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Intensity-Duration-Frequency Equations of heavy rainfall for Itabuna and bordering municipalities, Brazil

Equações de Intensidade-Duração-Frequência de chuvas intensas para Itabuna-BA e municípios limítrofes

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Abstract: The aim of this study is to determine the parameters of the intensity-duration-frequency (IDF) equation of intense rains for the municipalities of Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema, and Barro Preto in Bahia, Brazil. The stations that had more than 20 years of coherent data and whose historical series had records from 1980 were chosen. For each station, the series of maximum precipitation of one day were obtained for the following return periods (TR): 5, 10, 15, 25, 50, and 100 years. Then, the precipitation of one day was disaggregated into smaller intervals of 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720, and 1440 minutes. The adjustment of the IDF equation parameters is performed through nonlinear multiple regression, using the Generalized Reduced Gradient (GRG) iteration method. Twelve pluviometric stations were identified within the studied area, but three stations were discarded due to lack of data. Therefore, the data from nine pluviometric stations were adjusted, where the adjustment of the K, a, b, and c parameters of the Intensity-Duration-Frequency equation showed values above the coefficient of determination (R^2) of 0.997, demonstrating a very good fit to the observed data.

Keywords: Inundation; Maximum Precipitation; Return Period.

Resumo: Objetivou-se neste trabalho determinar os parâmetros da equação de intensidade duração e frequência (IDF) de chuvas intensas para os municípios baianos de Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema e Barro Preto. Foram escolhidas estações pluviométricas na Agência Nacional de Água que apresenta mais de 20 anos de dados e com registros a partir de 1980. Para cada estação foi obtida as séries de precipitação máxima de 1 dia, para os seguintes períodos de retorno (TR): 5, 10, 15, 25, 50 e 100 anos. Em seguida foi realizada a desagregação da precipitação de um dia em intervalos menores de 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720 e 1440 minutos. O ajuste dos parâmetros da equação IDF foi realizado por meio de regressão múltipla não linear, pelo método de iteração de Gradação Reduzida Generalizada (GRG) Não Linear. Foram identificadas 12 estações pluviométricas dentro da área trabalhada, porém 3 estações foram descartadas por falta de dados. Assim, fez-se o ajuste das 9 estações pluviométricas onde o ajuste dos parâmetros K, a, b e c da equação de Intensidade-Duração-Frequência apresentaram valores acima do coeficiente de determinação (R^2) 0,997, demonstrando um ajuste muito bom aos dados observados.

Palavras-chave: Inundação; Precipitação Máxima; Período de Retorno.

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1. Introduction

Rainfall is the main source of water in a hydrographic basin, and for its characterization, it is necessary to know its duration, intensity and frequency of occurrence or return period (Tr) (GARCIA; JUNIOR, 2022).

Intense rains or extreme rains are characterized by large precipitated depths in short intervals of time (NASCIMENTO; NASCIMENTO, 2022). According to Cecílio *et al.* (2009), by causing large surface runoffs, heavy rains are capable of causing damage, both in urban and agricultural areas, such as flooding of cultivated land, soil erosion, nutrient losses and siltation of water bodies.

Due to the lack of information on the equations of heavy rainfall for most areas of Bahia, many hydraulic works projects end up using data from rainfall stations closer to the region in question. However, this method can result in unreliable estimates due to the great spatial variability of rainfall data.

In this context, in view of the importance of knowing the equation that relates intensity, duration and frequency of rainfall, it is important to update the existing equations in the municipalities of Itabuna and the surrounding region. According to Del-Toro-Guerrero and Kretzschmar (2020), another relevant piece of information concerns the changes in precipitation characteristics that have been observed in response to climate change.

Thus, it is intended to obtain the historical series of precipitation of the pluviometric stations, as well as to verify and correct failures in these series, to estimate the maximum precipitation in one day for different return periods, to determine the parameters of the IDF equation and to compare the simulated values with the values observed in the historical series of the pluviometric stations, when available.

To achieve the objective, it is necessary to define the parameters of the intensity, duration and frequency equation (IDF) of intense rainfall in 12 pluviometric stations, using the data available in the database of the National Water Agency (ANA). The work determines parameters for the municipalities of Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema and Barro Preto, located in the south of Bahia.

The understanding of the formula that connects the intensity, duration and frequency (IDF) of rainfall arouses significant interest in technical terms in hydraulic projects, such as: calculation of the size of spillways, correction of river courses, construction of rainwater galleries and drainage systems for agriculture, urban areas and roads, among others. In addition, it is known that knowledge of rainfall characteristics allows for safer design of soil conservation structures (terraces, contour lines) and agricultural practices that maintain their cover (NETO *et al.,* 2020).

These parameters are important to understand and predict rainfall patterns in each region, helping in the management of water resources and in the planning of infrastructure works to deal with intense rainfall. The study plays a relevant role in the understanding and management of rainfall in the municipality of Itabuna and surrounding municipalities. In this way, the objective of this work was to determine the parameters of the intensity, duration and frequency equation (IDF) of heavy rainfall from 12 pluviometric stations, obtained through the ANA database, for the Bahian municipalities of Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema and Barro Preto.

2. Methodology

The scope of this paper covers the Bahian municipalities of Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema and Barro Preto (Figure 1).

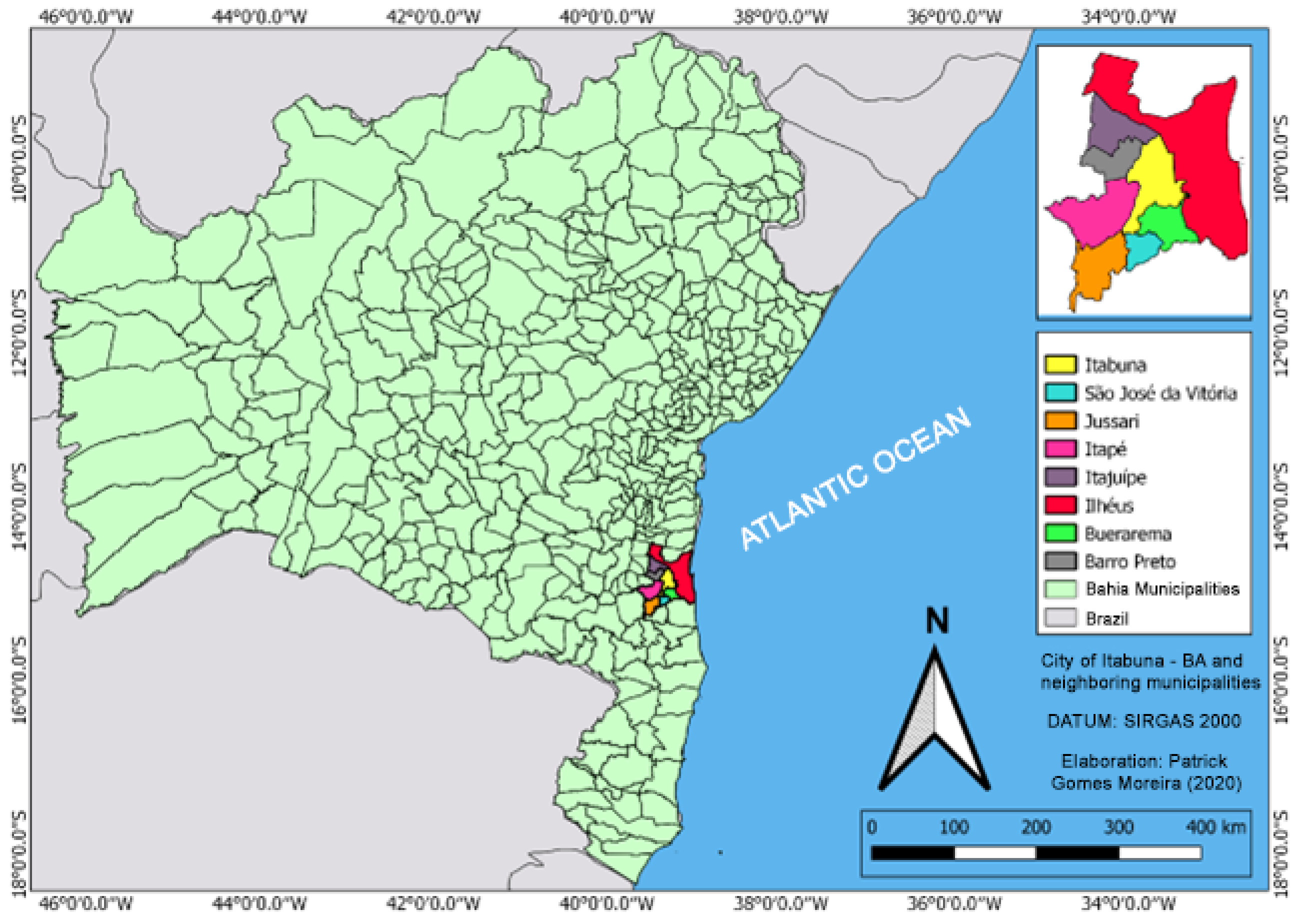

Figure 01 – Municipality of Itabuna, São José da Vitória, Jussari, Itapé, Itajuípe, Ilhéus, Buerarema, Barro Preto. Source: Authors (2025).

In accordance with the data from Brazilian Institute of Geography and Statistics (IBGE, 2022) the municipality of Itabuna - BA has about 214,123 inhabitants and an area of 401,028 km². The region's climate is tropical, hot and humid with forest vegetation cover, that is, the average monthly temperatures are above 18°C. With annual rainfall averages of 2000 mm, the predominant biome in the region is the Atlantic Forest. Ferraz *et. al* (2020) explains that in the driest month there is precipitation greater than 60 mm and the highest volume of rain is between the months of March and August.

According to data from the SOS Mata Atlântica Foundation & INPE (1995-2000), the Atlantic Forest had about 1.5 million km², which covered from the Brazilian coast to the east of Paraguay and northeast of Argentina. This biome is the second largest tropical rain forest on the American continent, second only to the Amazon Rainforest. It is also considered a biodiversity hotspot, that is, it has large amounts of endemic endangered species, hence they are preferred areas when it comes to conservation-related programs.

Initially, rainfall records from meteorological stations were collected, available in the database of the National Water Agency (ANA, 2016), with more than 20 years of daily observations, distributed in Itabuna and neighboring municipalities. Then, a search was performed for inconsistent data in the historical series and corrections were made to eliminate the inconsistent values. Based on this analysis, the stations that presented more than 20 years of coherent data and whose historical series had records from 1980 onwards were chosen. Figure 2 allows the identification of the location of the pluviometric stations used in this study.

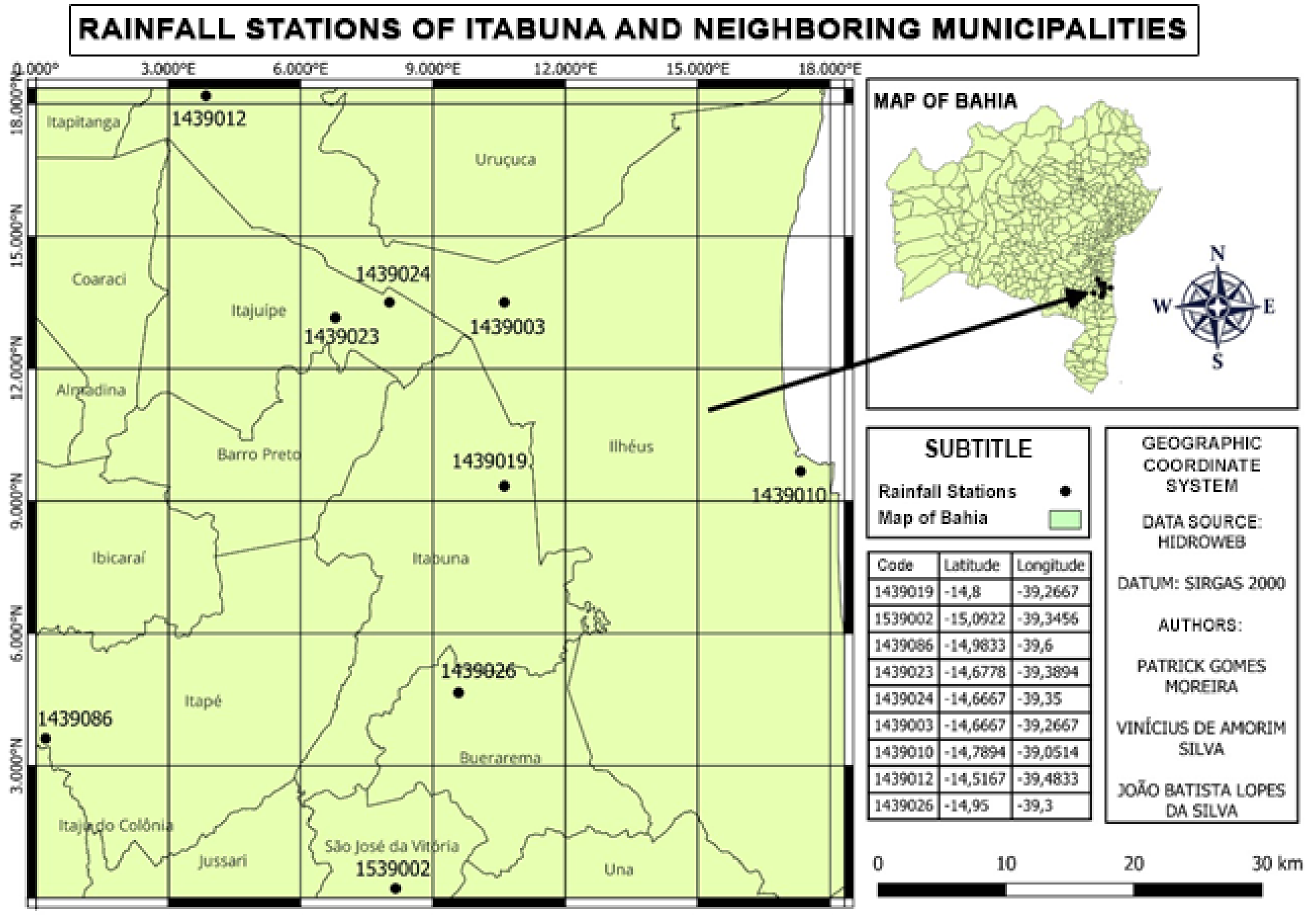

Figure 2 – Location of the study's rain gauge stations.
Source: Authors (2025).

The variation in intensity with frequency is related to the probability of occurrence or exceedance of the rainfall event, and is therefore obtained through a probability distribution function that allows for extrapolation to a period of years greater than the number of years of observation.

In this study, the series of maximum 1-day precipitation for each station were used, considering return periods (TR) of 5, 10, 15, 25, 50, and 100 years. These series were generated using different probability distributions, such as: Gumbel, Log-Normal II, Log-Normal III, Pearson III, and Log-Pearson III, following the methodologies proposed by Kite (1988) and Naghettini and Pinto (2007).

The maximum precipitations for each station were selected based on their fit to the probabilistic models using the Kolmogorov-Smirnov test. After the test, the distribution model with the lowest mean standard error was selected using the SisCAH tool, which assisted in all stages of this process (SOUSA et al., 2009).

Next, the 1-day precipitation was disaggregated into smaller intervals of 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720, and 1440 minutes using the rainfall disaggregation method proposed by CETESB (1979).

According to the Environmental Sanitation Technology Company (CETESB), the proposed method adopts an average factor of 1.14 to convert the maximum 1-day rainfall into 24-hour rainfall. It being estimated using the Gumbel distribution. For the other durations, the coefficients presented in Table 1 are used.

Table 1 – Rainfall disaggregation coefficients for shorter time intervals.

Transformation interval	Coefficients	Transformation interval	Coefficients
1 day for 24h	1,14	1 h for 30 min	0,74

1 day for 12 h	0,85	1 h for 25 min	0,91
24 h for 10 h	0,82	1 h for 20 min	0,81
24 h for 8 h	0,78	1 h for 15 min	0,7
24 h for 6 h	0,72	1 h for 10 min	0,54
24 h for 1 h	0,42	1 h for 5 min	0,34

Source: Cetesb (1979).

After disaggregating the precipitation into smaller intervals, the parameters K, a, b, and c of the intensity-duration-frequency equation were determined for each station:

$$IDF = \frac{K \cdot TR^{a}}{(t+b)^{c}} \tag{1}$$

Where:

IDF – Average maximum rainfall intensity, mm h^{-1};

TR – Return period, years;

t – Rainfall duration, minutes; and

K, a, b, and c – parameters adjusted based on the local rainfall data.

The adjustment of the IDF equation parameters is carried out using nonlinear multiple regression through the Generalized Reduced Gradient (GRG) Nonlinear iteration method. The Excel Solver tool package (SOLVER, 2010) was used to perform all the described steps, with the adjustment evaluation conducted using the coefficient of determination (R^2).

3. Results e discussions

Twelve rain gauge stations were identified within the studied area. Table 2 shows the list of the acquired codes, the names of the municipalities where the stations are located, the start and end dates of the series, as well as the length of each series for the 9 adjusted stations.

Table 2 – Selected rain gauge stations with more than 20 years of data and records starting from 1980, and their respective series lengths

Code	City	Beginning of the series	End of the series	Size of series
01439019	Itabuna	1964	1989	25
01539002	São José da Vitória	1970	2006	36
01439086	Itapé	1969	1989	20
01439023	Itajuípe	1945	2006	61
01439024	Itajuípe	1964	1989	25
01439003	Ilhéus	1965	1986	21
01439010	Ilhéus	1964	1991	27
01439012	Ilhéus	1964	1989	25
01439026	Buerarema	1964	1998	34

Source: Authors (2025).

Based on table 2, a verification was carried out for the stations with more than 20 years of data and records starting from 1980 onwards. Three stations were discarded: 01439017 and 01439018, that are located in Itabuna, and 01539032, located in Jussari, as shown in table 3. Of the discarded stations, 2 had records prior to 1980 with a return period greater than or equal to 20 years, and 1 station had a 15-year return period, but with an end of series before 1980. Thus, only 9 stations remained for the estimation of the IDF parameters.

Table 3 – Rainfall stations discarded for inconsistent records

Code	Municipality	Start of the series	End of the series	Series length
01439017	Itabuna	1945	1960	15
01439018	Itabuna	1943	1963	20
01539032	Jussari	1953	1978	25

Source: Authors (2025).

In this analysis of the maximum precipitation associated with a specific return period, the predominant probabilistic distribution was Log-Normal (LGN 3). The lowest value of the Mean Standard Error(MSE) was observed at the Itapé station (Estiva de Baixo), whose code is 01439086, with a value of 1,30. A value of 100,46 and the Pearson 3(PRS 3) probabilistic distribution were obtained for the adjustment precipitation corresponding to the five-year return period at the Itapé station.

At Ilhéus station (Inema), whose code is 01439012, the highest Mean Standard Error was recorded, represented by a value of 2,00. The value obtained for the precipitation adjustment associated with the 100-year return period was 133,16, with a Log-Normal 2 (LGN 2) probabilistic distribution, as demonstrated in table 4.

Table 4 – Analysis of maximum daily rainfall associated with a return period, with the best-fit statistical distribution and its Mean Standard Error (MSE).

	Rainfall associated with return period (mm)						**Statistical probabilistic distribution with best fit**						**MSE of the best-fit probabilistic distribution**					
Code	**5**	**10**	**15**	**25**	**50**	**100**	**5**	**10**	**15**	**25**	**50**	**100**	**5**	**10**	**15**	**25**	**50**	**100**
01439019	90,51	109,65	120,76	134,84	154,28	189,05	LGP3	LGP3	LGP3	LGP3	LGP3	GBL	9,16	12,97	15,48	18,93	24,09	29,08
01539002	89,37	99,98	105,6	113,71	123,55	133,12	LGN3	LGN3	LGN3	LGN2	LGN2	LGN2	4,46	5,72	6,76	8,22	9,62	10,99
01439086	100,46	105,88	108,22	110,61	113,15	115,11	PRS3	PRS3	PRS3	PRS3	PRS3	PRS3	3,52	3,8	4,59	5,91	7,92	9,96
01439023	103,39	118,12	125,97	135,32	152,48	166,95	LGN3	LGN3	LGN3	LGN3	LGN2	LGN2	4,77	6,16	7,33	9,1	11,39	13,19
01439024	82,88	92,74	97,64	103,2	109,93	115,96	PRS3	PRS3	PRS3	PRS3	PRS3	PRS3	5,87	6,86	7,7	8,96	10,93	13,09
01439003	71,72	82,28	87,78	94,21	102,3	109,84	LGN3	LGN3	LGN3	LGN3	LGN3	LGN3	6,1	7,63	8,87	10,71	13,59	16,81
01439010	93,54	107,1	114,08	122,18	132,28	141,62	LGN3	LGN3	LGN3	LGN3	LGN3	LGN3	7,2	8,86	10,2	12,19	15,29	18,74
01439012	79,25	94,61	101,65	110,3	121,8	133,16	LGP3	LGN2	LGN2	LGN2	LGN2	LGN2	6,61	9,31	10,67	12,36	14,66	16,95
01439026	91,89	103,63	109,65	116,61	125,24	133,18	LGN3	LGN3	LGN3	LGN3	LGN3	LGN3	5,5	6,73	7,71	9,17	11,44	13,95

Source: Authors (2025).

All equation adjustments indicated a very strong correlation, as they presented a coefficient of determination (R^2) above 0.997, with an average R^2 of 0.998, as shown in Table 5. Values between 0.9 and 1.0 demonstrate that the correlation between the variables is very strong. The results presented in this study are similar to those found by Souza et al. (2013), as in their work, the IDF equation parameters showed variation from one station to another, with R^2 values above 0.98.

Table 5 – Parameters of the IDF equation for the selected stations, along with the quality of the equation fit, R^2, Standard Error of the Mean, and the regression equation of the fit.

		Parameters of the Equation (IDF)				**Quality of the IDF equation**		
Code	**Municipality**	**K**	**A**	**b**	**c**	**R²**	**SPM**	**Equation**
0143909	Itabuna	728.683	0.246	11.158	0.759	0.999	1.447	y = 1.017x – 0.703
0153902	São José da Vitória	951.813	0.133	12.483	0.773	0.999	1.336	y = 1.008x – 0.005
0143906	Itapé	1212.832	0.045	12.269	0.771	0.999	1.301	y = 1.006x – 0.031
0143903	Itajuípe	1100.215	0.160	13.076	0.779	0.999	1.435	y = 1.013x + 0.166
0143904	Itajuípe	1033.277	0.112	14.239	0.790	0.998	1.838	y = 1.009x + 0.416
0143903	Ilhéus	809.074	0.142	13.499	0.783	0.998	1.692	y = 1.003x + 0.183
0143900	Ilhéus	1064.180	0.138	13.532	0.783	0.998	1.706	y = 1.002x + 0.252
0143902	Ilhéus	881.079	0.173	14.004	0.787	0.997	2.000	y = 1.000x + 0.238
0143906	Buerarema	1045.236	0.124	13.197	0.780	0.998	1.582	y = 1.003x + 0.174

Source: Authors (2025).

Note: The regression equation fit demonstrates the quality of the fit through the slope coefficient of the line. The closer it is to 1 (one), the better the fit, as the simulated data are closer to the real collected data.

The statement regarding a very strong correlation can also be affirmed through the regression equation of the observed and adjusted data, as the slope coefficient of the line was close to 1.0 for all stations analyzed in the study. The regression equation fit demonstrates the quality of the fit through the slope coefficient of the line, where the closer it is to 1, the better the fit, since the simulated data are closer to the real collected data.

Table 6 compares the equation parameters obtained for the city of Itabuna in the present study with the parameters extracted from the study by Ferraz et al. (2020) for the same city. Upon analyzing the results, it can be concluded that there is no significant discrepancy between the values obtained in both studies.

Table 6 – Comparison between the equation parameters and the coefficient of determination obtained by Ferraz et al. (2020) and by the authors (*).

		Parameters of the Equation (IDF)				**Coefficient of Determination**
Code	**Municipality**	**K**	**A**	**B**	**c**	**R²**
01439019	Itabuna	627.259	0.229	9.292	0.709	0.992
01439019	Itabuna	**k***	**a***	**b***	**c***	**R²***
		728.683	0.246	11.158	0.759	0.998

Source: Authors (2025).

Without asterisk: data obtained by Ferraz et al., 2020.

With asterisk: data obtained by the authors.

The values of the parameters K, a, b, and c obtained in the present study were 728.683; 0.246; 11.158; and 0.759, respectively. In contrast, in the study conducted by Ferraz et al. (2020), the values found were 627.259 for the parameter K, 0.229 for the parameter a, 9.292 for the parameter b, and 0.709 for the parameter c.

In Table 6, it can also be observed that the coefficient of determination (R^2) values for the same rainfall station, identified by code 01439019, are very close. The value obtained in this study was 0.999, while Ferraz et al. (2020) identified a value of 0.992.

According to the study by Almeida et al. (2013) on the parameters of the intense rainfall equation in the municipalities of Viçosa and Palmeira dos Índios, in the state of Alagoas, results were obtained with R^2 values above 0.99. The parameters of the fits (K, a, b, c) of the equations showed high variability from one station to another, a result similar to that found in the present study. Lima et al. (2013) also found similar results in their study on intense rainfall equations for the municipalities of Maceió and Arapiraca in Alagoas, with variation from one station to another and R^2 values higher than 0.99.

4. Final Considerations

The determination of the intensity, duration, and frequency equation is an important tool for the planning and sizing of hydraulic works and urban drainage systems in Itabuna and neighboring municipalities.

The parameters K, a, b, and c of the IDF equation show significant variation due to the distinct position of each rain gauge station addressed. This same variability was identified when comparing the results obtained with those from studies conducted by other authors in different locations.

The objective of estimating the parameters of the IDF equations for Itabuna and neighboring municipalities was achieved. In this sense, the coefficient of determination (R^2) was high for all stations analyzed, indicating that the IDF equation satisfactorily represents rainfall in the study area.

Therefore, it is recommended that these parameters be used in the analysis of urban drainage projects and the sizing of hydraulic works in Itabuna and surrounding municipalities in order to reduce the impacts caused by intense rainfall in the future.

Additionally, the importance of conducting similar studies in other areas is emphasized, to obtain a better understanding of rainfall characteristics in different locations, thus improving the techniques for planning and sizing hydraulic works and urban drainage systems.

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