ISSN 1808-8546 (ONLINE) 1808-3765 (CD-ROM)

PRECIPITAÇÃO PLUVIOMÉTRICA PROVÁVEL PARA O MUNICÍPIO DE BOTUCATU-SP

DANIELA ARAUJO DE OLIVEIRA[1]; ALBA MARIA GUADALUPE ORELLANA GONZALEZ [1]; LISETT ROCIO ZAMORA ORTEGA[1]; TAMIRES LIMA DA SILVA[1] E ALEXANDRE BARCELLOS DALRI[2]

[1] Departamento de Engenharia Rural, Faculdade de Ciências Agronômicas, Universidade Estadual Paulista (UNESP), Avenida Universitária, nº 3780 – CEP 18610-034, Altos do Paraíso, Botucatu, SP, Brasil, E-mail: araujo1daniela@gmail.com; oregonza9@gmail.com; zrocio9203@gmail.com; tamireslsilva@gmail.com;
[2] Departamento de Engenharia Rural, Faculdade de Ciências Agrárias e Veterinárias, campus de Jaboticabal, Universidade Estadual Paulista (UNESP), Via de Acesso Prof. Paulo Donato Castellane, s/n - CEP 14884-900 Jaboticabal, SP, Brasil, E-mail: alexandre.dalri@unesp.br

1 RESUMO

No balanço hídrico de um local ou região, a precipitação pluviométrica é o principal elemento de entrada; portanto, o conhecimento de sua disponibilidade é essencial para a gestão sustentável dos recursos hídricos. A precipitação pluviométrica provável é o valor extremo (mínimo ou máximo) de lâmina de chuva que tem uma probabilidade específica de ocorrência e pode ser calculada por meio de distribuições de probabilidades. Este estudo teve como objetivo estimar a precipitação pluviométrica provável nos níveis de 10, 20, 30, 40, 50, 60, 70, 80 e 90% de probabilidade de ocorrência para o município de Botucatu, SP, em períodos acumulados de 10, 15 e 30 dias, utilizando a distribuição de probabilidade Gama. O teste de aderência de Kolmogorov-Smirnov, ao nível de 5% significância, indicou que a distribuição Gama se ajustou à precipitação pluviométrica provável mensal do município de Botucatu-SP e não se ajustou à dez períodos decendiais e um período quinzenal. Comparado com estudos anteriores, foram observadas variações de tendência na precipitação pluviométrica para Botucatu-SP, com redução no período considerado chuvoso e aumento no período considerado seco.

Palavras-chave: chuva, distribuição Gama, Kolmogorov-Smirnov, planejamento agrícola.

OLIVEIRA, D. A. DE; ORELLANA-GONZALEZ, A. M. G.; ORTEGA, L. R. Z.; SILVA, T. L. DA; DALRI, A. B.

PROBABLE RAINFALL TO THE MUNICIPALITY OF BOTUCATU-SP

2 ABSTRACT

In the water balance of a place or region, rainfall is the main input element; therefore, knowledge of its availability is essential for the sustainable management of water resources. Probable rainfall is the extreme value (maximum or minimum) of rainfall that has a specific probability of occurrence and can be calculated through probability distributions. This study aimed to estimate the probable rainfall at levels of 10, 20, 30, 40, 50, 60, 70, 80, and 90% probability of occurrence for the municipality of Botucatu, SP, in cumulative periods of 10, 15,

Recebido em 10/08/2020 e aprovado para publicação em 20/10/2021
DOI: http://dx.doi.org/10.15809/irriga.2021v26n4p853-866

and 30 days, using the Gamma probability distribution. The Kolmogorov-Smirnov adherence test, at a 5% significance level**,** indicated that the Gamma distribution fitted the probable monthly rainfall in the municipality of Botucatu-SP and did not fit ten decennials' periods and one biweekly period. Compared to previous studies, trend variations in rainfall were observed for Botucatu-SP, with a reduction in the period considered rainy and an increase in the period considered dry.

Keywords: rainfall, Gamma distribution, Kolmogorov-Smirnov, agricultural planning.

3 INTRODUCTION

Rainfall, or rainfall, is the occurrence of precipitation in liquid form. Knowledge of rainfall availability in a given location or region is essential for sustainable water resource planning and is the determining factor in quantifying, for example, the need for crop irrigation (TUCCI, 2007).

According to Buriol, Estefanel, and Chagas (2004), rainfall is the main input element in the water balance of a location or region. It is a random phenomenon that presents spatial and temporal variation and can be analyzed and expressed in terms of probabilities. In studies of its temporal variability, historical series records can be analyzed by determining average values, rainfall frequency and intensity, probabilities of occurrence, and return times.

When analyzing a historical series of precipitation data, one can consider all months or just a specific month of the year (of regional interest, for example) and study the annual, monthly, biweekly totals, or any other cumulative period of interest. According to Mello and Silva (2013), studies that consider the total monthly, biweekly, and decennial precipitation of a given location are important for estimating the water balance of crops, aiming at irrigation management with 75, 90, or 95% exceedance, depending on the crop.

Probable rainfall can be defined as the minimum rainfall level with a specific probability of occurrence on the basis of the analysis of a data series and can be calculated for different daily intervals (FRIZZONE, 1979; CASTRO, 1994). According to Botelho and Moraes (1999), by knowing the behavior of rainfall, it is possible to determine the predominant critical periods in the analyzed location, thus obtaining information that can contribute to reducing the consequences caused by fluctuations in rainy and dry periods, contributing to the planning of hydraulic or irrigation projects or to the implantation of crops more suited to the local rainfall regime.

To characterize rainfall variability, it is necessary to analyze its distribution. To this end, distribution analyses and statistical tests are commonly used to determine which probability distribution function is most appropriate for calculating probable rainfall at a specific probability of occurrence (SILVA *et al*., 2007). The Gamma probability distribution has been widely used to estimate probable rainfall at different probabilities of occurrence (SAAD; FRIZZONE, 1998; MOREIRA *et al*., 2010; PASSOS; RAPOSO; MENDES, 2017; PASSOS; MENDES, 2018).

According to Naghettini and Pinto (2007), the Kolmogorov–Smirnov goodness-of-fit test is a qualitative nonparametric test that allows the conclusion of whether a given probability distribution is appropriate for a dataset. The test statistic is based on the maximum difference between the empirical (observed frequencies) and theoretical cumulative probability functions of continuous random variables.

Trends in rainfall in a region can be described by observing changes in the frequency and/or intensity of rainfall events. A study developed by Zilli *et al*. (2017), indicated a change in the rainfall pattern in the state of São Paulo over time, with an increase in the number of rainy days and in the frequency and intensity of extreme events.

Owing to the possibility of occurrence of trend variations in rainfall, the objective of this study was to estimate the probability of rainfall at different levels of probability of occurrence for the municipality of Botucatu-SP in accumulated periods of 10, 15 and 30 days via the gamma probability distribution.

4 MATERIALS AND METHODS

4.1 Location of the study area

The data used to fit the gamma probability distribution function (fd) were collected daily at the meteorological station of the Faculty of Agricultural Sciences - FCA, Unesp, located at Fazenda Lageado, Botucatu, SP, Brazil, at latitude 22°53'S, longitude 48°26'W and an altitude of 786 m (Figure 1). The data series used covered the period from January 1983--December 2019, totaling 37 years of data.

Figure 1. Location of the Meteorological Station at Fazenda Lageado, Botucatu, SP, Brazil.

Source: Sarnighausen *et al.* (2021).

4.2 Data analysis

Three classes of accumulated rainfall were created in periods of 10, 15 and 30 days. Estimates of probable monthly, biweekly and decennial rainfall were obtained for the levels of 10, 20, 30, 40, 50, 60, 70, 80 and 90% probability of occurrence via the probabilistic model incomplete Gamma distribution.

According to Thom (1958), the gamma probability density function f(x) is given by Equation 1, the gamma function Γ(α) is given by Equation 2, and the gamma cumulative distribution F(x) is given by Equation 3.

$$f(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} X^{\alpha-1} e^{\frac{X}{\beta}} \qquad (01)$$

$$\Gamma(\alpha) = \int_0^x X^{\alpha-1} e^{-x} d(X) \qquad (02)$$

$$F(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x X^{\alpha-1} e^{-\frac{X}{\beta}} d(x) \quad (03)$$

where α is the shape parameter, dimensionless; β is the scale parameter, in mm; e is the base of the Napierian logarithm; X is the precipitation, in mm; and Γ is the Gamma function.

Decennial average precipitation data to the gamma probability distribution were assessed via the Kolmogorov–Smirnov test at the 5% significance level. The values of the gamma distribution parameters (alpha and beta) and the Kolmogorov–Smirnov test results were calculated via STATISTICA *software* (version 10.0).

It is very common, especially in short periods, for no precipitation to occur—i.e., zero precipitation. A value of zero cannot be used in parameter estimation via the maximum likelihood method, and working only with nonzero values can lead to an overestimation of rainfall at a given probability level (CASTRO, 1994). Therefore, this study used values to one decimal place, replacing precipitation values of 0 mm with 0.1 mm.

5 RESULTS AND DISCUSSION

Table 1 presents the average and probable rainfall at the 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, and 90% probability levels for the ten-day periods studied. Notably, these probability levels refer to the probability of maximum probable rainfall occurring.

Table 1. Average **(**Pm) and probable rainfall, expressed in mm, for ten-day periods in Botucatu, SP, historical series 1983--2019.

Período	Pm	Probabilidade (%)								
		90	80	70	60	50	40	30	20	10
01 a 10/01	98,0	200,5	150,4	119,7	97,1	78,7	62,8	48,5	34,8	20,9
11 a 20/01	99,5	185,6	145,8	120,8	101,8	86,0	71,9	58,7	45,5	30,9
21 a 31/01	105,1	123,5	116,7	112,0	108,0	104,4	100,9	97,2	93,0	87,4
01 a 10/02	78,4	89,1	85,2	82,5	80,2	78,1	76,0	73,9	71,4	68,0
11 a 20/02	78,4	97,6	90,4	85,3	81,2	77,5	73,8	70,1	65,9	60,3
21 a 28/02	52,2	61,5	58,1	55,7	53,7	51,9	50,2	48,3	46,2	43,4
01 a 10/03	68,9	79,8	75,8	73,0	70,7	68,6	66,5	64,3	61,8	58,4
11 a 20/03	52,2	65,4	60,4	56,9	54,1	51,5	49,0	46,5	43,6	39,8
21 a 31/03	50,7	58,8	55,8	53,8	52,0	50,5	48,9	47,3	45,5	43,0
01 a 10/04	26,8	32,4	30,3	28,9	27,6	26,5	25,5	24,3	23,1	21,4
11 a 20/04	31,9	41,6	37,9	35,3	33,2	31,3	29,5	27,7	25,6	22,9
21 a 30/04	19,7	23,7	22,2	21,2	20,3	19,6	18,8	18,0	17,1	15,9
01 a 10/05	21,8	33,1	28,4	25,3	22,9	20,7	18,7	16,7	14,5	11,9
11 a 20/05	27,8	32,9	31,0	29,7	28,6	27,6	26,7	25,6	24,5	22,9
21 a 31/05	36,6	42,2	40,2	38,7	37,5	36,4	35,4	34,2	32,9	31,2
01 a 10/06	27,5	31,2	29,9	28,9	28,1	27,4	26,7	25,9	25,1	23,9
11 a 20/06	16,9	19,9	18,8	18,1	17,4	16,8	16,3	15,7	15,0	14,1
21 a 30/06	10,4	14,0	12,6	11,7	10,9	10,2	9,6	8,9	8,2	7,2
01 a 10/07	12,8	15,5	14,5	13,8	13,3	12,7	12,2	11,7	11,1	10,3
11 a 20/07	11,8	14,4	13,4	12,8	12,3	11,8	11,3	10,8	10,2	9,5
21 a 31/07	14,9	18,0	16,9	16,1	15,4	14,8	14,2	13,6	12,9	12,0
01 a 10/08	11,0	13,2	12,4	11,9	11,4	11,0	10,6	10,1	9,6	9,0
11 a 20/08	11,8	14,1	13,3	12,7	12,2	11,8	11,3	10,9	10,4	9,7
21 a 31/08	17,1	20,3	19,2	18,4	17,7	17,1	16,5	15,8	15,1	14,1
01 a 10/09	27,4	31,4	29,9	28,9	28,1	27,3	26,6	25,8	24,9	23,6
11 a 20/09	26,9	32,2	30,3	28,9	27,8	26,8	25,8	24,7	23,5	21,9
21 a 30/09	28,8	36,0	33,3	31,4	29,8	28,5	27,1	25,7	24,1	22,1
01 a 10/10	28,6	34,9	32,6	30,9	29,5	28,3	27,1	25,8	24,4	22,6
11 a 20/10	41,8	48,2	45,8	44,2	42,8	41,6	40,3	39,1	37,6	35,6
21 a 31/10	41,8	50,6	47,3	45,0	43,2	41,4	39,8	38,0	36,1	33,5
01 a 10/11	34,3	42,5	39,4	37,2	35,5	33,9	32,3	30,7	28,9	26,5
11 a 20/11	47,7	55,5	52,6	50,6	49,0	47,4	45,9	44,4	42,6	40,2
21 a 30/11	54,4	65,2	61,2	58,4	56,1	54,0	51,9	49,8	47,3	44,1
01 a 10/12	56,8	69,1	64,5	61,3	58,7	56,3	53,9	51,5	48,8	45,1
11 a 20/12	55,7	64,9	61,5	59,2	57,2	55,4	53,7	51,8	49,8	47,0
21 a 31/12	76,0	95,3	88,0	83,0	78,8	75,1	71,4	67,7	63,5	57,9

* Shaded values represent periods that did not fit the gamma probability distribution according to the Kolmogorov–Smirnov test.

Data from periods 01 to 10/05, 11 to 20/05, 11 to 20/06, 21 to 30/06, 01 to 10/07, 11 to 20/07, 21 to 31/07, 01 to 10/08, 11 to 20/08 and 21 to 31/08 did not fit the gamma probability distribution according to the Kolmogorov–Smirnov test. These results differ from those of Castro (1994), who studied the distribution of precipitation for the same municipality in periods of 5, 10, 15 and 30 days for a historical series of 31 years (1961--1991) and noted that the gamma distribution fit, through the Kolmogorov–Smirnov test at the 5% significance level, to all the periods studied. However, it is noteworthy that the period studied by Castro (1994) is different from that evaluated in the present study (1983--2019) and that in other studies, such as that of Araújo *et al.* (2001), the gamma probability distribution function did not fit the driest period. According to Rossi *et al.* (2018), the dry period in Botucatu begins in April and extends until September, thus comprising the period (May--August) in which the decennial data do not fit the gamma distribution.

Sampaio *et al*. (2007), when the probable precipitation for Londrina-PR, estimated by the gamma distribution, was analyzed, the fit accepted by the Kolmogorov–Smirnov test over three ten-day periods was not obtained. When studying monthly rainfall conditions in the same municipality, Ribeiro and Lunardi (1997) determined that the Gamma distribution represents local conditions. Similarly, Dourado Neto *et al*. (2005) recommend the Gamma distribution for daily precipitation probability estimates in Piracicaba-SP only for the months of January, February, March, October, November, and December (months with the highest rainfall), emphasizing that if the researcher has more than one model adjusted for a given period, he or she should choose the simplest, most versatile, and flexible distribution, as the quality of the results is the same.

For the third ten days of January, there is only a 10% chance that precipitation will be equal to or less than 87.4 mm, meaning that 90% of the precipitation will be greater than this amount during this period. For the period from January 1st to 10th, there is a 90% chance of rainfall reaching 200.5 mm; that is, in 1st to 10th years, precipitation in the first ten days in Botucatu will be greater than or equal to 200.5 mm. These data corroborate those of Cunha and Martins (2009), who analyzed precipitation data from 1971--2006 in Botucatu to determine the municipality's climate classification and reported the highest monthly precipitation value in January.

The average precipitation values from 1983--2019 revealed that the ten-day periods with the highest rainfall incidence occurred from January--March and November--December. The highest standard deviation values were also observed in these months. However, the month of November had the lowest standard deviation among the rainy months, which may indicate that rainfall in the ten-day period of November was more uniform than that in the other rainy periods.

The results of the probable rainfall for the 15-day periods are presented in Table 2. Notably, the Kolmogorov–Smirnov test agreed with the fit in practically all biweekly periods, except from August 1st--15th. Junqueira Júnior *et al* . (2007) mentioned that fitting probability models via the Kolmogorov–Smirnov test is more difficult for shorter periods. This means that the possibility of ten-day data fitting a probability distribution model is always lower than that of biweekly data, which is lower than that of monthly data, and so on. The authors state that by reducing the analysis period, the standard deviation and the coefficient of variation of the sample increase. Thus, the frequency of observed data has a distortion in relation to the theoretical frequency, influenced by the parameters of the probability models.

Table 2. Average (Pm) and probable precipitation, expressed in mm, for fortnightly periods in Botucatu, SP, historical series 1983--2019.

Período	**Pm**	**Probabilidade (%)**								
		90	**80**	**70**	**60**	**50**	**40**	**30**	**20**	**10**
1 a 15/01	155,9	289,8	228,0	189,2	159,7	135,1	113,2	92,5	71,9	49,1
16 a 31/01	146,6	279,4	217,3	178,5	149,2	125,0	103,5	83,5	63,8	42,2
01 a 15/02	119,5	227,8	177,1	145,5	121,6	101,8	84,3	68,0	51,9	34,4
16 a 28/02	88,8	154,3	125,2	106,6	92,3	80,1	69,0	58,4	47,5	34,8
01 a 15/03	88,9	167,3	130,9	108,1	90,8	76,4	63,7	51,7	39,9	26,8
16 a 31/03	81,3	160,8	122,7	99,2	81,7	67,3	54,7	43,2	32,0	20,1
01 a 15/04	42,1	104,3	69,1	49,2	35,6	25,4	17,4	11,1	6,1	2,3
16 a 30/04	36,2	93,4	59,6	40,9	28,5	19,5	12,7	7,6	3,8	1,2
01 a 15/05	33,9	66,7	51,1	41,4	34,2	28,2	23,0	18,2	13,6	8,6
16 a 31/05	52,2	129,1	85,6	61,0	44,2	31,6	21,8	13,9	7,7	2,9
01 a 15/06	35,0	99,7	56,0	33,9	20,5	11,9	6,3	2,9	1,0	0,2
16 a 30/06	19,9	56,6	31,9	19,3	11,7	6,8	3,6	1,7	0,6	0,1
01 a 15/07	17,3	49,2	27,9	17,1	10,4	6,1	3,3	1,5	0,5	0,1
16 a 31/07	22,2	63,7	35,4	21,1	12,6	7,1	3,7	1,6	0,5	0,1
01 a 15/08	12,8	38,5	18,9	9,9	5,0	2,4	1,0	0,3	0,1	0,0
16 a 31/08	27,1	78,6	42,8	25,1	14,6	8,1	4,1	1,7	0,5	0,1
01 a 15/09	40,5	113,7	65,6	40,8	25,4	15,3	8,5	4,1	1,5	0,3
16 a 30/09	42,7	106,8	70,1	49,4	35,4	25,0	17,0	10,7	5,7	2,1
01 a 15/10	48,9	114,4	79,1	58,5	44,1	32,9	23,9	16,4	10,0	4,5
16 a 31/10	63,2	112,3	90,2	76,2	65,5	56,4	48,1	40,3	32,3	23,2
01 a 15/11	58,3	110,7	86,2	70,9	59,4	49,8	41,3	33,4	25,6	17,0
16 a 30/11	78,1	152,3	117,1	95,3	78,9	65,4	53,6	42,7	32,0	20,6
01 a 15/12	97,0	183,8	143,3	118,0	98,8	82,9	68,9	55,7	42,7	28,5
16 a 31/12	104,5	184,1	148,4	125,8	108,3	93,5	80,1	67,3	54,2	39,2

*Shaded values represent periods that did not fit the gamma probability distribution according to the Kolmogorov–Smirnov test.

For the accumulated period of 15 days, the lowest probable rainfall values were observed in the first fortnight of July (July 1st to 15th), differing from that reported by Castro (1994), who reported the lowest probable rainfall for the same municipality in the second fortnight of July and first fortnight of August. Notably, in the present study, there was no adjustment of the data to the probability distribution analyzed for the first fortnight of August (August 1st to 15th) (Table 2). However, all these fortnights are within the periods of water deficiency in Botucatu, defined by Cunha and Martins (2009) as the months of April, July and August.

In 9 of the 24 fortnights, that is, 37.5%, the average precipitation exceeded 75 mm, and the first fortnight had the highest average (155.9 mm). Among the remaining fortnights, 4 had an average of less than 25 mm, and 11 ranged between 25 and 75 mm, demonstrating the temporal variability of rainfall at the studied location.

The analysis of probable rainfall over short periods, such as 5, 10, or 15 days, in a given region is an increasingly relevant tool in planning various agricultural activities, such as developing irrigation projects. Knowing the values of a minimum rainfall depth, with a safety margin, allows for better-sized irrigation projects, lower costs, reduced allowable flows, and better use of available water (RIBEIRO *et al*., 2007; DALLACORT *et al*., 2011).

Table 3 shows the results of the monthly averages, variance, standard deviation, coefficient of variation, and extreme values of rainfall. There is very large variability in the monthly total rainfall data for the Botucatu-SP region. For example, in January, which is considered a very rainy month, the monthly rainfall ranged from 712.3 mm (2011) to 67.6 mm (1998), and in July, which is considered a dry month, the rainfall ranged from 0 to 172.6 mm. The highest average monthly rainfall occurred in January (302.5 mm), and the lowest occurred in July (39.5 mm).

Table 3. Monthly averages, variance, standard deviation (S), coefficient of variation (CV) and extreme values of rainfall in Botucatu, SP, historical series 1983--2019.

Months	Average (mm)	Variance	S (mm)	CV (%)	Maximum (mm)	Minimum (mm)
Jan.	302.5	16558.1	128.7	42.5	712.3	67.6
Feb.	208.3	6244.2	79.0	37.9	367.1	66.6
Sea.	170.2	7219.2	85.0	49.9	426.1	49.0
Apr.	78.3	2207.4	47.0	60.0	250.1	2.8
May.	86.2	4059.7	63.7	74.0	286.8	1.3
Jun.	54.8	3438.5	58.6	107.0	228.4	0.0
Jul.	39.5	1872.1	43.3	109.5	172.6	0.0
Aug.	39.9	1717.9	41.4	103.8	164.6	0.0
Set.	83.1	3781.2	61.5	74.0	240.6	0.0
Oct.	112.1	4536.8	67.4	60.1	359.6	9.8
Nov.	136.4	4079.3	63.9	46.8	289.0	30.1
Ten.	201.4	6554.4	81.0	40.2	419.1	64.8

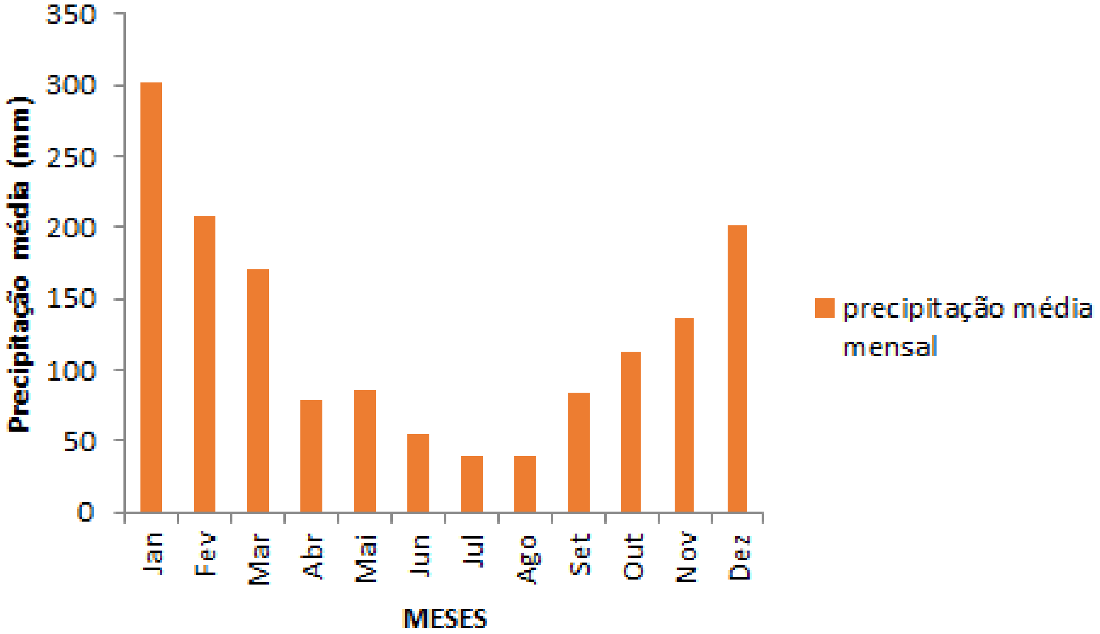
Table 3 also contains the estimated values of the means and variances of the two rainiest months (January and February) and two less rainy months (July and August). In general, as the average monthly precipitation increases, the variance also increases, which indicates that the observed values tend to be farther from the mean, and we have a more “spread out” distribution. Moreover, the variances are smaller in the less rainy months.

When analyzing the standard deviation, we found that the highest values occurred in the months of October, November, December, January, February, and March. This means that the analyzed data are well distributed around the mean in the rainiest months, whereas in the months of April, May, June, July, August, and September, the standard deviation is smaller, indicating that in the drier months, the data are condensed close to the mean. In other words, the smaller the standard deviation is, the more homogeneous the sample.

The variability, measured by the coefficient of variation (CV) (%) of the monthly precipitation data in Botucatu-SP, is high (CV>60%) in the months of May, June, July, August, September, and October, on the basis of the CV limits proposed by Warrick and Nielsen (1980). According to Landim (2003), the coefficient of variation provides a relative measure of the accuracy of the analyzed data and is quite useful in assessing data dispersion. In the studied region, there is greater data dispersion in the winter season (in the Southern Hemisphere).

In terms of the distribution of rainfall throughout the months, there is a concentration of rainfall (Figure 2), thus defining two seasons. The first, the wet season, occurs from October to March, with monthly rainfall indices ranging from 112.11 to 302.5 mm. The second, the dry season, extends from April to September, with fluctuations in rainfall from 39.49 to 86.15 mm. January had the highest rainfall, with an average monthly total of 302.5 mm, and July had the least rainfall, with 39.49 mm. In the study developed by Castro (1994) for the Botucatu-SP region, the monthly average rainfall during the analyzed period (1961--1991) ranged from 132.0 mm (October) to 231.0 mm (January) in the wet season. During the dry season, the rainfall ranged from 36 mm (July) to 79 mm (September). A comparison of the results for average rainfall (Table 3) with those obtained by Castro (1994) for Botucatu-SP revealed a 15.06% reduction in the average monthly rainfall in October and a 30.95% increase in the average monthly rainfall in January. Analyzing the dry season, slight increases in the average monthly rainfall of 9.72% and 5.18% were observed for the months of July and September, respectively.

Figure 2. Distribution of average monthly rainfall for the municipality of Botucatu, SP, historical series 1983--2019.



These results are similar to those reported by Teramoto & Escobedo (2012), who also observed for Botucatu an annual rainfall cycle characterized by two periods: a period with high precipitation (October--March), in which 75--90% of the total annual accumulated precipitation occurs, with January being the wettest month (288.2 mm), and a period with low precipitation (April--September), in which rainfall indices are less than 100 mm. According to Carvalho *et al*. (2004), Center for Weather Forecasting and Climate Studies - CPTEC (2010) and Reboita *et al* . (2010), during periods of high precipitation, the occurrence of rain and high cloud cover is the result of frontal systems and the formation of the South Atlantic convergence zone, whereas during periods of low precipitation, low cloud cover and low- to medium-intensity rains are the result of the passage of cold fronts.

The estimates of the parameters α and β of the gamma probability distribution for the rainfall data of the municipality of Botucatu, SP, are presented in Table 4.

Table 4. Alpha (α) and beta (β) parameters of the gamma probability distribution for average precipitation (Pm) and probability for monthly periods in Botucatu, SP, historical series 1983--2019.

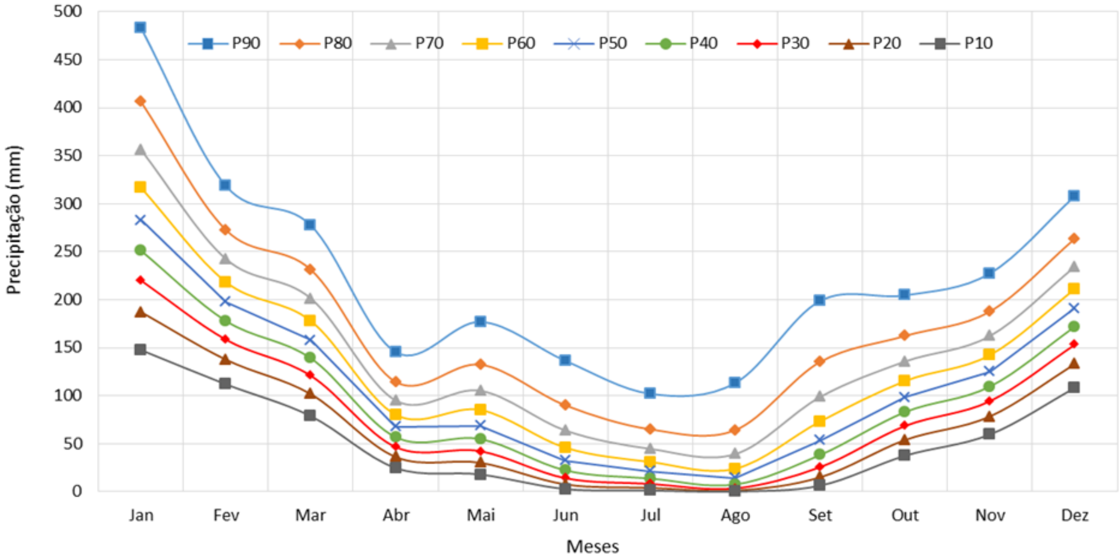
Months	**Parameters**	
	α	**β**
Jan.	5.0344	60.0876
Feb.	6.3675	32.7175
Sea.	4,5054	37.7735
Apr.	2.4431	32.0540
May.	1,5907	54.1622
Jun.	0.7270	75.3949
Jul.	0.6184	63.8780
Aug.	0.3909	102,2059
Set.	0.8558	97.1407
Oct.	2.6373	42.5122
Nov.	4.0286	33.8615
Ten.	6,3673	31.6375

According to estimates, the parameter α ranges from 0.3909 in August to 6.3675 in February. The values of α were greater in the months with high rainfall (October to March). According to Botelho and Morais (1999), the reason why α presents higher values in rainy months is the pronounced asymmetry of the data related to the period of low rainfall (April--September), since the asymmetry is inversely proportional to α.

The β values fluctuated from 31.6375 in December to 102.2059 in August. In contrast to the α parameter, the β parameter tended to present higher values in the driest period (April--September) (Table 4).

The probable monthly rainfall totals for Botucatu-SP associated with occurrence levels of 10, 20, 30, 40, 50, 60, 70, 75, 80 and 90% probability are presented in Figure 3. For example, for the month of January, the probability of 90% means that there is a 10% chance that the rainfall for this month will be equal to or greater than the probable rainfall (483 mm); that is, 90% of the rainfall for January should be less than this value.

Figure 3. Distribution of probable monthly rainfall for the municipality of Botucatu, SP, at different probability levels according to the Gamma distribution function, historical series 1983--2019.



P10 = 10% probability of occurrence; P20 = 20% probability of occurrence; P30 = 30% probability of occurrence; P40 = 40% probability of occurrence; P50 = 50% probability of occurrence; P60 = 60% probability of occurrence; P70 = 70% probability of occurrence; P80 = 80% probability of occurrence; and P90 = 90% probability of occurrence.

For the months of January (average = 302.5 mm), February (208.3 mm), March (170.2 mm), April (78.3), October (112.1 mm), November (136.4 mm) and December (201.4 mm), the average remained between the 50% and 60% probability levels. In the months of May (86.2 mm), June (54.8 mm), July (39.5 mm) and September (83.1 mm), the average probability level was between 60% and 70%. In August (39.9 mm), the average probability level was between 70% and 80% (Figure 3). As most of the monthly rainfall averages for the municipality of Botucatu-SP were located at levels lower than 75% probability (< 75%), which is the probability of occurrence usually used in irrigation projects, irrigation projects for this location should not be based on the average monthly rainfall value.

The nonparametric Kolmogorov–Smirnov goodness–of-fit test, at the 5% significance level, revealed that the gamma probability distribution was adequate for representing the monthly rainfall in the municipality of Botucatu-SP during the period studied.

6 CONCLUSIONS

The results of this work allow us to conclude the following:

a) The probabilistic Gamma model was adapted to the monthly rainfall in the municipality of Botucatu-SP.

b) For monthly data, in general, the estimates of the shape parameters (α) are smaller in the less rainy months and larger in the rainy months. Moreover, the estimates of the scale parameter (β) present higher values in the drier months.

c) Regarding the distribution of rainfall throughout the months, differences in its concentration are observed, clearly defining two periods: one with a high incidence of rainfall, called the rainy period, occurs between the months of October and March, with monthly rainfall indices ranging from 112.11 to 302.5 mm; and the other with a low incidence of rainfall, called the dry period, runs from April to September and is characterized by monthly rainfall ranging from 39.49 to 86.15 mm. January had the highest rainfall values, with an average monthly total of 302.5 mm, and July had the lowest value, with a monthly average of 39.49 mm.

d) Compared with previous studies, variations in rainfall trends were observed for Botucatu-SP, with a reduction in the rainy period and an increase in the dry period.

7 ACKNOWLEDGMENTS

The authors would like to thank the National Council for Scientific and Technological Development (CNPq) for granting scholarships.

8 REFERENCES

ARAÚJO, WF; ANDRADE JÚNIOR, AS de; MEDEIROS, RD de; SAMPAIO, RA Monthly rainfall probable in Boa Vista, Roraima State, Brazil probable in Boa Vista, Roraima State, Brazil probable in Boa Vista, Roraima State, Brazil. **Brazilian Journal of Agricultural and Environmental Engineering** , Campina Grande, v. 5, n. 3, p. 563-567, 2001.

BOTELHO, VAVA; MORAIS, AR Estimates of the Parameters of the Gamma Distribution of Rainfall Data for the Municipality of Lavras, State of Minas Gerais. **Science and Agrotechnology ,** Lavras, v.23, n.3, p.697-706, Jul./Sept., 1999.

BURIOL, GA; ESTEFANEL, V.; CHAGAS, AC Geographical Distribution of Rainfall in the State of Rio Grande do Sul. **Vidya Electronic Magazine** , Santa Maria, v. 24, n. 41, p. 133-145, Jan./June. 2004.

CARVALHO, LMV; Jones, C.; Liebmann , B. The South Atlantic Convergence Zone: Intensity, Form, Persistence, and Relationships with Intraseasonal to Interannual Activity and Extreme Rainfall **. Journal of Climate** , v.17, p.88-108, 2004.

CASTRO, R. **Probabilistic Distribution of Precipitation Frequency in the Botucatu Region-SP** . 1994. Dissertation (Master's in Agronomy-Energy in Agriculture) - Faculty of Agronomic Sciences, Unesp, Botucatu, 1994.

CPTEC - CENTER FOR WEATHER FORECASTING AND CLIMATE STUDIES/INPE. Climanálise – Climate monitoring and analysis bulletin. < http://climanalise.cptec.inpe.br/~rclimanl/boletim/>. January 24, 2020.

CUNHA, AR; MARTINS, D. Climate classification for the municipalities of Botucatu and São Manuel, SP. **Irriga** , Botucatu, v. 14, n. 1, p. 1-11, January-March, 2009.

DALLACORT, R. MARTINS, JA; INOUE, MH; FREITAS, PSL; COLETTI, AJ Rainfall distribution in the municipality of Tangará da Serra, mid-north of Mato Grosso State, Brazil **. Acta Scientiarum . Agronomy** , Maringá, v. 33, n. 2, p. 193-200, 2011.

DOURADO NETO, D.; ASSIS, JP; TIMM, LC; MANFRON, PA; SPAROVEK, G.; MARTIN, TM Adjustment of probability distribution models to historical series of daily rainfall in Piracicaba-SP . **Rev. Bras. Agrometeorologia** , v. 13, n. 2, p. 273-283, 2005.

FRIZZONE, J.A. **Analysis of five models for calculating the distribution and frequency of rainfall in the region of Viçosa-MG.** 1979. Dissertation (Master's in Agricultural Engineering) - Faculty of Agronomic Sciences, Federal University of Viçosa, Viçosa 1979.

JUNQUEIRA JUNIOR, JA; GOMES, MN; MELLO, CR; SILVA, AM Probable precipitation for the Madre de Deus region, Upper Rio Grande: probability models and characteristic values. **Agrotec .** , Lavras, v. 31, n. **3** , p. 842-850, May/June, 2007.

LANDIM, PMB **Statistical analysis of geological data** . 2nd ed. São Paulo. UNESP, 2003, 253 p.

MELLO, CR; SILVA, AM **Hydrology** : Principles and applications in agricultural systems. Lavras: Federal University of Lavras-UFLA, 2013. 455 p. ISBN 978-85-8128-029-6.

MOREIRA, PSP; DALLACORT, R.; MAGALHÃES, RA; INOUE, MH; STIELER, MC; SILVA, DJ; MARTINS, JA Distribution and Probability of Occurrence of Rainfall in the Municipality of Nova Maringá-MT. **Journal of Agro-Environmental Sciences,** Alta Floresta-MT , v. 8, n. 1, p. 9-20, 2010.

NAGHETTINI, M; PINTO, EJA **Statistical Hydrology** . Belo Horizonte: Geological Survey of Brazil, CPRM, 2007. 552 p. ISBN 978-85-7499-023-1.

PASSOS, MLV; MENDES, TJ Probable Monthly and Annual Rainfall for the Municipality of Turiaçu-MA . **Brazilian Journal of Irrigated Agriculture - RBAI** , Fortaleza, v. 12, n. 1, p. 2283-2292, Jan./Feb. 2018.

PASSOS, MLV; RAPOSO, AB; MENDES, TJ Probable Monthly and Annual Rainfall for the Municipality of São Mateus – ES. **Scientific Agriculture in the Semi-Arid Region-ACSA,** Patos-PB, v. 13, n. 2, p. 162-168, Apr./Jun. 2017.

REBOITA, MS; GAN, MA; ROCHA, RP; AMBRIZZI, T. Precipitation regimes in South America: A literature review. **Brazilian Journal of Meteorology** , v.25, p.185-204, 2010.

RIBEIRO, AMA; LUNARDI, DMC Probable monthly precipitation for Londrina-PR, through the Gamma function. **Energy in Agriculture Journal** , Botucatu, v.12, n.4, p. 37-44, 1997.

RIBEIRO, BT; AVANZI, JC; MELO, CR; LIMA, JM; SILVA, MLN Comparison of probability distributions and estimate of probable precipitation for the Barbacena-MG region. **Science and Agrotechnology** ., Lavras, v. 31, n. 5, p. 1297-1302, Sep./Oct. 2007.

ROSSI, LR *et al* . Seasonal Analysis of the Atmospheric Transmissivity of Global Infrared Solar Radiation in Botucatu/SP/Brazil. In: VII BRAZILIAN CONGRESS OF SOLAR ENERGY, 7., 2018, Gramado. **Proceedings [...].** Gramado: VII Brazilian Congress of Solar Energy, 2018. p. 1-9.

SAAD, JCC; FRIZZONE, JA Study of the Frequency Distribution of Rainfall for the Design of Irrigation Systems **. Irriga,** Botucatu, v. 03, n. 1, p. 13-19, Jan./Apr., 1998.

SAMPAIO, SC; QUEIROZ, MMF; FRIGO, EP; LONGO, AJ; SUSZEK, M. Estimation and distribution of decennial rainfall for the state of Paraná. **Irriga** , Botucatu, v. 12, n. 1, p. 38-53, January-March, 2007.

SARNIGHAUSEN, VCR; GOMES, FG; PAI, A. dal .; RODRIGUES, SA Estimation of Reference Evapotranspiration for Botucatu-SP using Regression Models. **Brazilian Journal of Climatology** , Curitiba, v. 28, p. 766-787, June 22, 2021. http://dx.doi.org/10.5380/rbclima.v28i0.71569 .

SILVA, JC; HELDWEIN, AB; MARTINS, FB; TRENTIN, G.; GRIMM, EL Rainfall distribution analysis for Santa Maria, RS. **Brazilian Journal of Agricultural and Environmental Engineering,** Campina Grande-PB, v. 11, n. 1, p. 67- 72, 2007.

TERAMOTO, ET; ESCOBEDO, JF Analysis of the annual frequency of sky conditions in Botucatu, São Paulo **. Brazilian Journal of Agricultural and Environmental Engineering** , v.16, n.9, p.985–992, 2012.

THOM, HCS A note on the Gamma Distribution. **Monthly Weather Review** , Washington, v.86 , n.4, p. 117-22, 1958.

TUCCI, CEM **Hydrology** : Science and Application. 4th ed. Porto Alegre: Federal University of Rio Grande do Sul-UFRGS/ABRH, 2007. 943 p. ISBN 978-85-7025-924-0.

WARRICK, AW; NIELSEN, DR **Spatial variability of soil physical properties in the field** . In: HILLEL, D. (Ed.). Application of soil physics. New York: Academic Press, 1980. 385 p.

ZILLI, MT; CARVALHO, LMV; LEIBMANN, B.; SILVA DIAS, MA A comprehensive analysis of trends in extreme precipitation over southeastern coast of Brazil. **International Journal of Climatology** , West Sussex, vol. 37, no. 5, p. 2269-2279, 2017. Available at : https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.4840. Accessed on: July 3, 2020.