Diversitas Journal
ISSN 2525-5215
Volume 8, Number 3 (jul./set. 2023) p. 2922 – 2935
https://diversitasjournal.com.br/diversitas_journal

Erosive potential of the rains of the county of Cacimbinhas - AL, obtained by mathematical models

Potencial erosivo das chuvas do município de Cacimbinhas – AL, obtido por modelos matemáticos

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ABSTRACT

Water erosion is a process that consists of the detachment, drag and deposition of soil particles. The capacity that rain has to cause soil erosion is called erosivity and due to the scarcity of rainfall data, in most counties rainfall data are used to determine this factor. The objective of this study was to determine erosivity through different mathematical models in the county of Cacimbinhas - AL. Rainfall data were obtained through the Hidroweb portal, between 1963 and 2000, being tabulated for the calculation of rain, rain coefficient and its relationship with erosivity, using six equations. Regression was performed using a spreadsheet. The average annual rainfall was 687.01 mm. In 1975 the highest rainfall record was obtained, while in 1998, the lowest precipitation. From April to July we had the highest rainfall and in October and November, the lowest rates. The total rainfall coefficient corresponds to 10.88% of the average precipitation in the period studied. For all mathematical models, the highest erosivity indices comprise the months of March to July, while November recorded the lowest index of this factor. The correlation between erosivity and rain coefficient was high for all models analyzed. Erosivity ranged from 246.51 to 4964.13 MJ mm ha^{-1} h^{-1} $year^{-1}$. Between March and July, the highest erosive potential was recorded, and in November, the lowest potential. Mathematical models can be used to estimate rainfall erosivity in the county of Cacimbinhas - AL.

INFORMAÇÕES DO ARTIGO

Histórico do Artigo:
Submitted: 10/05/2023
Approved: 25/06/2023
Published: 17/07/2023

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Keywords:
Soil erosion, Rainfall, Northeast.

RESUMO

A erosão hídrica é um processo que consiste no desprendimento, arraste e deposição de partículas de solo. A capacidade que a chuva possui em causar erosão no solo é denominada de erosividade e devido à escassez de dados pluviográficos, na maioria dos municípios utilizam-se dados pluviométricos para determinação desse fator. Objetivou-se determinar a erosividade através de diferentes modelos matemáticos no município de Cacimbinhas – AL. Obteve-se os dados pluviométricos através do portal Hidroweb, entre 1963 a 2000, sendo tabulados para realização do cálculo da chuva, coeficiente de chuva e sua relação com a erosividade, utilizando seis equações. A regressão foi realizada através de planilha de cálculo. A média anual de precipitação foi de 687,01 mm. O ano de 1975 obteve o maior registro pluviométrico, enquanto 1998, a menor precipitação. De abril a julho tivemos as maiores precipitações e em outubro e novembro, os menores índices. O coeficiente de chuva total corresponde a 10,88% da média de precipitação no período estudado. Para todos os modelos matemáticos, os maiores índices de erosividade compreendem os meses de março a julho, enquanto novembro registrou o menor índice deste fator. A correlação entre a erosividade

***Palavras-chave*:**
Erosão do solo, Pluviosidade, Nordeste.

DOI: 10.48017/dj.v8i3.2673

e o coeficiente de chuva foi alta para todos os modelos analisados. A erosividade variou de 246,51 a 4964,13 MJ mm ha^{-1} h^{-1} ano^{-1}. Entre março a julho registrou-se o maior potencial erosivo e, em novembro, o menor potencial. Os modelos matemáticos podem ser utilizados para estimar a erosividade das chuvas no município de Cacimbinhas – AL.

Introduction

Erosive processes occur naturally in the environment, slowly and gradually, causing changes in the relief and vegetation. Being the most harmful form of soil degradation, reducing crop productivity and can cause environmental damage. This degradation occurs mainly by the drag of the smaller, more nutrient-rich particles. A constant concern, in all cases related to the management of land and water use, has been the water erosion of soils and the resulting sediment production (Cogo et al., 2003; Santos et al., 2010).

Water erosion is defined as the result of the processes of soil particle breakdown, transport and deposition of these particles (Machado et al., 2013). The soil losses caused through this process, in most cases, reduce the thickness of the soil, decreasing the capacity of retention and redistribution of water in the profile, generating greater surface runoff and, eventually, higher rates of soil erosion (Santos et al., 2010).

Through the use of mathematical models, best practices of land use and management have been studied, as well as estimates of soil losses by the process of water erosion (Back, 2018a). There are different models for the determination of water erosion, one of the most used is the Universal Soil Loss Equation (*Equação Universal de Perda de Solo* - EUPS), proposed by Wischemeier and Smith (1978). In this equation, as reported by Back (2018a), the estimate of average soil losses is given by the product of six factors, which are the rainfall erosivity factor (R), the soil erodibility factor (K), the slope length factor (L), the slope degree factor (S), the use and management factor (C) and the conservation practice factor (P).

The erosivity of rain consists of the potential of rain to cause erosion, being represented by the product of the kinetic energy of rain by its maximum intensity in 30 min. (EI_{30}). The determination of erosivity values throughout the year allows the identification of the months in which the risk of erosion is highest, having importance for land use planning (Silva et al., 2009; Machado et al., 2013).

Several studies carried out in Brazil that correlate soil losses with erosivity indices indicate that the index EI_{30} is a good estimator of erosivity (Back, 2018a). Thus, in order to perform more reliable measurements and more detailed analyses of the erosivity of the rainfall of a stipulated region, it´s necessary to record long historical series of monitoring, around 20 years (Martins et al., 2020). However, this methodology is laborious and presents difficulties of execution (Back, 2018b).

In order to minimize this problem, different authors correlate the index EI_{30} with the rainfall coefficient, which is obtained based on the record of daily rainfall totals, and these data are available for several locations, which simplifies its obtainment, as well as maintains an accuracy in the estimation of the EI_{30} (Mello et al., 2007). With the scarcity or inexistence of rainfall data for several locations, the way to evaluate the accuracy of the use of different mathematical models with data from regions different from the one in which it was estimated, is done using regression curves that relate the erosivity index to the rainfall coefficients (Albuquerque, 1991; Lombardi Neto & Moldenhauer, 1992).

According to the Mineral Resources Research Company (CPRM, 2005) the county of Cacimbinhas is located in the northwest region of the state of Alagoas. It has an area occupying 272.80 km^2, inserted in the mesoregion of Sertão Alagoano and in the microregion of Palmeira dos Índios. The approximate altitude of Cacimbinhas is 270 m, with geographical coordinates of 9° 24' 01" of southern latitude and 36° 59' 25" of west longitude. Thus, the objective was to determine erosivity through different mathematical models for the county of Cacimbinhas - AL.

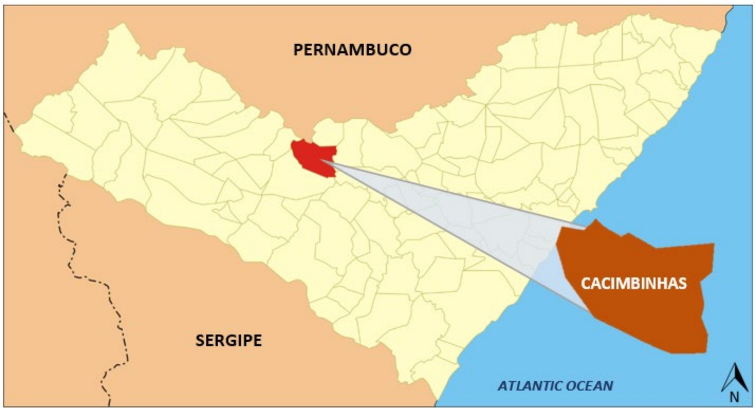
Methodology

Study location

The county studied is located in the northwestern region of the state of Alagoas (Figure 1), with the following geographical coordinates of 9° 24' 01" of southern latitude and 36° 59' 25" of west longitude (CPRM, 2005).

Figure 1.

Location of the county of Cacimbinhas on the map of the state of Alagoas.



Source: Adapted from Wellber Drayton (2010).

Rainfall data

The rainfall data were obtained through the Hidroweb portal, an integral tool of the National Water Resources Information System (*Sistema Nacional de Informação sobre Recursos Hídricos* - SNIRH), coordinated by the National Water Agency (*Agência Nacional de Águas* - ANA), for the period from 1963 to 2000. The mentioned data were tabulated to calculate rainfall, the rainfall coefficient and its relationship with erosivity using six equations.

Rainfall Coefficient Estimation (Rc)

To analyze the accuracy of rainfall erosivity values through rainfall data, it´s necessary to determine the rainfall coefficient (Rc). In this work, this coefficient based on rainfall data for the county of Cacimbinhas was estimated using equation (1) proposed by Lombardi Neto (1977), based on the Fournier model (1960), with certain changes:

$$\mathbf{Rc} = \left(\frac{p^2}{P}\right) \qquad \mathbf{(1)}$$

Where:

p = average monthly rainfall, in mm;

P = average annual rainfall, in mm.

Erosivity estimation through mathematical models

There are different mathematical models for determining rainfall erosivity. Six equations were chosen to carry out this work, described below:

Equation (2) proposed by Oliveira Júnior and Medina (1990), which is based on the Fournier model (1960).

$$\mathbf{R_x = 3{,}76 \times \left(\frac{M_x^2}{P}\right) + 42{,}77} \qquad \mathbf{(2)}$$

Where:

R_x = factor R, in MJ mm ha^{-1} h^{-1} $year^{-1}$;

M_x = average monthly rainfall, in mm;

P = average annual rainfall, in mm.

Equation (3) proposed by Lombardi Neto and Moldenhauer (1992), based on the model of Fournier (1960).

$$\mathbf{R_x = 68{,}73 \times \left(\frac{M_x^2}{P}\right)^{0{,}841}} \qquad \mathbf{(3)}$$

Equation (4) that was proposed by Val et al. (1986) also based on the model of Fournier (1960).

$$\mathbf{R_x = 12{,}592 \times \left(\frac{M_x^2}{P}\right)^{0{,}6030}} \qquad \mathbf{(4)}$$

Equation (5) developed through an exponential model, having been proposed by Leprun (1981).

$$\mathbf{R_x = 0{,}13 \times \left(M_x^{1{,}24}\right)} \qquad \mathbf{(5)}$$

Equation (6) developed based on linear models, which was proposed by Rufino et al. (1993).

$$\mathbf{R_x = 19{,}44 + (4{,}20 \times M_x)} \qquad \mathbf{(6)}$$

And the equation (7) developed by Morais et al. (1991) which is based on the model of Fournier (1960).

$$\mathbf{R_x = 36{,}849 \times \left(\frac{M_x^2}{P}\right)^{1{,}0852}} \qquad (7)$$

Soil erosivity classes

Erosivity was classified according to the classes available in Table 1, proposed by Carvalho (2008).

Table 1.

Classes for interpretation of the erosivity index.

Erosivity (MJ mm year^{-1} ha^{-1} h^{-1})	Erosivity class
$R \leq 2452$	Weak erosivity
$2452 < R \leq 4905$	Moderate erosivity
$4905 < R \leq 7357$	Moderate to strong erosivity
$7357 < R \leq 9810$	Strong erosivity
$R > 9810$	Very strong erosivity

Source: The authors (2023).

Statistical treatment of rainfall data

The data were tabulated and submitted to regression analysis, using a spreadsheet.

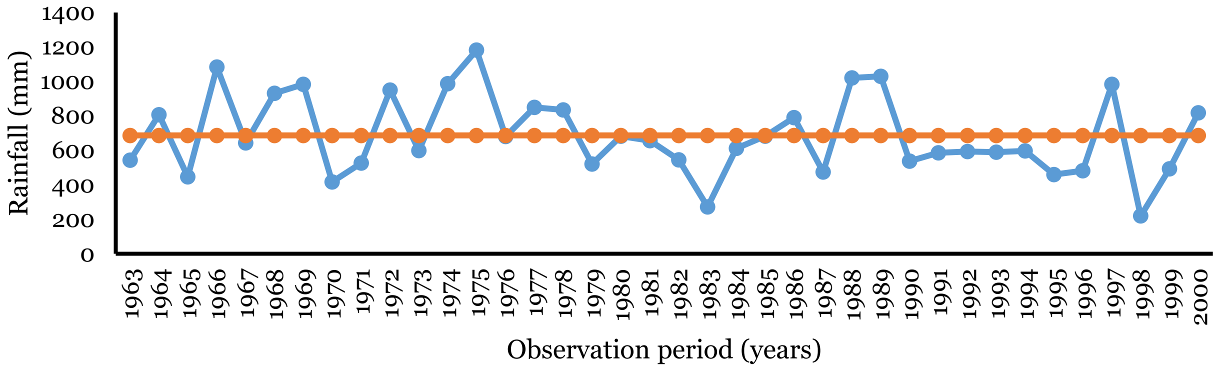
Results and discussion

Spatial and temporal distribution of rainfall in the county of Cacimbinhas

Figure 2 shows the mean values of the annual rainfall distribution for the county studied. The average annual rainfall for the county of Cacimbinhas - AL was 687.01 mm. Within the historical series of 38 years analyzed, 14 years with values above the average and 24 years with values below the average of rainfall were observed. The year 1975 is the one that obtained the highest rainfall record, with precipitation of 1181.30 mm, while the year 1998 refers to the lowest rainfall, registering 219.10 mm.

Figure 2.

Distribution of average annual rainfall in the period from 1963 to 2000, for the county of Cacimbinhas - AL.



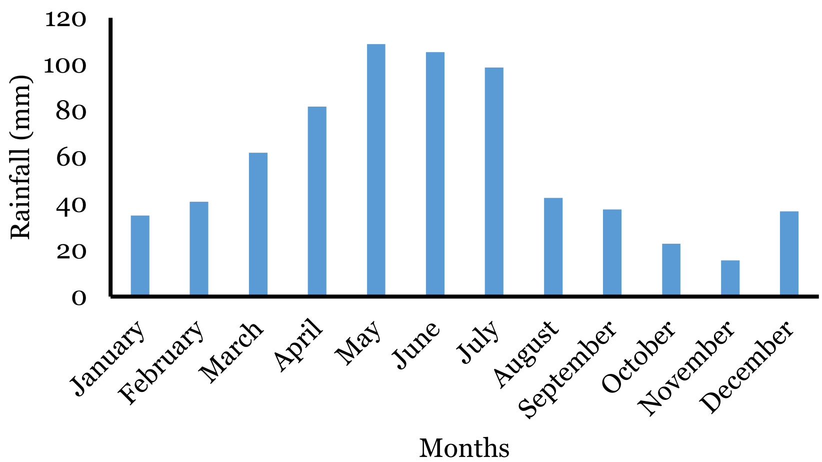
Source: The authors (2023).

Santos et al. (2020), working with erosivity for the county of Água Branca - AL, in the period of 1913 to 1985, obtained results similar to those of this research, with spatial and temporal variation of precipitations. Costa et al. (2020), in a study on the analysis of extreme climatic indices in the Northeast of Brazil, between the years 1961 to 2014, observed for most weather stations, a reduction in total annual precipitation, as well as in the frequency of rainy days in the region. Possibly contributing to the below average precipitation values for the county studied.

Figure 3 shows the mean values of the monthly distribution of rainfall for the county of Cacimbinhas. The four month period April-May-June-July had the highest rainfall, with average values of 81.79; 108,74; 105.22 and 98.67 mm, respectively, representing 57.41% of the annual precipitation of the county. The months with the lowest rainfall rates were October and November, with mean values of 22.75 and 15.54 mm, respectively, corresponding to 5.57% of the annual rainfall.

Figure 3.

Average monthly rainfall in the period from 1963 to 2000 for the county of Cacimbinhas - AL.



Source: The authors (2023).

Similar results were obtained by Wanderley et al. (2012), who studied with monthly data from 63 spatially distributed rainfall stations in the state of Alagoas, in the period 1965 to 1980, verified that the rainy season is between the months of April to July, while the period with the lowest precipitation rates corresponds to the months of October to January.

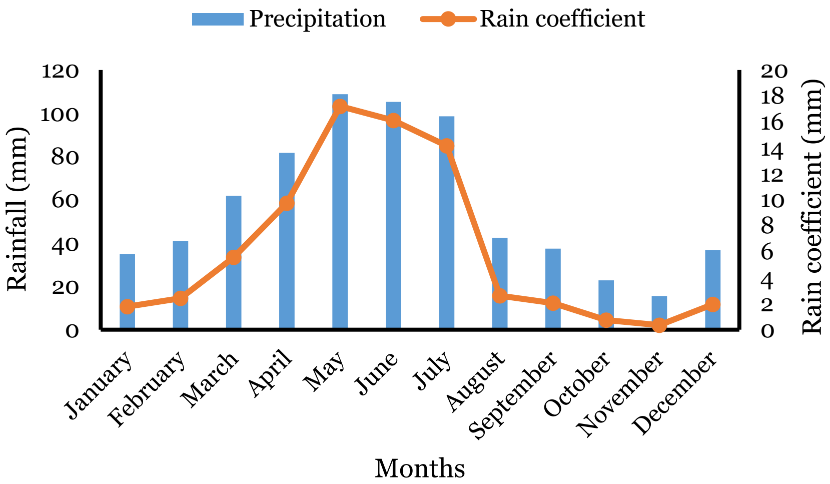
Silva et al. (2011), working with analysis of rainfall and rainy days in the Northeast region of Brazil, with data from more than 30 continuous years, obtained similar results with those of this study, when they observed that for the state of Alagoas, the average number of rainy days is higher between the months of April to August, while the months of November and December are the ones that present the lowest average number of rainy days. Justifying the rainfall data reached for the county of Cacimbinhas.

Rain Coefficient (Rc)

Figure 4 indicates a similarity between the monthly mean distributions of rainfall (P) and rainfall coefficient (Rc). Thus, it´s observed that for the months with the highest rainfall indices (April, May, June and July) the rainfall coefficient values were also higher. And, for the months with the lowest rainfall rates (October and November), the rainfall coefficients were also lower.

Figure 4.

Distribution of monthly average rainfall and rainfall coefficient in the period from 1963 to 2000 for the county of Cacimbinhas - AL.



Source: The authors (2023).

Amaral et al. (2014), studying the spatial variability of rainfall erosivity in the state of Paraíba, they obtained similar results, where the highest rainfall occurs between the months of February to June, presenting the highest rainfall rates and the lowest rainfall occurred in October and November, also having the lowest rainfall coefficient records.

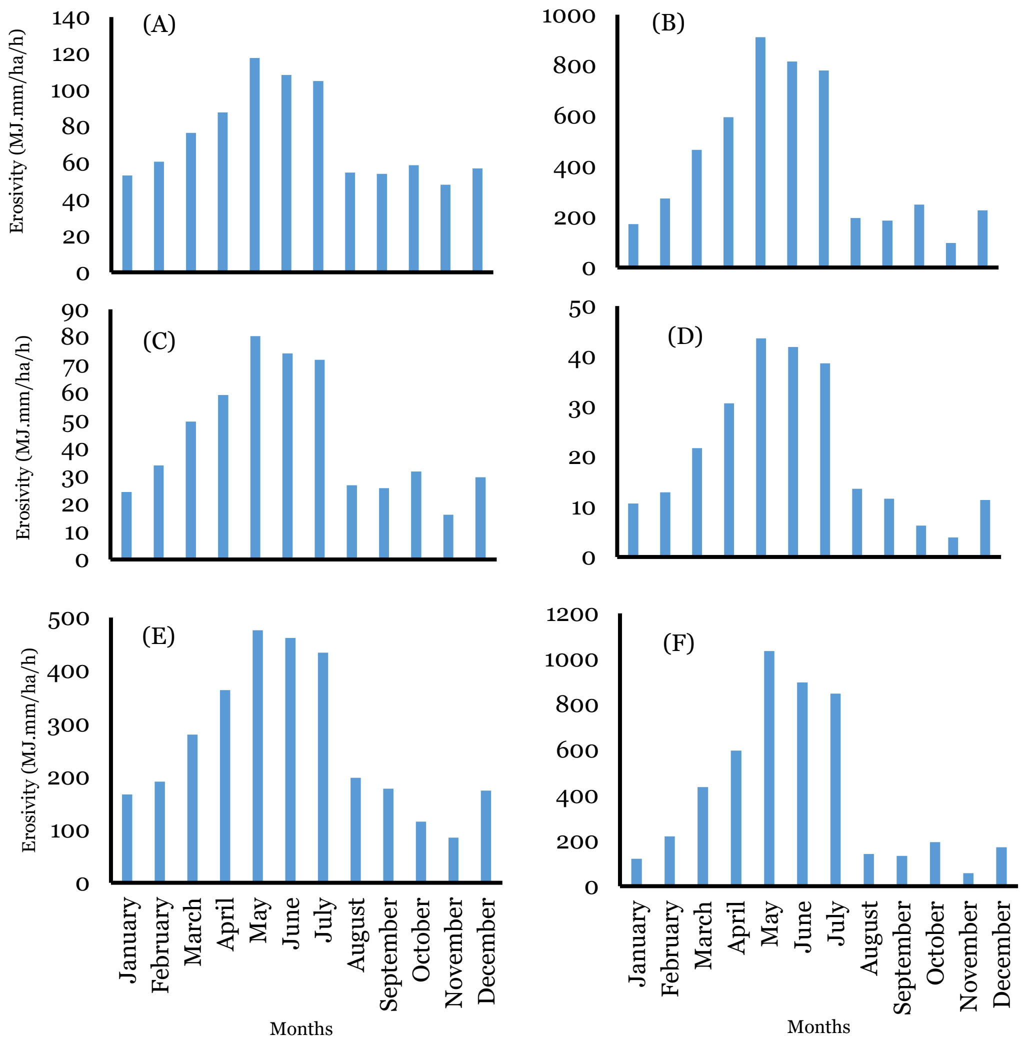
Rain erosivity obtained by mathematical models

Six mathematical models were used to carry out this work.

Figure 5 shows the monthly average erosivity indices obtained through the mathematical models in the period from 1963 to 2000 for the county of Cacimbinhas - AL. The erosivity obtained in Figure 5A presented an annual average of 881,13 MJ mm ha^{-1} h^{-1} $year^{-1}$. Framed as weak erosivity, according to table 1. The months of March to July recorded the highest rates of this factor studied, representing 56.16% of the annual average. While November is the month with the lowest erosivity index, accounting for 5.44% of the annual average. Duarte and Silva Filho (2019), estimating the erosivity of rainfall in the Juma River watershed in the county of Apuí - AM, and, using this mathematical model, obtained results close to those of this research, with the months of March, April and May among those that presented the highest erosivity indexes.

Figure 5.

Average monthly erosivity obtained by the model proposed by (A) Oliveira Júnior and Medina (1990); (B) Lombardi Neto and Moldenhauer (1992); (C) Val et al. (1986); (D) Leprun (1981); (E) Rufino et al. (1993) e (F) Morais et al. (1991).



Source: The authors (2023).

The erosivity obtained in Figures 5B and 5C presented an annual average of 4964,13 and 522,99 MJ mm ha^{-1} h^{-1} year^{-1}, respectively, being classified as moderate to strong erosivity and weak erosivity, as shown in Table 1. In Figure 5B, the months with the highest erosivity indexes are from March to July, corresponding to 71.83% of the annual average. While the month of November has the lowest index obtained, equivalent to 1.95% of the annual average. Similar to what was obtained in Figure 5C, where the months with the highest erosivity indexes are March, April, May, June and July, representing 64.07% of the annual average, and November represents the month with the lowest index, corresponding to 3.08% of the annual average. Silva et al. (2023), analyzing the spatial variability of the erosive potential of rainfall in Alagoas and using mathematical models, obtained similar results, recording the months of

May to July, the highest monthly average values of erosivity, while the months of September, October and November presented the lowest records of this index.

The erosivity obtained in figures 5D and 5E presented an annual average of 246.51 and 3120.02 MJ mm ha^{-1} h^{-1} $year^{-1}$, being classified as weak erosivity and moderate erosivity, according to table 1. In Figure 5D, the months of March to July present the highest erosivity indexes, totaling 71.49% of the annual average, and November is the month with the lowest index, corresponding to 1.58% of the annual average. The same was obtained in Figure 5E, in which the months of March to July have the highest erosivity values, equivalent to 64.56% of the annual average, and November is the month with the lowest index, corresponding to 2.71% of the annual average. Santos et al. (2020), estimating the erosivity for the county of Água Branca - AL, obtained similar results when using mathematical models, in which the months of April to July represent the highest erosivity indexes, while October and November are equivalent to the months with the lowest values of this index.

The erosivity obtained in Figure 5F presented an annual average of 4448.44 MJ mm ha^{-1} h^{-1} $year^{-1}$. Classified as moderate erosivity, according to table 1. The months of March to July obtained the highest erosivity values, representing 85.60% of the annual average, while November was equivalent to only 1.19% of this average. Rosa and Sousa (2018), using this model when estimating rainfall erosivity in Óbidos - PA, in the period from 1986 to 2015, obtained results close to those found in this study, with the March-April-May quarter being among those with the highest erosivity indexes.

It´s observed that the values of maximum and minimum erosivity in the study period for all applied models are related to the highest and lowest rainfall (Figure 3). And that, even in different regions, erosivity tends to increase with more intense rainfall.

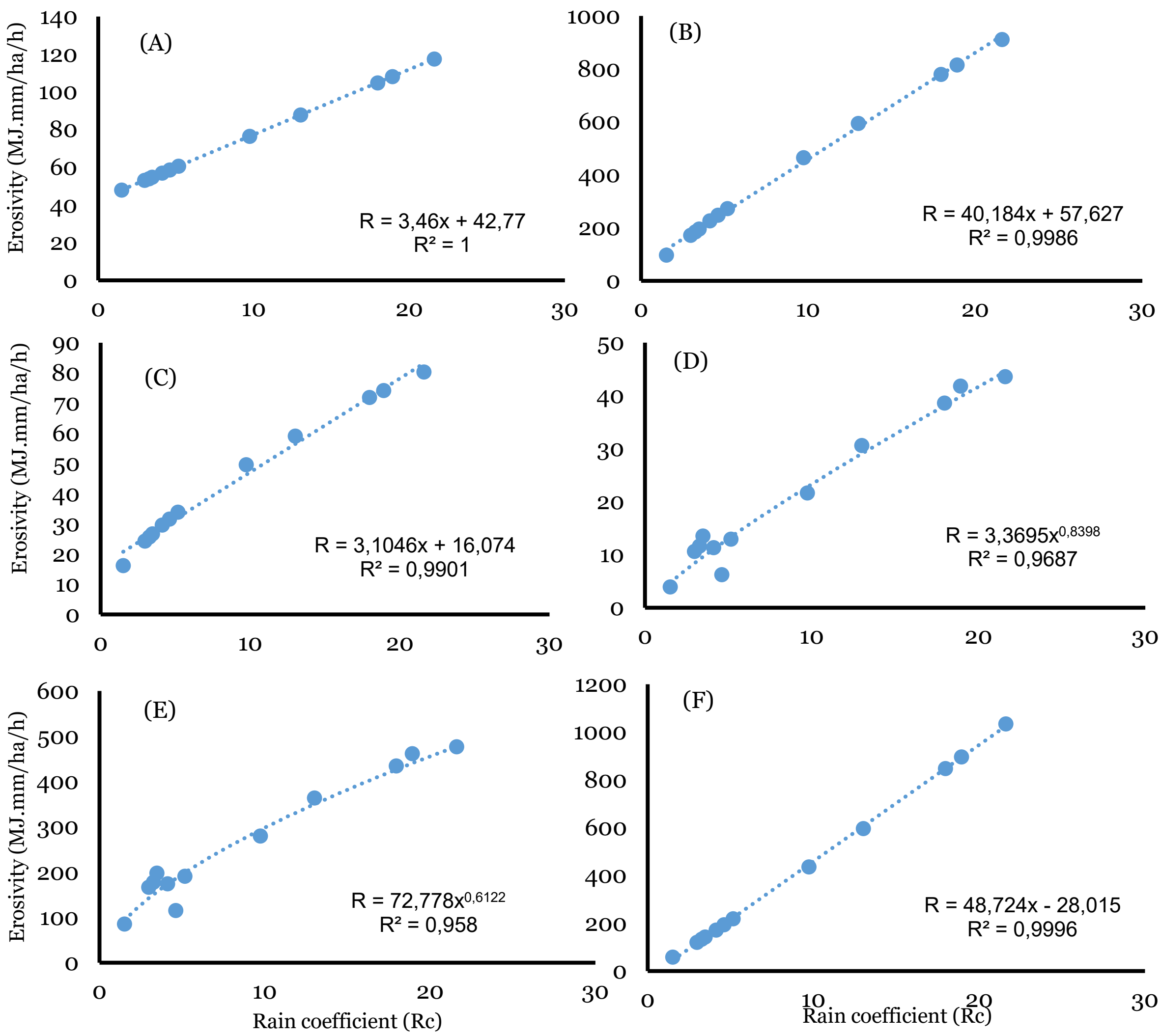
Correlation between erosivity and rainfall coefficient

The mathematical models used in this study were developed in different regions of Brazil. Thus, to analyze the accuracy of the values, regression curves are used that relate the erosivity index to the rainfall coefficients.

Figure 6 shows the regression curves between the average monthly erosivity obtained through the different mathematical models and the rainfall coefficient, for the rainfall data of the county of Cacimbinhas - AL in the period from 1963 to 2000.

Figure 6.

Regression curve between the mean monthly erosivity obtained by the (A) Oliveira Júnior and Medina (1990); (B) Lombardi Neto and Moldenhauer (1992); (C) Val et al. (1986); (D) Leprun (1981); (E) Rufino et al. (1993); (F) Morais et al. (1991) and the rainfall coefficient, in the period from 1963 to 2000 for the county of Cacimbinhas - AL.



Source: The authors (2023).

According to the regression analysis in figures 6A, 6B and 6C, a great correlation was observed between the mean monthly erosivity factor and the local rainfall coefficient. Confirming, in this way, the fact that the monthly erosivity of rainfall in the county can be measured using precipitation data. The correlations fit a linear model.

Silva et al. (2009), estimating the erosivity for two municipalities in the state of São Paulo, and using regression curves, obtained high coefficient of determination values, with $R^2 = 0.99$ for the county of Sete Barras e $R^2 = 0.95$ for the county of Juquiá, presenting a strong correlation, similar to that obtained in this study. Similar results were found by Silva et al.

(2023), analyzing the correlation between the rainfall coefficient and the erosivity factor for the county of Santana do Ipanema, with R^2 = 0.9812.

The correlations of figures 6D and 6E fit the mathematical power model, while figure 6F fit a linear model. Presenting great correlation between both factors studied, confirming the fact that the monthly erosivity of rainfall in the county of Cacimbinhas can be measured using rainfall data. Similar results were obtained by Rosa and Sousa (2018) who when studying the erosivity of rainfall in the county of Óbidos - PA, and using a regression curve, observed that the linear model was the one that presented the best correlation with R^2 = 0.9991. Similar to the results obtained by Rosa et al. (2016) when using a regression curve in rainfall erosivity data in Rondon do Pará - PA, obtaining a mathematical power model, with R^2 = 0.993.

Although some correlations studied differ from results found by other authors, all have a high coefficient of determination, indicating that rainfall data can be used by mathematical models to measure the erosivity factor in the county of Cacimbinhas - AL.

Conclusions

The mean annual erosivity obtained using the six mathematical models presented values ranging from 246.51 to 4964.13 MJ mm ha^{-1} h^{-1} ano^{-1} for the county studied.

The months of March to July represent the highest erosive potential of rainfall and November the month with the lowest potential of this factor.

All mathematical models can be used to estimate the average monthly and annual erosivity of rainfall in the county of Cacimbinhas - AL.

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