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Pluvial Distribution for Amparo De São Francisco – Sergipe

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ABSTRACT

Effective rainfall resolution gives great importance to studies of precipitation that aim to be applied in agriculture since this portion of precipitation is the one that will be contributing to the available water in the soil. Objective to estimate the monthly probable precipitation at different levels of probability using the Gama distribution model for Amparo de São Francisco - Sergipe. The Gamma probabilistic model and the adherence of monthly precipitation data to the distribution model were evaluated by the Kolmogorov-Smirnov test. The adjustments of the gamma probability distributions used were influenced by the climatic and geographic characteristics of the studied area. The Gama probabilistic model was adapted to the monthly rainfall data of the studied area. For the 75% probability level, the annual totals of the most significant effective precipitation are registered in March to August with oscillations from 111.0 mm to 251.6 mm. For 95% of the probability of precipitation, the only month that has rainfall rates below 100 mm in November. The 5% Ks test every month registered low levels of significance.

INTRODUCTION

The absence of up-to-date studies and climate knowledge followed by their analyzes and the characteristics of rainfall distribution and techniques based on probabilistic criteria, which generally involve risks, is what has led technicians and scientists to use an irrigation system based on certain probabilities. Sanchez (1972) and Louzada et al. (1991) stated that this methodology has some limitations such as variation in rainfall distribution and soil moisture at the time of precipitation.

The best methodology information for adjusting probability models is an indispensable link for reducing human vulnerability in the occurrence of natural disasters. Estimating the probability of extreme events that are potentially harmful to society, such as the annual maximum daily rainfall variability, is a strong motivation for the study and statistical modeling of these events. Since the occurrence of these precipitations is a random process (HARTMANN et al.,2011), not allowing a deterministic forecast in advance, the adjustment of a probabilistic model that best describes the process is necessary to make estimates of extreme events.

The estimation of parameters from the observed data can be done numerically, with the method of moments and the maximum likelihood being indicated. The estimation of parameters by the maximum likelihood method is accepted as being more efficient, although numerically difficult compared to the method of moments. For small samples, this method generally leads to poorer estimates, this method is less variable than the method of moments. (KITE, 1978; SEVRUK et al, 1981; CLARKE, 1994;).

The Gamma distribution, proposed by Thom (1958) is a probabilistic method for estimating probable rainfall under different conditions of the probability of occurrence and is commonly used in works with this proposal, adjusting to the total rainfall of monthly or shorter periods, such as can be observed in the works by Lima *et al.*(2008); Silva et al. (2007); Passoset al. (2017) and Passoset al. (2018), among others.

According to Naghettini et al. (2007), the parameters of probability distributions must be estimated by some procedure of mathematical statistics. According to some authors, there is a range of methods for estimating parameters, among which the method of moments, the maximum likelihood, and the L-moments stand out. Thus, a problem that arises in practice is the choice of the best adjustment method and the distribution of the most appropriate extreme values for a given sample of data.

Several studies carried out through the Gamma probability distribution to estimate the probably expected rainfall at different probabilistic levels of occurrence were developed by Pizzato et al., (2012); Batistão et al., (2013); Souza et al., (2013); Coan et al., (2014); Francisco et al., (2015); Francisco et al., (2016); Mossini Junior et al., (2016) and Passos *et al.,* (2017), which consolidates each of the methodologies as accepted, provided they are proven by an adherence test.

Theoretical probability distribution adjustments for a set of climatic elements were developed, highlighting the benefits of planning activities that minimize climatic risks such as precipitation (ASSAD et al., 1991; CATALUNHA et al., 2002; ASSIS et al., 2002; ASSIS et al., 2002; ASSIS et al., 2002; Berlato, 1987; CASTRO, 1996; BOTELHO et al., 1999).

The objective is to estimate the monthly probable rainfall at different levels of probability of occurrence applying the Gamma probability distribution model for Amparo de São Francisco – Sergipe.

MATERIALS AND METHODS

Amparo de São Francisco is located in a region characterized by two well-defined seasons, a rainy period ranging from February to August and a dry period from September to January. The climate is of the “As” type (hot and humid Tropical rainy), according to the classification of Köppen (1928); Köppen*et al.,*(1931), this classification was also determined by the authors (MEDEIROSet al, 2019; ALVARESet al., 2014). Amparo de São Francisco records an average temperature of 25.9ºC; 1126.8 mm precipitation; Total evaporation of 1553.0 mm and total evaporation of 899.5 mm. (FRANÇA, 2021).

Annual, monthly, and daily rainfall data provided by the Northeast Development Superintendence (SUDENE, 1990) and the Agricultural Development Company of Sergipe (EMDAGRO - SE, 2021) between 1964 and 2019 were used. Totaling 55 years with continuous observed data. The study of descriptive statistics of the observed values was carried out, about the mean, median, mode, standard deviation, coefficient of variation, kurtosis, asymmetry, absolute maximum and minimum, rainfall confidence level.

Estimation of probable monthly rainfall was achieved for levels of 10, 20, 30, 40, 50, 60, 70, 75, 80, 90 and 95% probability using the probabilistic Gamma model, as described by Thom (1958), where the probabilistic density function Gamma f(x) is given by equation 1.

$$f(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} X^{\alpha-1} e^{\frac{X}{\beta}} \quad 1$$

On what,

β - Scale parameter (mm);

α - shape parameter (dimensionless);

and - base of the neperian logarithm;

X - Precipitation (mm);

Γ(α) - Gamma function.

The Gamma function Γ(α) was calculated using equation 2.

$$\tau(\alpha) = \int_0^{\alpha} X^{\alpha-1} e^{-X}\, d(X) \quad 2$$

Finally, the Gamma F(x) cumulative distribution was determined by equation 3.

$$f(x) = \frac{1}{\beta^{\alpha}\tau(\alpha)} \int_o^{X} X^{\alpha-1}\, e^{-\frac{X}{\beta}}\, d(X) \quad 3$$

The fit elements of the Gamma distribution, α, and β, were estimated by the maximum likelihood method, with the polynomial approximation for the shape parameter proposed by Greenwood and Durand (1960) apud Wilks (2006), equation 4 and/or 5.

$$\hat{\alpha} = \frac{0{,}5000876 + 0{,}1648852A - 0{,}0544274A^2}{A} \qquad 0 \le A \le 0{,}5772;\ \text{ou} \quad 4$$

$$\hat{\alpha} = \frac{8{,}898919 + 9{,}059950A + 0{,}9775373A^2}{17{,}79728A + 11{,}968477A^2 + A^3} \qquad 0{,}5772 \leq A \leq 17{,}0. \qquad 5$$

Calculating A by equation 6.

$$A = \ln \bar{X} - \frac{1}{n}\sum_{j=1}^{n} \ln Xj, \qquad 6$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad 7$$

Subsequently, it was verified through the Kolmogorov-Smirnov test at a significance level of 5%, if the adjustment was adequate by Warrick et al. (1980).

RESULTS AND DISCUSSIONS

Probabilistic studies of climatic variables are extremely important for planning irrigation, agricultural, civil construction, tourism, leisure, transport, water resources, dam, and hydroelectric plant construction activities, among many other uses.

Figure 1 shows the annual rainfall fluctuations and the historical average for the years 1963 to 2019 in Amparo de São Francisco – Sergipe, with an annual historical average of 1138.2 mm. High rainfall rates occurred between 1963 and 1967, and 1972; and the smallest was registered in 1970, 1980, 1993, 2012, 2016, and 2018. These variabilities are by the studies by Marengo et. al, (2015); IPCC (2014); Holanda et al., (2020).

Studies show that the temporal variability of rainfall is of paramount importance to quantify the consequences caused by the availability of water in the soil, surface runoff, and erosion (NADARAJAH et al.,2007; WESTRA et al., 2013).

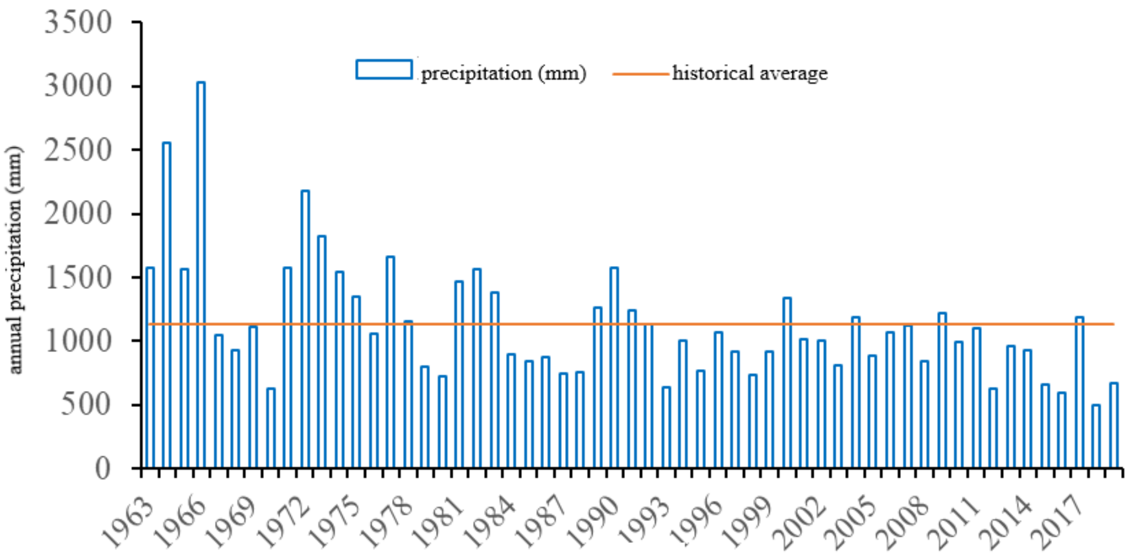

Figure 1. Annual rainfall and historical averages for the period 1963-2019 for Amparo de São Francisco – Sergipe.

Source: França (2021).

The actions of the convective systems generated several storm nuclei with variable intensities, aided by the topography and orography at short distances, which contributed to the elevation of hot and humid air and the intensities of the instability lines, the effects of the South Atlantic cyclone vortices and penetrations the cold fronts, strengthening this system and causing moderate to heavy rains in Amparo de São Francisco (TREFAULT et al., 2018; CALDANA et al., 2018; CALDANA et al., 2019). Sobral et al. (2018) highlight that in higher areas rainfall concentrations are higher.

Figure 2 shows the variability of annual rainfall anomalies between 1963 and 2019 for Amparo de São Francisco – Sergipe. Variations from 1894.6 mm in 1966 to -639.4 mm in 2018 were observed. Seventeen years had rainfall above the average; nine years with rainfall close to the average and thirty years with rainfall below the climatological average. Medeiros' study (2019); Marengo et al., (2017); Xavier et al., (2005) showed similarities with the discussions and rainfall anomalies observed in this study.

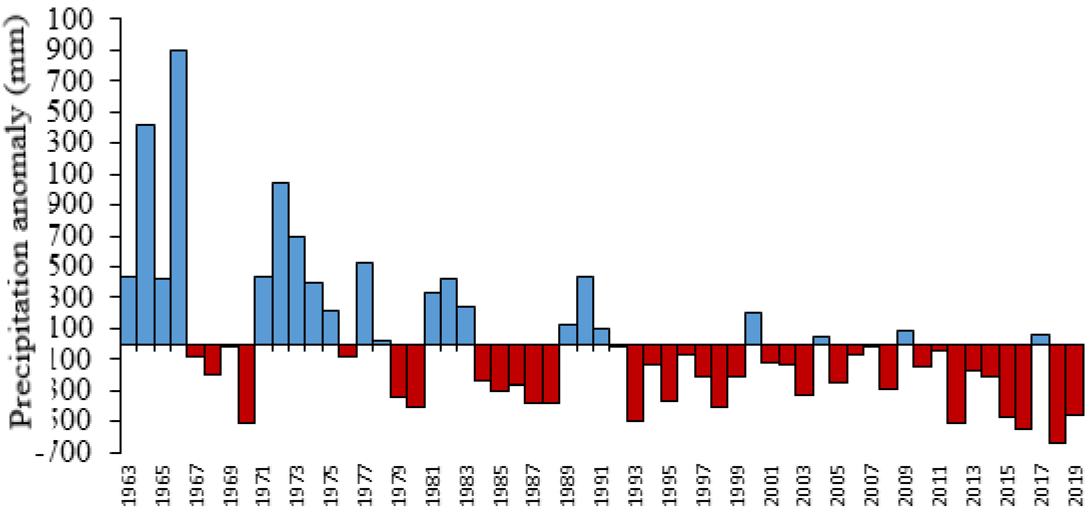

Figure 2. Annual rainfall anomalies from 1963 to 2019 in Amparo de São Francisco – Sergipe.

Source: França (2021).

Montebeller (2007) ensures that rainfall fluctuations in a certain region or area are conditioned by factors such as latitude, distance to the ocean, and orographic effects, in addition to dynamic factors, such as the movement of air masses that associated with each other, characterize the rainfall index. Of region. With a maximum annual rainfall of 3032.8 mm in 1966 and monthly fluctuations flowing between 189.4 mm (May) and 27.2 mm (November). The rainy four-month period is recorded from April to July and the dry four-month period from October to January.

The mean, median, mode, standard deviation, coefficient of variation, kurtosis, asymmetry, absolute maximum, and minimum rainfall confidence level in Amparo de São Francisco from 1963 to 2019 are presented in Table 1.

In terms of practical application, the median (Md) is used when one wants to observe the distribution, fifty-fifty (50%<Md<50%), of the data series; mainly, temporal. However, for other cases, Md is used instead of the simple arithmetic mean to represent the general behavior of the data when they present very significant extreme values. The median oscillations follow the average trends with the highest occurrences between April and July. The median would represent the future trend of precipitation. In the other months, the mode values deviate from the median and average approximations.

Table 1. Months, mean, median, mode, standard deviation, coefficient of variation, kurtosis, asymmetry, absolute maximum and minimum, the rainfall confidence level in Amparo de São Francisco 1963 to 2019.

Months	average	median	mode	Standard deviation	Coefficient of variation	kurtosis	asymmetry	Absolute maximum	Absolute minimum	Confidence level(95%)
January	47,7	35,6	56,0	63,6	133,2	22,2	4,1	0,7	425,8	16,7
February	59,4	37,4	10,2	77,6	130,6	24,3	4,2	0,1	533,2	20,4
March	81,8	71,9	#N/D	63,9	78,2	4,5	1,5	1,1	355,9	16,8
April	174,2	141,9	174,0	145,5	83,6	6,4	2,1	8,5	806,1	38,3
May	189,4	174,4	#N/D	114,2	60,3	1,7	1,1	10,3	540,0	30,0
June	159,9	156,7	153,8	59,5	37,2	0,6	0,4	15,0	326,2	15,7
July	149,6	155,1	169,5	44,7	29,9	1,9	0,3	54,8	299,0	11,8
August	87,6	86,1	#N/D	40,2	45,9	2,0	0,9	12,8	229,4	10,6
September	65,0	55,2	#N/D	48,0	73,8	1,3	1,2	0,1	211,4	12,6
October	40,1	24,6	0,001	46,5	116	6,5	2,4	0,1	230,7	12,2
November	27,2	22,2	1,4	28,7	105,8	5,8	2,0	0,1	152,5	7,6
December	45,0	32,4	18,6	48,5	107,9	2,9	1,7	0,1	222,7	12,8
Yearly	1138,2	993,4	#N/D	781,1	-	80,1	21,9	103,2	432,9	205,4

Caption: #N/A = values not statistically determined.

Source: França (2021).

Standard deviation is a measure of the dispersion of data relative to the mean, irregularities in the dispersion of measures of this element about the mean stand out, that is, the deviation would be closer to the mean than the median.

It is observed that from October to February there were the highest values of coefficient of variation, thus showing the heterogeneity of rainfall observed in these months over the years. Its highest values were observed between October and February, so there is a greater dispersion of data in the dry period in the region.

The asymmetry and kurtosis coefficients show centered measures and with little flattening asymmetry about normal. Asymmetry and kurtosis measures aim to assess the level of normality or deformation of a distribution. The kurtosis curve is of the mesokurtic type. The highest absolute values were recorded in April (806.1 mm) and May (548.0 mm), maximum values can be explained by the formations of convective systems, which are differentiated by the smallest spatial scopes, formed by the process of transference of conduction heat that occurs in intense vertical movements, leading to a rapid process of condensation and the formation of Cumulonimbus (CB) (CALDANA et al., 2018; CALDANA et al., 2019a). In these cases, rainfall is generally of short duration and high intensity, as a consequence, rainfall variability is observed (TREFAULT et al., 2018).

The minimum values occurred with fluctuations between 0.1 mm in February, September to December to 54.8 mm (August) as its annual minimum of 103.2 mm. With a maximum annual value of 423.9 mm, oscillations ranging from 152.5 mm (November) to 806.1 mm (April). Studies such as that by Marengo et al., (2008); Marengo et al., (2015): IPCC, (2007); IPCC, (2011) and IPCC, (2015) corroborate the observed results.

Probable monthly rainfall totals associated with probability occurrence levels of 10, 20, 30, 40, 50, 60, 70, 75, 80, 90, and 95% are shown in Table 2. These levels represent the occurrence of expected rainfall above these values.

The Kolmogorov-Smirnov test was applied to both grouped and individual data. Catalonia et al. (2002) showed that in the grouped data there is no restriction on the number or value of classes. It is based on the modulus of the greatest difference between the observed and estimated probability, which is compared with a tabulated value according to the number of observations in the series under test. This avoids the cumulative aspect of errors (VIEIRAet al., 2010).

Table 2. Probable monthly precipitation for Amparo de São Francisco - SE with different levels of probability, by the Gamma distribution function, for the period 1963 to 2019.

months	probability level (%)										
January	10	20	30	40	50	60	70	75	80	90	95
February	4,3	9,6	15,8	23,1	23,1	42,9	57,1	66,2	77,3	112,2	147,2
March	3,3	8,7	15,8	24,6	24,6	50,2	69,4	81,9	97,4	147,0	197,8
April	12,3	23,1	34,5	46,9	46,9	78,1	99,5	112,9	129,1	178,5	227,1
May	70.5	95.1	116.3	136.7	157,9	181.2	208.5	224.8	243.8	298.8	349.7
June	59,4	87,1	112,2	137,3	137,3	194,0	229,9	251,6	277,2	352,5	423,6
July	84,2	104,2	120,5	135,8	135,8	167,7	186,6	197,7	210,5	246,9	279,7
August	93,5	109,4	121,9	133,4	133,4	156,8	170,3	178,1	187,1	212,1	234,3
September	40,2	52,0	61,9	71,4	71,4	91,6	103,8	111,0	119,4	143,4	165,5
October	12,0	21,1	30,1	39,9	39,9	63,5	79,4	89,2	101,1	136,9	171,7
November	2,5	6,4	11,2	17,3	17,3	34,4	47,2	55,4	65,6	98,1	131,2
December	1,5	4,0	7,2	11,3	11,3	22,9	31,7	37,4	44,5	67,2	90,5
Yearly	2,2	6,0	11,2	17,8	26,3	37,2	52,1	61,8	73,9	112,7	152,7

Source: França (2021).

The effective rainfall values at a probability level of 95% can be applied in irrigation projects, where the crop is more sensitive to water stress, or in those with greater economic value; in the study area with a level of 95% and rainfall greater than 100 mm it was recorded in January, February, August, September, October, and December, with rainfall greater than 200 mm it was registered in March, June, and July. Rainfall rates above 400 mm would occur in April and May. For other cultures, the probability level of 75% can be used, as indicated by Doorembos et al., (1977, Silva et al., (1988), and Bernardo (1989). the months of March, June, July, August was greater than 100 mm, greater than 200 mm are registered in April and May.

In June and July, values greater than 100 mm are registered for the 20% probability levels. At the 30% level, there would be rain above 100 mm from May to July. For levels of 40%, 50%, and 60% rainfall above 100 mm predominated from April to July. At the 70% level, the months of June, July, and August would be greater than 100 mm and the months of April and May would predominate with rainfall above 200 mm. At the 80% level, rainfall fluctuations would range between 44.5 and 277.2 mm. At the 90% level, the months of October and November would be less than 100 mm. With this framework, it is possible to propose mitigating actions for the impacts of drought, such as the construction of dams, use of irrigation, adjustment of planting date, seeking to maximize water use.

Passos et al. (2017) found that in Chapadinha - MA in January, February, March, April, May, August, and October, the average flowed between levels of 40% to 50% probability and in June, July, November, and December the average was reduced between 30% and 40%.

Table 3 shows the alpha (α) and beta (β) adjustment coefficients of the Gamma distribution for rainfall data and the values of the Kolmogorov-Smirnov (Ks) test at 5% probability for the municipality of Amparo de São Francisco from 1963 to 2019.

Table 3. Coefficients of adjustment of the Gamma function and the values of the Kolmogorov-Smirnov test (Ks) at 5% probability for Amparo de São Francisco - SE.

months	gamma		test Ks a 5%	
			D	
	alpha (α)	Beta (β)	observed	critical
January	0,92	51,86	0,102	
February	0,74	79,87	0,062	
March	1,24	65,85	0,126	
April	3,51	49,64	0,119	
May	2,42	78,35	0,116	
June	6,04	26,48	0,098	0,179
July	10,15	14,74	0,122	
August	4,41	19,84	0,053	
September	1,44	45,15	0,067	
October	0,78	51,33	0,022	
November	0,74	36,54	0,088	
December	0,70	63,85	0,052	

Source: França (2021).

The oscillations of the alpha parameter (α) flow from 0.70 (December) to 10.15 (July), according to Botelho et al, (1999), the variation of α is related to the asymmetry of the months, with the asymmetry being inversely proportional to α. The beta parameter (β) ranged from 14.74 (July) to 79.87 (February). The highest monthly index β was registered in February, a month that presented rainfall of 59.4 mm and standard deviation, 77.6 mm, being an identifier of the variability of the data. It appears that the Gamma probability distribution was adequate to estimate monthly rainfall for the studied area.

CONCLUSION

The probabilistic Gamma model was adapted to the monthly rainfall data of the studied area.

The rainfall distribution registered an average annual temporal variability of 1138.2 mm, for an annual maximum of 3302.8 mm in 1966 and an annual minimum of 498.8 mm.

Analysis of rainfall data at the 70% level; 80% and 90% probability distinguish the months, April, May, and June with rainfall above 200 mm.

For the probability level of 75%, the annual totals of the most significant effective precipitation are registered in March to August with oscillations from 111.0 mm to 251.6 mm.

For 95% of the precipitation probability level, the only month that has rainfall below 100 mm in November.

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