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HYDROLOGICAL CHARACTERIZATION OF RAINFALL AND ITS POTENTIAL EROSIVITY IN THE MIDDLE COURSE OF SALITRE RIVER BASIN IN THE BRAZILIAN SEMI-ARID

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ABSTRACT: A characterization of the rains in the middle course of Salitre River Basin and its relation with the existing processes of water erosion is presented. Rainfall of 30 minutes was used to obtain the coefficient of disaggregation of rainfall. The annual maximum daily precipitation obtained from the National Water Agency database was adjusted according to the statistical distribution of Gumbel and the adjustment of the Kolmogorov-Smirnov adjustment. The individual erosive rains were established by the erosivity index (EI30) of each individual precipitation and kinetic energy were calculated according to Wischmeier and Smith, later compared to the methodology of Lombardi Neto and Moldenhauer. Higher precipitation intensities were observed for shorter run times and longer return periods. The highest rates of erosivity coincide with the highest rainfall indexes.

KEYWORDS: Intense rains; intensity-duration-frequency equations; water erosion

CARACTERIZAÇÃO HIDROLÓGICA DA PRECIPITAÇÃO E SUA POTENCIAL EROSIVIDADE NO CURSO MÉDIO DA BACIA RIO SALITRE NO SEMIÁRIDO BRASILEIRO

RESUMO: É apresentada uma caracterização das chuvas no médio curso da Bacia do Rio Salitre e sua relação com os processos existentes de erosão hídrica. A precipitação de 30 minutos foi utilizada para obter o coeficiente de desagregação das chuvas. A precipitação diária máxima anual obtida no banco de dados da Agência Nacional de Águas foi ajustada de acordo com a distribuição estatística de Gumbel e a avaliação do ajuste foi baseada no teste de Kolmogorov-Smirnov. Os parâmetros da equação IDF foram ajustados pelo modelo gradiente reduzido generalizado não-linear GRG. As chuvas erosivas individuais foram estabelecidas pelo índice de erosividade (EI30) de cada precipitação individual e energia cinética foi calculada de acordo com Wischmeier e Smith, posteriormente comparados a metodologia de Lombardi Neto and Moldenhauer. Intensidades de precipitação mais altas foram observadas para tempos de execução mais curtos e períodos de retorno mais longos. As maiores taxas de erosividade coincidem com os mais altos índices de precipitação.

PALAVRAS-CHAVE: chuvas intensas; equações intensidade-duração-frequência; erosão hídrica

CARACTERIZACIÓN HIDROLÓGICA DE LA PRECIPITACIÓN Y SU POTENCIAL EROSIVIDAD EN EL CURSO MEDIO DE LA CUENCA DEL RÍO SALITRE EN LA REGIÓN SEMIÁRIDA BRASILEÑA

RESUMEN: Se presenta una caracterización de las precipitaciones en el curso medio de la cuenca del río Salitre y su relación con los procesos de erosión del agua existentes. La precipitación de 30 minutos se utilizó para obtener el coeficiente de desagregación de las lluvias. La precipitación diaria máxima anual obtenida de la base de datos de la Agencia Nacional del Agua se ajustó de acuerdo con la distribución estadística de gumbel y el ajuste del kolmogorov-smirnov. Los parámetros de la ecuación IDF fueron ajustados por el MODEL GRG no lineal. Las precipitaciones erosivas individuales fueron establecidas por el índice de erosividad (EI30) de cada precipitación individual y la energía cinética se calculó de acuerdo con Wischmeier y Smith, más tarde en comparación con la metodología de Lombardi Neto y Moldenhauer. Se observaron mayores intensidades de precipitación para tiempos de ejecución más cortos y períodos de retorno más largos. Las tasas más altas de erosividad coinciden con las tasas de precipitación más altas

PALABRAS CLAVE: lluvias intensas; ecuaciones intensidad-duración-frecuencia; erosión del agua

1. INTRODUCTION

The occurrence of intense rains, characterized by being of high intensity and short duration, is a characteristic process in the semiarid Northeastern region of Brazil (De MOURA et al., 2006). In exposed soils and cultivated areas under inadequate management, they become a key factor in the occurrence of erosive processes, due to the direct impact of raindrops and the surplus runoff (BAZZANO et al., 2010).

One of the main ways to characterize intense rains is to establish the relationship between their intensity, duration and frequency, through the IDF (Intensity - Duration - Frequency) curves, whose parameters can be empirically adjusted through pluviometric data (CAMPOS et al. 2014). The obtained IDF curves represent, in different durations, the intensity and the frequency of the maximum precipitation events (FADHEL et al., 2017).

The characterization of rainfall thus makes it efficient in the decision making regarding conservation measures related to the use of the soil, among them the agricultural practices that maintain the vegetal cover, like method, and the dimensioning of terraces and contour lines, like structures, of conservation (BAZZANO et al., 2007).

For empirical predictions of the potential risk of water erosion the rainfall (R), erosivity factor are widely used (XIE et al., 2016). This factor proposed by Wischmeier and Smith (1978) relates the kinetic energy of the rain and its intensity in 30 minutes.

However, maximum precipitation data of 30 minutes, which are used both to evaluate rainfall erosivity and to obtain the IDF equation, require pluviographs data records. Due to the scarcity of such records, several studies have been using methodologies of disaggregation of rains, from daily pluviometric records, using coefficients that transform 24-hour rainfall into the rainfall of shorter durations (DAEE-CETESB, 1979; DA SILVEIRA, 2000; TEIXEIRA et al., 2011; BACK et al., 2012; PEREIRA et al., 2014; KOSSIERIS et al, 2018; BEYENE et al., 2019).

The hydrographic basin of the middle Salitre, located in the semi-arid region of Brazil, has rainfall between 400 mm and 800 mm on average, concentrated between January and April (ROSSI and SANTOS 2018), is and an example of the occurrence of intense water erosion processes (SILVA and RIOS 2018) and lack of records pluviograph, making the use of pluviometric series essential for surveying existing processes, making the projection and execution of soil and water conservation programs and projects more effective.

As an important tributary of the São Francisco River, the Salitre has been suffering intense silting processes over the years, to the point of making it an intermittent river, when it has been perennial, thus reducing its water availability (CEDRAZ, 2012).

Therefore, the objective of this work is to characterize the rains that occur in the middle course of the Salitre River hydrographic basin, in the Brazilian semi-arid, and to establish its relationship with the processes of water erosion existing in the region.

2 MATERIALS AND METHODS

2.1 STUDY AREA

Located in the Bahian semi-arid, the Salitre River Basin river is part of the São Francisco river basin, presenting a drainage area of 13,467.93 km², located in the north of the state of Bahia, with latitudes of 9 ° 27 'and 11 30 ° and longitudes of 40 ° 22 'and 41 ° 30' to the west, the Salitre River rises in the municipality of Morro do Chapéu - BA and has its downstream in the dam de Sobradinho, in Juazeiro - BA, with 333.24 km in length and (INEMA, 2018; ROSSI and SANTOS, 2018) (Figure 1).

Inserted in the semi-arid region, part of a region known in Brazil as "drought polygon"' the Salitre River basin is historically marked by conflicts of water and land use, and by a critical situation of water availability, which is still present (ROSSI and SANTOS, 2018).

Intense processes of water erosion and silting have already been reported for the middle Salitre river basin, in the region comprising the municipality of Campo Formoso - BA (SILVA and RIOS 2018). To quantify rain erosivity (EI_{30}) and to establish the Intensity - duration - frequency (IDF) equation, historical series were analyzed with values of daily rainfall obtained from the National Water Agency (ANA) station Junco.

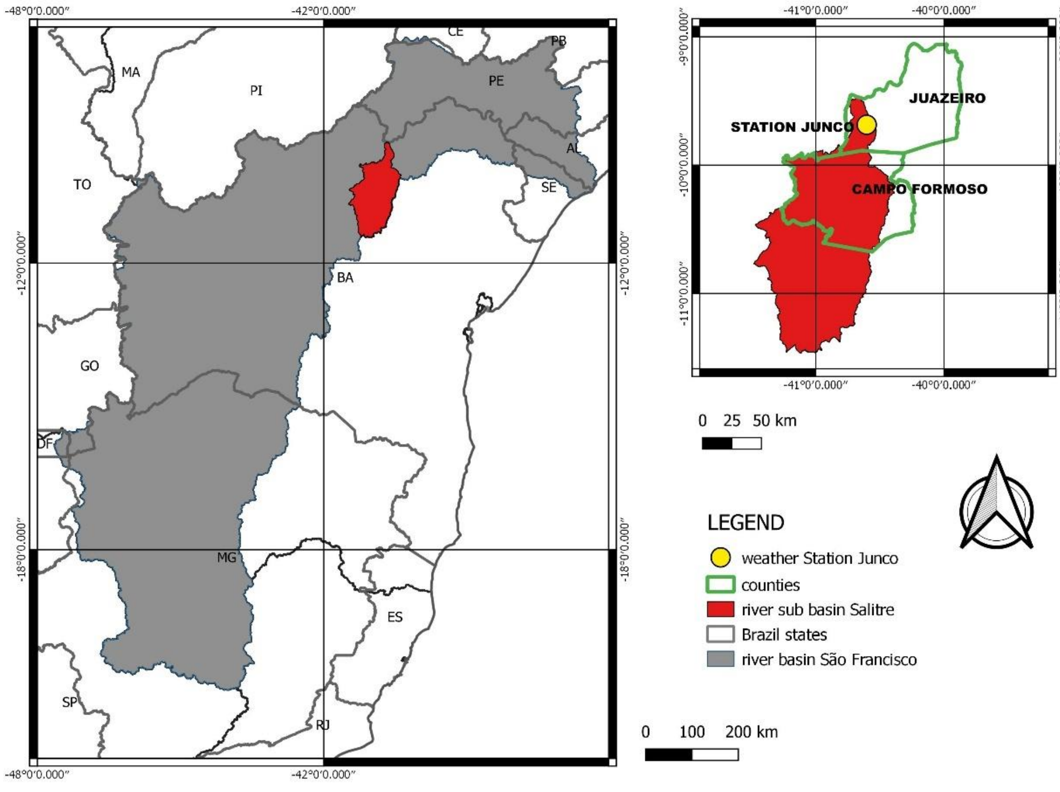

Figure 1 - Hydrographic location of the Salitre river basin, the São Francisco river sub basin, and the meteorological data station used in this study and representative municipalities.

2.2 OBTAINING RAINFALL DISAGGREGATION COEFFICIENTS

As in Brazil there is a shortage of pluviograph data, and abundant availability of pluviometric data, the rainfall breakdown coefficients proposed by DAEE-CETESB (1979) are widely used (SILVA et al., 2002; DAMÉ et al., 2008; TEIXEIRA, DAMÉ and ROSSKOFF, 2011; TEODORO, 2014; BORGES and THEBALDI, 2016; PEREIRA, DUARTE and SARMENTO, 2017), however, due to the spatial-temporal variation in rainfall, it is important to promote specific relationships for the place of study, and thus consider the characteristics of the rainfall in the region (Back, Oliveira and Henn, 2012).

Despite the lack of pluviograph data in the study area, Embrapa Semiarid has automatic agrometeorological stations in the region, in which meteorological data is measured every 60 seconds and recorded every 30 minutes (De MOURA et al., 2019).

Therefore, to determine the IDF equation, data of 30 minutes, between the periods from 2014 to 2017, provided by Embrapa Semiarid (Salitre weather station located in Juazeiro - BA with coordinates 09º30'0'' S and 40º38'0'' W) were used to obtain a relationship between the rain of 24 hours and rains of shorter durations. Maximum rainfalls by duration was grouped:30 minutes, 1h, 2h, 4h, 6h, 8h, 12h e 24h, and by linear regression between the maximum slides of each duration, the coefficient of disaggregation of the rain between the durations was obtained: 24h – 12h; 24h – 8h; 24h – 6h; 24h – 4h; 24h – 2h; 24h – 1h; 1h – 30 min. For this study, the one-day rains were considered to be 24-hour rainfall.

2.3 OBTAINING THE INTENSE RAINS EQUATION (IDF CURVES)

In this work, pluviometric series were selected from the Junco meteorological station (00940028) located at latitude -09°40’6”S, the longitude of -40°36’14”W and with an altitude of 397m (ANA, 2009) for the period 1975-2017, for having data volume current and greater than 30 years, as recommended by the World Meteorological Organization (WMO). According to WMO (1989), this period represents climatological values (average values of meteorological variables) and helps to identify variables in the climate and its trends.

The annual maximum daily precipitation, corresponding to the highest value of precipitation occurred in one day over a year, were adjusted according to the statistical distribution of Gumbel (1958) (Equation 1). The periods of return (TR), employees were: 2, 3, 5, 10, 15, 20, 25, 50 and 100 years, contemplating return times established by DNIT (2005). According to the coefficients obtained, using the method of relations (DAEE-CETESB, 1979), the rain of 1 day was disaggregated in a rain of 12h, 8h, 6h, 4h, 2h, 1h and the rain of 1h in 30min. After the rains were degraded, the rain intensity was estimated for each duration and return period. The intensities (mm hours^{-1}) were obtained by the ratio between precipitation (mm) and duration time (hours).

$$h_{TR} = \alpha - \beta \mathrm{Ln}\left[\ln\left(\frac{TR}{TR-1}\right)\right] \quad (1)$$

The parameters α (Equation 2) and β (Equation 3) of the Gumbel (1958) distribution were obtained, respectively, by the Moments Method (MOM) (Naghettini and Pinto, 2007), relating the standard deviation (Equation 4) and the mean (Equation 5) of the maximum annual precipitations.

$$\alpha = \frac{\sqrt{6}}{\pi} S \quad (2)$$

$$\beta = \overline{X} - 0{,}5772\,\alpha \quad (3)$$

$$\overline{X} = \frac{\sum_{i=1}^{n} Xi}{n} \quad (4)$$

$$S = \sqrt{\frac{\sum_{i=1}^{n}(Xi-\overline{X})^2}{n-1}} \quad (5)$$

The Kolmogorov-Smirnov test (Equation 6) was used at the significance level of 1% (α = 0.01) with a sample size of N = 45, and D_N,α to evaluate the adjustment of the Gumbel distribution, was obtained according to equation 7 (CRUTCHER, 1975) according to Naghettini and Pinto (2007). The maximum annual precipitations were classified in descending order P (X ≥ x), the empirical probability calculation was performed according to Kimball (Equation 8) (PEREIRA, ANGELOCCI, SENTELHAS, 2007; NAGHETTINI and PINTO, 2007) and the theoretical probability by the Gumbel (1958) frequency distribution (Equation 9).

$$D_N = \sup_{-\infty<x<\infty} |F_N(x) - F_X(x)| \quad (6)$$

At where:

F_N = Empirical probability,

F_X = Theoretical probability,

D_N = Greater difference between empirical and theoretical probabilities

$$D_{N,\alpha} = \frac{1.63}{\sqrt{N}} \quad (7)$$

$$P = \frac{m}{N+1} \quad (8)$$

At where:

m = order number for each precipitation value,

N = nth order number

$$f(x) = e^{-e^{-\left(\frac{x-\beta}{\alpha}\right)}} \quad (9)$$

At where:

x = precipitation value (mm) adjusted by Gumbel,

α and β = Gumbel distribution parameters

The adjustment of the parameters (k, a, b, c) of the IDF equation (VILLELA and MATTOS, 1975) (Equation 10) was performed with the nonlinear generalized reduced gradient (GRG) algorithm (LASDON and WAREN, 1981), using the Solver tool, available in the Excel (Microsoft® Excel 2004 for Windows version 16.0) To estimate the parameters, the objective was to minimize the root mean square error (RMSE) (PINTO, 2013).

$$I = \frac{K\,T^a}{(t+b)^c} \quad (10)$$

At where:

I = Precipitation intensity (mm h^{-1}),

T = time of return (years),

t = duration of rain (min),

K, a, b, c = parameters of the equation (dimensionless)

2.4 EROSIVITY OF RAIN

As we are analyzing erosivity using pluviometric data, some adjustments were made in the application of the methodology. the existing method was applied in a new arrangement and later its suitability was established in comparison with the standard method.As we start from daily rainfall data, from the criteria established by Wischmeier and Smith (1958), we adopt the one that considers individual erosive rains as those with precipitation height (mm) ≥ 10mm.

Disaggregation coefficients were applied to daily rainfall ≥ 10mm, to obtain rain for 24 hours and later to obtain its intensity in 30 minutes. The rains of 1 day were considered maximum daily rainfall, and according to Back et al. (2012) the 1 day rainfall data are lower than the 24 hour rainfall data, to avoid underestimating erosivity, the 1 day rainfall was transformed into 24 hour rainfall, applying the correction factor 1.14 (WEISS, 1964), the precipitations (≥ 10mm) were later transformed into 30 min precipitations (coefficients established in this article) to obtain I30.

The erosivity index (EI_{30}) of each individual precipitation (Equation 11) and kinetic energy (Equation 12) were calculated according to the equations proposed by Wischmeier and Smith (1958) mentioned in Haan, Barfield and Hayes (1994). Monthly erosivity was obtained by the sum of EI_{30} of all the rains that occurred in each month of the year, and thus, the sum of the monthly indices characterized the annual EI_{30} (WISCHMEIER and SMITH, 1958). To convert the I_{30} to international system of units (SI) (MJ mm ha $^{-1}$ h $^{-1}$ ano $^{-1}$) multiply the English Units by 17.02 (HAAN, BARFIELD and HAYES, 1994). The classification of rainfall erosivity was Carvalho (2008).

$$EI_{30} = \left[\left(\sum_{i=1}^{n} e\,h_i\right) I_{30}\right] / 100 \qquad (11)$$

$$e = 916 + log_{10}\, i \qquad i \leq 3\ in./\text{hr}$$

$$e = 1074 \qquad i > 3\ in./\text{hr} \qquad (12)$$

At where:

I_{30} = maximum precipitation intensity of 30 minutes (in. h^{-1})

h_i = rain height for each rainy period (in.)

e = kinetic energy (ft tonsf acre^{-1} in.$^{-1}$)

i = average intensity of the storm (in. hr^{-1})

when analyzing transformed data, to determine a coherence of erosions caused, we compare the annuais erosivity (R) data calculated according to an equation developed by Lombardi Neto and Moldenhauer (1992) (Equation 13) cited by (Araujo, 2003) that uses precipitation data annuais and monthly , and is used in the literature for work with pluviometric data (e.g.: ARAUJO, 2003).The data were correlated by linear regression (ANDRADE, 2006).

$$Rm = 67.355 \left(\frac{Pm^2}{Pa}\right)^{0.85} \qquad (13)$$

$$R = \sum_{m=1}^{12} Rm$$

At where:

R_m = monthly rainfall erosivity (MJ mm ha $^{-1}$ h $^{-1}$ month $^{-1}$)

R = annual erosivity (MJ mm ha $^{-1}$ h $^{-1}$ year $^{-1}$)

P_m = monthly precipitation (mm month^{-1})

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P_a = average annual rainfall (mm $year^{-1}$)

3 RESULTS AND DISCUSSION

3.1 OBTAINING RAINFALL DISAGGREGATION COEFFICIENTS

In the regression adjustment for the slides of different durations, the coefficients obtained presented a highly significant adjustment ($p < 0.0001$) (Figure 2), and are slightly larger than the national coefficients presented by DAEE-CETESB (1979) and coefficients proposed by Da Silveira (2000) and Back et al. (2012), an indication that rainfall has short durations. The coefficients obtained can also be seen in table 1.

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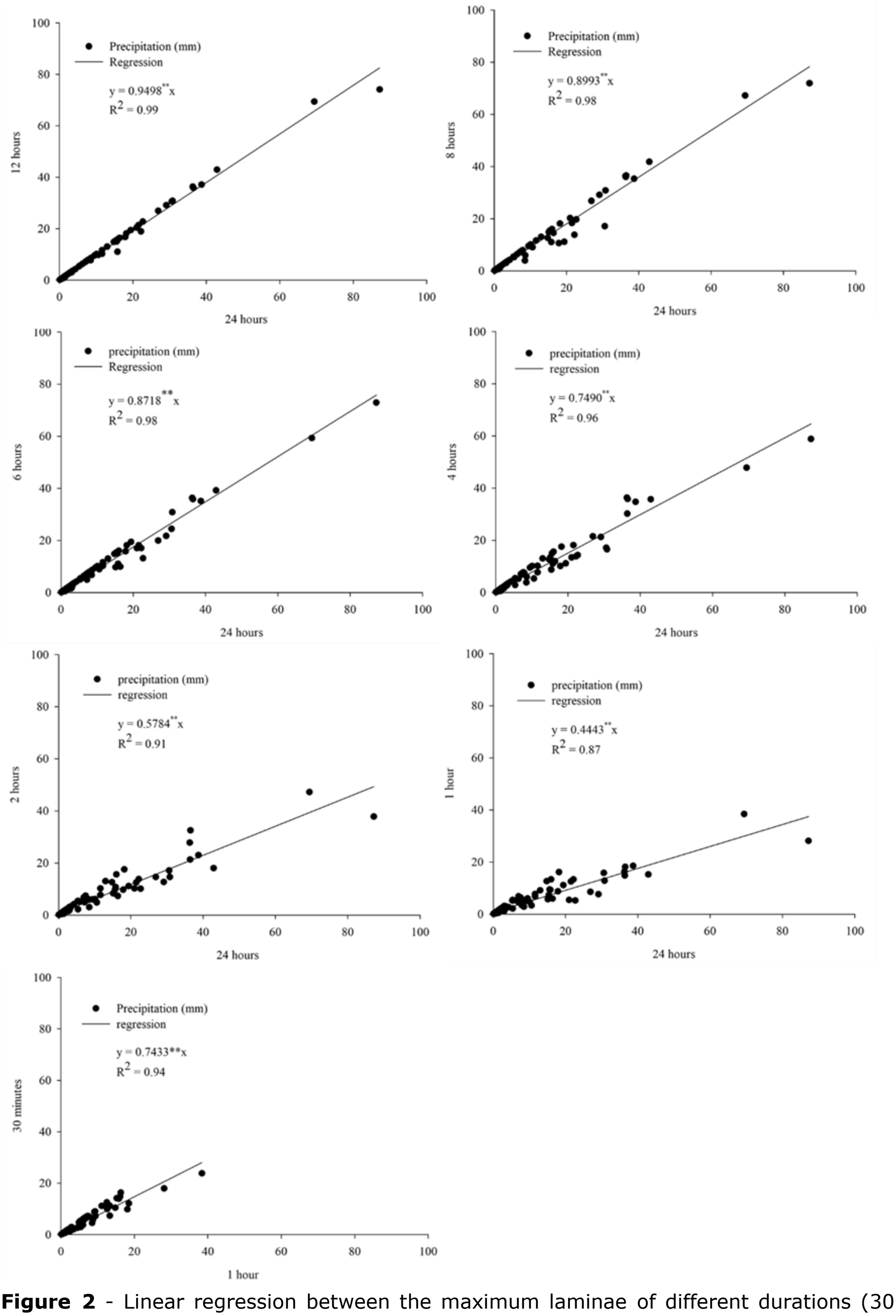

Figure 2 - Linear regression between the maximum laminae of different durations (30 min, 1 h, 2 h, 4 h, 6 h, 8 h, 12 h and 24 h) and disaggregation coefficients (angular coefficient of the straight).** significant at 1% probability.

Table 1 - coefficients of disaggregation.

relation of durations	relation of rain
24 / 12	0.9498
24 / 8	0.8993
24 / 6	0.8718
24 / 4	0.7990
24 / 2	0.5784
24 / 1	0.4443
1 / 0.5	0.7433

The determination of the coefficients for rain disaggregation also suffers interference from the precipitation regime, as well as the existing volume of records for its determination and the different methodologies used. For Teodoro et. al. (2014) when comparing the disaggregation coefficients proposed by Silveira (2000) Back et al. (2012) and CETESB (1986), observed that the different disaggregation coefficients in the literature influence the determination of the parameters of the IDF equation. Teixeira, Damé and Rosskoff (2011), to define the coefficients of disaggregation of rainfall data in the municipality of Pelotas-RS, by the method proposed by Silveira (2000) and compared to the method of relations (DAE-CETESB, 1979), despite the finding values considered close, an overestimation of the evaluation coefficients was observed for 12, 6 and 1 hour, underestimation for 24 hours and 30 min and a value equal to the shortest duration (15 min), in comparison to the DAEE-CETESB coefficients. coefficients.

The DAEE-CETESB presents coefficients widely adopted in studies of disaggregation of gloves, coefficients originating from the study of Pfafstetter (1957) that uses the Brazilian national territory, with paid values: 0.85 (12h - 24h); 0.82 (10h - 24h); 0.78 (8h / 24h); 0.72 (6 h - 24 h); 0.42 (1h - 24h) and 0.74 (1 – 30 min). Knowing that the semiarid has specific characteristics about the hydrological behavior, the relevance in the search for obtaining coefficients that represent the rainfall regime in the region is exalted. The coefficients obtained for this study show behaviors similar to those presented by the DAEE-CETESB coefficients, however, we emphasize that future works that have a larger database are relevant for determining coefficients that are more expressive, and closer to national coefficients.

3.2 OBTAINING THE INTENSE RAINS EQUATION (IDF CURVES)

The behavior of the annual maximum precipitations, which were later submitted to disaggregation in smaller durations, shows a good adherence between the observed values, estimated by the empirical probability, and those estimated by the theoretical frequency distribution (Gumbel) (Figure 3). Therefore, the results show that the adjustment is adequate according to the Kolmogorov-Smirnov test with $D_{N,0.01}$ = 0,2378 is obtained D_N = 0.0152, therefore $D_N < D_{N,0.01}$. Following the pattern presented by IDF relations, higher intensities were observed for shorter duration times and longer return periods (Table 2).

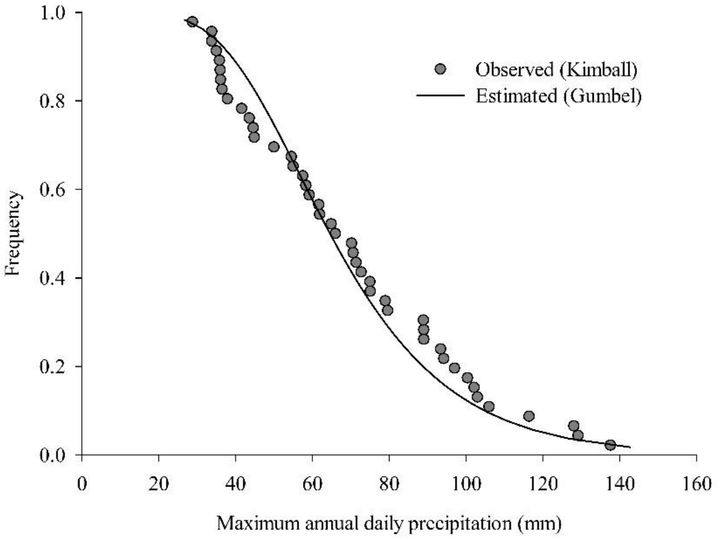

Figure 3 - Adjustment of frequency distributions for annual, observed (Kimball) and estimated (Gumbel) maximum precipitations

Table 2 - Intensities for precipitation adjusted by Gumbel (duration time of 24 hours) and for different duration times for each return period.

Duration time (hours)	coefficient	Intensity (mm h^{-1}) for different duration times for each return period (years)								
		2	3	5	10	15	20	25	50	100
24	1	2.72	3.22	3.78	4.48	4.87	5.15	5.37	6.02	6.68
12	0.9498	5.16	6.11	7.17	8.50	9.25	9.78	10.19	11.44	12.68
8	0.8993	7.33	8.68	10.19	12.08	13.15	13.90	14.48	16.25	18.02
6	0.8718	9.47	11.22	13.17	15.62	17.00	17.97	18.71	21.01	23.29
4	0.7490	12.20	14.46	16.97	20.13	21.91	23.15	24.11	27.07	30.01
2	0.5784	18.85	22.33	26.21	31.08	33.83	35.76	37.24	41.81	46.35
1	0.4443	27.45	32.52	38.17	45.27	49.28	52.08	54.24	60.90	67.50
0.5	0.7433	39.67	47.00	55.16	63.43	71.21	75.27	78.39	88.01	97.55

The adjusted of the maximum rainfall to the Gumbel model corroborating with the literature (SILVA et al., 2002; TEODORO, 2014; BORGES and THEBALDI, 2016; PEREIRA, DUARTE and SARMENTO, 2017) which assumes Gumbel as a model that expresses satisfactory adjustment to the maximum precipitations. Precipitation adjusted by Gumbel has shown that the shorter the duration, the lower the precipitation and the longer the return periods, the greater precipitation is expected.

Ran et al. (2012) are dominant factors, among precipitation characteristics, intensity and duration, which control the hydrological response. According to the authors, higher runoff peaks are generated by rains of higher intensities and / or duration, being directly linked to soil erosion processes.

The estimation of the parameters (K, a, b, c) from the observed intensities (Table 2) by the non-linear GRG method led to the equation of intense rainfall as presented (Equation 14).

$$I = \frac{645{,}0197\ T^{0{,}2064}}{(t + 17{,}6780)^{0{,}7258}} \quad (14)$$

Equation 15. IDF equation obtained by the GRG method (nonlinear).

The observed rainfall intensities (Table 2), presented a highly significant adjustment ($P < 0.0001$) to the estimated precipitations with the equations obtained by the non-linear GRG and Plúvio 2.1 method and a high coefficient of determination, however, the obtained equation is better adjusted to the values observed and about the line 1:1, when compared to the equation generated by the Plúvio 2.1 (SILVA, 2002) (Figure 4). The behavior of the precipitation intensity obtained by equation 15, as a function of the different duration times, for each payback period, can be observed in figure 5. IDF curves can be used for direct estimates of intensity, return period, and rain duration.

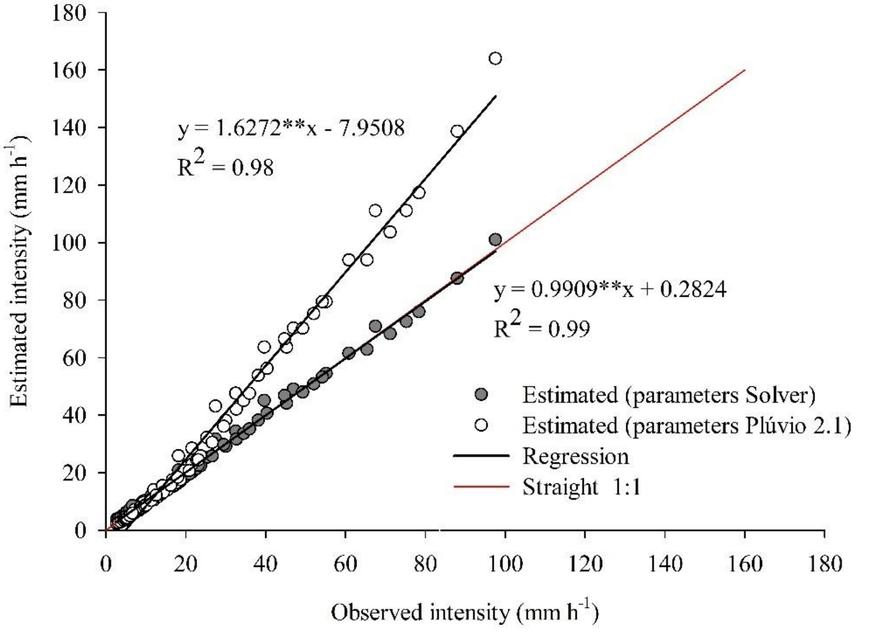

Figure 4 - Behavior of the relationship between precipitation intensities (mm) estimated with the parameters (K, a, b, c), by the GRG method (non-linear) and the Pluvio Program 2.1.** significant at 1% probability

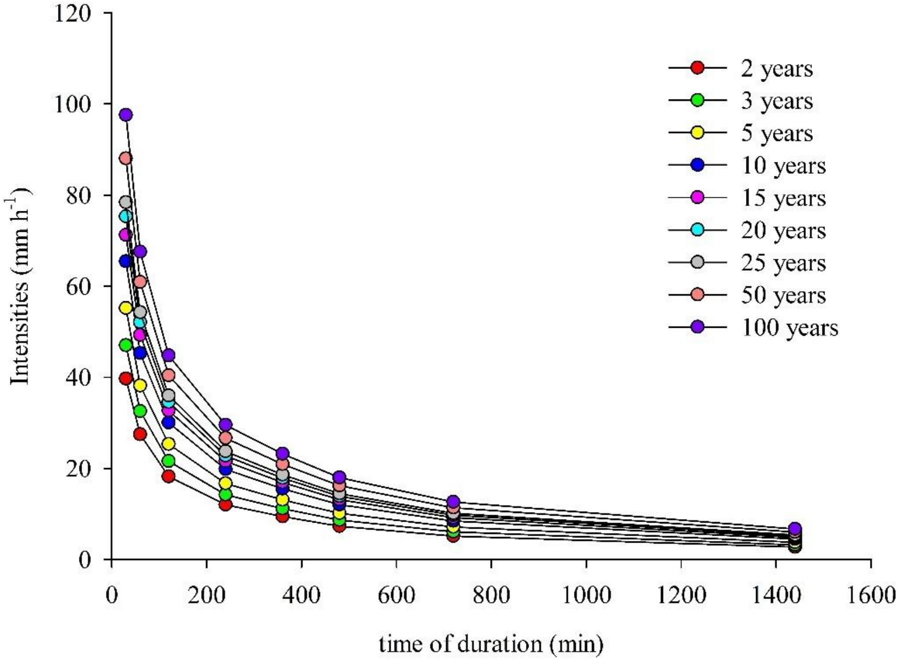

Figure 5 - Intensity (mm h^{-1}) of the precipitations as a function of the duration times (min), for the different times of return (years)

The best fit of the equation obtained to represent the intensity of the rain can be explained in terms of the data period considered for the estimates, and the influence of the differences in the methodologies used to obtain the results also stands out. The equation proposed by Silva et al. (2002) was obtained for data recorded over 24 years (1975-1999), while here we analyze data series with 45 years of rainfall records (1973-2017), a data volume reasonably superior to that recommended by WMO (30 years), to represent with greater reliability the behavior of intense rains. However, Silva et al (2002) analyzed data from 19 pluviographic stations in the state of Bahia, with data volume between 10 and 24 years of observations. according to Silva (2002), the possibility of relating intensity, duration and frequency combining different coefficients does not entail considerable losses in the accuracy of the estimates.

The equation obtained presents an acceptable estimate for the IDF curves, taking into account that direct pluviograph data were not used for the estimation. It is inferred that because we work with a good database (45 years), we have reliability that represented the events of maximum precipitation, in this way, extrapolations outside the limits of the curves can be accepted.

The characteristic presented by the precipitations, due to occur in short durations and high intensities, is a factor closely linked to soil losses due to water erosion. In the studied area, due to the process of caatinga degradation and soil exposure, water erosion processes are evident, as demonstrated by Silva and Rios (2018).

These findings are extremely important, serving as an indication of the times of the year in which plant cover must be maintained over the soil in areas of the basin that are of agricultural use, and for recommendations on the adoption of conservation management practices.

3.3 EROSIVITY OF RAIN

It is observed that higher rainfall is associated with higher erosivity indexes (Figures 6 and 7). For the years analyzed, the highest average monthly rainfall was concentrated in the first three months of the year, with consequent higher erosivity. In general, erosivity tends to increase with precipitation. The highest rainfall erosivity index, 761 MJ mm ha $^{-1}$ h $^{-1}$ month^{-1} was observed for the month of January, followed by February with 687 MJ mm ha $^{-1}$ h $^{-1}$ month^{-1}, and March with 580 MJ mm ha $^{-1}$ h $^{-1}$ month^{-1}, which presented the highest monthly means of precipitation respectively 82 mm, 79 mm e 79 mm (Figure 7).

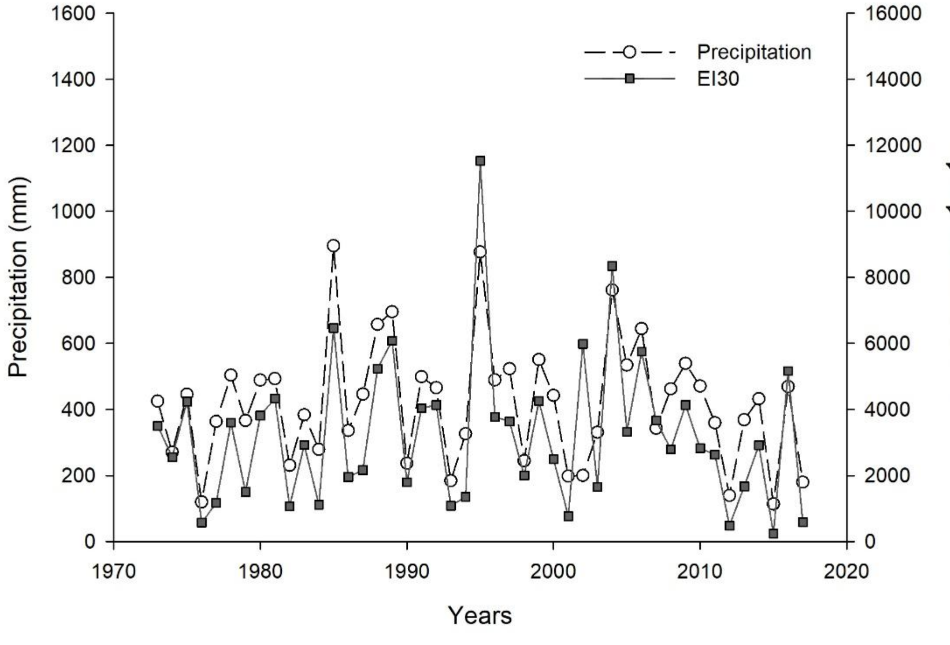

Figure 6 - Behavior of annual values of rainfall erosivity (EI30 - MJ mm ha^{-1} h^{-1}) and precipitation (mm).

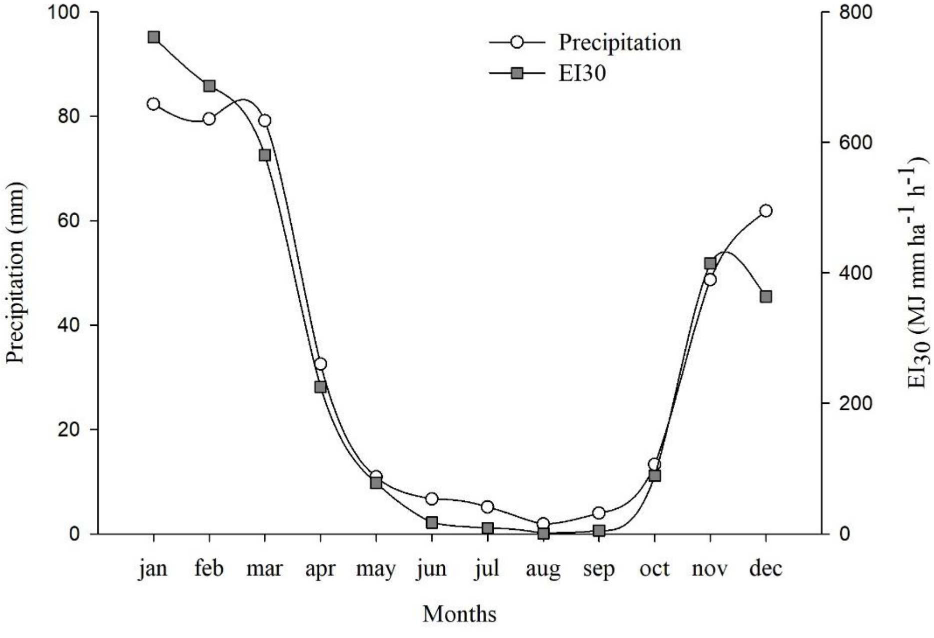

Figure 7 - Behavior of the monthly mean values of rainfall erosivity (EI30 - MJ mm ha^{-1} h^{-1}) and precipitation (mm)

As the erosive precipitation was concentrated in specific months (January, February and March), a relationship was established between monthly erosivity indexes and total daily precipitation (Figure 8), the adjustment was performed by the potential regression model, with coefficients of determination highly significant (<0.0001) and correlation of R^2 = 0.90.

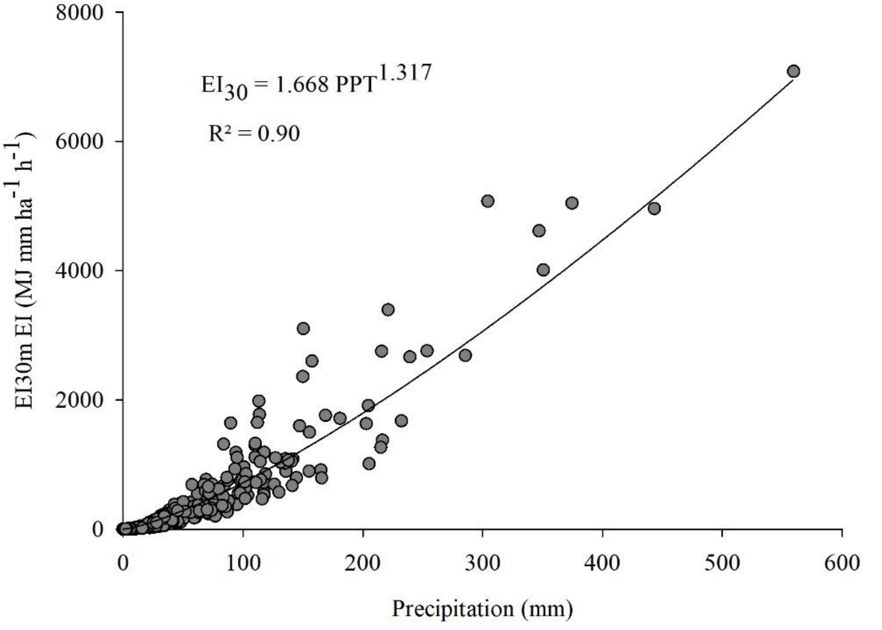

Figure 8 - Potential regression between the monthly erosivity index (EI30 - MJ mm ha^{-1} h^{-1}) and total daily precipitation (mm)

It is inferred that the adjustment, performed by the potential model, showed a good correlation (0.90) when compared to the determination coefficients established for other locations, by the same model. Almeida et al. (2011) obtained a coefficient of 0.91 for the city of Cuiabá - MT, while Santos and Montenegro (2012) obtained 0.71 for Agreste Central of Pernambuco.

Bonilla et al. (2011) studied the relationship between precipitation and annual erosivity in Central Chile, obtained adjusted parameters using a potential model of 0.87, for the authors, the highest number of data used to establish a relationship with the potential model (we used 45 years of data for this study), it is important, and they add that in this type of adjustment, the higher the precipitation values, the greater the erosivity increments.

The annual rainfall erosivity values (Table 3), in general, can be classified as moderate to strong, according to Carvalho (2008). The variation in rainfall erosivity (Table 3) was very high, showing a coefficient of variation (CV) between 116% (1985) and 346% (1976), an indication of the great variability in precipitation behavior in the study area, about the intensity and quantity, which are directly related to the erosive potential of the rain.

Table 3 - Total annual rainfall erosivity index (MJ mm ha^{-1} h^{-1}) for the studied area.

Years	rain erosivity (MJ mm ha^{-1} $year^{-1}$)	mean (MJ mm ha^{-1} $year^{-1}$)	standard deviation (MJ mm ha^{-1} $year^{-1}$)	coefficient of variation (CV%)
1973	3325	292	530	181
1974	2426	213	474	222
1975	4023	354	690	195
1976	540	48	165	346
1977	1105	97	156	161
1978	3415	300	781	260
1979	1425	125	241	193
1980	3619	318	787	247
1981	4109	361	1149	318
1982	1015	89	146	164
1983	2770	244	428	176
1984	1060	93	203	218
1985	6134	539	623	116
1986	1854	163	323	198
1987	2054	181	376	208
1988	4965	436	800	183
1989	5764	507	1411	278
1990	1703	150	492	328
1991	3825	336	472	140

1992	3921	345	765	222
1993	1029	90	201	222
1994	1280	113	255	227
1995	10932	961	1567	163
1996	3576	314	612	195
1997	3447	303	550	182
1998	1889	166	429	258
1999	4032	354	560	158
2000	2364	208	338	163
2001	730	64	128	199
2002	5673	499	1447	290
2003	1570	138	296	214
2004	7913	696	2022	291
2005	3150	277	546	197
2006	5453	479	787	164
2007	3474	305	972	318
2008	2645	233	492	211
2009	3918	344	401	117
2010	2675	235	345	147
2011	2498	220	422	192
2012	461	41	87	215
2013	1582	139	290	208
2014	2769	243	430	177
2015	213	21	43	210
2016	4917	430	1320	307
2017	557	49	88	180

When there is only the possibility of access to daily rainfall data, the relationship between EI30 and total daily rainfall is extremely useful for erosion calculations. For Angulo-Martínez and Beguería (2009) models involving daily rainfall records are potentially applicable in erosion studies, generating accurate predictions about rainfall erosivity.

According to Oliveira et al. (2013) rainfall erosivity values in Brazil vary from 1672 a 22.452 MJ mm ha $^{-1}$ h $^{-1}$ year^{-1}, for the author, the highest values of erosion are caused by intense rains that occur at certain times of the year, which are expressively related to erosive processes (RAN et al., 2012). Similarly, Montenegro et al. (2018) reported moderate to strong erosions between 2009 and 2011, with a CV of up to 227% when studying erosion rain patterns in the archipelago of Fernando de Noronha in Brazil. Albuquerque et al. (2001) and Albuquerque et al. (2005) also reported high dispersion of CV data of up to 259% in rainfall and soil loss studies in semi-arid cities, showing how annual irregularities are characteristic of the semi-arid region and how losses are linked soil erosion.

Although there are few precipitations in the Middle Salitre basin, between 400-800mm year^{-1}, the fact that they are unevenly distributed throughout the year, concentrating in a short period and presenting high intensity, is determinant for the erosive processes, mainly because it is a region of high natural vulnerability.

For Mohamadi and Kavian (2015) as they study precipitation patterns and their relationship with surface runoff and soil erosion, low rainfall intensities show a linear relation to soil losses, while very high intensities show nonlinear behavior, in sum, intense rainfall is responsible for producing higher flow surface erosion and soil erosion.

When comparing the results of annual erosivity, obtained by the two estimation methods (Figure 9), we notice that there is a good correlation between the results (0.76) with a highly significant coefficient of determination (<0.0001). It is understood that, in part, the differences observed in this work are due to the limitations existing in the methodology,howeverThe method used had an approximation up to 76% with the methodology of Lombardi Neto and Moldenhauer (1992) for pluviometric data, and therefore, represents the erosive processes that occurred in the study area were adequate, despite the limitations of the method addressed in this work.

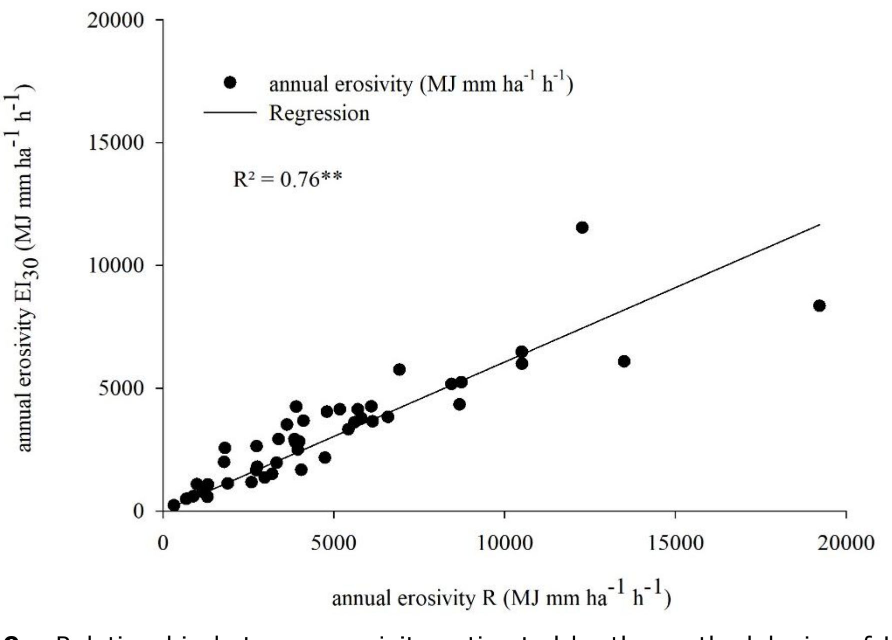

Figure 9 - Relationship between erosivity estimated by the methodologies of Lombardi Neto and Moldenhauer (1992) (R) and Wischmeier and Smith (1958) (EI_{30}).

** significant at 1% probability

Silva, et al (2000), to assess the determination of erosivity for oxisols in Brazil, by direct and indirect methods, with no correlation between the 23 models tested, while Xavier et al. (2019) when comparing three models (WISCHMEIER and SMITH, 1958; SILVA, 2004; CANTALICE et al., 2009), observed that, although there are quantitative differences for rainfall erosivity, qualitatively the results are similar to classify a larger area of erosion.

4. CONCLUSION

The obtained disaggregation coefficients do not present severe discrepancies, about other values obtained in several studies, an indication that their application is satisfactory for determining such disaggregation relations when pluviograph data are not available more pluviometric. However, new studies with a larger database are interesting to determine the coefficients in order to become even more accurate.

The equation of intense rains is satisfactory to be used in calculations of rain intensities in the study area, but also for regions of comprehensiveness of the station used for this study.

Despite the restrictions existing in the approached method to determine erosivity, the indexes found are indicators of increasingly intense erosion processes in the basin under study.

Since the rain erosivity processes showed strong intensity over 45 years, it is extremely important that mitigation and recovery measures in this area be implemented, to avoid the triggering of processes, of soil and water degradation, more complex.

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REFERENCES

ALBUQUERQUE, A. W.; GILSON FILHO, M.; SANTOS, J. R.; COSTA, J. P. V.; SOUZA, J. L. Determination of factors of the universal equation of soil loss in Sumé, PB. Brazilian Journal of Agricultural and Environmental Engineering, 9 (2), 153-160. 2005.

ALBUQUERQUE, A. W.; LOMBARDI NETO, F.; SRINIVASAN, V. S. Efeito do desmatamento da caatinga sobre as perdas de solo e água de um Luvissol em Sumé-PB. Revista Brasileira de Ciência do Solo, Viçosa, v. 25, n.1, p.121-128. 2001.

ALMEIDA, C. O.; AMORIM, R. S. S.; COUTO, E. G.; ELTZ, F. L. F.; BORGES, L. E. C. Erosive potential of Cuiabá rainfall, MT: Distribution and correlation with rainfall. Brazilian Journal of Agricultural and Environmental Engineering, v. 15, n.2, p. 178-184. 2011.

ANA – Agência Nacional das Águas. HidroWeb: hydrological information systems [Online]. National Water Agency, 2018. Available from: http://hidroweb.ana.gov.br [Accessed 2 july 2018].

Andrade, M. G. de. General and applied statistics. 3. ed., São Paulo: Atlas, 2006. 418 p.

ANGULO-MARTÍNEZ, M.; BEGUERÍA, S., Estimating rainfall erosivity from daily precipitation records: A comparison among methods using data from the Ebro Basin (NE Spain). Journal of Hydrology, 379, (1-2), 111-121. 2009.

ARAÚJO, J. C. de. Assoreamento em reservatórios do semi-árido: modelagem e validação. Brazilian Journal of Water Resources, v.8, n.2, p. 39-56. 2003.

BACK, A. J., OLIVEIRA. J. L. R.; HENN, A. Duration-frequency relationships of heavy rainfall in Santa Catarina, Brazil. Revista Brasileira de Ciências do Solo, v. 36, n. 3, p. 1015-1022. 2012.

BAZZANO, M. G. P.; ELTZ, F. L. F.; CASSOL, E. A. Erosivity, rainfall coefficient, patterns and rainfall return period of Quaraí, RS. Brazilian Journal of Soil Science, v. 31, n. 5, p. 1205-1217. 2007.

BAZZANO, M. G. P.; ELTZ, F. L. F.; CASSOL, E. A. Erosivity and hydrological characteristics of Rio Grande rainfall (RS). Brazilian soil science journal, v. 34, n. 1, p. 235-244, 2010.

BEYENE, T. D.; MOGES, M. A.; TILAHUN, S. A.Development of Rainfall Disaggregation Model in the Awash River Basin, Ethiopia. In: ZIMALE F.; ENKU NIGUSSIE T.; FANTA S., International Conference on Advances of Science and Technology. Springer Nature Switzerland: ICAST, 2018 v. 274, 2019, p. 50-64.

BONILLA, C.; A., VIDAL; KARIM, L., Rainfall erosivity in central Chile. Journal of Hydrology, v. 410, n. 1-2, p. 126-133. 2011.

BORGES, G. M. R.; THEBALDI, M. S. Estimation of annual maximum daily precipitation and intense rainfall equation for the municipality of Formiga, MG, Brazil. Magazine Environment & Water, v. 11, n. 4, p. 891-902. 2016.

CAMPOS, A. R.; SANTOS, G. G.; SILVA, J. B. L.; IRENE FILHO, J.; LOURA, D. DE S. Intensity-duration-frequency equations of rains for the state of Piauí. Agronomic Science Magazine, v. 45, n. 3, p. 488-498. 2014.

CEDRAZ, A. 2012. Programa de revitalização da bacia hidrográfica do São Francisco. Relatório de auditoria operacional. Brasília: TCU. 2008, 34-36 p.

CRUTCHER, H. L. A note on the possible misuse of the kolmogorav-smirnov test. Journal of applied meteorology, v.14, p.1600-1603. 1975.

DAEE-CETESB. Department of water and electricity. Company of environmental sanitation technology. São Paulo: Project manual, 1979.

DAMÉ, R. C. F.; TEIXEIRA, C. F. A. I; TERRA, V. S. S. Comparação de diferentes metodologias para estimativa de curvas intensidade-duração-frequência para Pelotas – RS. Revista Engenharia Agrícola, v. 28, n. 2, p. 245-255. 2008.

DA SILVEIRA, A. L. L. Equation for rainfall disaggregation coefficients. Brazilian Journal of Water Resources, v. 5, n.4, p. 143-147, 2000.

DNIT – Departamento Nacional de Infraestrutura de Transportes. Manual de Hidrologia básica para Estruturas de Drenagem. Rio de Janeiro, 2005, 133 p.

DE MOURA, M. S. B.; GALVINCIO, J. D.; BRITO, L. T. de L.; SOUZA, L. S. B. DE; SÁ, I. I. S.; SILVA, T. G. F. da. Climate and rainwater in the Semi-Arid. In: BRITO, L. T. de L.; MOURA, M. S. B. de; GAMA, G. F. B. Potentialities of rainwater in the Brazilian semi-arid region. [Online]. Semi-Arid Embrapa Publications Committee. Petrolina: Embrapa semi-arid, 2006. 36-59 p.

DE MOURA, M. S. B; SOARES, J. M.; TEIXEIRA, A. H. DE C. Agrometeorological Stations. Embrapa information agency. Brazil: Brasília – DF, 2019. Available from: https://www.agencia.cnptia.embrapa.br/Agencia22/AG01/arvore/AG01_2_2882 00612375.html [Accessed 2 july 2018].

FADHEL, S.; RICO-RAMÍREZ, M. A.; HAN, DAWEI. Uncertainty of Intensity–Duration–Frequency (IDF) curves due to varied climate baseline periods. Journal of hydrology, v. 547, p. 600-612, 2017.

GUMBEL, E. J. Statistics of extremes. New York: Columbia University Press. 1958.

HAAN, C. T.; BARFIELD, B. J.; HAYES, J. C. Design hydrology and sedimentology for small catchments. Elsevier, 1994. 588 p.

INEMA – Institute of the environment and water resources: Characterization of the Salitre basin. 2018. Available from: http://www.inema.ba.gov.br/gestao-2/comites-de-bacias/comites/cbh-salitre/ [Accessed 2 july 2018].

KOSSIERIS, P.; MAKROPOULOS, C.; ONOF, C.; KOUTSOYIANNIS, D. A rainfall disaggregation scheme for sub-hourly time scales: Coupling a Bartlett-Lewis based model with adjusting procedures. Journal of hydrology. v. 556, p. 980–992, 2018.

LASDON, L. S.; WAREN, A. D. GRG2: an all Fortran general purpose nonlinear optimizer. ACM SIGMAP Bulletin, v. 30, n. 30, p. 10-11. 1981.

LOMBARDI NETO, F.; MOLDENHAUER, W. C. Erosividade da chuva: sua distribuição e relação com as perdas de solo em Campinas (SP). Bragantia, v. 51, n. 2, p. 189-196, 1992.

MONTENEGRO, A. A. A.; SOUZA DOS S., SOUZA T. E. M.; DE, E. R., MONTENEGRO, S. M. G. L. Temporal dynamics of soil moisture and rainfall erosivity in a tropical volcanic archipelago. Journal of Hydrology, v. 563, p. 737-749. 2018.

MOHAMADI, M. A.; KAVIAN, A. Effects of rainfall patterns on runoff and soil erosion in field plots. International Research on Soil and Water Conservation, 3 (4), 273-281. 2015.

NAGHETTINI, M. PINTO, E. J. DE A. Statistical hydrology. Belo Horizonte: CPRM. 2007. 552 p.

OLIVEIRA, P. T. S., WENDLAND, E.; NEARING, M. A., Rainfall erosivity in brazil: a review. Catena, 100, p. 139-147. 2013.

PEREIRA, D. C., DUARTE, L. R. and SARMENTO, A. P. Determination of the intensity, duration and frequency curve of the municipality of Ipameri-Goiás. Electronic Civil Engineering Magazine, v. 13, n.2, p. 233-246. 2017.

PEREIRA, S. B.; NÓIA, C. P. Z.; ALMEIDA, R. A.; COELHO, C. D. Methodology adjustment and determination of the intensity, duration and frequency equations of maximum rainfall for the state of Mato Grosso do Sul. Revista de Engenharia Agrícola, v. 34, n.4), p. 716-726, 2014.

PEREIRA, A. R.; ANGELOCCI, L. R.; SENTELHAS, P. C. Meteorologia Agrícola. Piracicaba/SP, Edição Revista e Ampliada, ESALQ/USP, 2007. p. 202.

PFAFSTETTER, O. Chuvas intensas no Brasil. Brasília: Departamento Nacional de Obras e Saneamento. 1957. 419 p.

PINTO, E. J. DE A. Brazil's pluviometric atlas: methodology for defining the intensity-duration-frequency equations of the pluviometric atlas project. Belo Horizonte: CPRM, 2013. 11-18. p.

RAN, Q.; SU, D.; LI, P.; HE, Z. Experimental study of the impact of rainfall characteristics on runoff generation and soil erosion. Journal of Hydrology, v. 424-425, p. 99-111, 2012.

ROSSI, R. A.; SANTOS, E. Conflict and regulation of water in Brazil – the Salitre case. Caderno CRH, v. 31, n.82), p. 151-167, 2018.

SANTOS, T. E. M.; MONTENEGRO, A. A. A., Erosivity and hydrological patterns of precipitation in the Agreste Central of Pernambuco. Brazilian Journal of Agricultural and Environmental Engineering, v. 16, n.8, p. 871–880, 2012.

SILVA, A. J. P. DA; RIOS, M. L. Technical Bulletin: Alert of desertification in the middle course of the river Salitre, affluent of the São Francisco.1rd ed. Senhor do Bonfim, Goiano Federal Institute, 2018. 44 p.

SILVA, D. D.; GOMES FILHO, R. R. D.; PRUSKI, F. F., PEREIRA, S. B.; NOVAES, L. F. Heavy rains in the state of Bahia. Brazilian Journal of Agricultural and Environmental Engineering, v. 6, n.2, p. 362-367, 2002.

Silva, M. L. N.; CURI, N.; LIMA, J. M. DE; FERREIRA, M. M. Evaluation of indirect methods for determining the erodibility of Brazilian latosols (oxisols). Brazilian Agricultural Research, v. 35, n.6, p. 1207-1220, 2000.

TEIXEIRA, C. F. A.; DAME, R. DE C. F.; ROSSKOFF, J. L. C. Intensity-duration-frequency ratios obtained from annual records and partial duration records in the locality of Pelotas - RS, Brazil. Journal of Agricultural Engineering, v. 31, n. 4, p. 687-694, 2011.

TEODORO, PE.; NEIVOCK, M. P.; MARQUES, J. R. F.; FLORES, A. M. F.; BRAGA, C. Influence of different disaggregation coefficients in the determination of IDF equations for Aquidauana/MS. Revista eletrônica de Engenharia Civil, v. 9, n.2, p. 1-9, 2014.

WISCHMEIER, W. H.; SMITH, D. D. Rainfall energy and its relationship to soil loss. American Geophysical Union Transactions, Washington, D.C., v. 39, p. 285-291, 1958.

VILLELA, S. M.; MATTOS, A. Hidrologia aplicada. São Paulo: Editora McGraw-Hill do Brasil Ltda., 1975. 56-62 p.

WEISS, L. Ratio of true to fixed-interval maximum rainfall. Journal of the Hydraulic Division, v. 90, n. 1, p. 77-82, 1964

WMO - World Meteorological Organization. Calculation of monthly and annual 30-year standard normal. WMO, Geneva, Suiça, 1989. 341 p.

XAVIER, J. P DE S.; BARROS, A. H. C.; WEBBER, D. C.; ACCIOLY, L. J. DE OLIVEIRA; MARQUES, F. A.; ARAÚJO FILHO, J. C. DE, SILVA, A. B. DA. Estimation of erosivity by different methods and their impact on the universal soil loss equation in Pernambuco semi-arid. Brazilian Journal of Physical Geography, v.12, n. 3, p. 859-875, 2009.

XIE, Y.; YIN, S. Q.; LIU, B. Y.; NEARING, M. A.; ZHAO, YING. Models for estimating daily rainfall erosivity in China. Journal of Hydrology, v. 535 p. 547-558, 2016