DETERMINATION OF INTENSITY-DURATION-FREQUENCY EQUATIONS FOR PERNAMBUCO STATE MESOREGIONS THROUGH DISAGGREGATION METHOD

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ABSTRACT: The knowledge of high intensity rainfall patterns is extremely important due to its application in hydraulic engineering projects. The difficulty in obtaining intensity-duration-frequency equations through pluviographs because of the poor density of pluviographs network has led engineers to use other methods for determining these equations from pluviometric records. In this paper were used time series from 8 municipalities of mesoregions of Pernambuco State to determine intensity-duration-frequency equations using rainfall disaggregation method. The goodness of fit Gumbel distribution was confirmed by the Kolmogorov-Smirnov test with a significance level of 5%. The generated equations showed reasonable fitting with R^2 ranging from 97,5% to 97,9% for the rainfall disaggregation method.

Keys-words: high intensity rainfall, Pernambuco, disaggregation method.

1. INTRODUCTION

A design storm depends mainly on characteristics like precipitation depth, duration of the event and return period. The intensity-duration-frequency relations have direct application in rainfall flow models, in which the design flow can be calculated and used to the design of several hydraulic structures.

However, the determination of these relations is traditionally associated to data availability at pluviographic stations which, in many times, have rainfall series of insufficient size to a reliable determination of idf equations. Besides, many regions do not have any pluviograph station. For these cases, it can take advantage of greater availability of rainfall data in Brazil, in most existing to support in electric sector management and so to determine idf relations through alternative methods like disaggregation method and Bell's method (1969).

Regarding the generation of idf equations for Pernambuco, the work from Pfasteter (1957) with determined the relations for Nazaré da Mata and Olinda. More recently, Coutinho et al (2010) determined equations of intensity-duration and frequency for the some localities using the Bell methodology (1969) and disaggregation method. Silva et al (2012) used data of 12 pluviographic stations and 11 rainfall stations with historical data of 8 to 14 years of observations (rain gauge) and data of 10 to 34 years of records (pluviometer). Furthermore, Ramos e Azevedo (2010) updated the i-d-f equation to the city of Recife, using a pluviograph station that had data of 40 to 2007.

In Brazil, the rainfall disaggregation method was used by many authors like Robaina (1996) who evaluated the technique for 32 locations in the Rio Grande do Sul State.

The goal of this paper was to determine the i-d-f relations for counties of different climatic mesoregions in Pernambuco state through the disaggregation method.

2. METHODOLOGY

Daily rainfall historical data from Nacional Water Agency (ANA, 2010) were used for 8 rainfall stations in Pernambuco State, mesoregions (Metropolitana, Mata, Agreste, Sertão and São Francisco).

Table 1- Characteristics of the selected rainfall stations for Pernambuco State

STATION	COUNTY	RESP.	COD.	LAT.	LON.	TIME PERIOD
Engenho Sítio	São Lourenço	ANA	00735050	07:58’05”	35:9’24’’	45 years
Goiana	Goiana	INMET	00735052	07:34'00"	35:00'00"	43 years
Açude Aboboras	Parnamirim	SUDENE	00839001	08:04’00”	39:26’00’’	32 years
Fazenda Jacaré	Floresta	SUDENE	00837016	08:25'00"	37:56'00’’	32 years
Arcoverde	Arcoverde	SUDENE	00837005	08:26’'00"	37:04'00"	14 years
Usina Ipojuca	Ipojuca	IAA	00835060	08:24'00"	35:4'00"	16 years
Palmares	Palmares	ANA	00835141	08:40’46”	35:34’38”	22 years
Afogados da Ingazeira	Afogados da Ingazeira	ANA	00737023	07:44’20”	37:38’54”	99 years

It was selected, for all studied localities and for each year, the maximum values of daily rainfalls, allowing the preparation of annual data of extreme values. Aiming to obtain the maximum rainfalls possible of being equalized or overcome each 2, 5, 10, 25, 50 and 100 years, from annual data, it was used the 24 hours rainfall disaggregation method.

As it was described in Tucci (2004), i-d-f curves can be expressed by generic equations which have the following configuration:

$$i = \frac{a.TR^{b}}{(t+c)^{d}} \quad (1)$$

where i = intensity, expressed in mm/h; TR = return time, in years; t = rainfall duration, in minutes, and a, b, c e d are parameters to be determined for each location.

For the statistics analysis, it was used Gumbel's distribution. For Naghettini (2007), Gumbel's distribution (maximum) is the most used extreme distribution in the analysis of frequency of hydrological variables, with many applications in the determination of intensity-duration-frequency relations of heavy rainfalls and flood flow study.

The cumulative probability function of Gumbel's distribution is given by:

$$Fy(y) = \exp\left[-\exp\left(-\frac{y-\beta}{\alpha}\right)\right] \quad (2)$$

in which, β represents the scale parameter and α the position parameter.

The inverse of the cumulative probability function of Gumbel's distribution can be written as follows:

$$x(T) = \beta - \alpha \ln\left(-\ln\left(1-\frac{1}{T}\right)\right) \quad (3)$$

where β is the position parameter, α is the scale parameter, which was already defined above, and T is the return time in years.

Estimating the distribution parameters by the method of moments, it is obtained:

$$\beta = \bar{X} - 0{,}45 s_x \quad (4)$$

$$\alpha = \frac{s_x}{1{,}283} \quad (5)$$

in which $\bar{X}$ and s_x represent, respectively, the sample average and standard deviation.

To evaluate the quality of adjustments of the statistics distribution, it was used Kolmogorov-Smirnov's adherence test (KS), with level of significance of 5%.

The Kolmogorov-Smirnov's adherence test (KS) is a nonparametric test, whose test statistics has as its basis the maximum difference among cumulative probability function, empirical and theoretical, of continuous random variables.

The KS test statistics is given by:

$$D_N = \sup_{-\infty<x<\infty} |F_{N(x)} - F_{X(x)}| \quad (6)$$

and corresponds, thus, to the greater difference between the empirical and theoretical probabilities.

The rainfall disaggregation method developed by DAEE/CETESB (1980) adopts the average factor of 1.14 to the transformation of 1 day maximum rainfall, in 24 hours rainfall; for the other rainfalls duration times, it is used the coefficients shown in tables easily found in classic works like Tucci (2004). However, Silveira (2000) presents the equation 7, greatly improving these relations in various programmable media like scientific calculators and spreadsheet.

$$C(24h/d) = e^{1{,}5.ln\left(\frac{ln(d)}{7{,}3}\right)} \quad (7)$$

In order to validate the determined idf equations, it was used the determination coefficient (R^2) (equation 8) and the statistics criteria of Branching Ratio (RD) and the Residual Mass Coefficient (CMR) (equations

9 and 10), where it will be considered Mi to the values calculated through models and Ti to the observed values of historical data. To the value of the determination coefficient, it is expected to the value 1 (one). This coefficient determines the proportion of variance in experienced values that can be assigned to the observed. The RD coefficient describes the ratio between the dispersion of observed values and values calculated theoretically, and it should tend to one, occurring when there is equality between the observed and calculated values. The CMR expected value tends to zero, in absence of systematic deviations between the observed and calculated values, and it can indicate the overestimation (CMR>0) or the underestimation (CMR<0) of values estimated by theoretical probability distribution. The optimal values of CMR and RD are 0 and 1, respectively (Willmott et al, 1985).

$$R^2 = \frac{[n.(\sum Mi.Ti)-\sum Mi.\sum Ti]^2}{n.[\sum Ti^2-(\sum Ti)^2][n.\sum Mi^2-(\sum Mi)^2]} \quad (8)$$

$$\mathrm{RD} = \frac{\sum(\mathrm{Mi}-\mathrm{M}')^2}{\sum(\mathrm{Ti}-\mathrm{M}')^2} \quad (9)$$

$$CMR = \left(\frac{\sum Mi-\sum Ti}{\sum Mi}\right) \quad (10)$$

3. RESULTS AND DISCUSSION

Gumbel's distribution proved to be appropriate for the studied counties in what refers to the estimation of maximum rainfall evaluated by Kolmogorov-Smirnov's test to a level of significance of 5% of probability. Figure 1 shows the frequency distributions of data of annual maximum daily rainfalls observed and estimated by Gumbel's model, for the counties of São Lourenço da Mata, Goiana, Parnamirim, Floresta, Arcoverde, Ipojuca, Palmares and Afogados da Ingazeira, respectively. It can be seen, in this figure, good adherence between the observed and theoretical distributions.

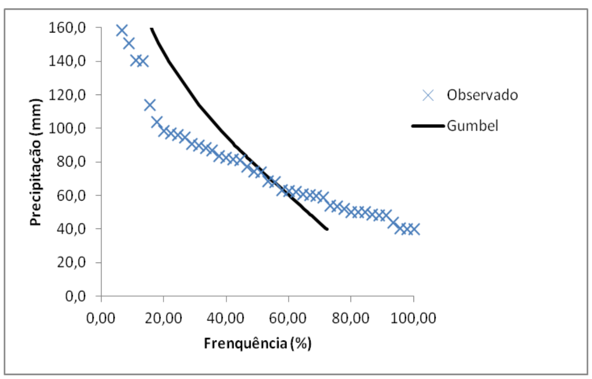

Figure 1A. São Lourenço da Mata

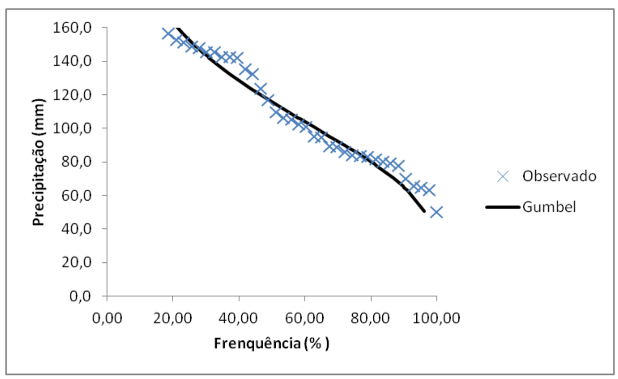

Figure 1B. Goiana

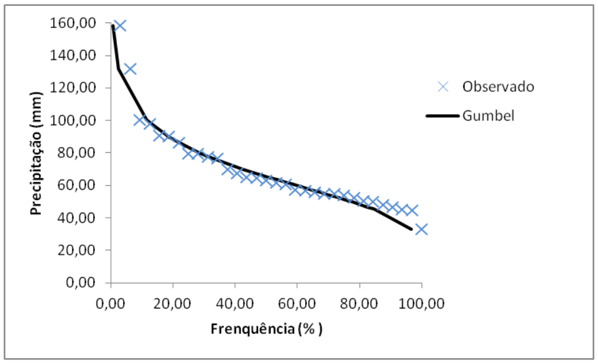

Figure 1C. Parnamirim

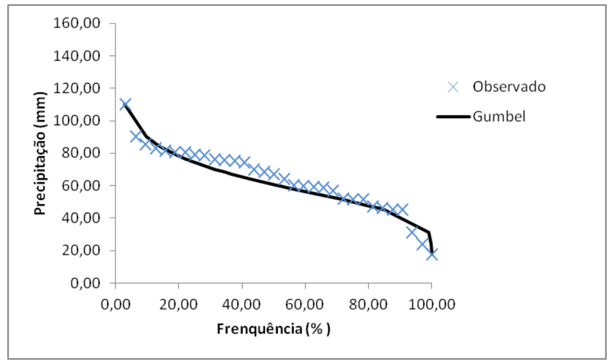

Figure 1D. Floresta

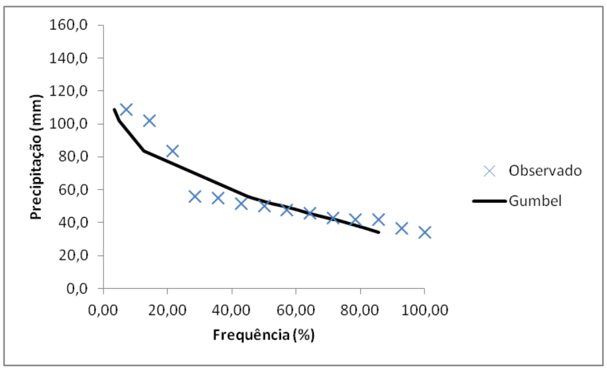

Figure 1E. Arcoverde

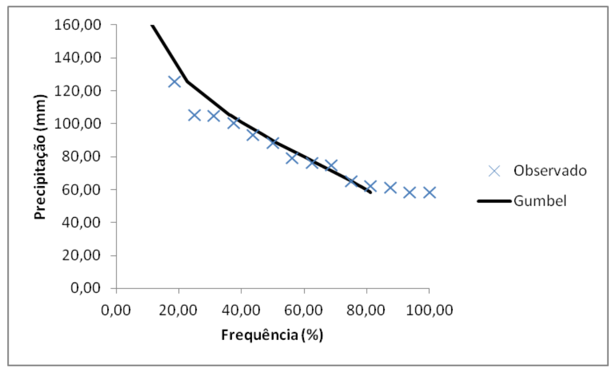

Figure 1F. Ipojuca

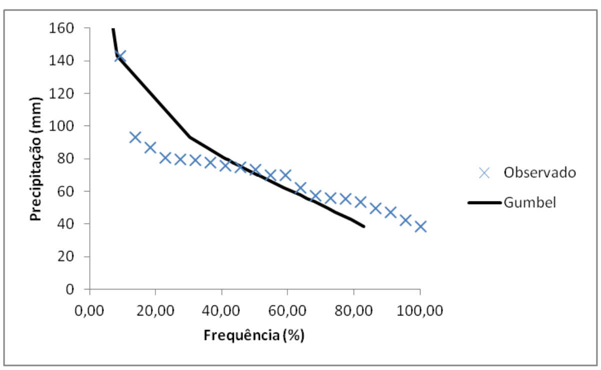

Figure 1G. Palmares

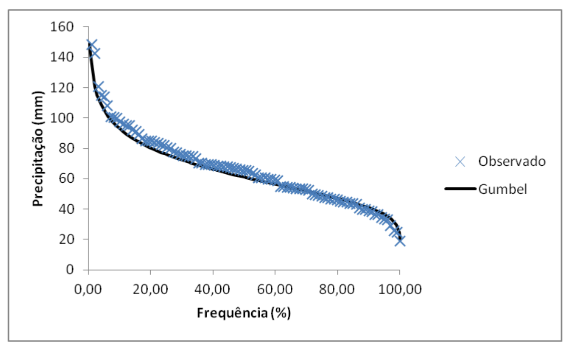

Figure 1H. Afogados da Ingazeira

Figure 2. Recorded and estimated rainfall by Gumbell distribution for 8 stations for Pernambuco state mesoregions

After verification of the goodness of fit to Gumbel's model, for all counties the maximum daily rainfalls for the return period of 2, 5, 10, 25, 50 and 100 years was estimated, as shown in Table 2. The highest estimated rainfalls were for the counties of São Lourenço da Mata and Goiana.

Table 2 – Maximum daily rainfalls (mm) estimated through Gumbel's distribution

Station / Return Period	São Lourenço da Mata	Goiana	Parnamirim	Floresta	Arcoverde	Ipojuca	Palmares	Afogados da Ingazeira
2	77,03	115,64	65,41	60,78	53,07	89,86	70,84	61,12
5	145,42	163,38	88,37	78,35	73,94	130,54	110,03	80,21
10	190,70	194,99	103,58	89,98	87,76	157,48	135,98	92,85
25	247,92	234,92	122,79	104,68	105,23	191,52	168,76	108,82
50	290,36	264,55	137,04	115,58	118,18	216,77	193,08	120,66
100	332,50	293,96	151,19	126,41	131,04	241,83	217,23	132,42

Figure 2 shows the IDF curves for the Goiana County through the disaggregation method. It was determined the curves for the other counties as well.

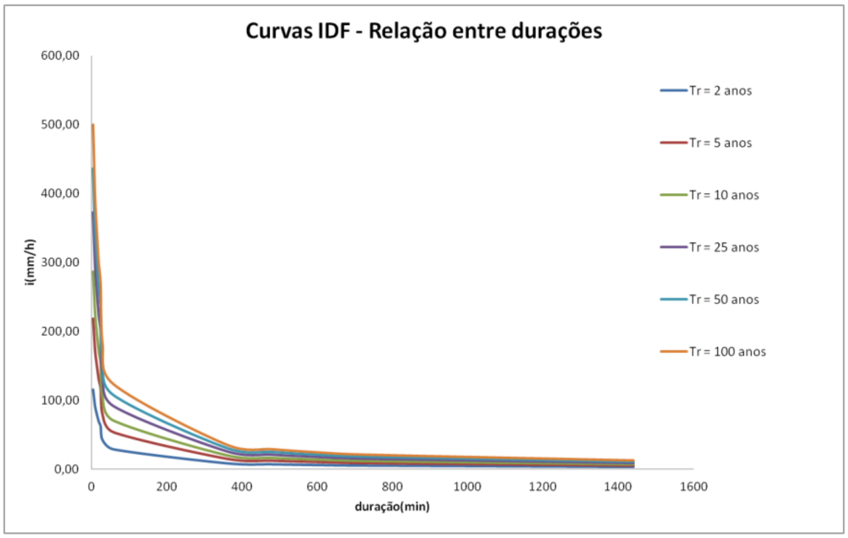

Figure 2. IDF curves – Disaggregation Method – São Lourenço da Mata/PE

Table 3 shows the estimated values of a, b, c and d for equation 1, after regression using the methodology proposed by CETESB (1989), for each county.

Table 3. Parameters of intensity-duration-frenquency Equations through Disaggregation Method.

Parameters of Heavy Rainfall Equations				
Station	**a**	**b**	**c**	**d**
São Lourenço da Mata	631,875	0,35552	3,7974	0,7483
Goiana	927,587	0,23138	3,79735	0,7483
Parnamirim	414,107	0,27442	3,7975	0,7389
Floresta	489,28796	0,18279	3,79608	0,7483

Arcoverde	425,7129	0,22442	3,797463	0,7483
Ipojuca	720,86	0,24511	3,797379	0,7483
Palmares	569,86	0,2761	3,79758	0,7483
Afogados da Ingazeira	371,32	0,1924	3,7974	0,7046

The determination coefficients (R^2), the residual mass coefficient (CMR) and the branching ratio (RD) were calculated for the validation of the parameters presented in Table 3, as shown in the following table 4.

Table 4 - Statistics Parameters determined for each county.

Statistics Parameters/ County	São Lourenço de Mata	Goiana	Parnamirim	Floresta	Arcoverde	Ipojuca	Palmares	Afogados da Ingazeira
R^2	0,938539	0,938672	1,265491	1,074665	1,007572	1,010446	1,025105	0,986351
CMR	0,009434	0,006372	0,004452	0,005923	0,006203	0,006511	0,006989	-0,15718
RD	1,161118	1,105399	1,186760	1,096542	1,103520	1,108969	1,119187	0,736408

4. CONCLUSION

For the studied rainfall stations, Gumbel probability distribution proved to be appropriated to represent the estimates of maximum rainfall values to the level of significance of 5%, through Kolmogorov-Smirnov's test.

The intensity-duration-frequency equations determined in this work showed good fitting, with determination coefficients for the disaggregation method between 0.975 and 0.979. These equations represented a major contribution to the Pernambuco State mesoregions, being a good imput to of hydraulics design. It is suggested that these equations can be used to return period of 100 years or less and duration up to 24 hours.

The obtained validation coefficients (R^2, CMR and RD) made were quite satisfactory, most of them very close to their optimal values (1, 0 e 1).

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