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Intensity-duration-frequency of maximum rainfall in Mato Grosso State

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ABSTRACT

Intensive rainfall is an important meteorological variable that is of technical interest in hydraulic projects. This study therefore generated Intensity-Duration-Frequency equations (IDF) for 14 weather stations in Mato Grosso State, based on pluviograph analysis. Annual maximum rainfall data regarding 10-to-1440-minute long rainfall events were collected from digitized daily pluviographs. Data adherence to the generalized extreme value distribution (GEV) was checked through the Kolmogorov-Smirnov test at a 20% significance level. Next, the maximum probable rainfall for return periods such as 2, 5, 10, 20, 30, 50 and 100 years was calculated and the IDF equations were adjusted. The performance of the IDF equations was evaluated based on mean absolute error (MAE), root mean square error (RMSE), bias, Willmott's concordance index and Nash-Sutcliffe efficiency index (ENS). Adjusting the IDF equations was only possible for rainfall durations ranging from 10 to 360 min at each station due to the low frequency of longer rainfalls. High variation was present in parameters of the IDF equation and in maximum rainfall intensity between stations. The satisfactory performance of the models, as attested to by statistical indices, allows using IDF equations adjusted for rainfall durations from 10 to 360 min, and return periods from 2 to 100 years, in the regions of the Mato Grosso weather stations.

Keywords: IDF, intense rainfall, project rain, water resource management.

Intensidade-duração-frequência de precipitação máxima em Mato Grosso

RESUMO

A chuva intensa é uma importante variável meteorológica que apresenta interesse técnico em projetos hidráulicos. Assim, este estudo teve como objetivo obter equações intensidade-duração-frequência (IDF), obtidas por análise de pluviógrafos, para 14 estações no Estado do

Mato Grosso. As séries anuais de intensidade máximas de chuva com duração de 10 a 1440 min foram obtidas de Pluviogramas diários digitalizados. Verificada a aderência das séries à distribuição generalizada de valores extremos, pelo teste de Kolmogorov-Smirnov à 20% de significância, calculou-se as chuvas máximas prováveis para os tempos de retorno de 2, 5, 10, 20, 30, 50 e 100 anos e, ajustaram-se as equações IDF. O desempenho das equações IDF foi avaliado pelo erro absoluto médio (MAE), erro quadrático médio (RMSE), bias, índice de concordância de Willmott e índice de eficiência de Nash-Sutcliffe (ENS). Em todas as estações foi possível ajustar apenas equações IDF para chuvas com duração de 10 a 360 min, devido à baixa frequência de chuvas com duração superior. Houve grande variação na intensidade máxima da chuva e dos parâmetros da equação IDF entre as estações estudadas. O bom desempenho dos modelos, conforme atestados por índices estatísticos, permitem a utilização das equações IDF para as durações de 10 a 360 min e tempo de retorno de 2 a 100 anos, nas regiões das estações do Mato Grosso.

Palavras-chave: chuva de projeto, chuvas intensas, IDF, gestão de recursos hídricos.

1. INTRODUCTION

Intensive rainfall is one of the most important meteorological variables in climate studies, as it generates a considerable volume of water in short intervals (Pereira *et al.*, 2017). Thus, knowledge regarding the variables characterizing maximum rainfall, as well as the correlations between rainfall intensity, duration and frequency, are of technical interest to hydraulic projects such as spillways, channel terraces, agricultural, urban and road drainage systems, among others (Cheng and Amir, 2014).

The most accepted way to characterize maximum rainfall relies on the intensity-duration-frequency equation (IDF) (Campos *et al.*, 2014). The IDF curves are based on historical rainfall time-series data and are designed to capture the intensity and frequency of precipitation for different durations by fitting a theoretical probability distribution to annual extreme rainfall (Oriani *et al.*, 2017; Ouarda *et al.*, 2019). The first uses of IDF relationships date back to the 1930s (Bernard, 1932) and the first curve in Brazil was done in 1958 (Pfafstetter, 1958). Nowadays, because of its importance and ease of application, IDF curves are widely used in water management and other engineering design applications (Cheng and Amir, 2014).

Therefore, the difficulty in generating intense rainfall equations in Brazil is mainly attributed to the limited availability of data about rainfall network density and time range (Silva *et al.*, 2012). These issues are particularly concerning in the Northern and Central-Western regions of the country, as in Mato Grosso State, where pluviograph data sets comprise less than 30 years of collected data - the assessment period recommended by the World Meteorological Organization.

In addition to the lack of historical data about intense rainfall events, Mato Grosso State presents a large area that includes the Cerrado, Pantanal and Amazon Biomes, which have distinct rainfall characteristics (Marcuzzo *et al.*, 2011). Moreover, the State has been facing deep land-use and occupation changes in the last decades, mainly because of increasing urbanization, expansion of agriculture and construction of hydroelectric power plants.

However, the State has not yet defined intense rainfall equations based on the analysis of pluviograph records for most of its counties, since previous studies focused on adjusting IDF equations to Mato Grosso State were based on daily rainfall data disaggregation processes (Fietz *et al.*, 2010; Pizzato *et al.*, 2012; Mossini Junior *et al.*, 2016). Thus, the current study calibrated and evaluated the statistical performance of intensity-duration-frequency equations generated for 14 pluviograph stations located in the Cerrado, Amazon and Cerrado-Amazon-Pantanal transition biomes in Mato Grosso State.

2. MATERIALS AND METHODS

Mato Grosso State is located between geographic coordinates 06°00' S, 19°45' S and 50°06' W, 62°45' W; its territory covers 903,202,446 km^2 (IBGE, 2017). According to the Köppen classification, Aw (tropical savanna climate) and Cwa (tropical climate) are the predominant climates in the region; mean monthly temperature ranges from 23.00°C to 26.84°C, and total annual rainfall ranges from 1,200 to 2,000 mm (Souza *et al.*, 2013). The region has two well-defined seasons: the rainy season, from October to April; and the dry season, from May to September.

Rainfall data were collected from pluviographs belonging to the National Hydrometeorological Network (CPRM / ANA); these pluviographs referred to 14 counties (Table 1): 4 in the Amazon Biome (Northern mesoregion), 3 in Cerrado-Amazon-Pantanal transition biomes (Southwestern mesoregion) and 7 in the Cerrado biome (Southeastern mesoregion) (IBGE, 2012; 2013) (Figure 1). Since the stations did not have coincident data periods, no baseline study was adopted. In addition, only stations with at least 10 years of data were selected, however, and it was decided not to fill in data gaps in order to avoid bias in the estimation of the maximum annual rainfall.

Rainfall data recorded by rain gauges were obtained through the rainwater digitization system (HidroGraph 1.02) developed for the National Water Agency (ANA) by the Water Resource Research Group of the Agricultural Engineering Department of the University of Viçosa. Maximum annual precipitation heights recorded by each station for 10, 20, 30, 40, 50, 60, 120, 180, 240, 360, 720 and 1440-minute-long rainfall events were used to build the annual dataset about extreme rainfall events.

Table 1. Pluviograph rainfall stations belonging to the National Hydrometeorological Network (CPRM / ANA) used in the current study - Mato Grosso State, Brazil.

Code	Station Name	Lat.	Long.	Alt.	Dataset
	Amazon Biome (North Mesoregion)				
00956001	1 - Jusante Foz Peixoto de Azevedo	-09.64	-56.02	290	2002-2012
00956000	2 - Alta Floresta	-09.87	-56.10	400	2000-2010
01059000	3 - Humboldt	-10.18	-59.45	242	2002-2012
01157000	4 - Porto dos Gaúchos	-11.54	-57.42	260	2000-2011
	Ecotone of the Cerrado-Amazon-Pantanal Biomes (Southwest Mesoregion)				
01559006	5 - Mato Grosso	-15.01	-59.95	209	2002-2005 / 2007-2012
01559000	6 - Pontes e Lacerda	-15.22	-59.35	236	2001-2010
01558005	7 - Porto Esperidião	-15.85	-58.47	166	2001-2010
	Cerrado Biome (Southeast Mesoregion)				
01454000	8 – Paranatinga	-14.42	-54.05	484	2000-2010
01452000	9 – Xavantina	-14.67	-52.35	263	2001-2003 / 2007-2010
01654000	10 – Rondonópolis	-16.47	-54.66	220	2000-2010
01652001	11 - Ponte Branca	-16.77	-52.84	380	2000-2012
01653004	12 - Alto Garças	-16.94	-53.53	564	2000-2012
01753000	13 - Alto Araguaia	-17.30	-53.22	659	2000-2012
01853000	14 - Fazenda Taquari	-17.81	-53.29	845	2000-2012

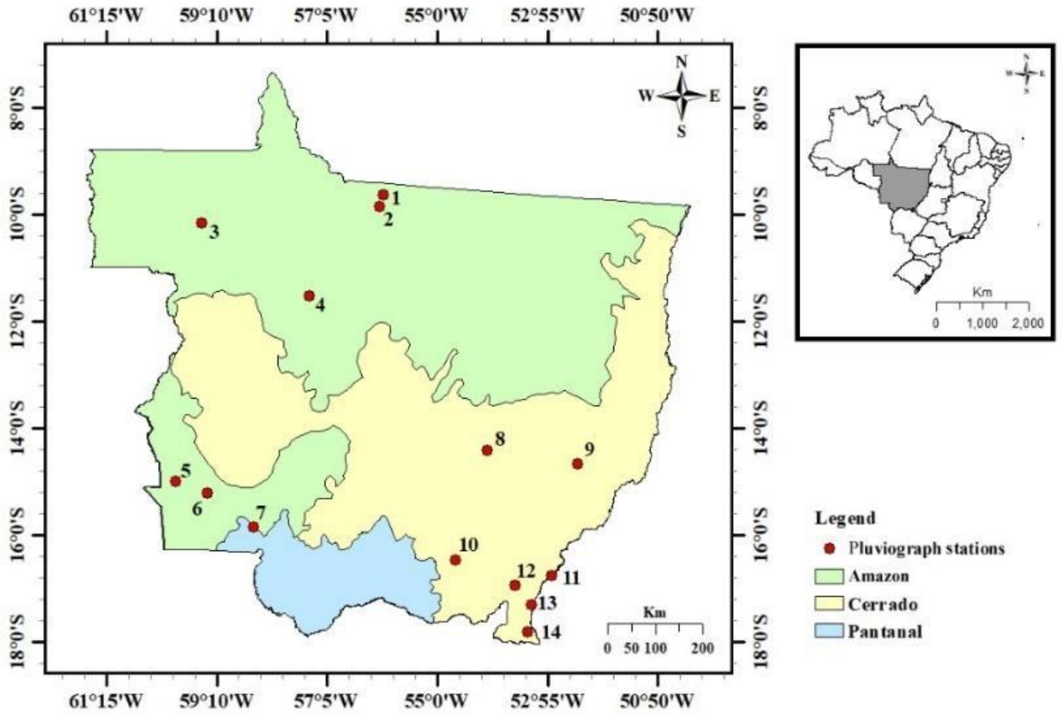

Figure 1. Location of pluviograph stations listed in Table 1.

The data set was tested for non-stationarity using the Mann-Kendall Test Modified as recommended in Cheng and Amir (2014) and Ouarda (2019). Then, the annual dataset for extreme rainfall events was adjusted to Generalized Extreme Value distribution (GEV), based on the maximum likelihood estimation (MLE) method applied to estimate probability distribution parameters. The adherence of the adjustments made in the series to the GEV distribution was investigated through the Kolmogorov Smirnov test, at a 20% probability level. This significance level was selected to limit the hypothesis test, since increased significance levels reduce the critical value of the statistical test (Naghettini and Pinto, 2007). After the GEV distribution parameters were adjusted, the probable maximum rainfall of each rainfall duration was estimated for return periods of 2, 5, 10, 20, 30, 50 and 100 years.

Parameters of the intensity-duration-frequency equation applied to each station were determined based on the Gauss-Newton non-linear adjustment technique (Chapra and Canale, 2006; Naghettini and Pinto, 2007), by using the maximum annual rainfall intensity recorded for return periods (RP) of 2, 5, 10, 20, 30, 50 and 100 years and rainfall durations (t) of 10, 20, 30, 40, 50, 60, 120, 180, 240, 360, 720 and 1440 minutes, as shown in Equation 1:

$$i = \frac{K \times RP^{a}}{(t+b)^{c}} \quad (1)$$

Where in: *i* is the maximum intensity (mm h^{-1}); RP is the return period (years); *t* is the rain duration time (min); and *K*, *a*, *b* and *c* are the adjusted local coefficients.

The performance of the IDF equations , whose models were significant at α: 0.05%, was evaluated based on the following statistical means: mean absolute error (MAE), root mean square error (RMSE), bias, Willmott's concordance index and Nash-Sutcliffe efficiency index (E_{NS}) (Willmott, 1982; Stone, 1993; Krause *et al.*, 2005; Pereira *et al.*, 2014), as shown in Equations 2, 3, 4 ,5 and 6, respectively.

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|O_i - P_i| \quad (2)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - P_i)} \quad (3)$$

$$Bias = \frac{1}{N}\sum_{i=1}^{N}(O_i - P_i) \quad (4)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O| + |O_i - O|)^2}\right] \quad (5)$$

$$E_{NS} = 1 - \left[\frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - O)^2}\right] \quad (6)$$

Where in: P_i is the estimated intensity (mm h^{-1}); O_i is the observed intensity (mm h^{-1}); O is the mean of observed intensities (mm h^{-1}); and N is the number of sample values.

3. RESULTS AND DISCUSSION

Table 2 presents the means and standard deviations of the annual series of maximum rainfall intensities corresponding to rainfall durations from 10 to 1440 minutes recorded by the stations in Mato Grosso State. Although some stations presented a nonstationarity tendency, in order to avoid inconsistencies between the evaluations of different stations and due to the fact that the data series generally only had 10 years, the data series were treated in a traditional way without considering non-stationary influences.

Maximum rainfall intensities tended to be higher in the Amazonian biome (Northern region of the State), whose means varied from 102.4 mm h^{-1} (10-min-long rainfalls) to 0.7 mm h^{-1} (for 360-min-long rainfalls). Stations located in the Southwestern and Southeastern regions of the State presented similar means, which ranged from 97.8 and 98.8 mm h^{-1} (10 min) to 0.1 and 0.3 mm h^{-1} (360 min), respectively. These results match the ones found by Marcuzzo *et al.* (2011), who recorded higher rainfall indices in the Amazonian biome (Northern Mato Grosso State) than in other phyto physiognomies in Southern Mato Grosso State.

There was no record of 1440-min-long (or longer) rainfall events in Mato Grosso State; however, there were only 7 records of 720-min-long rainfall events in the State. Alves *et al.* (2013) conducted a study in Cuiabá County-MT and also found low frequency of long-term rainfall events: there were three 1440-min-long rainfall events and thirteen 720-min-long events in a 22-year dataset.

The low frequency of rainfalls longer than 360 minutes results from the predominance of convective precipitations in the State, which, according to Salio *et al.* (2007), overall last less than 9 hours. On the other hand, longer precipitations are linked to frontal rainfall caused by cold fronts brought from the Southern region of the country by polar anticyclones (Seluchi, 2009). However, the incidence of polar anticyclones strong enough to cause precipitation is rare and often results in low-intensity/volume rainfalls (Nimer, 1972; Seluchi, 2009).

Table 3 presents the IDF equations applied to the herein-investigated locations and the respective values of the adjusted parameters "K", "a", "b" and "c". Parameters "K" and "b" showed higher coefficient of variation (CV), thus, according to Silva and Oliveira (2017) indicating no spatial dependence between stations. Parameters "a" and "c" presented average variability in the State; CV values were 33.39% and 21.08%, respectively.

Table 2. Mean- and standard deviation (mm h^{-1}) of the annual dataset regarding maximum rainfall intensities with durations ranging from 10 to 1440 minutes, Mato Grosso State - Brazil.

Station	Rainfall Duration (min)											
	10	20	30	40	50	60	120	180	240	360	720	1440
Amazon Biome (North Mesoregion)												
1 – Jus. Foz Peixoto de Azevedo	105.9	79.2	65.1	59.4	43.9	34.4	11.9	4.4	2.3	1.5	0.0	0.0
	(38.5)	(23.4)	(18.6)	(15.9)	(17.1)	(20.6)	(14.4)	(10.1)	(4.2)	(3.9)	(0.1)	(0.0)
2 - Alta Floresta	106.3	84.3	67.3	56.5	53.6	41.7	16.9	9.7	4.6	0.7	0.0	0.0
	(27.1)	(19.5)	(18.1)	(12.8)	(10.8)	(19.1	(13.9)	(10.5)	(6.4)	(1.2)	(0.0)	(0.0)
3 - Humboldt	94.9	75.5	64.3	55.8	52.5	44.8	17.7	10.1	5.6	0.2	0.0	0.0
	(33.2)	(17.1)	(15.1)	(14.4)	(11.7)	(11.8	(18.0)	(13.6)	(11.8)	(0.2)	(0.0)	(0.0)
4 - Porto dos Gaúchos	102.1	80.8	67.9	58.5	48.5	43.7	17.2	6.4	0.7	0.4	0.0	0.0
	(23.3)	(19.3)	(21.2)	(21.0)	(23.9)	(25.7)	(13.6)	(10.5)	(1.3)	(1.0)	(0.1)	(0.0)
Mean	102.4	80.1	66.3	57.6	49.7	41.3	16.0	7.6	3.2	0.7	0.0	0.0
S	29.8	19.4	17.9	16.0	16.8	19.9	14.6	11.0	6.9	2.1	0.1	0.0
CV (%)	0.29	0.24	0.27	0.28	0.34	0.48	0.91	1.44	2.14	3.02	2.80	0.00
Ecotone of the Cerrado-Amazon-Pantanal Biomes (Southwest Mesoregion)												
5 - Mato Grosso	79.2	69.0	61.0	55.2	37.7	34.8	3.8	0.6	0.4	0.1	0.0	0.0
	(18.7)	(12.8)	(14.8)	(12.8)	(17.8)	(14.8	(7.1)	(0.8)	(0.7)	(0.1)	(0.0)	(0.0)
6 - Pontes e Lacerda	108.2	70.8	65.2	52.1	45.8	34.6	9.2	0.6	0.2	0.2	0.0	0.0
	(36.2)	(26.0)	(28.0)	(20.6)	(20.5)	(17.6	(15.1)	(1.0)	(0.3)	(0.3)	(0.0)	(0.0)
7 - Porto Esperidião	106.9	84.6	63.8	47.5	45.5	31.7	10.2	2.2	2.0	0.1	0.0	0.0
	(24.9)	(23.8)	(19.5)	(13.2)	(12.7)	(13.9)	(9.6)	(3.3)	(3.4)	(0.1)	(0.0)	(0.0)
Mean	97.8	74.9	63.3	51.6	42.9	33.7	7.7	1.1	0.9	0.1	0.0	0.0
S	29.6	21.9	20.5	15.5	17.0	14.9	10.9	2.2	2.2	0.2	0.0	0.0
CV (%)	0.30	0.29	0.32	0.30	0.40	0.44	1.42	1.89	2.41	1.43	0.0	0.00
Cerrado Biome (Southeast Mesoregion)												
8 - Paranatinga	94.4	74.2	66.9	53.1	43.4	39.9	12.6	4.2	0.2	0.1	0.0	0.0
	(19.7)	(13.9)	(14.2)	(14.0)	(13.9)	(13.7	(9.6)	(7.7)	(0.1)	(0.1)	(0.0)	(0.0)
9 - Xavantina	136.1	95.6	81.3	72.3	59.3	51.7	8.5	7.4	4.6	1.3	0.0	0.0
	(19.4)	(30.2)	(24.8)	(22.5)	(12.8)	(16.4	(6.0)	(6.5)	(6.0)	(3.1)	(0.0)	(0.0)
10 - Rondonópolis	90.8	71.2	61.5	49.0	42.0	35.5	4.6	0.2	0.2	0.1	0.0	0.0
	(32.8)	(26.2)	(20.8)	(19.6)	(14.9)	(15.3	(6.7)	(0.3)	(0.1)	(0.1)	(0.0)	(0.0)
11 - Ponte Branca	93.2	67.9	56.2	48.6	44.7	39.9	14.2	2.2	0.7	0.1	0.0	0.0
	(20.8)	(12.6)	(15.0)	(13.4)	(13.6)	(14.8	(11.5)	(2.8)	(1.2)	(0.1)	(0.0)	(0.0)
12 - Alto Garças	115.6	81.3	67.3	54.0	46.0	38.2	10.2	3.2	2.2	0.1	0.0	0.0
	(49.4)	(38.0)	(30.4)	(20.6)	(17.1)	(14.8	(9.6)	(5.4)	(5.3)	(0.0)	(0.0)	(0.0)
13 - Alto Araguaia	86.8	65.9	57.9	49.6	41.3	36.1	10.5	1.1	0.3	0.2	0.1	0.0
	(20.4)	(13.0)	(15.0)	(12.6)	(13.0)	(12.6	(12.5)	(2.0)	(0.3)	(0.2)	(0.2)	(0.0)
14 - Fazenda Taquari	89.1	70.4	55.8	49.7	36.7	32.5	5.2	2.8	0.6	0.5	0.0	0.0
	(35.6)	(13.8)	(8.7)	(11.8)	(10.3)	(10.4)	(9.3)	(7.4)	(1.3)	(1.3)	(0.0)	(0.0)
Mean	98.8	74.0	62.7	52.6	43.9	38.3	9.5	2.8	1.1	0.3	0.0	0.0
S	33.3	23.3	20.0	17.0	14.5	14.3	10.0	5.4	3.0	1.1	0.1	0.0
CV (%)	0.34	0.32	0.32	0.32	0.33	0.37	1.06	1.94	2.86	3.87	4.41	0.00

The number in parentheses (below the mean) corresponds to the standard deviation (S).

Table 3. Parameters "K", "a", "b" and "c" calibrated for Intensity-duration-frequency equations, Mato Grosso State - Brazil.

Station	**K***	**a***	**b***	**c***
Amazon Biome (North Mesoregion)				
1 – Jus. Foz Peixoto de Azevedo	3407.410	0.163	19.952	1.029
2 - Alta Floresta	4766.289	0.098	29.239	1.036
3 – Humboldt	470.837	0.112	4.347	0.580
4 - Porto dos Gaúchos	5979.295	0.131	48.214	1.022
Mean	3655.957	0.126	25.438	0.915
Standard Deviation	2369.071	0.028	18.331	0.224
****CV (%)**	64.80	22.33	72.06	24.43
Ecotone of the Cerrado-Amazon-Pantanal Biomes (Southwest Mesoregion)				
5 - Mato Grosso	987.684	0.207	13.729	0.831
6 - Pontes e Lacerda	748.555	0.205	9.945	0.700
7 - Porto Esperidião	9750.604	0.102	33.438	1.215
Mean	3828.948	0.171	19.037	0.915
Standard Deviation	5129.698	0.060	12.614	0.267
****CV (%)**	133.97	35.12	66.26	29.23
Cerrado Biome (Southeast Mesoregion)				
8 – Paranatinga	9895.483	0.124	46.840	1.174
9 – Xavantina	6246.965	0.101	23.534	1.100
10 -Rondonópolis	14615.726	0.207	39.234	1.331
11 - Ponte Branca	10828.492	0.086	47.690	1.190
12 - Alto Garças	6037.949	0.182	17.764	1.178
13 - Alto Araguaia	7339.183	0.121	37.977	1.161
14 - Fazenda Taquari	7964.394	0.228	21.612	1.351
Mean	8989.742	0.150	33.521	1.212
Standard Deviation	3051.357	0.055	12.386	0.093
****CV (%)**	33.94	36.92	36.95	7.66
State of Mato Grosso				
Mean	6359.919	0.148	28.108	1.064
Standard Deviation	4134.327	0.049	14.484	0.224
****CV (%)**	65.01	33.39	51.53	21.08

* Parameters of equations adjusted for rainfalls with duration time (t) ranging from 10 to 360 minutes. ** CV <12% - low variability; 12% < CV <60% - average variability; CV> 60% - high variability (Silva and Oliveira, 2017).

High variation in parameters of the IDF equation were also reported in Bahia (Silva *et al.*, 2002); Tocantins (Silva *et al.*, 2003), Mato Grosso do Sul (Santos *et al.*, 2009), Pernambuco (Silva *et al.*, 2012), and Piauí (Campos *et al.*, 2014) states; such variation was associated with the large number of attributes involved in the process of modeling the dynamics of environmental phenomena (Mello and Silva, 2009).

Although the parameters of the IDF equation presented high variation in most stations of Mato Grosso State, the ones located near each other in the Cerrado Biome (Southeastern Meso-region) recorded average CVs for parameters "k" (33.94%) and "A" (36.92) , as well as low variability for "b" (36.95%) and "c" (7.66%).

Table 4 presents the results of the performance analysis applied to the IDF curves generated to estimate the maximum rainfall intensity at pluviographic stations in Mato Grosso State, based on different durations and return periods. The analysis of statistical indices showed that all the equations presented satisfactory performance, as seen in R^2 values higher than 86.65%

(Humboldt), which reached maximum value of 95.96% (Jusante Foz Peixoto de Azevedo). Mean absolute error (MAE) and root mean square error (RMSE) estimates showed good fit of the equations, which recorded 15.2 mm h^{-1} (MAE) and 18.9 mm h^{-1} (RMSE) for Pontes and Lacerda stations, as well as 9.9 mm h^{-1} (MAE) and 12.7 mm h^{-1} (RMSE) when all stations were taken into consideration.

Table 4. Performance of maximum annual rainfall intensity estimates in rainfall stations in Mato Grosso State, Brazil.

Stations	**R^{2*}**	**MAE ($mm\ h^{-1}$)**	**RMSE ($mm\ h^{-1}$)**	**Bias**	**d**	**Ens**
Amazon Biome (North Mesoregion)						
1 – Jus. Foz Peixoto de Azevedo	0.9596	8.21	10.25	-1.87	0.9902	0.9631
2 - Alta Floresta	0.9579	6.82	8.40	-0.45	0.9899	0.9616
3 - Humboldt	0.8665	10.57	14.17	-0.76	0.9656	0.8781
4 - Porto dos Gaúchos	0.8918	12.49	14.87	-5.35	0.9707	0.9012
Ecotone of the Cerrado-Amazon-Pantanal Biomes (Southwest Mesoregion)						
5 - Mato Grosso	0.8876	12.84	14.24	-5.84	0.9710	0.8973
6 - Pontes e Lacerda	0.8912	15.18	18.91	-8.78	0.9701	0.9007
7 - Porto Esperidião	0.9275	9.31	12.34	-1.95	0.9802	0.9338
Cerrado Biome (Southeast Mesoregion)						
8 - Paranatinga	0.9447	7.46	9.58	-4.05	0.9855	0.9495
9 - Xavantina	0.9287	10.62	13.25	-1.99	0.9835	0.9349
10 -Rondonópolis	0.9536	9.49	11.77	-4.63	0.9876	0.9577
11 - Ponte Branca	0.9269	7.92	9.73	-2.78	0.9808	0.9333
12 - Alto Garças	0.9414	9.33	15.69	-2.28	0.9857	0.9465
13 - Alto Araguaia	0.9263	7.99	10.29	-2.72	0.9808	0.9327
14 - Fazenda Taquari	0.9227	9.98	13.94	0.31	0.9803	0.9295

*Significant models at α: 0.05.

The bias index analysis indicated that all models were underestimated, except for Fazenda Taquari station, where there was a model overestimation of 0.3 mm h^{-1}. The Willmott concordance (d) and the Nash-Sutcliffe efficiency (Ens) indices confirmed the good fit of the models, since their values were close to 1 and they were classified as suitable, according to the criterion set by Van Liew *et al.* (2007).

Figure 2 shows the results of the adjusted rainfall intensities at different return periods, based on IDF equations of maximum rainfall intensities in Mato Grosso State. For the probable maximum precipitation estimates to design hydro-agricultural projects, usually those obtained for rains of 10-min-duration in a 10-year return period, Alto Garça station recorded the highest intensity (183.2 mm h^{-1}), while the lowest was recorded at Ponte Branca station (106.1 mm h-1). These results are on average 9.5 mm h^{-1} lower than the ones found by Fietz *et al.* (2010) for the same stations at Mato Grosso. Although, it's important to notice that the estimates presented by Fietz *et al.* (2010) were done by means of desegregation of daily precipitation and not by pluviograph analysis, which could lead to rainfall-intensity overestimation, as can be shown when compared to the study of Castro *et al.* (2011) that found by pluviogram analysis an intensity of 165.6 mm h^{-1} at Cuiabá, results these similar to those of this work.

The lowest 60- and 360-minute rainfall estimates were recorded for Fazenda Taquari station (35.2 and 4.4 mm h^{-1}, respectively). Porto do Gaúchos and Pontes e Lacerda stations recorded the highest intensity for 60- and 360-minute-duration rainfalls (67.3 and 19.1 mm h^{-1}, respectively). The highest rainfall intensity variations happened at rainfall durations shorter than 120 minutes due to the prevalence of convective rains; the curve smoothed after 120-minute-duration rainfalls.

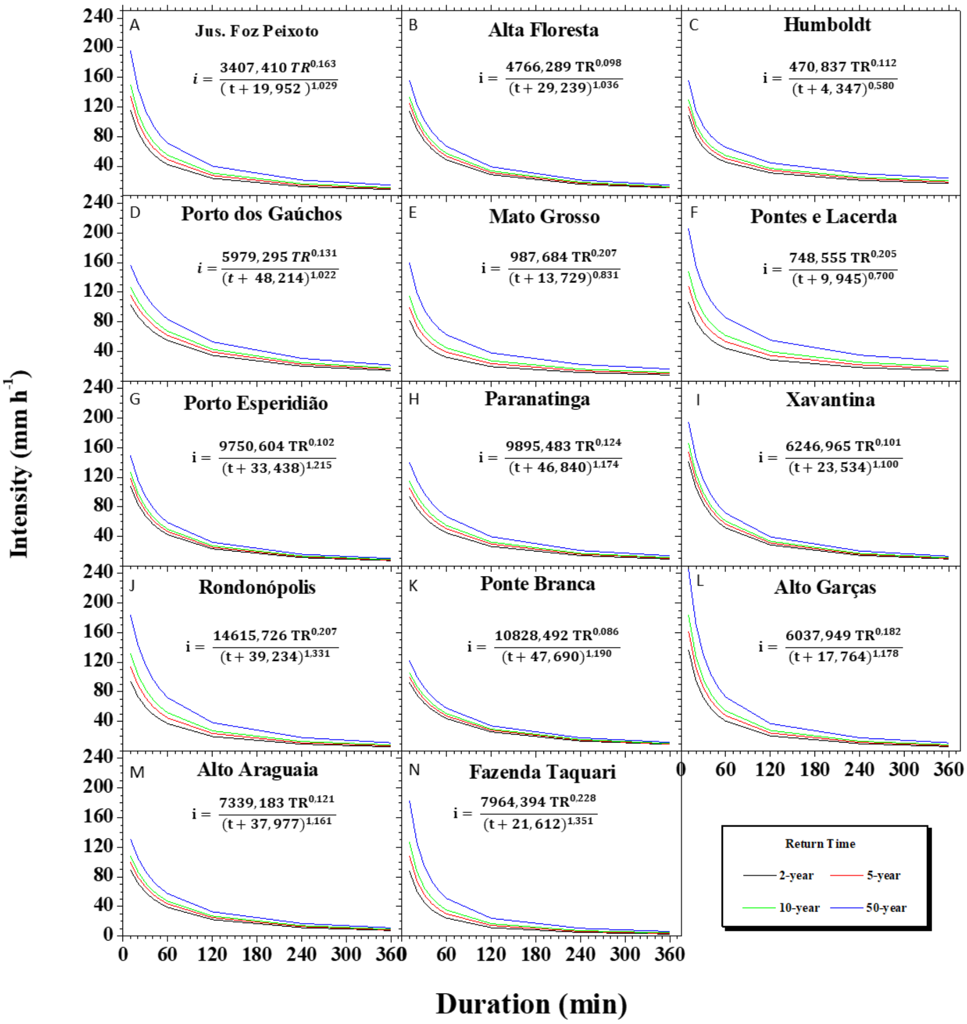

Figure 2. Maximum rainfall intensity curves recorded for different return periods and adjusted through the IDF equations - Mato Grosso State.

Topography is also a key factor for rainfall intensity in Mato Grosso State (Souza *et al.*, 2013), and as such similar rainfall estimates were found in Amazon Biome stations located at altitudes ranging from 242 to 400 m, and high variation was found in estimates for the Cerrado Biome located at Petrovina Mountain, where the altitude varied from 220 to 845 m. The orographic effect became evident when Alto Garça station was compared to Ponte Branca station. These stations were 75 km away from each other; however, they recorded rainfall-estimate differences of 77.1 mm h^{-1}, (183.2 mm h^{-1} at Alto Garça and 106.1 mm h^{-1} at Ponte Branca) for hydro-agricultural rainfall projects, corresponding to precipitation of 10-minute duration and 10 years of return time.

The small-scale variability of rainfall intensity can sensibly increase the complexity of the hydrological response, conditioned by weather and soil indicators and topography (elevation) (Oriani *et al.*, 2017). For Haiden e Pistotnik (2009), in mountainous terrain (similar to what occurs in the southern and central regions of Mato Grosso state), elevation differences strongly contribute to the small-scale spatial variability of precipitation. The effect is most pronounced for long accumulation periods such as monthly or annual; however, they may interfere with the intensity of local precipitation.

4. CONCLUSIONS

The IDF equations presented satisfactory adjustments, with determination coefficients above 87%, allowing the estimation of intense rainfall with 10 to 360 minutes duration and return periods from 2 to 100 years. The equations may therefore be used as a basis for hydrological studies in the state of Mato Grosso, and may also serve as a reference for engineering projects and prevention of extreme precipitation events.

The regionalization of the IDF equations for the state is not indicated due to the high variability of the IDF curves parameters of the current stations. The high variability is still indicative of the need for more weather stations to be distributed in Mato Grosso.

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