ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v29i1.8553 V.28, p.571-578, 2020

EQUATIONS OF INTENSITY, DURATION AND FREQUENCY FOR THE PERUÍPE, ITANHÉM AND JUCURUÇU RIVER BASINS

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Keywords:
Hydrology
Intense rainfall equation
Rainfall

ABSTRACT

The intense rainfall equations present a great technical interest for hydraulic works projects. In the State of Bahia, there are only 19 equations of intensity, duration and frequency modeling, requiring a greater number of equations for the State. The most recent ones are almost 15 years old, with only two in the Peruípe, Itanhém and Jucuruçu river basins. Thus, the objective of this work was to determine the parameters of the equations of intensity, duration and frequency (IDF) of the rainfall stations for different locations of the basins of the Peruípe, Itanhém and Jucuruçu rivers, located in the far southern Bahia State. Initially, 59 stations were selected, out of which only those with over 20 year-old data and records from 1980 onwards. Rainfall disaggregation was carried out using the method proposed by Cetesb (Environmental Company of the State of São Paulo, Brazil) and the parameters (K, a, b and c) were adjusted through nonlinear multiple regression using the nonlinear-generalized reduced gradient interaction method, where adjustment was evaluated by the coefficient of determination (R^2). In the end, 29 equations were adjusted, with coefficient of determination greater than 0.99, therefore, improving the perspective of planning hydraulic works in the region. This correlation could also be observed by the regression equation of the observed data with the adjusted ones, where the slope coefficient of the line was close to 1.0 for all rainfall stations.

Palavras-chave:
Equação de chuvas intensas
Hidrologia
Precipitação

EQUAÇÕES DE INTENSIDADE, DURAÇÃO E FREQUÊNCIA PARA AS BACIAS DOS RIOS PERUÍPE, ITANHÉM E JUCURUÇU

RESUMO

As equações de chuvas intensas apresentam grande interesse de ordem técnica para os projetos de obras hidráulicas. No Estado da Bahia existem somente 19 equações de intensidade duração e frequência ajustadas necessitando de maior número de equações. As mais recentes apresentam quase 15 anos, havendo apenas duas nas bacias dos rios Peruípe, Itanhém e Jucuruçu. Assim, o objetivo desse trabalho foi determinar os parâmetros das equações de intensidade duração e frequência (IDF) das estações pluviométricas para distintas localidades das bacias dos rios Peruípe, Itanhém e Jucuruçu, localizadas no Extremo Sul da Bahia. Foram selecionadas inicialmente 59 estações, destas somente estações com mais de 20 anos de dados e registros a partir de 1980. Fez-se a desagregação da chuva pelo método proposto pela Cetesb (Companhia Ambiental do Estado de São Paulo) e ajuste dos parâmetros (K, a, b e c) através de regressão múltipla não linear, pelo método de interação de gradação reduzida generalizada não linear, com a avaliação do ajuste pelo coeficiente de determinação (R^2). Ao final foram ajustadas 29 equações, com coeficientes de determinação acima de 0,99, melhorando a perspectiva do planejamento de obras hidráulicas na região. Essa correlação também pôde ser observada pela equação de regressão dos dados observados com os ajustados, onde o coeficiente angular da reta foi próximo de 1,0 para todas as estações pluviométricas.

Recebido para publicação em 21/06/2019 • Aprovado em 22/12/2020 • Publicado em 31/12/2020

INTRODUCTION

The knowledge of the equations that relate intensity, duration and frequency (IDF) of rainfall is important for the dimensioning of hydraulic, irrigation, water availability projects for domestic and industrial supply, flood control works and soil erosion. It also allows to design more safely the structures for soil conservation (terraces, contour lines) and farming practices that maintain their cover, such as: dams; drainage channels; and drainage works (BAZZANO *et al*., 2007; CECÍLIO *et al*., 2009; NASCIMENTO; JESUS, 2017; RODRIGUES *et al*., 2008; SANTOS *et al*., 2010).

The variation in the intensity and frequency of rainfall is related to the probability of occurrence or overcoming of the event, which can be achieved through a probability distribution function, which allows extrapolation to a greater number in years in relation to the number of years of observation (CAMPOS *et al*., 2014).

The IDF equation has parameters (K, a, b and c) that are empirically adjusted. The adjustment of the parameters of the IDF equation is made using the rainfall data of weather stations. The annual maximum rainfall values are analyzed and the annual rainfall probability distribution is made over multiple years. When necessary, the rainfall disaggregation in shorter periods is performed. After this initial step, the parameters must be adjusted using linear or non-linear regression equations (ARAGÃO *et al*., 2013; CAMPOS *et al*., 2014; MELLO; SILVA, 2005; OLIVEIRA *et al*., 2005), based on the values extracted from rainfall data series.

The state of Bahia, Brazil, has 19 IDF equations adjusted by Pfafstetter (1957), Denardin and Freitas (1982). There is a need to adjust the IDF equations as the last adjustment was made by and Silva *et al*. (2002) over fifteen years ago. It is necessary to incorporate data from new rainfall stations, especially in the Peruípe, Itanhém and Jucuruçu river basins, located in the far southern Bahia State. It is also necessary to consider the geographical distance between the locations and the new stations and, finally, the changes in the characteristics of rainfall in the face of the climate changes.

The major objective of this work is to determine the parameters of the equations of intensity duration and frequency (IDF) of the rainfall stations for locations in the basins of the Peruípe, Itanhém and Jucuruçu rivers, located in the far southern Bahia State.

MATERIAL AND METHODS

The total experimental area is located on the border of the states of Minas Gerais and Bahia. It corresponds to 16,730.90 km2 (Figure 1). There are three large basins in the experimental area: 1) Peruípe Basin: 4,118 km^2; 2) Itanhém River Basin: 6,193 km^2; 3) Jucuruçu River Basin: 5,850 km^2.

The climate in the region is tropical, hot and humid, with average monthly temperatures above 18°C and with an average rainfall greater than 60 mm. The experimental region is in the domain of the Atlantic Forest Biome (INEMA, 2019). Rainfall data from 29 weather stations from the bank of the National Water Agency (ANA, 2016) were used, with more than 20 years of daily observations, distributed in the municipalities surrounding the Itanhém, Peruípe and Jucuruçu river basins (States of Bahia, Minas Gerais and Espírito Santo). Only the stations with more than 20-year-old data consistent with records from 1980 were selected.

For this stage, it was used raster images of the SRTM base (Shuttle Radar Topography Mission) (USGS, 2015) containing the elevation information from the MDE (Digital Elevation Model), with a spatial resolution of 90 m imported from the USGS website (United States Geological Survey). The topographic base MDE was used to obtain the topographic boundaries of the three hydrographic basins.

However, it could only ideally represent the surface runoff processes with the execution of the following procedures for MDEHC (Hydrologically Consistent Digital Elevation Model) obtaining: first, a mosaic of the study area was done, and later,

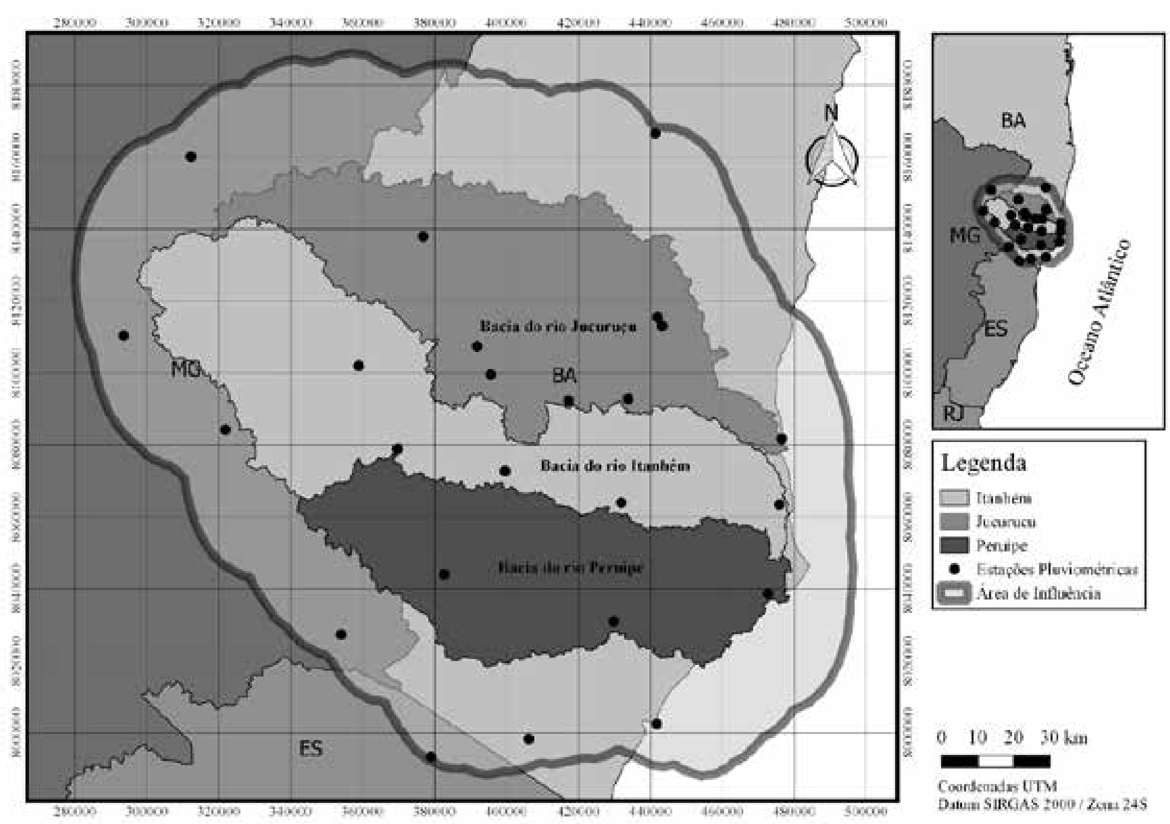

Figure 1. Identification influence area at a radius of 30 km from Peruípe, Itanhém and Jucuruçu river basins with the 29 selected rainfall stations

a reinterpolation of the altimetry data from the MDE was carried out to obtain a spatial resolution of 30 m.

After reinterpolation, spurious depressions were removed. Such depressions are imperfections in the model that do not allow the progressive surface runoff due to failures in the data collection of SRTM images. Flow direction and accumulated flow models were generated, and numerical drainage was obtained from the latter.

As a result, MDHEC executes in a reliable manner all surface drainage processes at full scale. Its use allowed to obtain the delimited areas of each hydrographic basin. Finally, a 30-km area of influence was created from the banks of all basins where the rainfall stations were identified. All of these steps were performed using the GIS QGIS 2.18 software.

It was obtained in this work the maximum 1-day rainfall series for each station, for the following return periods (RP): 5, 10, 15, 25, 50 and 100 years, from probability distributions. The probability distributions used were: Gumbel; Log-Normal II; Log-Normal III; Pearson III; Log-Pearson III (KITE, 1988; NAGHETTINI; PINTO, 2007).

The distributions are shown in Table 1, in which: μ – mean of the random variable x; σ – standard deviation of the random variable x; α – scale parameter; β – shape parameter; γ – position parameter; Γ - gamma function.

For each station, the maximum rainfall was selected, in which the series data showed greater adhesion to the probabilistic model by the Kolmogorov-Smirnov test, with the distribution model that had the lowest mean standard error was selected after the Adhesion Test.

All of these steps were carried out with the aid of the Sicca software (SOUSA *et al.* 2009). After, one-day rainfall disaggregation was performed at intervals of less than 5, 10, 15, 20, 25, 30, 60, 360, 480, 600, 720 and 1440 minutes using the rainfall disaggregation method proposed by CETESB (1979), using the coefficients shown in Table 2.

Table 1. Functions of the probability distribution used to estimate maximum rainfall associated with the return period (RP) of 5, 10, 15, 25, 50 and 100 years

Functions	Overall equation
Gumbel	$f(x) = \frac{1}{\alpha} \exp\left[\frac{x-\beta}{\alpha} - \exp\left(\frac{x-\beta}{\alpha}\right)\right]$ para $x>0$
Log-Normal II	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} \exp\left[-\frac{\ln(x)-\mu}{2\sigma}\right]$ para $x>0$
Log-Normal III	$f(x)=\frac{1}{(x-a)\sigma\sqrt{2\pi}} \exp\left\{-\frac{1}{2}\left[\frac{\ln(x-a)-\mu}{\sigma}\right]\right\}$
Pearson III	$f(x)=\frac{1}{\alpha x\Gamma(\beta)}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1} \exp\left(-\frac{x-\gamma}{\alpha}\right)$
Log-Pearson III	$f(x)=\frac{1}{\alpha x\Gamma(\beta)}\left[\frac{\ln(x)-\gamma}{\alpha}\right]^{\beta-1} \exp\left[-\frac{\ln(x)-\gamma}{\alpha}\right]$ para $\beta>1$ e $\frac{1}{\alpha}>0$

Table 2. Rainfall disaggregation coefficients for shorter time intervals

Transformation interval	Coefficients	Transformation Interval	Coefficients
1 day for 24 h	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	0.70
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)

Following the rainfall disaggregation into shorter intervals, the parameters K, a, b, and c of the intensity-duration-frequency equation (Eq. 1) were determined for each station. The adjustment of the parameters was performed through non-linear multiple regression, using the Non-Linear Generalized Reduced Gradation (GRG) interaction method (SOLVER, 2010), with the evaluation of the adjustment by the coefficient of determination (R^2).

$$IDF=\frac{K \cdot RP^a}{(tab)^c} \quad (1)$$

Where:
IDF = mean maximum rainfall intensity, mm h^{-1};
RP = return period, years;
t = rainfall duration, min; and
K, a, b, and c = parameters adjusted on the basis of the local rainfall data.

Data adjustment was also carried out using the regression equation of the observed data in relation to the estimated data, observing in this case the slope coefficient of the line. All of these steps were performed with the aid of the Solver toolkit for Excel (SOLVER, 2010).

RESULTS AND DISCUSSION

In the analysis of maximum rainfall associated with a return period, all data showed adhesion to the Kolmogorov-Smirnov test, with a predominance of the Log-Normal III probabilistic distribution. In the maximum daily rainfall estimates, another station was discarded for presenting inconsistent data, so, 29 stations were selected.

With the disaggregated rainfall of the 29 stations, all adjustments of the parameters of the IDF equation presented a coefficient of determination (R^2) greater than 0.99 (Table 3), a result similar to those found by Souza *et al.* (2013) where the parameters varied from one station to another with R^2 greater than 0.98.

Table 3. Parameters of IDF equation for selected station together with adjustment quality of the equations, R^2, Mean Standard Error and adjustment regretion equation

Code	Local	IDF equation parameters				IDF adjustment quality		
		K	a	b	c	R²	EPM	Equation
01739010	Alcobaça - BA	1324.9852	0.1470	13.6620	0.7842	0.9978	1.7547	y = 1.0021x + 0.3464
01739007	Caravelas - BA	1105.8722	0.1756	12.9389	0.7773	0.9986	1.4964	y = 1.0061x + 0.032
01740000	Carlos Chagas - MG	860.8550	0.1399	11.5058	0.7630	0.9995	1.2623	y = 1.0051x – 0.2771
01839001	Conceição da Barra – ES	938.9153	0.2022	10.9936	0.7577	0.9993	1.5144	y = 0.9995x – 0.5068
01639026	Guaratinga - BA	1173.5541	0.1301	13.4187	0.7819	0.9981	1.6619	y = 1.0026x + 0.2531
01639007	Guaratinga - BA	1023.0382	0.1346	9.9076	0.7462	0.9990	2.8529	y = 0.9825x – 1.0277
01639008	Guaratinga - BA	993.4640	0.1542	13.1900	0.7797	0.9984	1.5497	y = 1.0054x + 0.1574
01740022	Ibirapuã – BA	1039.8146	0.1783	13.2506	0.7803	0.9983	1.5959	y = 1.0047x + 0.1343
01739005	Itamaraju - BA	973.5650	0.1637	12.8985	0.7769	0.9987	1.4628	y = 1.006x + 0.0659
01739004	Itamaraju - BA	1191.6993	0.1157	13.2760	0.7805	0.9982	1.6108	y = 1.0028x + 0.2261
01740021	Itanhém – BA	966.0885	0.1730	11.1747	0.7596	0.9992	1.3766	y = 1.0118x – 0.6445
01740008	Itanhém – BA	961.3151	0.1683	13.1197	0.7790	0.9984	1.5476	y = 1.0047x + 0.1141
01640000	Jacinto – MG	931.6102	0.1962	13.6376	0.7840	0.9979	1.7196	y = 1.0043x + 0.2046
01641002	Jequitinhonha - MG	946.1749	0.1443	12.8444	0.7763	0.9987	1.4572	y = 1.0054x + 0.0629
01740005	Medeiros Neto - BA	763.9725	0.2093	10.8325	0.7560	0.9992	1.5892	y = 0.9982x – 0.4433
01740017	Medeiros Neto - BA	1040.1274	0.1147	13.0133	0.7780	0.9985	1.5170	y = 1.004x + 0.1315
01740019	Medeiros Neto - BA	1348.4082	0.1608	13.7734	0.7853	0.9977	1.7956	y = 1.0022x + 0.3716
01840012	Montanha - ES	1235.2590	0.1297	13.2778	0.7805	0.9982	1.6101	y = 1.0032x + 0.2247
01839003	Mucuri – BA	954.8071	0.2031	14.3947	0.7911	0.9972	1.9726	y = 1.0048x + 0.4214
01840006	Mucurici - ES	1139.9161	0.1359	12.5627	0.7736	0.9990	1.3640	y = 1.007x + 0.0083
01740001	Nanuque - MG	1120.7942	0.1316	14.2500	0.7898	0.9977	1.8400	y = 1.0089x + 0.4566
01739006	Nova Viçosa - BA	1009.9063	0.1780	13.1361	0.7792	0.9985	1.5466	y = 1.0053x + 0.108
01839000	Pedro Canário - ES	921.3126	0.1593	11.7524	0.7655	0.9993	1.3137	y = 1.0044x – 0.2558
01639003	Porto Seguro - BA	1332.0209	0.1250	13.0796	0.7786	0.9984	1.5403	y = 1.0039x + 0.1818
01739001	Prado – BA	836.0718	0.2229	10.8058	0.7557	0.9990	1.6882	y = 0.9964x – 0.5027
01640007	Santa Maria do Salto –MG	948.6960	0.1821	12.0925	0.7689	0.9991	1.3752	y = 1.0039x – 0.2059
01740026	Umburatiba - MG	944.5452	0.2131	14.6743	0.7937	0.9969	2.0776	y = 1.0051x + 0.4872
01740020	Vereda – BA	927.4355	0.1500	11.7017	0.7650	0.9994	1.2936	y = 1.0047x – 0.2573
01740006	Vereda – BA	1021.6416	0.0771	12.7675	0.7756	0.9987	1.4452	y = 1.0042x + 0.0858

Thus, for all the analyzed stations, the parameters of the IDF equation had a “very strong correlation” with R^2 greater than 0.99. This correlation can also be observed by the regression equation of the observed data with the adjusted ones, where the slope coefficient of the line was close to 1.0 for all stations (Table 3).

In a work on the parameters of the intense rainfall equation in the municipalities of Viçosa and Palmeira dos Índios in the State of Alagoas, Almeida *et al*. (2013) obtained similar results with the R^2 values also greater than 0.99, and the adjustment parameters (K, the , b, c) presented high variability among stations. Likewise, the results found by Lima *et al*. (2013) for the cities of Maceió and Arapiraca, Alagoas State, also vary among the stations with an R^2 greater than 0.99.

The lowest value for parameter K was 763.9725 for station 1740005, and the highest value was 1348.4082 for station 1740019 both in the municipality of Medeiros Neto. The variation in rainfall intensities reinforces the need to obtain equations of intense rainfall for each location of interest. It should be said that one of the ways to minimize the inaccuracies in the intensity estimation is to increase the number of studied locations more and more (SOUZA *et al*., 2012).

Two locations evaluated in this work, Itamaraju and Medeiros Neto, had already had parameters of the IDF equation adjusted by Silva *et al*. (2002), thus, a comparison was made among the adjusted values of this work (Table 4). This comparison showed that the performance of the parameters of the IDF equation adjusted in this work were similar to the performance of the parameters adjusted by Silva *et al*. (2002), where the value of the determination coefficient (R^2) was 0.9867 for Itamaraju and 0.9667 for Medeiros Neto, both in Bahia State.

Although the R^2 values are very close to those obtained in this work, the parameters of Silva *et al*. (2002) presented a higher standard error of the mean, 15.1300 for Itamaraju - BA and 12.1000 for Medeiros Neto – BA.

CONCLUSIONS

- For the 29 stations, the adjustment of parameters K, a, b and c of the Intensity-Duration-Frequency equation showed values of the coefficient of determination (R^2) greater than 0.99, demonstrating a very good adequacy to the observed data.
- Although the R^2 values are close to the results found by other authors in the region of the Peruípe, Itanhém and Jucuruçu river basins, the Standard Error of the Mean was lower.

Table 4. Comparison between the parameters of the IDF equation adjusted by Silva *et al.* (2002) and the adjusted values of this work for the same locations, together with the adjustment quality of the equations, R^2, Standard Error of the Mean and the adjustment regression equation

Code /Source	Locality	IDF equation parameters				adjustment quality of the parameters		
		K	a	b	c	R²	EPM	Equation
01739005	Itamaraju - BA	973.5650	0.1637	12.8985	0.7769	0.9987	1.4628	y = 1.0060x + 0.0659
01739004	Itamaraju - BA	1191.6993	0.1157	13.2760	0.7805	0.9982	1.6108	y = 1.0028x + 0.2261
Silva *et al.* 2002	Itamaraju - BA	4032.8600	0.2110	28.6050	1.0600	0.9867	15.1300	y = 1.1912x – 3.5579
01740005	Medeiros Neto - BA	763.9725	0.2093	10.8325	0.7560	0.9992	1.5892	y = 0.9982x – 0.4433
01740017	Medeiros Neto - BA	1040.1274	0.1147	13.0133	0.7780	0.9985	1.5170	y = 1.0040x + 0.1315
01740019	Medeiros Neto - BA	1348.4082	0.1608	13.7734	0.7853	0.9977	1.7956	y = 1.0022x + 0.3716
Silva *et al.* 2002	Medeiros Neto - BA	6899.2170	0.2270	40.9130	1.1070	0.9667	12.1000	y = 1.0215x – 0.5498

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