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DETERMINAÇÃO DA EQUAÇÃO INTENSIDADE-DURAÇÃO-FREQUÊNCIA PARA ALGUMAS LOCALIDADES DO ESTADO DA BAHIA

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1 ABSTRACT

The objective of this study was to fit intensity-duration-frequency equations (IDF) for sites in Bahia state, Brazil. Maximum annual rainfall lasting 5, 10, 15, 20, 30, 60, 360 and 1440 minutes were fitted to Gumbel distribution. Equation parameters were estimated using Gauss Newton method for non-linear regressions. According to Kolmogorov-Smirnov test, all equations were fitted to Gumbel distribution. From fitted distributions, maximum annual rainfall intensity was calculated for 2, 10, 20, 50 and 100years return periods, which were used to define the equation for intense rainfall events. Fitting parameters of the equations varied across rain gage stations, especially for the parameter K, suggesting the need for determining these equations for each site, thereby providing information when designing agricultural and hydraulic projects.

Keywords: Hydrology. Extreme Rainfall. Distribution of Gumbel.

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2 RESUMO

O objetivo deste estudo foi determinar equações de intensidade-duração-frequência (IDF), com base em chuvas extremas para algumas localidades do Estado da Bahia. As precipitações máximas anuais com duração de 5, 10, 15, 20, 30, 60, 360 e 1440 minutos foram ajustadas à distribuição de Gumbel. Os parâmetros da equação foram estimados pelo método de regressão

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não linear de Gauss Newton. De acordo com o teste Kolmogorov-Smirnov houve ajuste de todas as equações à distribuição de Gumbel. Através das distribuições ajustadas, calcularam-se os valores de intensidade máxima anual de precipitação para períodos de retorno de 2, 10, 20, 50 e 100 anos, que serviram de base para definir a equação de chuvas intensas. Os valores dos parâmetros ajustados das equações variaram entre as estações, notadamente o parâmetro K, evidenciando a necessidade da determinação dessas equações para cada localidade para dimensionamento de projetos agrícolas e de obras hidráulicas.

Palavras-chave: Hidrologia. Chuvas Intensas. Distribuição de Gumbel.

3 INTRODUCTION

The knowledge of climatic variables is an important tool in planning urban and rural constructions; studying precipitation, which is one of the climate components, aids in structuring spaces and gaining insight into hydrological and agricultural dynamics.

Water enters a watershed mainly through rainfall, which is considered as a key variable for the climate; however, rainfall is hard to study since it is not a continuous variable (Trenberth, Zhang & Gehne, 2017). Quantifying rainfall, as well as knowing its temporal and spatial distribution, are essential for studies on irrigation, water availability for domestic and industrial demand, soil erosion, flood control, among others (Cecílio et al., 2009; Santos; Griebeler; Oliveira, 2010). Mondal & Mujumdar (2014) verified the variability of each characteristics composing extreme rainfall and emphasized the need for a comprehensive structure for assessing potential flood threats resulted from rainfall.

Intense rainfall may be defined as having high water depths occurring at short period of time (Campos et al., 2014). As rainfall is the main cause of erosion, it reduces soil depth and hence its capacity of storage and redistribution of water (Santos 2009), limiting crop yields. In urban areas, intense rainfall leads to flooding, pavement deterioration, as well as clogging of poorly-designed drainage systems.

Intensity-duration-frequency equations (IDF) are the main way of characterizing the relationship between these parameters (Prusky et al., 2006). The parameters composing IDF curves are fitted empirically using rainfall data of each station and site (Campos et al., 2014). These parameters can be adjusted using either linear or non-linear regressions (Aragão et al., 2013) based on data recorded from historical series of rainfall. Among probability distributions, Gumbel distribution has been most used in studies on extreme rainfall events (RODRIGUES et al., 2008).

Determining IDF curves might be difficult owing to the low density of pluviometers or rain gages and the size of the rainfall database. Therefore, as it is important to know the IDF curve for agricultural and drainage designing, this study aimed to estimate the parameters composing IDF equation for sites in Bahia state, Brazil, using rainfall data collected in the regions.

4 MATERIAL AND METHODS

The study was carried out at the State University of Southeastern Bahia, campus Vitória da Conquista, Bahia state, Brazil. Rainfall data from the municipalities of Canavieras, Lençóis, and Monte Santo were collected from the database of BDMEP, on INMET’s website.

The data were organized on Excel spreadsheets. Maximum annual rainfall for each year was selected to create a historic rainfall data averaging 24 years. Afterwards, data were sorted out in a descending order, and then, maximum rainfall events were disaggregated for each year using the disaggregation coefficient proposed by CETESB (1986) (Table 1).

Table 1. Disaggregation coefficients for different rainfall duration

Ratio between rainfall depths	Disaggregation factor
1 d/ 24 h	1.14
12 h/ 24 h	0.85
6 h/ 24 h	0.72
1 h/ 24 h	0.42
30 min/ 1 h	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 frequency was calculated using the method proposed by Villela & Mattos (1957). The return period (RT) was also calculated and represents an average time, in years, in which a given rainfall event is likely to occur or be exceeded at least once.

After disaggregating rainfall data into shorter events, mean and standard deviation were computed for each disaggregated time within a historic data. After, maximum events were estimated for each duration as 2-, 10-, 20-, 50-, and 100 years rainfall return periods using the Gumbel statistical distribution. Goodness of fit was tested by Kolmogorov-Smirnov test at 5% significance level (Teodoro et al., 2014).

With rainfall intensity for each duration and return period, the parameters of the IDF equation were determined, according to the model below (Equation 1), by Gauss Newton method for non-linear regression using the statistical software SAEG.

$$I = \frac{KTR^a}{(t+b)^c} \quad (1)$$

5 RESULTS AND DISCUSSION

Maximum annual rainfall events recorded at each rain gauge station were fitted to Gumbel distribution using Kolmogorov-Smirnov test at 5% significance level. Similar results were reported by Santos et al. (2010); Back et al. (2011); Souza et al. (2012); Mello, Viola (2013); Franco et al. (2014), Martins et al. (2017), and Wanderley et al. (2018), justifying the use of Gumbel distribution for analyzing extreme events.

Table 2 shows fitting parameters of IDF equations using data from five rain gauge stations in Bahia state, identified by the municipalities where stations are installed.

Table 2. Fitted parameters “K”, “a”, “b” and “c” of equation of intense rainfall for some sites in Bahia state and their respective coefficient of determination (r^2).

Sites	K	a	b	c	r^2
Canavieiras	876.93668	0.20071	9.26459	0.70799	0.995
Lençóis	866.26540	0.19800	9.23605	0.70710	0.995
Monte Santo	540.37399	0.23463	9.27312	0.70825	0.991

Fitting parameters, K, a, b, and c, varied across rain gage stations due to large spatial and temporal differences across rainfall distributions for each site. Among determined parameters, “K” fluctuated the most by ranging from 540.37399, in Monte Santo, to 876.93668, in Canavieiras. These changes reinforce the need for determining the parameters of IDF equation for each site for better estimating maximum rainfall, thereby increasing security when designing hydraulic projects as well as decreasing costs.

Fitted equations for all sites had good fittings by exhibiting r^2 above 0.98. These findings are corroborated by those reported by Santos et al. (2009) and Silva et al. (2003) who conducted similar studies for Mato Grosso do Sul and Tocantins states. These authors found coefficients of determination averaging 0,99 and 0,98 respectly.

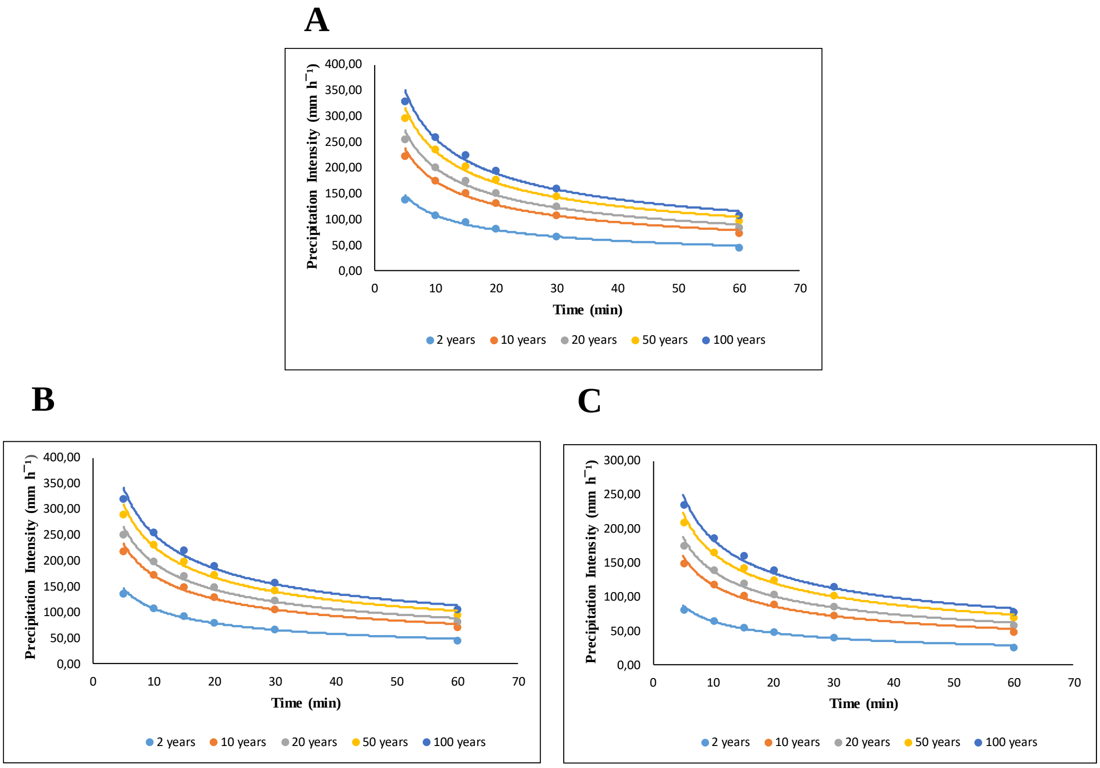
The way in which the parameters “K” are distributed spatially is similar to results obtained by Campos et al. (2014) who, fitting intensity-duration-frequency equations for Piauí state with linear and non-linear equations, reported that the parameter “K” had an opposite behavior to the parameter “a”; the regions that had higher intensity values were also those where higher values of “K” and lower values of “a” were observed, as shown in Table 2 for this study.

The highest values of the parameter "K" were observed in the municipality of Lençóis located in Chapada Diamantina; according to Koppen classification, the climate in Lençóis is Aw, which indicates the existence of a tropical climate with rainy summers, and Canavieiras that also has a tropical climate Af. Both municipalities have well distributed rainfall during the summer above 1000 mm per year. The lowest value of “K” was observed in the municipality of Monte Santo, which is in the semi-arid where long drought periods predominate and rainfall during rainy periods does not exceed 900 mm per year. Conversely, parameter “a” showed its highest values in the northeastern region of Bahia, and lower values in the south, central south and extreme west regions. These results reinforce the need for specific studies of extreme rainfall events for each region as the climate in these municipalities are ever changing, rainfall patterns differs, and hydro-agricultural works need to be sized for structures to withstand these events for the desired return period.

Furthermore, this study also suggests that rainfall intensities in the municipalities were higher where the parameter “K” were higher, and lower where the same parameter were lower, which is consistent with Santos (2015); this author that studied maximum intensities erosion caused by rainfall in Rio Grande do Norte state, and observed the highest values of "K" in areas located in the western and eastern regions of the state, which are the ones with the highest annual mean rainfall.

Figure 1 represents rainfall intensities according to different rainfall durations (5 to 60 minutes), for the return periods lasting 2, 10, 20, 50, and 100 years.

Figure 1. Rainfall intensities according to rainfall duration for the return periods (RP) of 2, 10, 20, 50, and 100 years in the municipalities of Canavieiras (A), Lençóis (B), and Monte Santo (C).



According to Figure 1, rainfall intensities are directly proportional to the return periods, and inversely proportional to rainfall durations, that is, more intense rainfall is expected in the first minutes of rainfall and for longer return periods. Similar results were observed by Petrucci & Oliveira, who obtained the intensity-duration-frequency relatonships for intense rainfall in the city of Uberlândia, Minas Gerais state, Brazil.

The difference in rainfall intensities shows the need for distinct equations for each evaluated site. Such variations might occur owing to characteristics of hydrological events within semi-arid regions in Bahia, where there is a high spatial and temporal variability in rainfall events. Major fluctuations in the fitting parameters of IDF equations, within the same regions, were also reported by FREITAS et al. (2001), GENOVEZ and ZUFFO (2000), and SILVA et al. (1999).

In general, for all return periods, the intensities are greater in the first 10 minutes, and for 2 years return period, the rain is milder than for a return period of 100 years. And from 15 minutes onwards, rainfall intensities gradually decrease.

6 CONCLUSION

For the sites studied herein, Gumbel distribution was suitable for estimating mean maximum intensity data, at 5% significance level, using Kolmogorov-Smirnov test. Fitted parameters of equations varied across equations, especially the parameter K, suggesting the need of determining these equations for each site.

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