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INTENSITY-DURATION-FREQUENCY RELATIONSHIPS: STOCHASTIC MODELING AND DISAGGREGATION OF DAILY RAINFALL IN THE LAGOA MIRIM WATERSHED, RIO GRANDE DO SUL, BRAZIL

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ABSTRACT: This study aimed to investigate information gain by using rainfall intensity-duration-frequency (IDF) relationships, with data gathered within N+M years from seven rain gauge stations located in the Lagoa Mirim Watershed (South Atlantic basin). After N years of daily rainfall, the transition probabilities of a time homogeneous two-state Markov chain were defined to simulate rainfall occurrence, as well as gamma distribution to measure it; for that, daily rainfall series were composed of N+M years, with M being the generated series. The series were adjusted to Gumbel distribution, being used in annual maximum daily rainfall disaggregation for durations of 10, 20, 30, 40, 50, 60, 120, 360, 720 and 1440 min. Daily rainfall disaggregation was validated through IDF relationships taken from pluviograph records of N years and from N+M years, using the "t" test of relative mean squared error. We can infer that there was information gain using IDF relationships of rainfall occurrence when using N years of observed data and M years of generated data by stochastic modeling compared to those obtained from a composed series of N years.

KEY WORDS: intense rainfall, hydrologic modeling, pluviographic records, hydrological series.

RELAÇÕES INTENSIDADE-DURAÇÃO-FREQUÊNCIA: MODELAGEM ESTOCÁSTICA E DESAGREGAÇÃO DA CHUVA DIÁRIA NA BACIA HIDROGRÁFICA DA LAGOA MIRIM/RS/BRASIL

RESUMO: Objetivou-se verificar se há ganho de informação em termos de relações Intensidade-Duração-Frequência (IDF) de ocorrência de chuva, obtidas a partir de N+M anos de dados para sete estações pluviométricas, pertencentes à bacia hidrográfica da lagoa Mirim (bacia do Atlântico Sul). A partir de N anos de chuva diária observada, foram ajustadas as probabilidades de transição da cadeia de Markov homogênea de dois estados, utilizada na simulação da ocorrência de dias secos e chuvosos, bem como a distribuição Gama, para quantificar a chuva, sendo a série de chuva diária composta por N+M anos, e M a série gerada. As séries compostas foram ajustadas à distribuição de Gumbel e utilizadas na desagregação da chuva máxima diária anual para as durações de 10, 20, 30, 40; 50; 60; 120; 360; 720 e 1440 min. Na validação da metodologia da desagregação da chuva diária, foram comparadas as relações IDFs, a partir de registros pluviográficos, com as obtidas a partir de N anos, bem como as obtidas a partir de N+M anos, utilizando o teste "t" do erro relativo médio quadrático. Concluiu-se que houve ganho de informação em termos de relações IDF de ocorrência de chuva, quando são utilizados N anos de dados observados e M anos de dados gerados, mediante a modelagem estocástica, comparativamente às obtidas a partir da série composta de N anos.

PALAVRAS-CHAVE: chuva intensa, modelagem hidrológica, registros pluviográficos, séries hidrológicas.

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INTRODUCTION

The Lagoa Mirim Watershed has a prominent role in terms of water resources management, since it is a cross-border basin between Brazil and Uruguay. Despite its importance, water-flow information are scarce, which complicates the design of hydraulic structures as spillways, drainage canals, as well as those related to soil and water conservation, among others (TEIXEIRA et al., 2011). To get around this situation, hydrological models have been applied for rainfall-runoff transformation (FIORIO et al., 2012; LALOZAEE et al., 2013). Among them, the Soil Conservation Service model (SCS, 1972) makes use of intensity-duration-frequency (IDF) relationships to estimate hyetograms and unit histogram for routing surface runoff.

Long series of rainfall data are available for the Lagoa Mirim watershed but with missing records, hindering estimation of the IDF relationships. Garcia et al. (2011), aiming to obtain intense rainfall equations for the municipalities of Cáceres, Cuiabá and Rondonópolis, in Brazil, used pluviograph analysis, 24-h rainfall disaggregation, and the Bell’s method (1969). These authors also used a discontinuous series and concluded that the disaggregation method was most sensitive to such series size if compared to the Bell’s one. Moreover, for different durations and return period, the disaggregation method has also shown better performance.

DAMÉ et al. (2014) estimated the IDF relationships using daily rainfall disaggregation method for stations located in the southern half of Rio Grande do Sul State, in Brazil, and compared them with those obtained by homogeneous pluviograph records. The authors concluded that the maximum rainfall intensity by disaggregation are similar to those obtained by IDF equations and, therefore, this method constitutes a feasible alternative in obtaining the IDF relationships.

As it is an extreme phenomenon, intense rainfall ought to be characterized by continuous and representative data series. This way, the longer the series used in the IDF equation, the greater the chance of contemplating extreme phenomena. Although the city of Pelotas already owned a set IDF relationship that covers the period between 1961 and 1991 (30 years), TEIXEIRA et al. (2011) evaluated a longer data series, from 1921 to 2009 (79 years) and, thus, it could be contemplated the extreme events of 1959 (208.4 mm) and of 2004 (292.6 mm.

In order to fill the missing values of daily rainfall and therefore increasing series size, Markov and probabilistic models can be used to generate synthetic series. The Markov process considers a minimum of two transition states, rainfall presence or absence and, which is quantified by a parametric distribution, such as Gamma or Exponential (STERN & COE, 1984). The knowledge on rain behavior over time can be enabled by mixing observed data and those estimated by the above-mentioned stochastic process.

Aiming to simulate a daily rainfall over large areas and focusing on risk analysis studies, SERINALDI & KILSBY (2014) reported a few time series models such as the Markov chain, aside from generalized and parametric linear models. Regarding the Markov modeling, the authors emphasized the importance of estimating parameters for an improved representation of transition probabilities, regardless of the order used in alternation of precipitation states.

ARAÚJO et al. (2012) applied the same model for a 47-year rainfall daily data series of 75 stations in the states of Bahia and Sergipe, Brazil. They found that the rainy days of each season in this region were well represented by the Markovian likelihood function, which is a seasonal average of unconditional probability of rainy days.

This study aimed to check information gains when estimating rainfall intensity-duration-frequency relationships through the Markov chain and Gamma distribution, by comparing them with a daily rainfall disaggregation method. For that purpose, we used data gathered during N + M years, in which a two-state Markov chain is fit to N continuous years of daily data and used to fill M years of missing data for a few cities within the Lagoa Mirim Watershed.

MATERIAL AND METHODS

Daily rainfall data were taken from seven rain gauge stations located inside the Lagoa Mirim Watershed (88), which is inserted into the South Atlantic basin (8). The study area is located between parallels 31° 30’ and 34° 30’ Southern latitude and 52° 00’ and 56° 00’ Western longitude, with an area of around 62,250 km^2, of which 29,250 km^2 (47%) in Brazil and 33,000 km^2 (53%) in Uruguay. Table 1 shows information on the rain gauge stations provided by the *Agência Nacional de Águas - ANA* (National Water Agency), which comprises code, name and location, as well as geographic coordinates, altitude and data gathering period.

TABLE 1. Rain gauge stations used in the study.

Code	Name	Location	Latitude (S)	Longitude (O)	Altitude (m)	Period
3152003	Canguçu	Canguçu	31°24’16”	52°40’24”	400	1943–2012
3152004	Cascata	Pelotas	31°28’00”	52°31’00”	224	1967–1981
3152005	Vila Freire	Pedro Osório	31°40’10”	52°46’22”	250	1977–2012
3152008	Granja São Pedro	Pelotas	31°40’08”	52°10’50”	3	1967–2012
3152010	Morro Redondo	Morro Redondo	31°38’00”	52°39’00”	245	1966–1981
3252003	Estação do Curtume	Rio Grande	32°26’00”	52°36’00”	4	1964–1976
3252008	Granja Santa Maria	Rio Grande	32°24’16”	52°33’21”	12	1966–2006

Table 2 presents the stations with continuous periods of years effectively used to obtain rainfall occurrence modeling, as well as series descriptive statistics.

Watershed rainfall modelling by a two-state Markov chain, which defines the probability of one day being dry or rainy, depends singly on the previous day condition, wherein days are considered dry (0) or rainy (1) (STERN & COE, 1984). Daily rainfall below 1 mm was regarded as dry day (MINUZZI & LOPEZ, 2014). Transition probabilities between dry and rainy conditions, i.e. P(0,0), P(0,1), P(1,0) and P(1,1) (BAÚ et al., 2013), were determined for an annual series, without considering monthly stationarity, since this study aimed to fulfill daily gaps and subsequently set an annual maximum daily rainfall series.

TABLE 2. Descriptive statistics of a daily rainfall series and period of obtaining the transition probabilities (N years).

Code	Name	Period	Average (mm)	Standard deviation (mm)	CV (%)	Maximum (mm)
3152003	Canguçu	1966–1990	4.43	10.72	24.2	123.30
3152004	Cascata	1976–1980	4.50	11.98	26.6	132.70
3152005	Vila Freire	1977–1998	4.28	11.93	27.9	152.40
3152008	Granja São Pedro	1967–1995	3.50	10.83	31.0	195.20
3152010	Morro Redondo	1971–1975	4.36	11.62	26.7	114.80
3252003	Estação do Curtume	1971–1975	2.90	9.14	31.5	96.00
3252008	Granja Santa Maria	1966–1996	3.53	11.25	31.9	201.00

After estimating transition probabilities, 100 sequences of dry/rainy days were generated for the entire period where gaps occurred. From these sequences, we could estimate precipitation amounts on the rainy days using a two-parameter Gamma distribution (DETZEL & MINE, 2011), whose parameters were set by moment method.

Once missing data were fulfilled, continuous series of annual maximum daily rainfall data were established for each of the seven stations. For this purpose, the Gumbel’s theoretical probability distribution was used in association with return periods of 5, 10, 20, 50 and 100 years (QUADROS et al., 2011). Then, this annual maximum daily rainfall was disaggregated into periods of 10, 20, 30, 40, 50, 60, 120, 360, 720 and 1440 min by relation methods (TEIXEIRA et al., 2011).

From the disaggregated data transformed into average maximum rainfall intensity, IDF relationship parameters were adjusted (MICHELE et al., 2011), minimizing the objective function $(f_{obs} - f_{mod})^2$ using the Excel function Solver with a non-linear optimization code, known as Generalized Reduced Gradient.

The results were validated by following these items:

a) N-year IDF relationships of disaggregated daily rainfall in hourly and sub-hourly durations were compared with those of PRUSKI et al. (2006), considering their closeness (LUDWIG et al., 2013) (Table 3). The null hypothesis stated that maximum obtained values do not have significant differences at a 5% level. Therefore, we used the Student's t test with n-k degrees of freedom, in which *n* is the sample size and *k* is the number of explanatory variables for linear (β_0) and angular (β_1) coefficients. The hypothesis is accepted when the Student's t test is less than its critical value. Moreover, standard error was estimated for maximum values within established return and duration periods;

b) N-year IDF relationships of disaggregated daily rainfall in hourly and sub-hourly durations were compared with those obtained within N+M years. Likewise, t test and estimate standard error were used;

c) The method was considered valid for low standard errors when comparing maximum rainfall obtained from a series of N+M years with those of N years.

It is noteworthy highlighting that in an item, we singly validated the daily rainfall disaggregation method for IDF relationship estimation; whilst in b, besides that, we also validated the use of Markov chain and Gamma distribution.

TABLE 3. Intensity-duration-frequency relationships of rainfall occurrence used for validation.

Location	Standardized IDF	Station to be validated	Station name
Encruzilhada do Sul	$I = \frac{431.09\ Tr^{0.19}}{(t + 3.70)^{0.64}}$	3152003	Canguçu
Rio Grande	$I = \frac{774.14\ Tr^{0.23}}{(t + 6.90)^{0.74}}$	3252003	Estação do Curtume
		3252008	Granja santa Maria
Pelotas	$I = \frac{5684.10\ Tr^{0.10}}{(t + 52.23)^{1.01}}$	3152004	Cascata
		3152005	Vila Freire
		3152008	Granja São Pedro
		3152010	Morro Redondo

I – Average maximum rainfall intensity (mm h^{-1}); Tr – Return period (years); t – rainfall duration (min).

RESULTS AND DISCUSSION

Table 4 presents the transition probabilities values P (0,0), P(0,1), P(1,0) and P(1,1) of Markov chain used in simulation sequences for the seven stations in the Lagoa Mirim Watershed, Rio Grande do Sul, Brazil. P (0,0) ranged from 0.76 (3154004) to 0.84 (3152008 and 3252003), while for P(1,1) the amplitude was between 0.36 (3152008) and 0.54 (3152003 and 3152004). The highest values of P (1,1) were registered in 3152003, 3152004, 3152005 and 3152010 gauge stations, which are at a higher altitude (400, 224, 250 and 245 m, respectively). Conversely, the lowest values were found in stations at lower altitudes as 3152008 at 3 m, 3252003 at 4 m, and 3252008 at 12 m. Mean values of annual rainfall in Pelotas and Rio Grande (RS), Brazil, which are located in the coastal plain, were 1379 and 1207 mm, respectively; while in the other locations within the southeastern mountain slope, these annual values were 1552 mm (Canguçu), 1480 mm (Morro Redondo) and 1562 mm (Pedro Osório).

TABLE 4. Transition probabilities P(0,0), P(0,1), P(1,0) and P(1,1) of Markov chain and Gamma distributions parameters of shape (α) and scale (β), from N years, for the seven stations in the Lagoa Mirim watershed, Rio Grande do Sul, Brazil.

Station	Transition probabilities				Gamma distribution parameters	
	P(0,0)	P(0,1)	P(1,0)	P(1,1)	α	β
3152003	0.79	0.21	0.46	0.54	0.39	8.36
3152004	0.76	0.24	0.46	0.54	0.89	9.34
3152005	0.80	0.20	0.49	0.51	1.09	9.30
3152008	0.84	0.16	0.64	0.36	1.38	8.45
3152010	0.79	0.21	0.52	0.48	0.88	9.06
3252003	0.84	0.16	0.57	0.43	1.21	7.13
3252008	0.83	0.17	0.55	0.45	1.53	8.77

Larger rainfall volumes occurred at higher altitudes. BACK et al. (2012) determined relationships among rainfalls of different time lengths in Santa Catarina state (Brazil) and noted a relief contribution on their distribution in different areas of the state, being most abundant in areas near mountain slopes, since moist and warm air raise favors large rainfall volumes. Gamma distribution parameters of shape (α) and scale (β) used to estimate daily precipitated water depth is shown in Table 4.

Descriptive statistics data (average - mm, standard deviation - mm, coefficient of variation - %, and maximum of the series values of N+M years – mm) are displayed in Table 5. In comparison to the statistics presented in Table 2, referring to N years, we observed that, in general, there was no change in the descriptive statistics of the composed series of N+M years. One of the stochastic modeling assumptions is the preservation of statistical characteristics from historical series to generated series (BACK et al., 2011); thus, our results met such assumption.

TABLE 5. Descriptive statistics of the daily rainfall series whose gaps were filled using the Markov chain and Gamma distribution, as well as the period used to obtain annual maximum daily rainfall (N+M years).

Code	Name	Period	Average (mm)	Standard deviation (mm)	CV (%)	Maximum (mm)
3152003	Canguçu	1943–2012	4.01	11.02	27.5	177.30
3152004	Cascata	1967–2012	2.93	8.05	27.5	132.70
3152005	Vila Freire	1977–2012	4.15	11.82	28.5	152.40
3152008	Granja São Pedro	1966–2012	3.51	10.95	31.2	195.20
3152010	Morro Redondo	1967–2012	2.51	7.56	3.01	114.80
3252003	Estação do Curtume	1964–2012	2.13	6.57	30.9	200.20
3252008	Granja Santa Maria	1966–2012	3.49	11.01	31.6	201.00

However, for the stations 3152003 (Canguçu) and 3252003 (Estação do Curtume), the highest values of maximum daily rainfall ranged from 123.30 mm (N years) to 177.30 mm (N+M years) and from 96 mm (N years) to 200.20 mm (N+M years), respectively. Therefore, we may highlight that the values of series of N+M years are somehow similar to the other stations. Furthermore, these values seem to represent more accurately local intense rainfall behaviors whether compared to the series of N years, which is required in estimating the IDF relationships (TEIXEIRA et al., 2011).

The maximum daily rainfall series, constituted by N years of observed data and N years of observed data + M synthetic years, were adjusted to Gumbel distribution, whose parameters of scale (λ) and location (γ), as well as the results of the Kolmogorov-Smirnov adherence test (KS) (ARAGON et al., 2013) at 5% significance level are shown in Table 6. The KS statistic values were lower than critical statistics ones were, what means that Gumbel's adjustment was appropriate.

Similar statement was achieved by TEIXEIRA et al. (2011), who adjusted maximum rainfall intensity values in Pelotas (RS) Brazil; they concluded Gumbel's distribution was adequate since there was adherence between observed and adjusted values that was evidenced by the KS test; thus, there is a consensus on its use for extreme data adjustment.

Considering the Gumbel's distribution parameters, λ values had low variation among stations in the two series. In contrast, γ values show discrepancy for the stations 3152004, 3152010 and 3252003 compared to the others. This result might be derived from the small number of years used to adjust the N-year series, what may have had a reflection on the N+M year series parameter values. QUADROS et al. (2011) adjusted maximum rainfall series for Cascavel (PR), in Brazil, using GEV and Gumbel probability distributions, considering a period of 22 years. These authors established that long-term data series are required to enable considerations of frequencies as probabilities, since the probabilistic laws are synthetic and are intended to describe general characteristics of facts.

TABLE 6. Parameters of scale (λ) and location (γ) of Gumbel distribution and Kolmogorov-Smirnov (KS) test values at 5% significance level, obtained from N and N+M years of data.

Station	Series of N years				Series of N+M years			
	λ	γ	KS_{calc}	KS_{crit}	λ	γ	KS_{calc}	KS_{crit}
3152003	0.0675	66.05	0.56	2.88	0.0417	68.86	0.66	5.58
3152004	0.0459	85.45	0.60	1.44	0.0479	49.27	0.56	3.91
3152005	0.0502	80.84	0.68	3.29	0.0501	79.45	0.61	3.75
3152008	0.0497	80.28	0.59	3.24	0.0491	81.07	0.59	4.16
3152010	0.0939	94.41	0.79	1.92	0.0566	45.76	0.61	4.21
3252003	0.1739	82.67	0.60	1.44	0.0617	39.70	0.51	3.64
3252008	0.0424	86.30	0.63	3.58	0.0421	84.39	0.60	4.16

Table 7 lists the values of Gumbel rainfall distribution for return periods of 5, 10, 20, 50 and 100 years in both series. As recommendation for hydro-agricultural planning is 10 years (MOSQUE et al., 2009), we can emphasize that the lowest values ranged in 76.03 mm (N + M years) for 3252003 station, and in 113.15 mm (N years) for Morro Redondo station (3152010). In the 3252008 station, the highest values were 137.92 mm (N + M years) and 143.55 mm (N years). Overall, for a 5-year return period, the estimated values considering a number of N + M years for the stations 3152004 (110.77/ 80.56 mm), 3152010 (105.81/ 76.38 mm) and 3252003 (111.00/ 55.53 mm) overestimated water depths in 27, 27 and 50%, respectively. On the other hand, for larger return periods, these differences tend to decrease.

TABLE 7. Relations between maximum daily rainfall (mm) from the Gumbel distribution and return periods (Tr) of 5, 10, 20, 50 and 100 years for the seven stations in the Lagoa Mirim Watershed.

Code	Tr (years)				
	5	10	20	50	100
3152003	101.61*/104.19**	113.48/119.17	125.34/134.15	141.02/153.96	152.88/168.94
3152004	110.77/80.56	123.99/90.22	137.20/111.24	154.67/130.68	167.88/145.24
3152005	121.42/111.87	135.79/125.76	150.17/139.64	169.17/158.00	183.55/171.89
3152008	118.72/115.88	134.95/130.90	151.18/145.92	172.63/165.77	188.86/180.79
3152010	105.81/76.38	113.15/89.61	120.49/102.83	130.19/120.31	137.53/133.54
3252003	111.00/55.53	121.48/76.03	131.96/96.53	145.81/123.63	156.29/144.13
3252008	127.69/121.87	143.55/137.92	159.40/153.96	180.35/175.17	196.20/191.22

*N years; **N+M years.

Table 8 displays the intensity-duration-frequency equations for rainfalls throughout N and N+M years. The t test values for angular coefficient obtained comparing maximum intensities in IDF relationships (N and N+M years), for all stations and return periods, showed no significant difference at 5% α level (Table 9), since calculated statistics values were lower than the critical ones, i.e. H_0 is accepted.

Once test results were not significant, relative mean squared error was employed to evaluate information gains by IDF relationship, when pluviograph records and daily rainfall disaggregation are used (Pluvio_N), as well as daily rainfall disaggregation according to Markov chain extension (N_N+M). For all studied stations and return periods, Table 10 demonstrates that composed series of N+M years had the lowest error values compared to N-year ones.

TABLE 8. Rainfall intensity-duration-frequency (IDF) relationships from daily rainfall disaggregation technique, within N and N+M years of data.

Code	Station name	Location	N years	N+M years
3152003	Canguçu	Canguçu	$I = \frac{838.44\ Tr^{0.13}}{(t + 9.37)^{0.73}}$	$I = \frac{938.37\ Tr^{0.16}}{(t + 10.53)^{0.75}}$
3152004	Cascata	Pelotas	$I = \frac{734.21\ Tr^{0.14}}{(t + 7.53)^{0.68}}$	$I = \frac{1112.18\ Tr^{0.15}}{(t + 10.53)^{0.75}}$
3152005	Vila Freire	Pedro Osório	$I = \frac{1103.94\ Tr^{0.14}}{(t + 10.21)^{0.75}}$	$I = \frac{1030.45\ Tr^{0.14}}{(t + 10.53)^{0.75}}$
3152008	Granja São Pedro	Pelotas	$I = \frac{1543.18\ Tr^{0.15}}{(t + 13.47)^{0.83}}$	$I = \frac{1060.41\ Tr^{0.15}}{(t + 10.53)^{0.75}}$
3152010	Morro Redondo	Morro Redondo	$I = \frac{934.11\ Tr^{0.087}}{(t + 9.37)^{0.73}}$	$I = \frac{667.68\ Tr^{0.18}}{(t + 10.52)^{0.75}}$
3252003	Estação do Curtume	Rio Grande	$I = \frac{943.38\ Tr^{0.12}}{(t + 9.37)^{0.73}}$	$I = \frac{435.82\ Tr^{0.29}}{(t + 10.53)^{0.75}}$
3252008	Granja Santa Maria	Rio Grande	$I = \frac{1218.48\ Tr^{0.08}}{(t + 9.37)^{0.73}}$	$I = \frac{1112.18\ Tr^{0.15}}{(t + 10.53)^{0.75}}$

I – Average maximum rainfall intensity $(mm\ h^{-1})$; Tr – Return period (years); t – rainfall duration (min).

In relation to the average relative errors, ZANETTI et al. (2006), aiming to generate daily total rainfall synthetic series through ClimaBR model in 12 Brazilian locations, concluded that distribution simulations by number of rainy days, from the Markov model, were representative, even in situations of large regional weather variability.

TABLE 9. Linear fit results ($Y = \beta_0 + \beta_1 X$) among maximum rainfall intensities (mm h^{-1}) by PRUSKI et al. (2006), for the seven stations and return periods of 5, 10, 20, 50 and 100 years.

Code	Tr (years)	PRUSKI et al. (2006) – N years			N – N+M years		
		β_0	β_1	$t(\beta_1)$	β_0	β_1	$t(\beta_1)$
3152003	5	0.2097	1.1318	0.1163	-0.422	1.037	0.0098
	10	0.2301	1.0888	0.0810	-0.213	1.147	0.0061
	20	0.2525	1.0474	0.0452	-0.237	1.122	0.0047
	50	0.2855	0.9951	-0.0491	-0.274	1.089	0.0039
	100	0.3133	0.9573	-0.0430	0.220	1.060	0.0023
3152004	5	-3.7699	1.3322	0.1141	-1.376	0.813	0.00081
	10	-4.1452	1.1615	0.1359	-1.572	0.844	0.00067
	20	-4.5578	1.1916	0.1572	-1.795	0.877	0.00050
	50	-5.1670	1.2326	0.1844	-2.140	0.922	0.00023
	100	-5.6813	1.2645	0.2097	-1.623	0.952	0.00030
3152005	5	-6.2380	1.2641	0.2043	0.090	0.922	0.00256
	10	-6.8533	1.2958	0.2232	0.099	0.925	0.00257
	20	-7.5293	1.3283	0.2417	0.110	0.929	0.00259
	50	-8.5264	1.3725	0.2654	0.125	0.933	0.00262
	100	-9.3675	1.4069	0.2899	0.643	0.982	0.04254
3152008	5	-8.0333	1.2635	0.2041	-2.295	0.740	0.00091
	10	-8.9213	1.3092	0.2311	-2.539	0.737	0.00092
	20	-9.9075	1.3566	0.2572	-2.809	0.734	0.00093
	50	-11.3800	1.4218	0.2903	-3.209	0.731	0.00094
	100	-12.6390	1.4733	0.3257	-3.026	0.725	0.00105
3152010	5	-4.8484	1.0863	0.0780	-0.308	0.742	0.00184
	10	-5.1493	1.0765	0.0690	-0.350	0.792	0.00176
	20	-5.4689	1.0667	0.0610	-0.396	0.845	0.00162
	50	-5.9220	1.0540	0.0501	-0.468	0.921	0.00120
	100	-6.2895	1.0444	0.0412	0.598	0.973	0.06208
3252003	5	2.7943	0.9518	-0.0510	-0.310	0.705	0.00188
	10	3.0217	0.8775	-0.1394	-0.352	0.739	0.00184
	20	3.2675	0.8091	-0.2357	-0.399	0.774	0.00174
	50	3.6235	0.7267	-0.3757	-0.471	0.824	0.00168
	100	3.9183	0.6701	-0.4535	-0.534	0.864	0.00155
3252008	5	3.4070	1.1602	0.1379	-0.490	0.912	0.00127
	10	3.5933	1.0433	0.0415	-0.543	0.958	0.00072
	20	3.7899	0.9382	-0.0658	-0.601	1.006	0.34660
	50	4.0663	0.8154	-0.2262	-0.688	1.073	0.00459
	100	4.2887	0.7332	-0.3269	-0.762	1.127	0.00336

β_0 and β_1: linear and angular coefficients of the linear fit; $t_{tab\ (5\%)} = 2.75$; Significance: 5%, 2 tails, N-2 degrees of freedom.

The number of years was relevant both for Markov chain transition probabilities and for Gamma distribution parameters in order to obtain the lowest relative mean squared errors. In this sense, PAIVA & CLARKE (1997), adjusting rainfall stochastic models in the Brazilian Amazon, using daily records of 402 stations, concluded that parameter adjustment was adequate for stations with longer time records, covering periods of over 1,000 days.

TABLE 10. Relative mean squared error among maximum rainfall intensity (mm h^{-1}) by PRUSKI et al. (2006) (PLUVIO) and among the evaluated stations, over the periods of N and N+M years for various return periods.

Station	IDF	Tr (years)				
		5	10	20	50	100
3152003	Pluvio_N	2.00	2.19	2.40	2.72	3.02
	N_N+M	0.20	0.22	0.25	0.28	0.80
3152004	Pluvio_N	9.00	14.80	10.88	12.33	13.56
	N_N+M	0.38	0.44	0.50	0.60	1.25
3152005	Pluvio_N	9.93	10.90	11.98	13.57	14.46
	N_N+M	0.30	0.15	0.16	0.18	0.52
3152008	Pluvio_N	10.31	11.45	12.71	14.60	16.22
	N_N+M	1.76	1.95	2.16	2.47	2.98
3152010	Pluvio_N	8.55	9.08	9.64	10.44	10.77
	N_N+M	0.20	0.21	0.22	0.24	1.30
3252003	Pluvio_N	1.93	2.09	2.26	2.51	2.71
	N_N+M	0.21	0.22	0.24	0.27	0.29
3252008	Pluvio_N	2.36	2.49	2.62	2.81	2.97
	N_N+M	0.25	0.27	0.28	0.30	0.32

CONCLUSIONS

Stochastic modeling using a homogeneous first order Markov chain showed to be adequate to estimate sequences of dry and rainy days. The statistics values of observed daily rainfall series were preserved when it was used the Gamma probability distribution to simulate the amount of rainfall. This proposed methodology is useful to fill missing data and extent daily rainfall series. The daily rainfall disaggregation technique presented a good performance, composing a feasible alternative for estimations of rainfall intensity-duration-frequency relationships. Mostly important is that there was information gain on intensity-duration-frequency relationships by using N+M years of disaggregated rainfall daily data compared to N years.

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