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Estimate of the rain erosivity in the municipality of Piaçabuçu - AL

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Abstract
Soil erosion is a process caused by several factors, including precipitation. Causing the water erosive process, through the detachment and transport by surface runoff of soil particles. This phenomenon depends on the intensity, frequency and duration of events in a given region. Thus, the objective was to determine the rainfall erosivity indices through rainfall data. The period of rainfall data used was between the years 1943 to 1985, for the municipality of Piaçabuçu, located in the lower São Francisco Alagoano region. These data were tabulated to calculate rainfall, rainfall coefficient and its relation to erosivity using six equations. The municipality of Piaçabuçu has an average annual rainfall distribution of 1128.52 mm for the observation period of 42 years, with a wide variation in the distribution of rainfall over the years, with the rainy season concentrated in the months of March to August , presenting average values above the average, in this period it precipitated more than 70% of the rains for the municipality. Todos os seis modelos de estimativas da erosividade apresentaram correlação considerada alta, o que os capacita para a estimativa da erosividade do município em estudo. All six erosivity estimation models presented a high correlation, which enables them to estimate the erosivity of the municipality under study.
Keywords: climatology of Alagoas; pluviometric data; mathematical models.

Estimativa da erosividade das chuvas no município de Piaçabuçu - AL

Resumo
A erosão do solo é um processo causado por diversos fatores, dentre eles a precipitação. Ocasionando o processo erosivo hídrico, através do desprendimento e o transporte pelo escoamento superficial de partículas do solo. Tal fenômeno depende da intensidade, frequência e duração dos eventos em uma determinada região. Desta forma, objetivou-se determinar os índices de erosividade das chuvas através de dados pluviométricos. O período de dados pluviométricos utilizados foi entre os anos de 1943 a 1985, para o município de Piaçabuçu, localizado na região do baixo São Francisco Alagoano. Os referidos dados foram tabulados para cálculo da chuva, coeficiente de chuva e sua relação à erosividade utilizando seis equações. O município de Piaçabuçu apresenta uma distribuição pluviométrica anual média de 1128,52 mm, para o período de observação de 42 anos, apresentando uma ampla variação de distribuição da precipitação pluviométrica ao longo dos anos, com o período chuvoso concentrado nos meses de março a agosto, apresentando valores médios acima da média, neste período precipitou mais de 70% das chuvas para o município. Todos os seis modelos de estimativas da erosividade apresentaram correlação considerada alta, o que os capacita para a estimativa da erosividade do município em estudo.
Palavras-chave: climatologia de Alagoas; dados pluviométricos; modelos matemáticos.

Introduction

The erosive process is a phenomenon that has a direct impact on the quality of agricultural soils, causing serious socio-economic and environmental damage, which has attracted the attention of institutions and governments around the world. Such erosive processes start with the action of the impact of raindrops on the soils, starting three stages in the environment, first, disaggregation of soil particles, promoted by the action of the kinetic energy of the raindrop that is transferred to the soil or cover, which if uncovered will clog the pores; second, it is characterized by the formation of a layer of water on the ground, depending on the conditions of topography, micro relief and surface roughness; and in the third stage, the displacement of the sediment mass over the soil surface occurs, characterized by runoff (SÁ *et al.*, 2020; OLIVEIRA *et al.*, 2018).

According to the literature, water erosion is a phenomenon that involves the direct and indirect action of several factors, including rainfall and surface runoff (GOMES *et al.,* 2021; OLIVEIRA; AQUINO, 2021). Rainfall is considered one of the main factors in promoting the water erosive process, this highlight is in part related to the kinetic energy of the raindrops, which translates into a driving force, putting energy into the system, where the constituent factors will be viewed in varying ways (PINTO *et al.,* 2020). The understanding of the water erosive process incorporated the effects of the kinetic energy of rain, this phenomenon that involves the driving force of the process, was fundamental for its characteristics to be understood in a broad and definitive way. The driving force of rain in the erosive process must be studied through its intensity, frequency and duration of events in a particular region or location (SABINO *et al.*, 2020). Among the climatic variables, precipitation is considered the most important in tropical regions.

According to Castro and Santos (2020), the expression of the kinetic energy of rain in causing soil degradation is defined as the erosivity of rainfall due exclusively to the physical characteristics of the rain itself. The rainfall erosivity, represented by the R factor, means a numerical value of the potential of rainfall and runoff to provide water erosion in a given region or locality (BERTOL *et al.,* 2018). According to Nascimento, Romão and Sales (2018), the numerical representation of the values of the kinetic energy of rain is through the EI_{30} (Rain Erosivity Index), which is obtained by multiplying two specific parameters of the precipitation of a given location: energy total kinetics of rain (E) and maximum intensity in 30 min (I_{30}). To obtain rainfall erosivity values for a region or locality, historical series rainfall data of at least 20 years is used (BACK; POLETO, 2018).

In Brazil there is a shortage of rainfall data, which is considered the standard method for calculating rainfall erosivity. In these cases, it is necessary to calculate this erosivity through rainfall characteristics. Given the relevance of the subject, the objective was to determine the erosivity factor (R) based on rainfall data from 1943 to 1985 in the municipality of Piaçabuçu - AL.

Material and methods

The study was developed for the city of Piaçabuçu - AL, presenting climate As according to the climate classification of Köppen (1948) and an average temperature of 22 °C. Climatic data from 1943 to 1985 were obtained through the Sudene bulletin of the municipality under study, these data were tabulated to calculate rainfall, rainfall coefficient and its relationship with erosivity.

To estimate rainfall erosivity (R) rainfall data should be used, however, these data are generally difficult to find as they are not computed or stored, so it is better to be calculated using rainfall data (SILVA *et al.,* 2021). According to Bertoni and Lombardi Neto (2017), these data are difficult to obtain, almost becoming scarce in Brazil. To solve this problem, several mathematical models were proposed to obtain these pluviometric data.

To verify the veracity of rainfall erosivity values by rainfall data models, it is necessary to determine the rainfall coefficient (Rc). Lombardi Neto and Moldenhauer (1992) proposed this calculation through equation 1, which was based on Fournier's model (1960), with some modifications:

$$Rc = \frac{p2}{P} \quad (1)$$

Where, p is the monthly average rainfall (mm); and P is the mean annual rainfall (mm).

Equation 2, proposed by Oliveira Júnior and Medina (1990), supported by the Fournier model (1960), is used to calculate erosivity with rainfall data from a given region:

$$Rx = 3{,}76 * \frac{(M_x^2)}{P} + 42{,}77 \quad (2)$$

Where, R_x is the R factor (MJ mm ha^{-1} h^{-1} year^{-1}) and M_x is the monthly mean precipitation (mm).

Morais *et al.* (1991) developed equation 3, based on the Fournier model (1960).

$$Rx = 36{,}849 * \left(\frac{M_x^2}{P}\right)^{1{,}0852} \quad (3)$$

Leprun (1981), analyzing rainfall in the Northeast, developed equation 5, through an exponential model, where Rx expresses the average erosivity for a region under study.

$$Rx = 0{,}13 * (M_x^{1{,}24}) \quad (4)$$

Equation 5 suggested by Val *et al.* (1986), to calculate the rainfall erosivity of a location based on rainfall data, is based on the Fournier model (1960).

$$Rx = 12{,}592 * \left(\frac{M_x^2}{P}\right)^{0{,}603} \quad (5)$$

Equation 6 was created by Lombardi Neto and Moldenhauer (1992) based on the Fournier model (1960).

$$Rx = 68{,}73 + \left(\frac{M_x^2}{P}\right)^{0{,}841} \quad (6)$$

Rufino *et al.* (1993) developed equation (7) supported by linear models to determine the erosivity of a region based on rainfall data.

$$Rx = 19{,}44 + (4{,}20 * \ M_x) \quad (7)$$

Erosivity was characterized based on the rainfall erosivity classes shown in table 1.

Table 1. Classes of average annual and monthly rainfall erosivity.

Classes	Erosivity (MJ mm ha^{-1} h^{-1} ano^{-1})
Very low	R ≤ 2452
Low	2452 < R ≤ 4905
Average	4905 < R ≤ 7357
High	7357 < R ≤ 9810
Very high	R > 9810

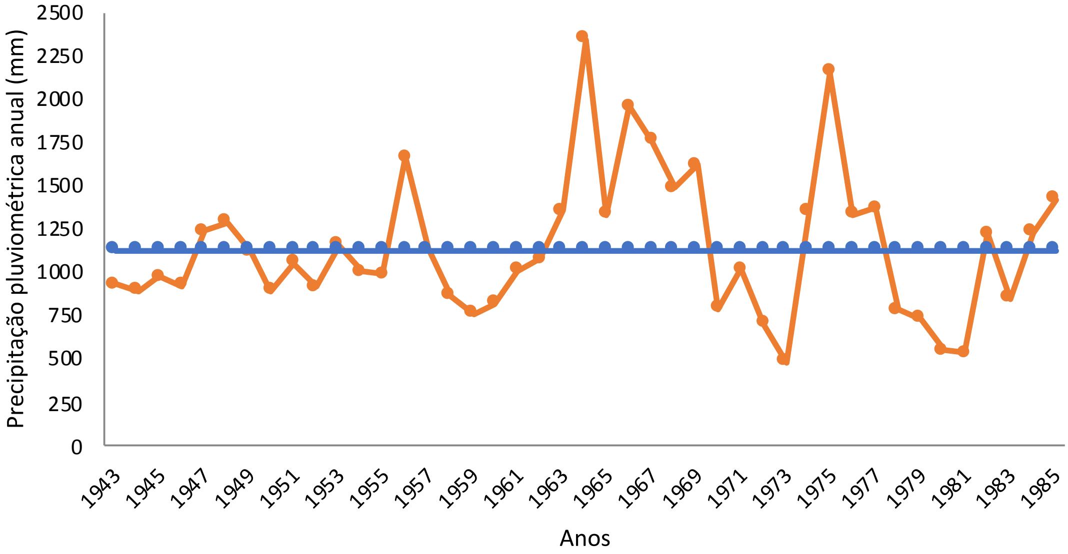
Source: Carvalho (2008).

Erosivity data were submitted to linear regression analysis using the Sisvar statistical program.

Results and discussion

The municipality of Piaçabuçu has an average annual rainfall of 1128.52 mm (Figure 1), according to monthly rainfall observation data for the period 1943 to 1985 (42 years), according to monthly rainfall data from the SUDENE station - Northeast Development Superintendence (1990). A characteristic observed in the municipality's rainfall analysis is the amplitude and variability of rainfall volumes during the evaluation period, which presents years well below the historical average and years above the average. The years 1973, 1980 and 1981 had the lowest rainfall volumes, with 482, 533 and 553 mm, respectively, values below 50% of the historical average for the municipality. The highest values were registered in the years 1964, 1966 and 1975, with averages of 2340, 1952 and 2149 mm, respectively, such values correspond to 107, 90 and 76% above the average of the observation period.

Figure 1. Distribution of mean annual precipitation in the municipality of Piaçabuçu - AL, with an average value for the observation period from 1943 to 1985.

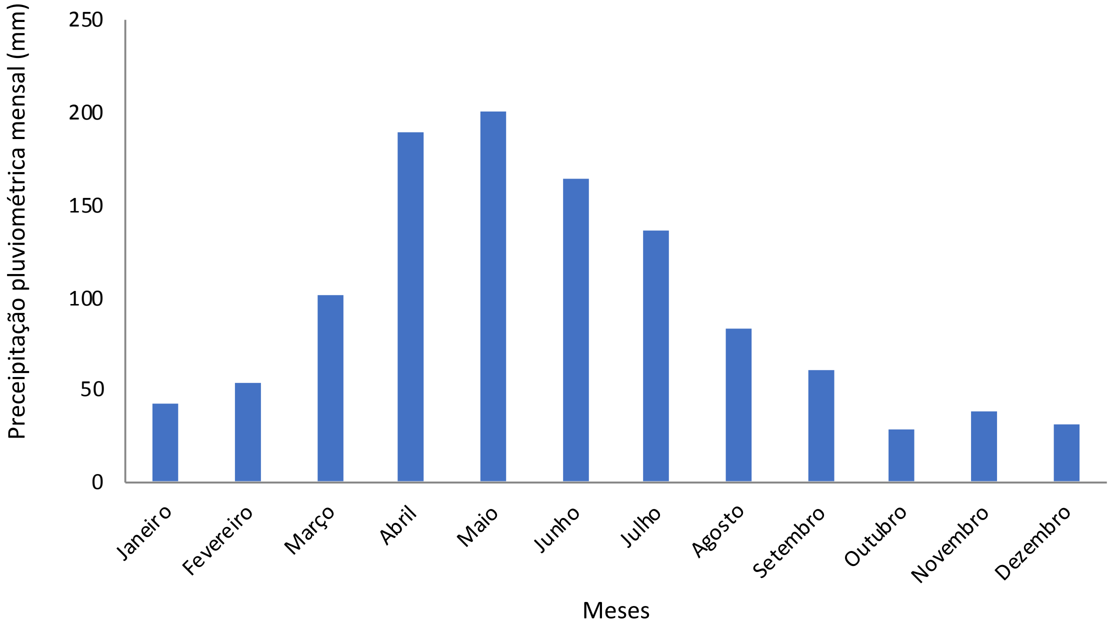


The high variation observed in rainfall data may be associated with the occurrence of ENSO events (El Niño and La Niña). According to Brubacher; Oliveira and Guasselli (2021) in tropical regions, rainfall is characterized by presenting great spatial and temporal variation in its occurrence. These characteristics are also observed in the Northeast region of Brazil, where its rainfall is influenced by ENSO events, promoting interannual and intraseasonal variability (BARATO; WOLLMANN, 2017).

In the municipality of Piaçabuçu, the probable effects of the ENSO events can be observed in the years 1973 and 1975 (Figure 1), which present opposite conditions. Where in 1973 (year of occurrence of El Niña forte) only 482 mm were recorded, which corresponds to 43% of the average, while in 1975 (year of occurrence of La Niña forte) rainfall levels of 2149 mm were recorded, a volume precipitation 90% above the historical average. Santos *et al.* (2020) studying the erosivity of the municipality of Água Branca, in the extreme west of the state of Alagoas, they observed a similar behavior for rainfall data for a historical series of 72 years of observations, where in 1973 it presented rainfall rates around 73% below the average, while the year 1975 presented a volume of precipitation greater than 50% of the historical average, results such as these can be attributed to ENSO events in the municipality.

The monthly distribution of rainfall is shown in Figure 2. The rainy season starts in March, with more than 7% higher than the historical average of the year, and ends in July, these months represent more than 70% of the rainfall that occurs in the city. The other months of the year had below average rainfall. According to this historical series, the month with the highest precipitation values is May, exceeding by more than 100% the monthly average of the municipality and the month of October has the lowest occurrence of precipitation, a result also observed by Santos *et al.* (2020).

Figure 1. Distribution of average monthly precipitation in the municipality of Piaçabuçu - AL, with an average value for the observation period from 1943 to 1985.



Lombardi Neto and Moldenhauer (1992) expresses that the Rc represents a mathematical relationship between the monthly rainfall records squared divided by the product of the annual precipitation of a given location, this calculation was only possible after the publication of the work by Fournier (1960), which establishes the mathematical bases (SILVA; SANTOS, 2020; WAGNER; FLORES, 2020).

The mean rainfall coefficient (Rc) values, determined by equation 1, are shown in Table 2. The Rc's follow the same pattern of annual rainfall distribution, corresponding on average to 11.08% of the total precipitation recorded in the period.

Table 2. Monthly rainfall coefficient values for the municipality of Piaçabuçu - AL, from 1943 to 1985.

Month	Rain coefficient (Rc)	
	mm	%
January	1,63	1,23
February	2,55	1,92
March	9,13	6,87
April	31,58	23,76
May	35,69	26,85
June	23,75	17,87
July	16,23	12,28
August	6,12	4,60
September	3,32	2,30
October	0,73	0,55
November	1,26	0,95
December	0,83	0,63
Total	132,94	100

In Figure 3A are the erosivity indices for the municipality of Piaçabuçu, these monthly rainfall values were submitted to the exponential model developed by Oliveira Júnior and Medina (1990), working with rainfall in the southwest region of the state of Mato Grosso. The average annual erosivity for the municipality of Piaçabuçu is 1013.10 MJ mm ha^{-1} h^{-1} $year^{-1}$, a value that fits into the erosivity class proposed by Carvalho (2008) as very low. The period with the highest levels of erosivity is from April to August.

The model proposed by Oliveira Júnior and Medina (1990) despite having been developed in another location, different from the climatic conditions of the municipality, presented a good correlation with a linear model adjustment and R^2 = 0,99 (Figure 3B). It is justified because the equation is linear and uses Rc as the slope (slope of the line), thus adjusting 100% of the points in a linear line. As a result, this model can be used in the climatic conditions of the city of Piaçabuçu.

Figure 2. Average monthly erosivity index (A) and relationship between erosivity and rainfall coefficient (B) obtained by Oliveira Júnior and Medina (1990).

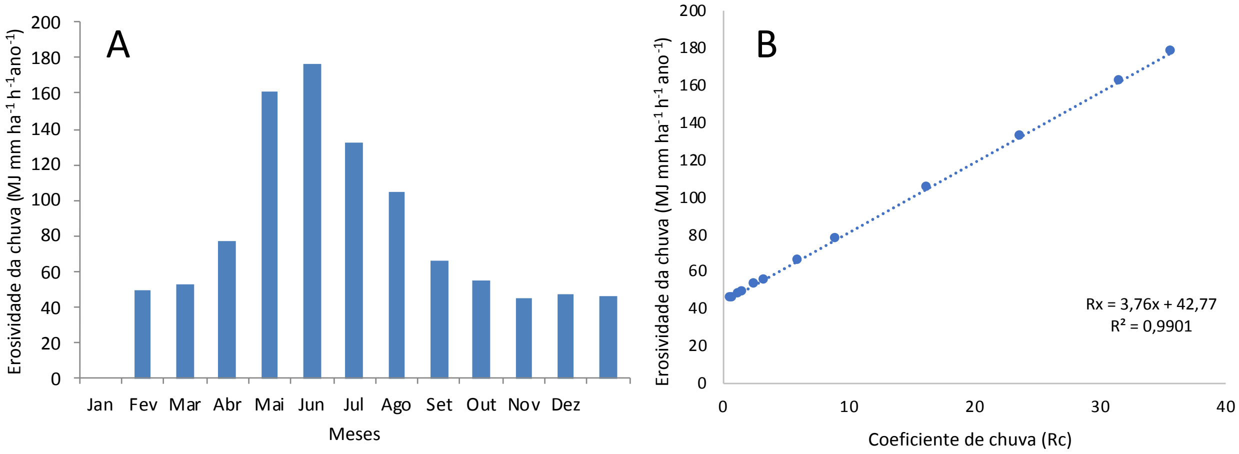
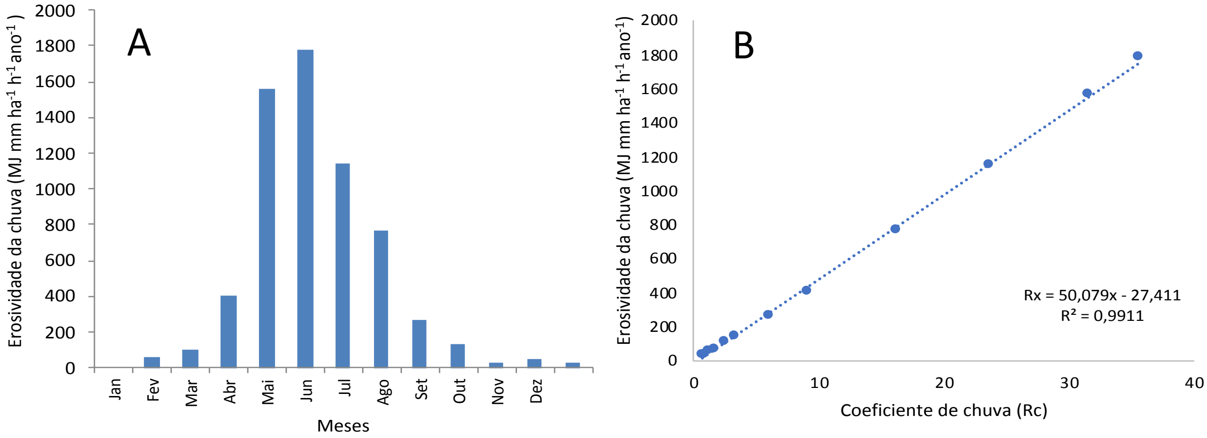


Figure 4A shows the rainfall erosivity indices calculated using the mathematical model proposed by Morais *et al.* (1991). According to this model, the total rainfall erosivity index is 6328,58 MJ mm ha^{-1} h^{-1} $year^{-1}$, this value is included in the moderate erosivity class, proposed by Carvalho (2008). Similar results were obtained by Santos *et al.* (2020), using this proposed model reaching an index of 6990 MJ mm ha^{-1} h^{-1} $year^{-1}$. Several researches were carried out in the Northeast in order to determine the erosivity indices, such as the works by Leprun (1981) and Silva (2004) who found values between 3000 and 7000 MJ mm ha^{-1} h^{-1} $year^{-1}$for the northeastern hinterland, while Rabelo, Girão and Araújo (2018) found values around 2208 to 4802 MJ mm ha^{-1} h^{-1} $year^{-1}$ for Rio Grande do Norte and Paraíba, characterized as a low erosive potential according to Carvalho (2008).

In verifying the accuracy of this model in estimating erosivity based on rainfall data with the rainfall coefficient, a trend line adjusted to the linear type was verified, with a coefficient of determination of 99.01%, being considered a strong correlation (Figure 4B). Similar results were obtained by Abreu *et al.* (2019) working in the state of Espirito Santo, found coefficients of determination of 0.9.

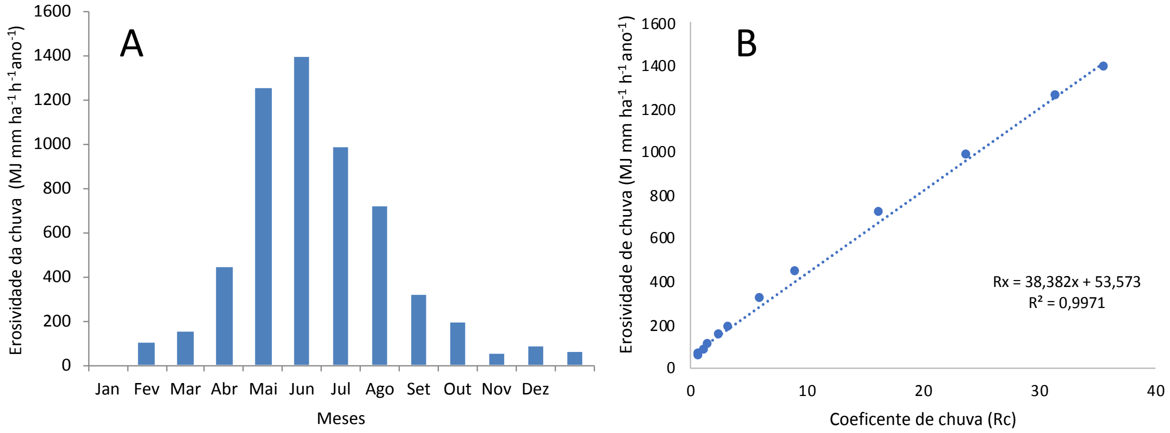
Figure 3. Average monthly erosivity index (A) relationship between erosivity and rainfall coefficient (B) obtained by Morais *et al.* (1991).



One of the best known and most used models in several regions of Brazil, mainly due to the scarcity of rainfall data, with a duration of at least 20 years of observations, is the mathematical model developed by Lombardi Neto and Moldenhauer (1992). The use of this model in the municipality of Piaçabuçu generated a rainfall erosivity index of 5745.36 MJ mm ha^{-1} h^{-1} $year^{-1}$ (Figure 5A), this value is classified in the moderate class according to the methodology proposed by Carvalho (2008). This model was used by Santos *et al.* (2020) for the municipalities of Água Branca and Palmeira dos Índios, in Alagoas, where they obtained moderate erosivity indices. Amaral *et al.* (2014), studying the erosive potential for the state of Paraíba, found a result that fits into this same category of erosivity classes, using the same model in question.

In Figure 5B, the results of the linear model are presented, relating the rainfall erosivity indices estimated by the equation proposed by Lombardi Neto and Moldenhauer (1992) to the rainfall coefficients for the municipality studied. Obtaining a linear model fitted to the data and obtaining a coefficient of determination of 99,71%.

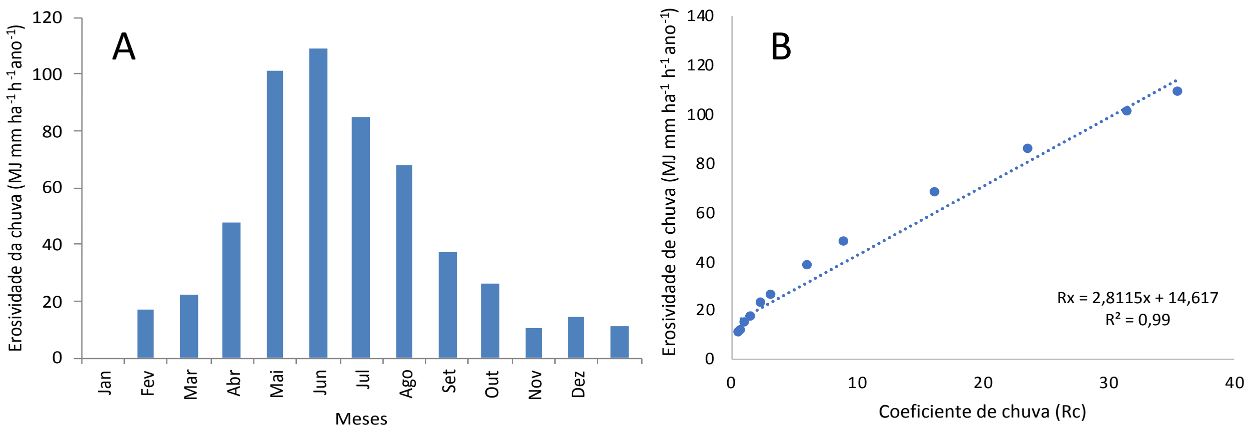
Figure 4. Average monthly erosivity index (A) and relationship between erosivity and rainfall coefficient (B) obtained by Lombardi Neto and Moldenhauer (1992).



The result of the estimate of rainfall erosivity using the model proposed by Val *et al.* (1986) is shown in Figure 6A. The average annual erosivity value for the municipality, estimated by this method, is 549,16 MJ mm ha^{-1} h^{-1} $year^{-1}$. The upper limit of the erosivity class is very low, for this fact it is not allowed to use the methodology proposed by Carvalho (2008) to frame this value in the erosivity classes. Although this model was developed based on the Fournier principle and with data from tropical regions, it does not present a good performance for use.

To measure the accuracy of this model against the city's climatic conditions, it was correlated with the rainfall coefficient and adjusted to a linear trend line, with a coefficient of determination of 0.99, which is quite strong (Figure 6B).

Figure 5. Average monthly erosivity index (A) and relationship between erosivity and rainfall coefficient (B) obtained by Val *et al.* (1986).

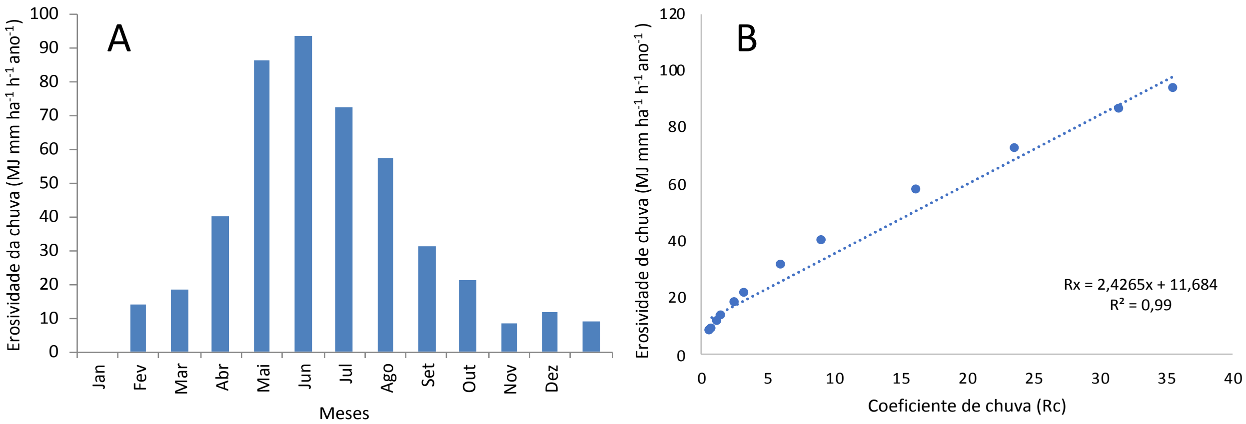


Leprun (1981) analyzing rainfall data from various meteorological stations in the Northeast proposed an exponential mathematical model based on the principle proposed by Founier (1960) for estimating erosivity based on rainfall data.

According to the result obtained in Figure 7A, the monthly erosivity index value was 462.78 MJ mm ha^{-1} h^{-1} $year^{-1}$, showing a similar behavior with the highest erosivity values following the highest precipitation indices in the municipality, a fact registered in all tested models. The rainfall erosivity values obtained by this model cannot be included in the erosivity classes proposed by Carvalho (2008) because they present low compatibility, reaching only about 20% of the limit value of the very low erosivity class.

Figure 7B shows the correlation between the average monthly erosivity index estimated by the model proposed by Leprun (1981) and the rainfall coefficient. The correlation was fitted to a linear trend line, with a coefficient of determination of 0.99, showing a strong correlation.

Figure 6. Average monthly erosivity index (A) and relationship between erosivity and rainfall coefficient (B) obtained by Leprun (1981).

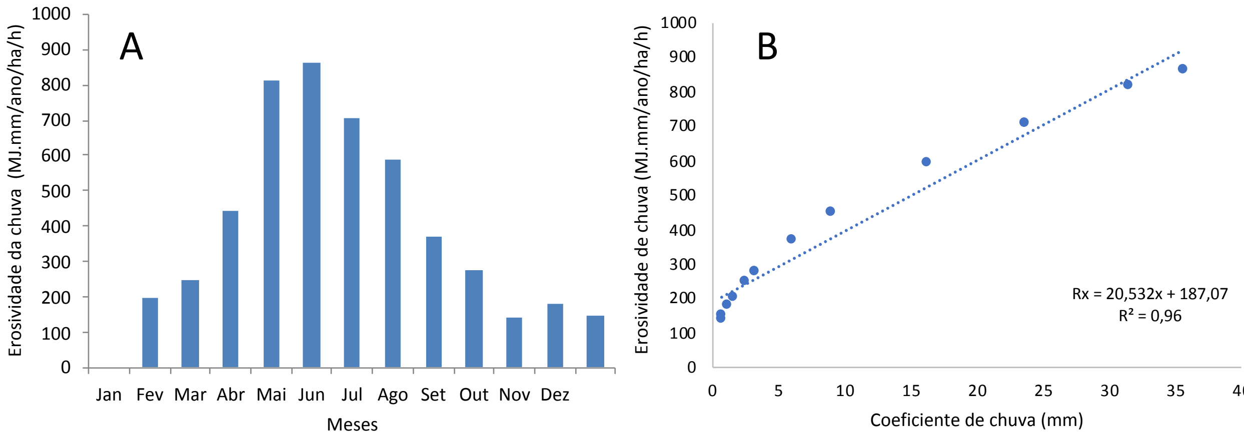


The model proposed by Leprun (1981) was generated with precipitation data from various regions of the Northeast, its importance for the region was highlighted by Silva (2004) when he proposed the division of the country into eight homogeneous regions according to rainfall. This model was proposed to represent the coastal region of the Northeast. The results obtained in this research are similar to those of Santos *et al.* (2020) who obtained a strong correlation, this may be related to the objective of developing this model, which was to meet the demands of erosivity based on rainfall data, since rainfall data are scarce in the Northeast region.

The monthly mean values of erosivity estimated using the linear mathematical model proposed by Rufino *et al.* (1993) are arranged in Figure 8A. Applying in that municipality, an average annual value of 4974,39 MJ mm ha^{-1} h^{-1} $year^{-1}$ was obtained, this value fits as low erosive potential, within the scale of erosivity classes of Carvalho (2008). This value differs from the estimated erosivity values for several regions or localities in the Northeast. However, the aforementioned method was proposed using rainfall data from the state of Paraná, southern Brazil, subtropical region.

Figure 8B shows the correlation between the monthly rainfall erosivity index estimated by the model proposed by Rufino *et al.* (1993). This model presented an adjustment to a linear trend line, with a coefficient of 0.96, considered strong. This model was among all the models studied, which showed the lowest correlation value, but within the range found by several researchers, such as the determination of 0.99 obtained by Matos *et al.* (2017) for Barbalha – CE and above the result found by Back and Poleto (2018), which was 0.47 for Porto União – SC. Other researchers have already applied this model in the state of Alagoas and observed a strong correlation between the erosivity values obtained and the rainfall coefficient index for two municipalities located in the semiarid region of Alagoas.

Figure 7. Average monthly erosivity index (A) and relationship between erosivity and rainfall coefficient (B) obtained by Rufino *et al.* (1993).



Rocha *et al.* (2019) studying the erosive potential of the rains in Belterra, in the state of Pará, found rains with high erosive potential. In the State of Paraíba, Amaral *et al.* (2014), studying the state's erosive potential, found an average value considered moderate. The works for estimating rainfall erosivity for the state of Pernambuco, were selected only those developed in the semiarid region, a wide range of values ranging from 1500 to 8.000 MJ mm ha^{-1} h^{-1} $year^{-1}$, were recorded, recorded in the works by Xavier *et al.* (2019), Pinheiro and Souza (2018), Almeida *et al.* (2017), Silva (2004) and Leprun (1981).

It is noteworthy that the models used were developed with rainfall data from different regions of Brazil. One way to assess the accuracy of using a mathematical model with data from a particular region or location other than the one in which it was estimated is to use regression curves that relate the erosivity index to rainfall coefficients (LOMBARDI NETO; MOLDENHAUER, 1992; BATISTA *et al.,* 2018).

Conclusion

The models analyzed recorded the highest erosivity values from May to July.

The month of May had the highest erosivity rates for the city under study.

The average annual values of erosivity had a rate of variation from low to high.

The erosivity estimation models presented a high correlation, which enables them to estimate the erosivity of the municipality under study.

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