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Rainfall erosivity via mathematical modeling in a dry tropical region in the state of Alagoas

Erosividade das chuvas por modelagem matemática em região tropical seca no estado de Alagoas

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Keyword
R factor
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ABSTRACT
Water erosion is one of the main soil degradation processes caused by the impact of raindrops, resulting in the disintegration of particles and the transport and deposition of sediments. This study aims to determine the erosivity of rainfall (R factor) in the municipality of Minador do Negrão, Alagoas, via mathematical models and rainfall data from a 27-year historical series (1963-1989). The data were obtained from the Hidroweb portal and tabulated for regression analysis. Six mathematical models, including models proposed by different authors, were used to calculate the R factor. The results revealed an annual average rainfall of 646.76 mm, with the months from April to July having the highest rainfall rates, accounting for 60.93% of the annual rainfall. The analysis of the R factor allowed the classification of erosivity into different classes, ranging from weak to moderate, which is essential for soil conservation management. This factor was greater in the months with the highest rainfall. The correlation was high for all the mathematical models analyzed. Thus, the months from April--July were the most critical for the R factor. The mathematical modeling of this research can be used to determine the R factor in the municipality studied. Thus, this study contributes to the knowledge about the R factor in regions with scarce rainfall data, providing valuable information for the implementation of soil conservation practices during critical periods and assisting in the planning of sustainable management strategies.

Palavras-Chave
Fator R
Precipitação
EUPS
Processos erosivos

RESUMO
A erosão hídrica é um dos principais processos de degradação do solo, causada pelo impacto das gotas de chuva, resultando na desagregação de partículas, transporte e deposição de sedimentos. Este estudo visa determinar a erosividade das chuvas (fator R) no município de Minador do Negrão, Alagoas, utilizando modelos matemáticos e dados pluviométricos de uma série histórica de 27 anos (1963-1989). Os dados foram obtidos do portal Hidroweb e tabulados para análise de regressão. Seis modelos matemáticos foram empregados para calcular o fator R, incluindo modelos propostos por diferentes autores. Os resultados mostraram uma média anual de precipitação de 646,76 mm, com os meses de abril a julho registrando os maiores índices pluviométricos, concentrando 60,93% da precipitação anual. A análise do fator R permitiu classificar a erosividade em diferentes classes, variando de fraca a moderada, sendo essencial para o manejo conservacionista do solo. Este fator foi maior nos meses com as maiores precipitações. A correlação foi alta em todos os modelos matemáticos analisados. Desta forma, os meses de abril à julho foram os mais críticos ao fator R. A modelagem matemática desta pesquisa pode ser utilizada para determinar o fator R no município estudado. Assim, este estudo contribui para o conhecimento sobre o fator R em regiões com dados pluviográficos escassos, fornecendo informações valiosas para a implementação de práticas de conservação do solo durante períodos críticos e auxiliando no planejamento de estratégias de manejo sustentável.

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Introduction

One of the main soil degradation processes is water erosion (SCHICK et al., 2014), which results from the impact of raindrops on the surface, causing the disintegration of particles, their transport and, subsequently, their deposition (TRINDADE et al., 2016). Understanding the erosive potential of rainfall is essential for quantifying soil losses (BACK and POLETO, 2018). This topic has been widely addressed in both national (BACK and POLETO, 2017; COSTA and BLANCO, 2018; SILVA NETO et al., 2020) and international (MEUSBURGER et al., 2012; PANAGOS et al., 2015; LEE et al., 2022) studies.

Among the indirect methods for measuring soil losses due to erosion, the universal soil loss equation (USLE) is the most widely used (XAVIER et al., 2019). According to these authors, to calculate these losses, the evaluation of rainfall erosivity (R factor of the USLE) is essential since it expresses the capacity of rainfall to erode unprotected soil. This factor is determined from rainfall data; however, owing to the scarcity of such information for most locations, monthly rainfall averages are used for this determination (BACK, 2018). From this perspective, determining the R factor makes it possible to identify the months in which the risk of soil loss is highest (SILVA NETO et al., 2020), which is essential for managing conservation practices that prioritize soil cover during critical periods.

Although rainfall is not the only factor that influences the erosion potential of a region, given the scarcity of data and the need to evaluate erosion processes, R factor analysis is important for generating knowledge and information in critical areas (ROSA et al., 2016). To evaluate the accuracy of different mathematical models, with data from regions other than the one in which it was determined, regression curves are used that relate the R factor to the rainfall coefficients (LOMBARDI NETO and MOLDENHAUER, 1992).

Thus, considering the scarcity of rainfall data for the state of Alagoas, this study aims to determine rainfall erosivity (R factor) via mathematical models and rainfall data in a 27-year historical series for the municipality of Minador do Negrão.

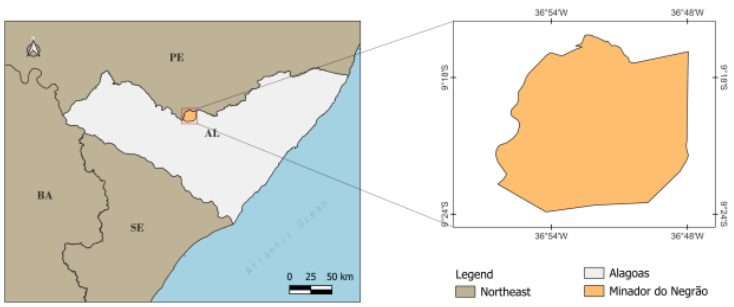
Material and Methods

The municipality of Minador do Negrão is located in the state of Alagoas (Figure 1) at the following geographic coordinates: 9° 18’ 28’’ S and 36° 51’ 27’’ W. With an altitude of 400 m above sea level, it has a hot and dry climate (IBGE, 2022).

Rainfall data were obtained from the Hidroweb portal (https://www.snirh.gov.br/hidroweb/serieshistoricas), which is coordinated by the National Water and Basic Sanitation Agency (ANA), for a 27-year historical series (from 1963-1989). These data were tabulated to calculate the precipitation, the rainfall coefficient and its relationship with the R factor via six mathematical models.

To verify the accuracy of the R factor values through rainfall data, it is necessary to determine the rainfall coefficient (Rc). In this research, Rc was estimated via equation (1) proposed by (FOURNIER, 1960).

Figure 1. Location of the municipality of Minador do Negrão in Alagoas.



Source: Authors (2024)

$$Rc = \left(\frac{p^2}{P}\right) \quad \text{(Eq.1)}$$

where:
Rc = rainfall coefficient, in mm;
p = average monthly precipitation, in mm;
P = average annual precipitation, in mm.

Rainfall erosivity can be determined via different mathematical models. In this research, six models were used, as described below: Models (1), (2), (3) and (4) were proposed by (VAL et al., 1986; OLIVEIRA JÚNIOR and MEDINA, 1990; MORAIS, 1991; LOMBARDI NETO and MOLDENHAUER, 1992), respectively. All of them are based on the model proposed by (FOURNIER, 1960).

$$\text{MODEL 1 – V: } Rx = 12{,}592 \times \left(\frac{M_x^2}{P}\right)^{0{,}6030} \quad \text{(Eq.2)}$$

$$\text{MODEL 2 – OJM: } Rx = 3{,}76 \times \left(\frac{M_x^2}{P}\right) + 42{,}77 \quad \text{(Eq.3)}$$

$$\text{MODEL 3 – M: } Rx = 36{,}849 \times \left(\frac{M_x^2}{P}\right)^{1{,}0852} \quad \text{(Eq.4)}$$

$$\text{MODEL 4 – LNM: } Rx = 68{,}73 \times \left(\frac{M_x^2}{P}\right)^{0{,}841} \quad \text{(Eq.5)}$$

Model (5) was proposed by (LEPRUN, 1981) and was developed through an exponential model:

$$\text{MODEL 5 – L: } Rx = 0{,}13 \times \left(M_x^{1{,}24}\right) \quad \text{(Eq.6)}$$

Model (6) was proposed by (RUFINO et al., 1993) and was developed on the basis of linear models:

$$\text{MODEL 6 – R: } Rx = 19{,}44 + (4{,}20 \times M_x) \quad \text{(Eq. 7)}$$

where:
Rx = R factor, in Megajoule (MJ) mm ha^{-1} h^{-1} $year^{-1}$
Mx = average monthly precipitation, in mm;
P = average annual precipitation, in mm.

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

Table 1. Classes for interpreting the erosivity index

R Factor (MJ mm ha^{-1} h^{-1} ano^{-1})	Classes
R ≤ 2452	Weak erosivity
2452 < R ≤ 4905	Moderate erosivity
4905 < R ≤ 7357	Moderate to strong erosivity
7357 < R ≤ 9810	Strong erosivity
R > 9810	Very strong erosivity

Source: Carvalho (2008)

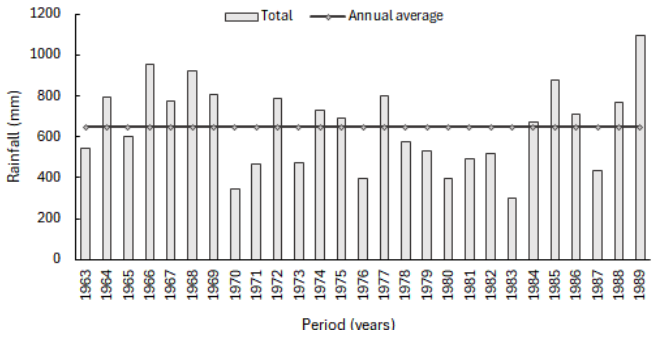
Rainfall data were tabulated and subjected to regression analysis via a Microsoft Excel® spreadsheet (2019).

Results and Discussion

The distribution of precipitation in the municipality studied is shown in Figure 2. An annual average of 646.76 mm was recorded over the 27-year period. Within this historical series, 14 years presented above-average precipitation, and 13 years presented below-average values. The highest precipitation index was recorded in 1989, at 1095.9 mm. Moreover, 1983 had the lowest record, with 298.3 mm.

Studying the indices of climate extremes in Northeast Brazil between 1961 and 2014, (COSTA, 2020) reported a reduction in total annual precipitation, as well as in the occurrence of rainy days at most meteorological stations. These data probably explain the below-average records obtained in this research.

Figure 2. Distribution of precipitation from 1963-1989 in Minador do Negrão–Alagoas.

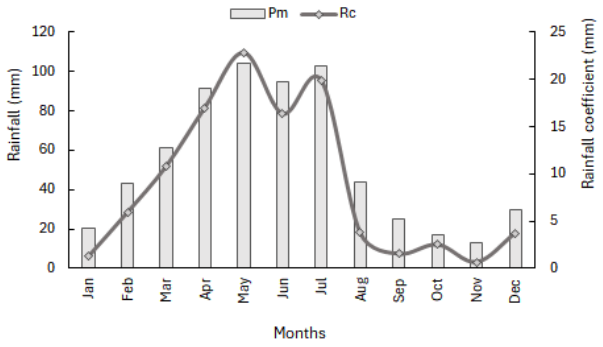


Source: Authors (2024)

The distributions of the monthly precipitation and rainfall coefficients are shown in Figure 3. The months that recorded the highest precipitation were April, May, June and July, with values of 91.78, 104.56, 95.15 and 102.6 mm, respectively, accounting for 60.93% of the annual precipitation. The month of November had the lowest record, with 12.77 mm, corresponding to 1.97% of the average annual precipitation.

This behavior was observed in other municipalities in the state of Alagoas, with the months of April to July recording the highest precipitation (NORONHA et al., 2023) and October and November the lowest records (SILVA et al., 2023) in different historical series.

Figure 3. Distribution of the average monthly precipitation (Pm) and the rainfall coefficient (Rc) from 1963-1989 in Minador do Negrão–Alagoas.



Source: Authors (2024)

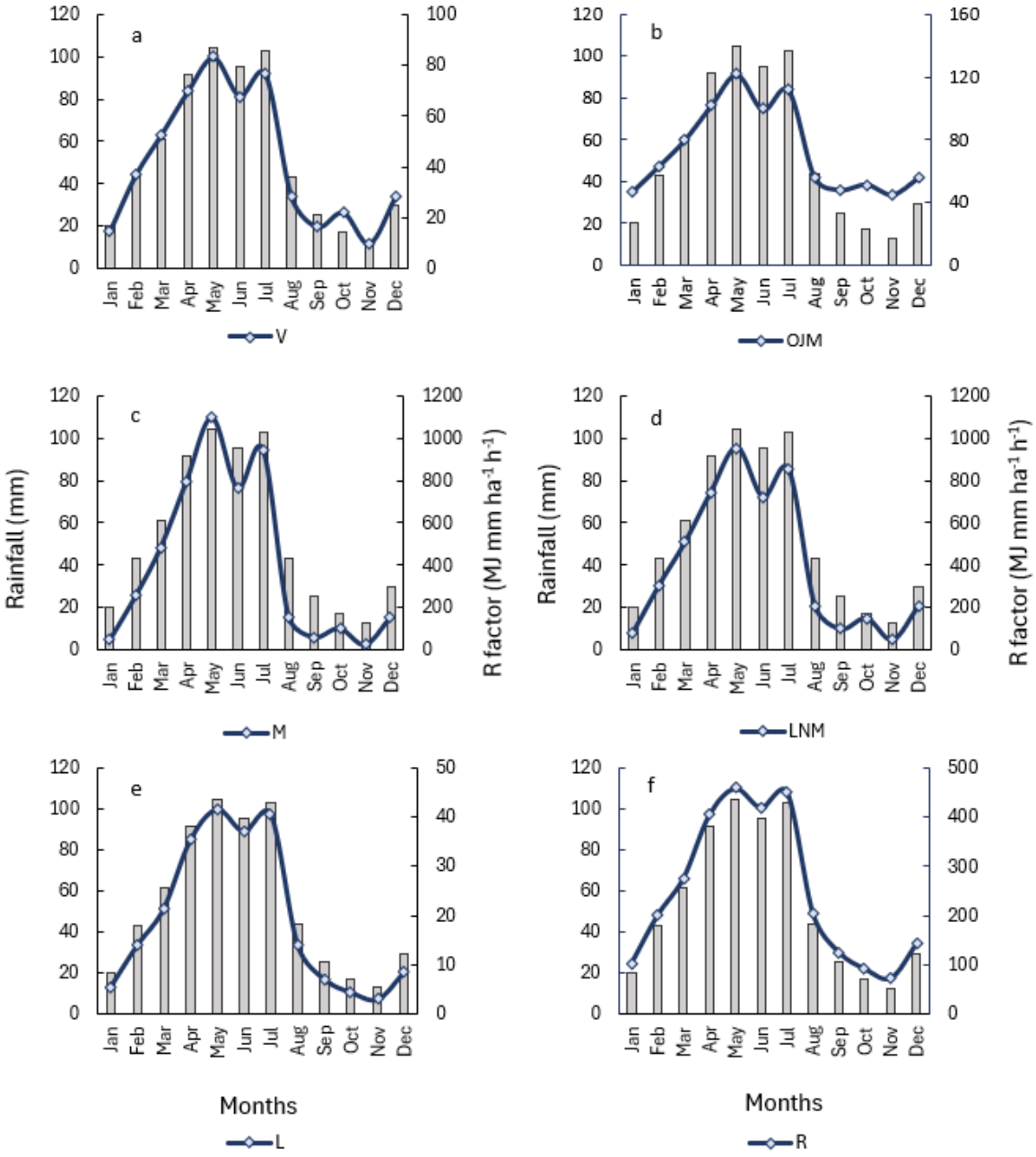
In Figure 3, the similarity between precipitation and the rainfall coefficient can be seen, indicating that this index is dependent on the volume of precipitated water, since it is higher in the months with the highest rainfall records. This finding corroborates the results obtained in studies carried out in the municipality of Água Branca - Alagoas by (SANTOS et al., 2020), who reported the same pattern for the rainfall coefficient.

Figure 4 shows the monthly R factor estimated through the different mathematical models. The R factors of models 3, 4 and 6 were 4886.69, 4883.24 and 2951.00 MJ mm ha^{-1} h^{-1} $year^{-1}$, respectively, classified as moderate erosivity, according to Table 1.

In these models, the months of April to July obtained the highest R factor indices, similar to the distribution of precipitation, since it is a factor dependent on this agent. The month of November registered the lowest values.

Similar behavior was observed in studies by (ALBUQUERQUE, 2021) in the municipality of Castanhal, Pará, in a historical series of 39 years, where they reported that the month with the lowest precipitation index (November) obtained the lowest record of the R factor and by (BACK et al., 2023) for the municipality of Ituporanga, Santa Catarina, in the period from 1941-2021, where the R factor presented similarity to that obtained in this study, with higher values in the months where rainfall was higher.

Figure 4. Monthly average R factor determined by mathematical models 1 (a), 2 (b), 3 (c), 4 (d), 5 (e) and 6 (f) in the period from 1963-1989 in Minador do Negrão, Alagoas.



Source: Authors (2024)

The R factors of models 1, 2 and 5 (Figures 4a, 4b and 4e) were 505.12, 880.97 and 232.03 MJ mm ha^{-1} h^{-1} $year^{-1}$, respectively, classified as weak erosivity, according to Table 1. Like the previous models, this factor was greater between the months of April and July and lower in the month of November. Thus, the maximum and minimum R factor values in all the mathematical models analyzed are related to the highest and lowest precipitation values, respectively. Similar results were observed by (ROCHA et al., 2023) in a historical series of 39 years and by (AMARAL et al., 2014) when the R factor in the period from 1911-1990 was analyzed.

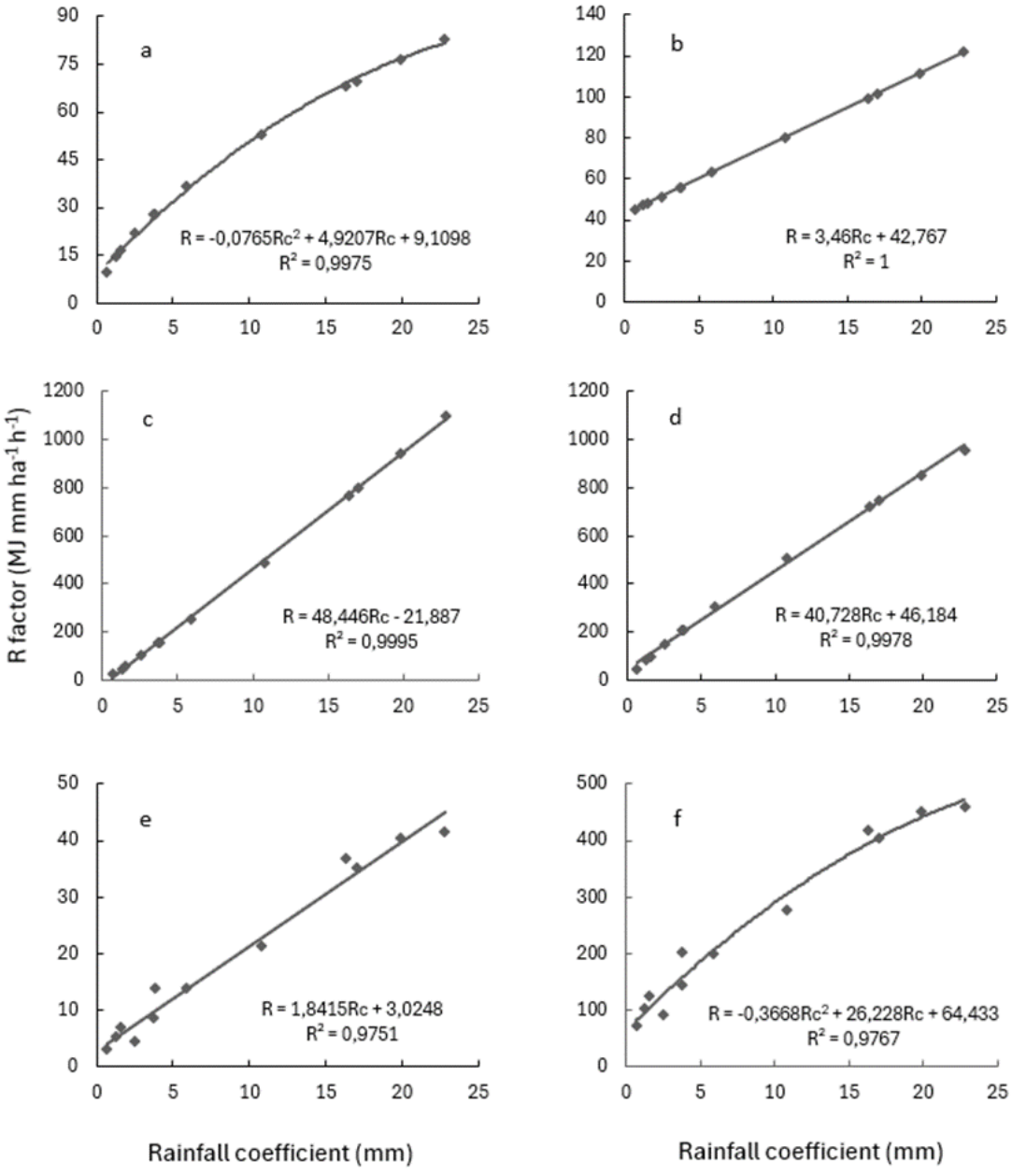
The highest R factor indices occurred during the rainiest period in the historical series studied. This highlights the importance of adopting conservation practices that aim to cover the soil surface, reducing the impact caused by raindrops that cause erosion processes. Given the scarcity of rainfall data in the municipality of Minador do Negrão, the results obtained from rainfall data made it possible to expand knowledge about rainfall erosivity in this region, providing valuable information that assists in soil use and management during more critical periods, aiming at sustainable management and contributing to the mitigation of erosion processes.

To analyze the accuracy of the values obtained, it is necessary to correlate the R factor with the rainfall coefficient since the mathematical models used were developed in different regions.

Figure 5 shows the regression between the R factor and the rainfall coefficient for all the mathematical models used. Figures 5b, 5c, 5d and 5e show linear behavior with high coefficients of determination, ranging from 0.9751 to 1, indicating that these mathematical models can be used to estimate the R factor. Recent research on the R factor indicates similarity with the results obtained in this research. The correlations between the R factor and the rainfall coefficient presented high coefficients of determination, as in the study of the Apodi River basin in Mossoró, RN, with regression curves ranging from 0.9902-0.9959 (SILVA et al., 2020), and in research on the R factor with mathematical modeling in the municipality of Santana do Ipanema, AL, where the regressions between these two factors ranged from 0.9685-0.9993 (SILVA et al., 2023).

In Figures 5a and 5f, the behavior diverges from that obtained by the other mathematical models, with the best fit being the polynomial type, in which the coefficients of determination are 0.9975 and 0.9767, respectively. This behavior indicates that the mathematical modeling used can be used to estimate the R factor in the municipality studied. This polynomial adjustment was observed in studies on the R factor in Rondon do Pará – PA, where the coefficient of determination was 0.9991 (ROSA et al., 2016).

Figure 5. Regression between the R factor and the rainfall coefficient for mathematical models 1 (a), 2 (b), 3 (c), 4 (d), 5 (e) and 6 (f) in the period from 1963-1989 in Minador do Negrão – Alagoas.



Source: Authors (2024)

Conclusions

The R factor obtained by the mathematical models ranged from 232.03 to 4886.69 MJ mm ha^{-1} h^{-1} $year^{-1}$ for the municipality studied.

The months from April to July are the most critical for the R factor, and November is the month with the lowest risk of soil loss because of this factor.

The mathematical modeling used in this research can be used to determine the R factor in the municipality of Minador do Negrão in Alagoas.

The information obtained in this study makes it possible to manage land use in critical periods, reducing erosion processes.

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