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INTENSE RAIN EQUATIONS FOR THE CACHOEIRA RIVER BASIN - SOUTH OF BAHIA - BRAZIL

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ABSTRACT

For the dimensioning of several hydraulic works, it is necessary to know the intensity-duration-frequency (IDF) of the precipitation, which will guarantee the safety and economic viability of the project. Thus, the present work aimed to estimate the parameters of the intense rain equation for ten stations located within the limits of the hydrographic basin of the Cachoeira River, using two regression methods: multiple linear regression and non-linear regression. The adjustment of the parameters of the IDF equations using the linear and non-linear regression methods showed good results, with performance coefficients greater than 0.98% for both. Differences were observed between the maximum intensity calculated for the same station using the different adjustment methods, so that the choice of the regression method can affect the design calculation of hydraulic structures, as well as their design costs. The variability of parameters K and "a" reinforce the need to model and adjust the IDF parameters for each location, with a view to a better estimate of the intensity of the precipitation.
KEYWORDS: Precipitation, IDF ratio, hydraulic works.

EQUAÇÕES DE CHUVAS INTENSAS PARA A BACIA HIDROGRÁFICA DO RIO CACHOEIRA - SUL DO ESTADO DA BAHIA - BRASIL

RESUMO

Para o dimensionamento de diversas obras hidráulicas, faz-se necessário o conhecimento da relação intensidade-duração-frequência (IDF) da precipitação, o que garantirá a segurança e viabilidade econômica do projeto. Assim, o presente trabalho possuiu como objetivo realizar a estimativa dos parâmetros da equação de chuvas

intensas para 10 estações localizadas dentro dos limites da bacia hidrográfica do rio Cachoeira, utilizando dois métodos de regressão: regressão linear múltipla e regressão não linear. O ajuste dos parâmetros das equações IDF utilizando os métodos de regressão linear e não linear apresentaram bons resultados, com coeficientes de desempenho superiores a 0,98% para ambos. Foram observadas diferenças entre a intensidade máxima calculada para uma mesma estação utilizando os diferentes métodos de ajuste, de forma que a escolha do método de regressão pode afetar o cálculo de dimensionamento de estruturas hidráulicas, bem como seus custos de projeto. A variabilidade dos parâmetros K e “a” reforçam a necessidade de modelar e ajustar os parâmetros da IDF para cada localidade, com vistas a uma melhor estimativa da intensidade de precipitação.
PALAVRAS-CHAVE: Relação IDF, Obras hidráulicas, Precipitação.

INTRODUCTION

Knowledge of the spatial and temporal distribution of the variables that make up the hydrological cycle is fundamental for the correct management of water resources. Among these variables, precipitation stands out, which is the main form of water entering hydrographic basins. However, despite the ease of obtaining data from rainfall stations already operating in Brazil through online databases, depending on the region and the scarcity of rainfall collectors, series with hourly data may be non-existent, scarce or flawed, and as precipitation is a continuous variable, its study becomes a challenge (BACK, 2009; BACK et al., 2012; TRENBERTH; ZHANG, 2017).

Intense precipitations or extreme rains are pluviometric events that generate large precipitated blades in a short period of time (BERTONI; TUCCI, 2013). These events can cause small and large scale damage in both urban and rural areas, strengthening that knowledge about the intense rainfall in a region is essential for planning water and land use. (SOUZA et al., 2012; TUCCI, 2013; SILVA NETO, 2016).

The study of the three variables that make up the intensity-duration-frequency equation (IDF) is the main tool to characterize and analyze the IDF parameters and study the intense rains (SOUZA et al., 2012; DORNELLES; COLLISCHONN, 2016). These equations are adjusted empirically by applying different probability principles to the historical series of rainfall data for each station (ARAGÃO et al., 2013).

Among some ways of adjusting the parameters of the IDF equation, there are methods of multiple linear regression and non-linear regression. Several studies (SILVA; ARAÚJO, 2013; DIAS et al, 2020; FERRAZ, et al., 2020; PANSERA, et al., 2020) used these regression techniques to estimate the parameters of the intense rainfall equation, however, there are few studies that apply different methodologies and evaluate the differences in the estimation of maximum precipitation intensities.

In this way, this study aims to estimate the parameters of the equation of intense rain for 10 stations located within the limits of the hydrographic basin of the Cachoeira River, using two regression methods: multiple linear regression (MLR) and nonlinear regression (NLR).

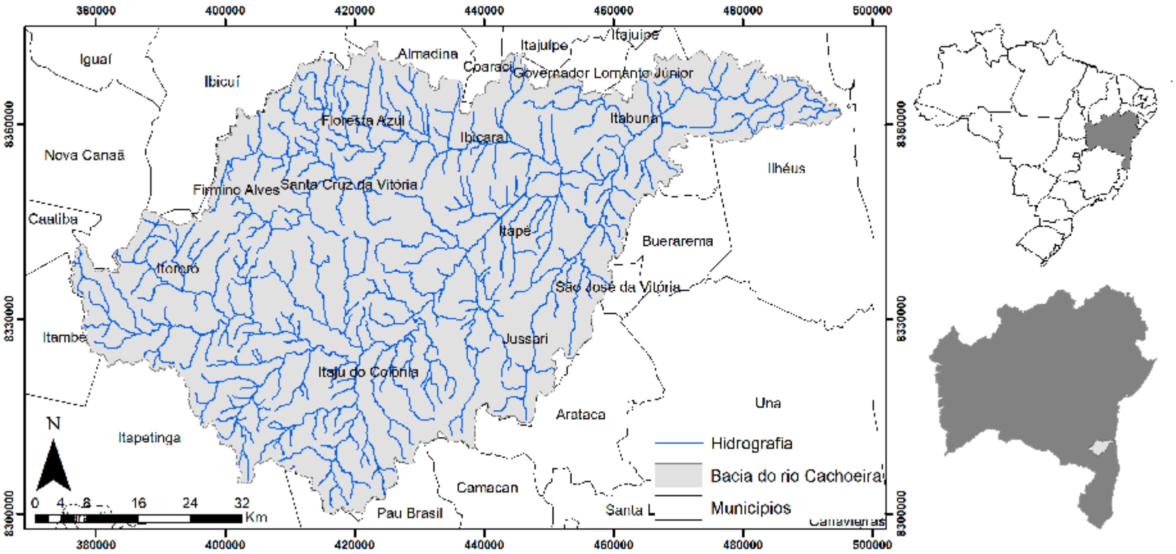
MATERIALS AND METHODS

Location and characterization of the study area

The Cachoeira river basin is located in the southern portion of Bahia (Figure 1), occupying an area of 4.273 km^2. It presents the Atlantic Forest as a predominant biome and concentrates an estimated population of almost 500.000 according to data from IBGE (2019), covering the municipalities of Ilhéus, Itabuna, Ibicaraí, Itapé, Jussari, Santa Cruz da Vitória, São José, Itajú do Colônia, Floresta Azul, Itororó, Itapetinga, Firmino Alves e Lomanto Júnior.

The predominant climates in the basin are classified as Tropical Wet Forest (Af), with high temperatures and high humidity and Tropical Wet and Sub-humid (Am), transition climate between Af and Aw (KÖPPEN, 1936). The region has an average monthly rainfall greater than 60mm, with a rainy period between November and April (ENGELBRECHT et al., 2019). The basin represents great importance for the socioeconomic development of the region, as it is a source of water for irrigation and a subsistence base for riverside families that use the tributaries as a source of food, income and leisure.

FIGURE 1 – Location of the Cachoeira river basin.



SOURCE: Authors (2020)

Input database

The daily rainfall data were obtained from the database of the National Water Agency - ANA, accessible on the Hidroweb Portal. Ten rainfall monitoring stations located inside the limits of the basin were used, whose criterion adopted for choosing was to have more than 20 years of daily data (Table 1).

TABELA 1 - Description and location of rainfall stations.

Code	City	Altitude (m)	Latitude	Longitude	Period (years)
1439001	Lomanto Júnior	151	-14.8103	-39.4714	48
1439002	Floresta Azul	210	-14.8597	-39.6583	50
1439089	Ibicaraí	163	-14.8694	-39.5880	34
1439044	Santa Cruz da Vitória	243	-14.9589	-39.8075	50
1539008	Itaju do Colônia	182	-15.1389	-39.7242	56
1539016	Itaju do Colônia 2	180	-15.1544	-39.7692	49
1439010	Ilhéus	78	-39.0514	-14.7894	36
1439019	Itabuna	55	-39.2667	-14.8000	25
1439023	Itajuípe	107	-14.6771	-39.3893	75
1539002	São José	153	-15.0921	-39.3456	49

SOURCE: ANA (2020).

The precipitation data were organized in spreadsheets on the Excel platform and later, the maximum daily precipitation records were obtained. The 24-hour rainfall data were disaggregated for shorter durations: 1440, 360, 60, 30, 20, 15, 10 and 5 minutes, using the CETESB (1986) coefficients, shown in Table 2.

TABLE 2 – Coefficients used to disaggregate rainfall.

Relationship between pluviometric heights	Disaggregate coefficient
1 dia/ 24h	1.14
12 hr/ 24h	0.85
6 hr/ 24h	0.72
1 hr/ 24h	0.42
30 min/ 1h	0.74
20 min/ 30 min	0.81
15 min/ 30 min	0.70
10 min/30 min	0.54
5 min/30 min	0.34

SOURCE: CETESB (1986)

The observed frequencies were calculated according to the Kimbal equation, which determines the frequency with which a given event can be equaled or exceeded at least once in a period of years (VILLELA; MATTOS, 1975):

$$F=\frac{m}{n+1} \qquad \text{(Equation 1)}$$

Where: f is the observed frequency, m is the order number of the maximum annual rainfall and n is equal to the number of years in the observed series. The return time (TR), was calculated using Equation 2 and describes the interval in years in which a precipitation event can be equaled or overcome at least once in a given time.

$$TR=\frac{1}{P(x \geq xi)} \qquad \text{(Equation 2)}$$

Where: TR is the return period and P is the probability of occurring a value equal to or greater than that analyzed, in the considered return period.

Subsequently, the maximum rainfall was estimated for each duration and RT of 2, 10, 20, 50 and 100 years, applying the Gumbel distribution, assessing adherence previously by the Komolgorov-Sminorv test at the significance level of 5 % probability. Subsequently, the parameters in Equation 3 were adjusted for each station. The methods for estimating the parameters were: multiple linear regression and Generalized Reduced Gradation (GRG), a non-linear regression method calculated using the Microsoft Excel Solver tool.

$$i = \frac{K \times T^a}{(t+b)^c} \quad \text{(Equation 3)}$$

Where: i is the maximum rain intensity, in (mm / h), T is the return period, in years; t is the duration of the rain, in minutes; and K, a, b, and c are parameters that depend on each rainfall station.

Performance analysis

The performance analysis of the equations was performed using the determination coefficient R^2 (Equation 4) and Pearson's correlation coefficient (Equation 5). The coefficient of determination (R^2) is widely used in hydrological studies and describes the degree of collinearity between simulated and observed data, ranging from -1 to 1, these extremes being considered optimal values. The Pearson coefficient, on the other hand, ranges from 0 to 1, with 0 without agreement and 1 perfect agreement.

$$R^2 = \left[\frac{\sum_{i=1}^{n}(x_{o,i} - x_{o,m})\,(x_{s,i} - x_{s,m})}{\sqrt{\sum_{i=1}^{n}(x_{o,i} - x_{o,m})^2}\,\sqrt{\sum_{i=1}^{n}(x_{s,i} - x_{s,m})^2}}\right]^2 \quad \text{(Equation 4)}$$

$$r = \frac{\sum(x_o - \bar{x}).(y_o - \bar{y})}{\sqrt{(\sum(x_o - \bar{x})^2).\sum(y_o - \bar{y})^2}} \quad \text{(Equation 5)}$$

Where R^2 is the coefficient of determination; r is the correlation coefficient; y_s the observed intensity of the moments method; x_s is the intensity predicted by the model; $\bar{y}$ is the average of the intensity of the method; x_o is the observed intensity, $x_{o,m}$ is the average observed intensity, and $x_{s,m}$ is the average simulated intensity.

To evaluate the modeling performance based on the described statistical coefficients, the criteria proposed by Hopkins (2000) and Moriasi et al. (2015), described in Table 3.

TABLE 3 – Criteria for evaluating model performance

Pearson coefficient (r)	Classification	R²	Classification
0.90-1.00	Almost perfect	**>0.85**	Very good
0.70-0.90	Great	**0.75-0.85**	Great
0.50-0.70	High	**0.61-0.75**	Good
0.30-0.50	Moderate	**0.51-0.60**	Satisfactory
0.10-0.30	Low	**0.40-0.50**	Unsatisfactory
0.00-0.10	Very low	**<0.4**	Sufferable

SOURCE: Hopkins (2000); Moriasi et al. (2015)

RESULTS AND DISCUSSION

All stations showed an adjustment to the Gumbel distribution, which was verified by the Kolmogorov-Smirnov adhesion test at 5% probability. Other studies, as Souza et al. (2019); Oliveira Júnior et al. (2019); e Petrucci e Oliveira (2019); Nascimento et al. (2020) e Lima et al. (2020), also presented similar results, justifying the use of this distribution function in the analysis of extreme events. Tables 4 and 5 show the values of the parameters obtained by non-linear regression and multiple linear regression, respectively, as well as the model's performance statistics for each method.

TABLE 4 - Parameters adjusted by non-linear regression and performance statistics.

City	***K***	***a***	***b***	***c***	**R²**	**r**
Lomanto Júnior	645.3651	0.2434	9.2416	0.7073	0.9904	0.9952
Floresta Azul	605.2813	0.2035	10.4999	0.7446	0.9942	0.9971
Ibicaraí	585.0570	0.2204	9.3305	0.7099	0.9928	0.9964
Santa Cruz	602.2241	0.2159	9.2545	0.7077	0.9932	0.9966
Itajú	607.0524	0.2322	9.2889	0.7087	0.9916	0.9958
Fazenda Manaus	611.8550	0.2204	9.2945	0.7089	0.9928	0.9964
Ilhéus	773.3384	0.2011	9.2545	0.7077	0.9945	0.9981
Itabuna	627.2586	0.2289	9.2918	0.7088	0.9920	0.9960
São José	650.4715	0.1785	9.2631	0.7079	0.9961	0.9973
Itajuípe	502.0071	0.2593	9.2751	0.7083	0.9884	0.9942

TABLE 5 - Parameters adjusted by multiple linear regression and performance statistics.

City	***K***	***a***	***b***	***c***	**R²**	**r**
Lomanto Júnior	759.9834	0.2065	12.5077	0.7684	0.9935	0.9967
Floresta Azul	685.4907	0.1874	12.4220	0.7676	0.9946	0.9972
Ibicaraí	759.4844	0.2065	12.4959	0.7683	0.9935	0.9967
Santa Cruz	791.6774	0.2012	12.4728	0.7681	0.9938	0.9968
Itajú	785.6087	0.2202	12.5605	0.7688	0.9926	0.9962
Fazenda Manaus	798.4894	0.2063	12.5070	0.7684	0.9935	0.9967
Ilhéus	1025.6797	0.1848	12.4232	0.7676	0.9947	0.9973
Itabuna	813.4937	0.2162	12.5396	0.7686	0.9929	0.9963
São José	635.1561	0.2542	12.7693	0.7706	0.9896	0.9947
Itajuípe	869.6056	0.1609	12.3451	0.7670	0.9957	0.9978

The parameters adjustment of the IDF equation for both the MLR and NLR methods presented correlation coefficients with performance considered “almost perfect” for Pearson’s coefficient and “very good” for the determination coefficient, according to the criteria shown in Table 3. On the adjustments of the equations, only one station (São José) presented R^2 equal to 0.98% by both MLR and NLR method.

In the adjustment made by linear regression, a variation in the values of *K* and *a* was observed. The highest *K* value was 1025.6797 for the municipality of Ilhéus, and the lowest was 635.1561 at the São José station. The parameter varied from 0.2593 (Itajuípe) to 0.1785 observed in São José. The parameters *b* and *c* presented little variability, which is explained by the fact that they are values fixed in the adjustment for the arrangement of the other parameters.

In the adjustment made by non-linear regression, it was also possible to observe differences between their values. The highest *K* value (773.3384) was observed in the municipality of Ilhéus and the lowest value (502.0071) for São José station. Parameter *a* ranged from 0.1785 for Itajuípe to 0.2593 for the station in São José. Parameter *b* had the lowest value 9.2416 for the Lomanto Júnior station and 10.4999 as the highest value for Floresta Azul, as well as the *c* values, in which the Lomanto Júnior station also had the lowest value (0.7073) and the highest for Floresta Azul (0.7446). This method also showed low variation between the values of parameters *b* and *c*.

The way that the *K* parameter is spatially distributed is similar to the results obtained by Campos et al. (2014), who also adjusted the IDF equations using the MLR and NLR methods. The authors concluded that the *K* and *a* parameters presented an inverse behavior, so the regions with higher precipitation intensity values presented higher *K* values and lower *a* values.

The *K* parameter also showed higher values in regions with greater precipitation intensity in the studies by Back and Cadorin (2020), which estimated the IDF equations for the state of Acre and perceived high values for this parameter because it is a region with high rainfall levels. Campos et al. (2017), carrying out the analysis of intense rains for the state of Paraíba, observed similar behavior, concluding that the highest *K* values were observed in areas with high average annual precipitation values.

Thus, this great variation between *K* and *a* can be explained due to the great spatial variability of rainfall distributions, as they are parameters directly related to rainfall behavior. These variations corroborate the need to model and adjust the IDF parameters for each location, with a view to a better estimate of extreme events, an idea shared by several authors (CAMPOS et al., 2014; GONÇALVES et al., 2019; FERRAZ et al., 2020; NASCIMENTO et al., 2020).

After estimating the parameters, the maximum precipitation intensity was calculated. The Ilhéus station showed a value of 247.64 mm/h using the equation in which the parameters were adjusted using the NLR method (Table 6). When the parameters obtained by MLR were used, the maximum intensity value was 297.87mm/h. Thus, a change was observed between the maximum values estimated for the same station using different methods, a fact justified by Campos et al. (2014) due to the differences between both methodologies used, and the choice of the parameter adjustment method can affect the dimensioning of hydraulic works and their project costs.

TABLE 6 – Estimated intensities (mm/h) for each duration and return time considering the different regression methods for the Ilhéus station.

	Non-linear regression							
TR	**min**							
	1440	**360**	**60**	**30**	**20**	**15**	**10**	**5**
10	7.05	18.54	60.53	90.45	111.37	127.17	149.74	185.28
50	8.63	22.70	74.14	110.78	136.41	155.76	183.41	226.93
100	9.42	24.77	80.91	120.89	148.85	169.97	200.15	247.64
	Linear regression							
TR	**min**							
	1440	**360**	**60**	**30**	**20**	**15**	**10**	**5**
10	7.12	18.74	61.25	91.53	112.70	128.69	151.53	187.45
50	9.84	25.90	84.66	126.52	155.78	177.88	209.45	259.11
100	11.31	29.77	97.32	145.45	179.09	204.49	240.78	297.87

CONCLUSION

For the locations studied, the Gumbel distribution proved to be adequate in the estimates of the parameters of the IDF equation, with a 5% significance level by the Komolgorov-Smmirnov test.

The adjustment of the parameters of the equations using the linear and non-linear regression methods, presented good results, with performance coefficients above 0.98%.

Differences were observed between the maximum intensity values calculated for the same station using different adjustment methods, so the choice of the regression method can affect the calculation of the design of hydraulic structures, as well as the design costs.

The variability of *K* parameters and *a* reinforce the need to model and adjust the IDF parameters for each location, with a view to a better estimate of the intensity of the precipitation.

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