	Probability (%)					Pentad	Probability (%)				
	50	75	80	90	95		50	75	80	90	95
1	4.90	5.44	5.54	5.74	5.84	37	1.75	2.24	2.36	2.67	2.89
2	4.77	5.47	5.60	5.87	5.99	38	1.66	2.19	2.34	2.73	3.05
3	4.69	5.39	5.55	5.93	6.18	39	1.87	2.41	2.55	2.93	3.22
4	4.59	5.35	5.53	5.97	6.26	40	1.65	2.12	2.25	2.58	2.85
5	4.72	5.26	5.39	5.71	5.94	41	1.88	2.29	2.39	2.63	2.80
6	4.61	5.31	5.46	5.80	6.00	42	2.11	2.63	2.75	3.07	3.29
7	4.53	5.21	5.37	5.77	6.05	43	2.26	2.84	2.99	3.35	3.61
8	4.47	5.15	5.31	5.72	6.01	44	2.25	2.80	2.94	3.29	3.55
9	4.30	4.89	5.04	5.41	5.68	45	2.38	2.93	3.06	3.37	3.57
10	4.18	4.80	4.93	5.24	5.42	46	2.36	2.90	3.04	3.40	3.67
11	3.84	4.34	4.45	4.69	4.84	47	2.75	3.44	3.61	4.02	4.31
12	4.22	4.91	5.06	5.41	5.63	48	2.76	3.26	3.37	3.65	3.83
13	3.98	4.46	4.57	4.81	4.96	49	2.78	3.30	3.40	3.62	3.74
14	4.05	4.47	4.56	4.78	4.93	50	3.10	3.75	3.89	4.24	4.48
15	3.85	4.26	4.34	4.50	4.58	51	2.80	3.49	3.67	4.11	4.45
16	3.64	4.20	4.34	4.69	4.95	52	3.05	3.57	3.68	3.93	4.08
17	3.52	4.09	4.22	4.51	4.70	53	3.02	3.58	3.73	4.13	4.47
18	3.32	3.78	3.88	4.11	4.26	54	3.07	3.67	3.81	4.12	4.31
19	3.24	3.69	3.79	4.01	4.15	55	3.38	3.84	3.95	4.21	4.39
20	3.01	3.41	3.50	3.71	3.85	56	3.43	3.91	4.03	4.35	4.59
21	2.81	3.25	3.35	3.59	3.76	57	3.50	4.14	4.30	4.70	4.99
22	2.58	3.12	3.25	3.57	3.79	58	3.68	4.16	4.27	4.51	4.67
23	2.48	2.91	3.02	3.30	3.52	59	3.99	4.53	4.65	4.95	5.15
24	2.40	2.83	2.93	3.17	3.33	60	4.03	4.58	4.71	5.02	5.25
25	2.26	2.63	2.71	2.86	2.93	61	4.01	4.63	4.78	5.15	5.41
26	2.07	2.49	2.60	2.87	3.06	62	4.36	4.92	5.04	5.35	5.56
27	1.95	2.41	2.53	2.81	3.01	63	4.43	5.07	5.22	5.59	5.85
28	1.79	2.18	2.27	2.47	2.60	64	4.50	5.04	5.16	5.47	5.69
29	1.78	2.17	2.26	2.48	2.62	65	4.55	5.01	5.13	5.42	5.64
30	1.62	2.01	2.11	2.38	2.59	66	4.81	5.41	5.54	5.83	6.01
31	1.64	2.06	2.16	2.38	2.52	67	4.66	5.27	5.41	5.73	5.95
32	1.54	1.96	2.07	2.35	2.55	68	4.73	5.35	5.50	5.84	6.09
33	1.67	2.09	2.19	2.41	2.54	69	4.77	5.32	5.43	5.63	5.73
34	1.57	2.02	2.13	2.37	2.50	70	4.83	5.48	5.62	5.97	6.20
35	1.55	2.01	2.12	2.39	2.58	71	4.82	5.36	5.47	5.72	5.88
36	1.66	2.11	2.22	2.52	2.74	72	4.67	5.29	5.43	5.75	5.95

Jensen (1974) also highlighted that in most irrigated regions, reference evapotranspiration is used at the level of 75% probability of occurrence, for purposes of dimensioning irrigation systems. The probability of 75% is also indicated by Assis et al. (2014), Bernardo et al. (2006), Uliana et al. (2017).

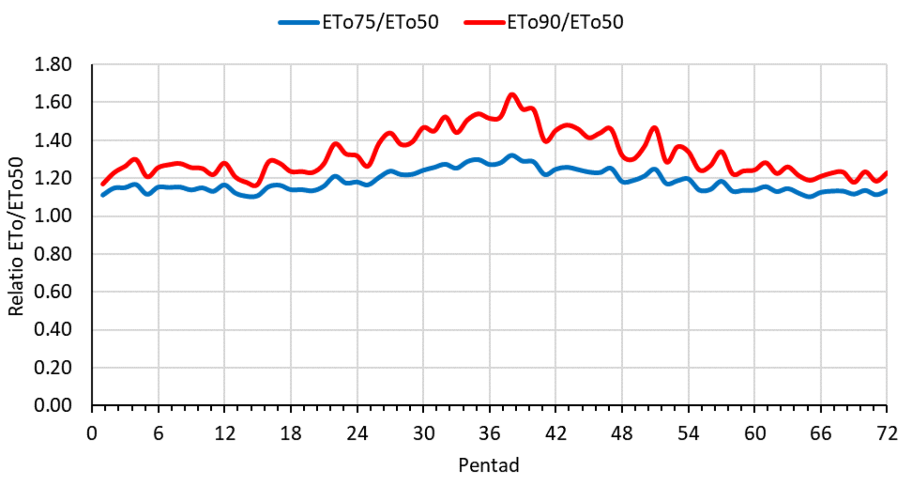

Figure 2. Relationship between evapotranspiration with 75% probability (ETo_{75}) and 90% probability (ETo_{90}) and evapotranspiration with 50% probability (ETo_{50}) for Chapecó, SC.

Gurski et al. (2021) consider that although ETo with 75% probability is recommended in most of the literature on irrigation systems design, considering the climatic characteristics of Paraná state, more restrictive probability levels (such as 90%) can be indicated for the region northeast and less restrictive (such as 50%) for the southeast region of the state of Paraná.

The ETo value with 75% probability (ETo75) presents values ranging from 10 to 32% above the ETo value with 50% probability (ETo50) (Figure 2). These results show that the use of the average ETo value or with 50% probability in the dimensioning of irrigation projects may imply in underestimation of the water demands at the peak. For pentads 26 to 48, which correspond to the months of May to August, the ETo75/ETo50 ratio is greater than 1.20, showing that the underestimation is greater in the winter months. Saad et al. (2002), analyzing ETo data from Piracicaba (SP) found that the ETo with 75% probability presented values from 7.1 to 16.7% higher than the ETo with 50% probability. For ETo with 90% probability of Chapecó, these differences vary from 17 to 65%, showing that the analysis of the distribution of ETo frequencies allows the designer to dimension the most appropriate irrigation system according to the risks admitted for each project.

CONCLUSIONS

The reference evapotranspiration for Chapecó has an average annual value of 1205.3 mm, with monthly values ranging from 49.5 mm in June to 146.4 mm in December. The estimation by the Penman-Monteith method presents values higher than those obtained with regression equations based on geographic coordinates. The ETo values of dry days present an average of 38% higher than those of rainy days. The reference evapotranspiration grouped in pentads fitted the Beta probability distribution well. The reference evapotranspiration with 75% probability presents values ranging from 10 to 32% higher than the ETo values with 50% probability. For the design of irrigation projects, it is recommended to use ETo values with 75% probability.

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