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Erosivity Index Obtained with Mathematical Models for The Municipality of Amparo De São Francisco, Sergipe State, Brazil

Manoel Viera de França[1], Raimundo Mainar de Medeiros*[1], Romildo Morant de Holanda[1], Luciano Marcelo Fallé Saboya[2], Francisco de Assis Salviano de Souza[2], Fernando Cartaxo Rolim Neto[1]

1 Universidade Federal Rural de Pernambuco, Brasil

2 Universidade Estácio de Sá, Brasil

3 Universidade Federal de Campina Grande, Brasil

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ABSTRACT

The rainfall Erosivity Factor (R) is a numerical indicator that estimates rainfall erosion in any location. The objective of this work is to estimate the rainfall erosive index in the municipality of Amparo de São Francisco, Sergipe State, Brazil, using mathematical models applied to the monthly rainfall series of 1963-2019. Monthly and annual rainfall data provided by the Superintendência de Desenvolvimento do Nordesteand the Empresa de Desenvolvimento Agropecuário de Sergipe were used. Rainfall data were used to calculate rainfall coefficients to erosivity based on ten equations. The mathematical models of Morais et al., (1991) and Silva (2001), adjustable to linear models, presented coefficients of determinations (R^2) of 0.68 and 0.77, respectively, being, therefore, considered as models not applicable to the study area. The other models studied can be used since the R^2 was considered good for the studied location. The high erosive values for the ten models studied show that the months from April to July have high erosive indices, with the lowest index being centered in November.

INTRODUCTION

The methods for estimating soil erosion consist of the technique that covers steps such as detachment, dragging, and accumulation of soil particles (PRUSKI, 2009). These processes are powered by wind, water, and rain.

The distinction of the pluvial erosive potential between several applications has allowed better dimensioning in the structures of soil and water preservation (CANTALICE et al., 2009). The standard calculation of the erosive index of a certain location is made using rainfall data, which generate the Erosive Indexes (EI_{30}), but these data are rare and difficult to access, making it slow and laborious to obtain (BERTONI et al., 2018; MOREIRA et al., 2006; MELLO et al., 2007).

Rainfall erosive processes cause several problems in agricultural areas and with loss of soil, causing damage to the environment and contaminating watercourses with sediments (LEE et al., 2011). In Brazil, the growing percentage of areas affected by the soil erosion process has become one of the major environmental concerns because it is a major impact on productive sectors in several states of the federation (MELLO et al., 2013).

França et al.(2020a) performed analyzes of the pluvial erosive index in the hydrographic basin of the Ipojuca River, comprised between the years 1962 to 2016. The authors obtained a high correlation between the erosivity index and the rainfall coefficient. The authors suggest that the R factor should be used safely for the areas surrounding the Ipojuca river basin, whose climatic characteristics are similar, thus expanding the possibility of using this factor in the conservation planning of agricultural activities.

França et a*l.*(2020b) studied the geospatialized variability by generating erosive index and monthly and annual rainfall maps, taking into account the Equation of Soil Loss, erosive return time, probability, and erosion classification, in addition to the rainfall coefficient of the basin of the Paraíba River between the years 1962-2018. They showed that there is a need for prior soil preparation in the implementation of orchards, agricultural projects, including fruit trees to make it difficult to move the soil. It was verified in the monitoring that soil changes occur in slope regions, considering the terrain contour lines. Agricultural areas and their surroundings are located throughout their territory, and their climatic regions have different erosive potentials. Therefore, knowledge of this potential will be of great value in choosing the best soil management to be adopted, aiming to control the erosive process. This study contributes to the policies and planning of regional or local management, which will contribute to encouraging the development of new studies.

Medeiros (2019) characterized the erosive potential of quarterly rainfall in the dry and rainy periods, of total and annual erosivities in the State of Piauí, Brazil, using rainfall data collection from 15 microregions, between the years 1962 to 2016, as they are the series with the highest rates rainwater distributed in these microregions. In determining the erosive factor, the equation suggested by (WISCHMEIER et al.1958;WISCHMEIER et al.1971; WISCHMEIER et al.1978) was used. In this study, kriging as a statistical method takes into account the position and relationship between the data. Thus, the results found are consistent with the reality of each of these microregions. Agricultural areas in microregions are located throughout the territory and have climatic regions with different erosion potentials. Knowledge of this potential will be of enormous value in choosing the best soil management to minimize the erosion process.

The erosivity R factor of soil losses determines the rainfall erosive potential of a certain area or region, assuming rainfall data periods of 20 to 30 years. The R factor weighs the erosive potential of rainfall in a given location, where the rainfall capacity and potential to cause erosion are known (MENEZES et al., 2011). This index was based on several articles on erosivity, according to research carried out by (ZANIN et al.,2017; JARDIM 2017).

Medeiros *et al.*(2017) estimated the erosivity rainfall in the Uruçuí Preto, Piauí river basin, Brazil, using the Universal Soil Loss Equation in 48 locations, in the critical period of intense rainfall occurrence in that basin. In the critical period, from October to March, it rains 90.74% of the annual total. Based on the results, it was found that in four localities advanced stages of erosivity were registered: Fazenda Cachoeira, in the municipality of Santa Filomena, with 51,955,2 MJ mm ha^{-1} h^{-1}; Santa Filomena with 41,244,6 MJ mm ha^{-1} h^{-1}; Fazenda Paus, in Monte Alegre do Piauí, with 37,322.6 MJ mm ha^{-1} h^{-1}, and Fazenda Melancia, in Gilbués, with 34,923.4 MJ mm ha^{-1} h^{-1}. The municipality of Colônia do Gurguéia, with 19,608,5 MJ mm ha^{-1} h^{-1}, is the place with the lowest risk of erosivity. In the other 43 municipalities, erosivity indices were moderate to strong.

The objective of this work was to estimate the rain erosivity index in the municipality of Amparo de São Francisco, in Sergipe state, Brazil, using mathematical models with rainfall series, between the years 1963 to 2019.

MATERIALS AND METHODS

The municipality of Amparo does São Francisco is located in the northeast region of the State of Sergipe and is limited to Telha municipality to the east and south, municipality of Canhoba to the West, and the State of Alagoas to the north. The area of the municipality is 39.8 km^2, and the municipal center has an altitude of 51 meters and geographic coordinates of 10°08'04" S and 36°55'46" W (Figure 1).

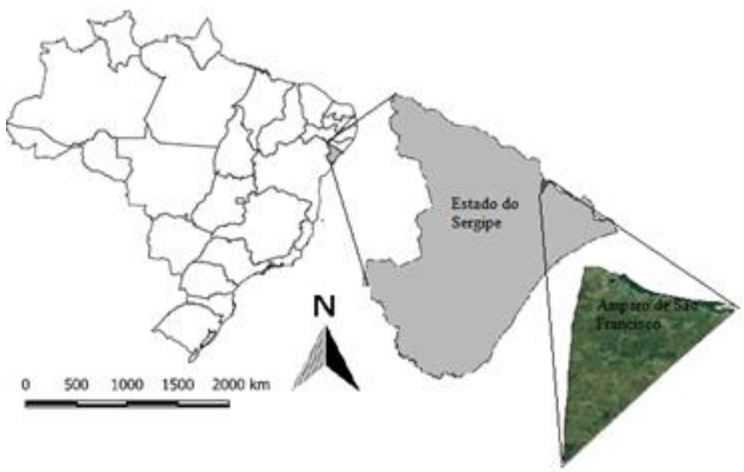


Figure No.1 - Location of the municipality of Amparo de São Francisco, state of Sergipe, Brazil.

Source: França (2021).

Amparo de São Francisco is located in a region characterized by two well-defined seasons: a rainy period, ranging from February to August, and a dry period, from September to January. According to the climatic classification of (KÖPPEN 1928; KÖPPEN et al.1931), the study area has an “As” climate (hot and humid Tropical rainy). Annual rainfall is 1138.2 mm and the average air temperature is 25.9°C (MEDEIROS, 2020).

It is interesting to note that the rainy season is marked by intense and frequent rains of short duration, favoring the occurrence of erosions, given that due to the frequency of intense short rains, runoff water cannot infiltrate into the soil and causes, therefore, the carrying of solid particles.

Monthly and annual rainfall data, provided by the Superintendência de Desenvolvimento do Nordeste (SUDENE, 1990) and the Empresa de Desenvolvimento Agropecuário de Sergipe (EMDAGRO - SE, 2020), from 1963 to 2019, were used. Rainfall data were tabulated to calculate the rainfall, rainfall coefficient, and its relationship with erosivity, using ten equations.

Table 1 shows the equations of the erosive mathematical models that were used in this work, and their respective authors and years.

Table No.1 - Erosive equations and their respective authors and years.

Equations	Formula	Authors (Year)
1	$Rc = p^2/P$	Lombardi Neto (1977), based on the Fourier model (1960)
2	Rx= 3,76∗(Mx*2P)+ 42,77	Oliveira Júnior & Medina (1990)
3	Rx= 36,849∗(Mx*2P)*1,0852	Morais et al.(1991), based on the Fourier model (1960)
4	Rx= 12,592∗(Mx*2P)*0,6030	Val *et al.*(1986)
5	Rx=68,73+(Mx*2P)*0,841	Lombardi Neto & Moldenhauer (1992)
6	Rx=19,44 +(4,20∗Mx)	Rufino et al.(1993)
7	EI_{30}	Wischmeier & Smith (1978)
8	Rx= 42,307*(Pm^2/Pa)+69,763	Silva (2001)
9	Rx= 0,13*(Pm)^1,24	Leprun (1981)
10	Rx= 0,66*Pm+8,88	Oliveira Jr (1998)

Source: Adapted by França (2021).

The rainfall coefficient (Rc) was calculated by Equation 1, suggested by Lombardi Neto (1977) based on the Fourier model (1960). On what:p - monthly precipitation (mm); and P - annual precipitation (mm).

Equation 2 developed by Oliveira Júnior & Medina (1990), based on the Fourier model (1960).On what: Rx - R factor ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$); Mx - monthly precipitation (mm); andP - annual precipitation (mm).

Morais et al. (1991) developed Equation 3, based on the Fourier model (1960). On what: Rx - mean erosivity value ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$); Mx - monthly precipitation (mm); andP - annual precipitation (mm).

Leprun (1981), studying the rains of Northeast Brazil, developed Equation 9. On what: Rx - R factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$) of a region; Mx - precipitation (mm). Equation 4 proposed by Val et al.(1986) to determine the rainfall erosivity of a location-based on rainfall data is based on the Fourier model (1960). On what: Rx - R factor ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$);Mx - monthly precipitation (mm); and - Annual precipitation (mm).

Equation 5 was developed by Lombardi Neto & Moldenhauer (1992), based on the Fourier model (1960), which takes the rainfall coefficient (Rc) = p2/P, which in this equation was modified by Mx, which represents precipitation monthly average for a location.On what: Rx - R factor ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$);Mx - monthly precipitation (mm); and P - Annual precipitation (mm).

Rufino et al.(1993) developed equation 6, based on linear models to determine the erosivity of a location based on rainfall data. On what: Rx - R factor ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$);Mx - monthly precipitation (mm); andP - Annual precipitation (mm).

Table 2 presents the classification of monthly and annual rainfall erosivity, developed by Carvalho (2008).

Table No. 2 - Monthly and annual rainfall erosive classifications.

Erosivity classes	Erosivity values ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$)
Very low (VL)	$R \leq 2452$
Low (L)	$2452 < R \leq 4905$
Medium (M)	$4905 < R \leq 7357$
High (H)	$7357 < R \leq 9810$
Very high (VH)	$R \geq 9810$

Source: Carvalho (2008).

RESULTS AND DISCUSSION

Soil erosion is the result of an action performed by an erosive factor, like rainfall, whose potential source activates the process of erosion endowed with energy, which acts on the fraction of the soil. Rain is the driving force of the hydric erosive process, where the detachment and transport of sediments by surface runoff depend on the intensity, frequency, and duration of events in a given area (AMARAL et al., 2014).

Table 3 shows the erosive classifications in the studied area, according to the methodology of (CARVALHO 2008).

The Oliveira Jr et al.(1990) model, showed a very low erosive rating (VL) in all months of the year. For the mathematical model of Morais et al.(1991) the types of classifications were registered: High in January, March, and July; Very High in February, April, May, and June; classification of medium erosivity in August, October, and December; and the month of November was presented as Low erosivity. The model by Oliveira Jr (1998) recorded Very Low erosivity for all months of the year. The mathematical model developed by (SILVA 2001) presents the following classifications: January, February, March, and July with Medium (M)erosivity; very high (VH) erosivity in April and May; High (H) erosivity in June; and Low (L) erosivity from August to December. The classification of the erosive class, according to Lombardi Neto (1997), was of very low erosivity for all months of the years.

Table No. 3 - Months of the year, erosivity values from mathematical models, and their respective erosive classifications according to the methodology of Carvalho(2008).

Months	Oliveira Jr. et al. (1990)	Class	Morais et al, (1991)	Class	Oliveira Jr. (1998)	Class	Silva (2001)	Class	Lombardi (1997)	Class
January	539,8	VL	8752,5	H	40,4	VL	5661,9	M	5,6	VL
February	646,2	VL	10792,4	VH	47,8	VL	6859,8	M	8,4	VL
March	535,1	VL	7870,8	H	61,9	VL	5609,6	M	9,4	VL
April	1148,3	VL	19228,3	H	122,8	VL	12508,8	VH	45,5	VL
May	1008,5	VL	15943,5	VH	135,2	VL	10936,4	VH	43,5	VL
June	725,6	VL	10635,4	VM	115,9	VL	7752,8	H	26,0	VL
July	656,0	VL	9410,5	H	107,9	VL	6969,5	M	21,6	VL
August	440,9	VL	5988,3	H	67,3	VL	4549,9	B	8,3	VL
September	418,4	VL	5817,4	M	52,1	VL	4296,3	B	5,8	VL
October	392,8	VL	5710,0	M	35,8	VL	4008,7	B	3,3	VL
November	257,0	VL	3295,1	L	26,9	VL	2479,8	B	1,4	VL
December	403,9	VL	5796,2	M	38,5	VL	4132,6	B	3,9	VL

Abbreviation meaning: VL - Very low; L - Low; M – Medium; H - Alta; VH - Very High

Source: França (2021).

The mathematical model by Lombardi et al.(1992) was registered the following classifications: Low in January, February, March, August, September, and October; Medium erosivity in May, June, and July; and Very Low erosivity in November. The mathematical models of Val et al.(1986) and Leprun (1981) was recorded Very Low erosivity during the months of the years, according to Table 3. The models of Rufino et al.(1993) and the Model $EI_{30}$of Wischmeier *et al.*(1978) registered Very Low erosivity for the months from January to March and from August to December; from April to July, it was registered Low erosivity.

Continuation of Table 3.

Lombardi et al. (1992)	Class	Val etal. (1986)	Class	Rufino et al. (1993	Class	EI_{30}	Class	Leprum (1981)	Class
3346,3	L	17,0	VL	698,5	VL	1780,7	VL	17,0	VL
3962,5	L	22,1	VL	858,0	VL	2112,2	VL	22,1	VL
3808,8	L	30,1	VL	1160,9	VL	2037,4	VL	30,1	VL
7427,6	H	77,6	VL	2470,4	VL	3980,0	VL	77,6	VL
7018,6	M	85,0	VL	2736,7	L	3743,3	L	85,0	VL
449,7	M	67,1	VL	2321,6	L	2902,8	L	67,1	VL
5012,8	M	60,7	VL	2149,3	L	2671,3	L	60,7	VL
3392,6	L	32,0	VL	1276,8	VL	1807,4	L	32,0	VL
3063,6	L	23,0	VL	950,1	VL	1634,7	L	23,0	VL
2641,3	L	13,7	VL	599,2	VL	1404,8	VL	13,7	VL
1784,9	VL	8,3	VL	407,7	VL	952,4	VL	8,3	VL
2778,8	L	15,4	VL	657,3	VL	1488,2	VL	15,4	VL

Abbreviation meaning: VL - Very low; L - Low; M – Medium; H - Alta; VH - Very High.

Source: França (2021).

Rainfall Coefficient (Rc) represents a mathematical relationship between monthly rainfall records squared divided by the annual precipitation of a certain location (MELLO et al., 2007; OLIVEIRA et al., 2012). Lombardi Neto (1977) based on the Fourier model (1960) establishing monthly rainfall values for a given annual period. The Rc was computed for Amparo de São Francisco, Sergipe, which follows the same annual rainfall distribution pattern, corresponding on average to 11.3% of the total rainfall recorded in the 1963-2019 series (Table 4).

Table No. 4 - Monthly and annual rainfall values and their rainfall coefficients (RC) for Amparo de São Francisco, Sergipe State, Brazil, between 1963-2019.

Months	Precipitation (mm)	%	Coefficient chuva (Rc)
Jan	47,8	4,23	2,0
Feb	59,0	5,22	3,1
Mar	80,4	7,11	5,7
Apr	172,6	15,27	26,4
May	191,3	16,93	32,4
Jun	162,1	14,34	23,3
Jul	150,0	13,27	19,9
Aug	88,5	7,83	6,9
Sep	65,5	5,8	3,8
Oct	40,8	3,61	1,5
Nov	27,3	2,42	0,7
Dec	44,9	3,97	1,8
Total	1130,4	100	127,4

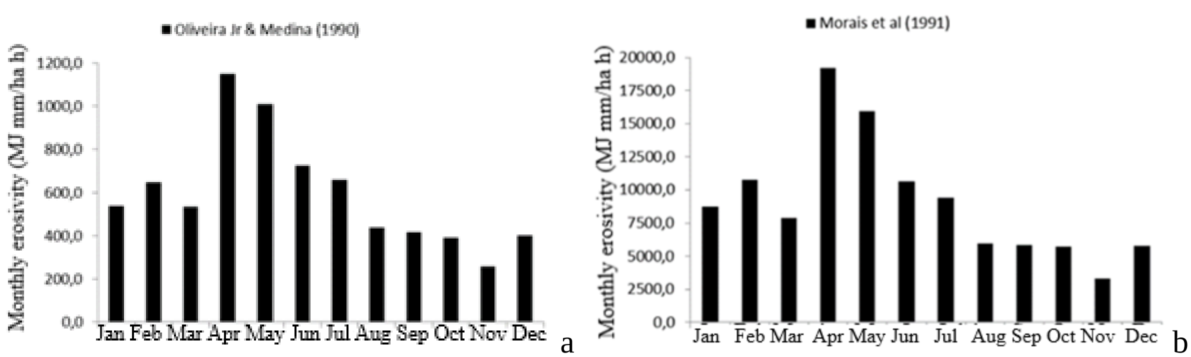
Source: França (2021).

The Rc provided a similar performance with the rainfall distribution with the highest values registered between April and July (Table 4). Several researchers have been developed articles aiming to determine the values and temporal and spatial behavior of the Rc, mentioning some studies such as the one by Moreti et al.(2003) that, studying the characteristics of rainfall in the municipality of São Manuel, São Paulo state, Brazil, obtained results of rainfall coefficients of about 15% for the rainy season studied. Bazzano et al.(2010), evaluating the characteristics of rainfall in the municipality of Rio Grande, Rio Grande do Sul state, Brasil, obtained similar results, with an average of 15% of the total rainfall. Studies such as those by the authors (LOMBARDI NETO et al.,1992; MAZURANA et al. 2009), for the city of Campinas, São Paulo state, Brazil, and for the state of Rio Grande do Sul, were faced with similar results for rainfall coefficients.

The effects of rainfall erosivity in Amparo de São Francisco, Sergipe state, are shown in Figures 2 (a, b, c, d, e, f, g, h, i, j, and k) for the period 1963 to 2019, comprising a series 57-year rainfall of monthly records.

Figure 2a and 2b show the monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe, Brazil, from 1963 to 2019 by for the figures A: B: C: Leprun et al.(1981), figures D: Val et al.(1986), figures E: Lombardi Neto; Moldenhauer, (1992), figures F: Rufino et al. (1993).

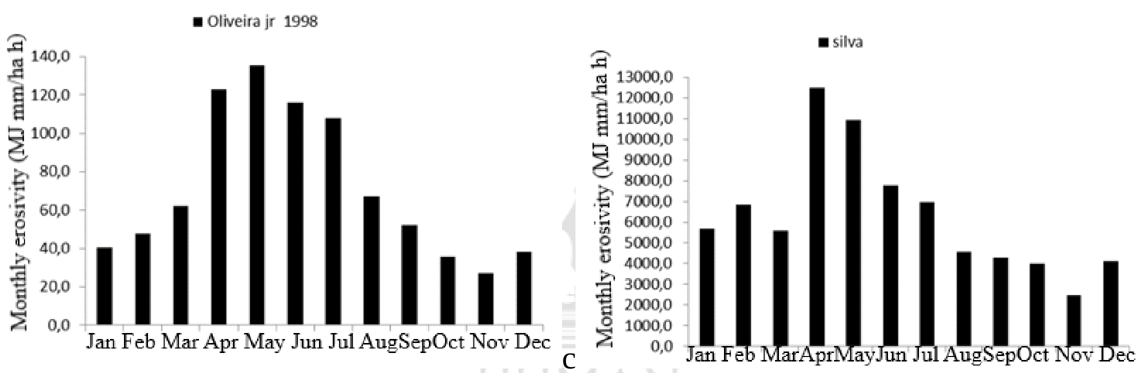
In Figure 2a and 2b, formulated by the mathematical models of Oliveira Jr & Medina (1990) and by Morais et al.. (1991), the graphics are similar but the erosive powers are more intense for the model of Morais et al.(1991).In Figure 2a, the months from April to July with the highest erosive indices are highlighted, and in the months from August to October there is a leveling off in the erosive indices. November is the month with the lowest erosive power and for the four months December to March, irregularities are observed in its indexes, where these irregularities are caused by extreme rainfall events that occur in the study area and corroborate the result of the study by Medeiros (2020). In Figure 2b it is observed that the erosive buoyancy was irregular with oscillations flowing between 0.0 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$ to 20000 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$ and with erosive potentials higher than in Figure 2a. Similar results were presented in studies by França *et al.*(2020a) and França *et al.* (2020b), corroborating the result discussed in the present work.



Figures 2a and 2b - Monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019, according to the model of (a) Oliveira Jr.& Medina (1990) and (b) Morais et al. (1991).

Source: França (2021).

The computation of monthly and annual erosivities for Amparo de São Francisco, by the mathematical models of Oliveira Jr. (1998) and Silva (2001), are represented in Figures 2c and 2d, respectively. In Figure 2c it is observed that between April and August the highest erosive indexes were registered, flowing between 65.5 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} to 138.9 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}; between October and January the low erosive indexes were below 40 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}. The months of February and September registered erosivity of 48.8 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} to 59.7 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}. The months from April to June were characterized by higher erosive indices.In Figure 2d, the erosive oscillations flowed between 2080 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}, in the month of November,and 12000 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} in April. These values were considered to have moderate erosive potential, according to the classification proposed by Carvalho (2008).



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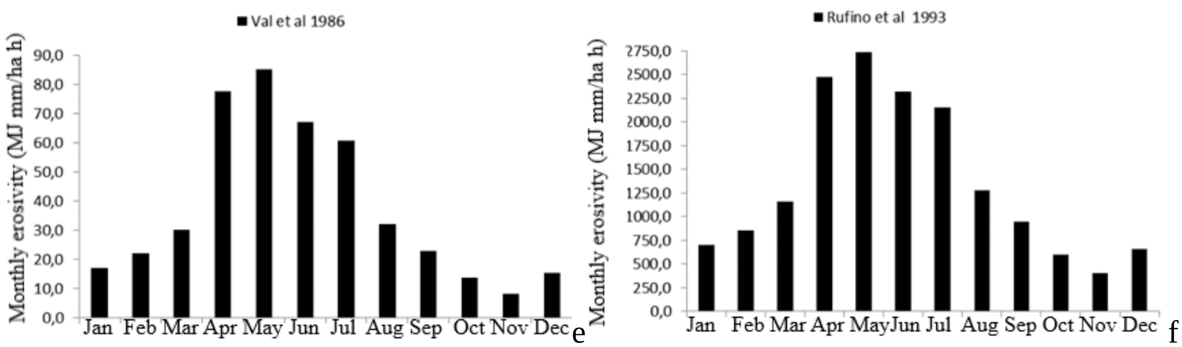
Figures 2c and 2d - Monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019, according to the model of (c) Oliveira (1998) and (d) Silva (2001).

Source: França (2021).

Figure 2e shows the monthly rainfall erosivity values for Amparo de São Francisco, based on the equation proposed by Val et al. (1986), for 57 years of observations. Erosive indices flowed between 10 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} in November,and 85.5 MJ.mm.ha^{-1}.h^{-1}.yr^{-1} in May. The high erosive power four-month period focuses on the months from April to July. From October to January the lowest erosive indices are registered. In February, March, August, and September the erosive indices are of moderate intensity.

The mathematical model defined by Rufino et al.(1993) is shown in Figure 2f. Erosive oscillations flow between 375MJ.mm.ha^{-1}.h^{-1}.yr^{-1}and 2750 MJ.mm.ha^{-1}.h^{-1}.yr^{-1}. The months from

April to August registered the highest erosive powers with a rainfall contribution of 65% of its annual total. From September to March occurred the lowest erosive indices with a contribution of 35 of its annual rainfall.

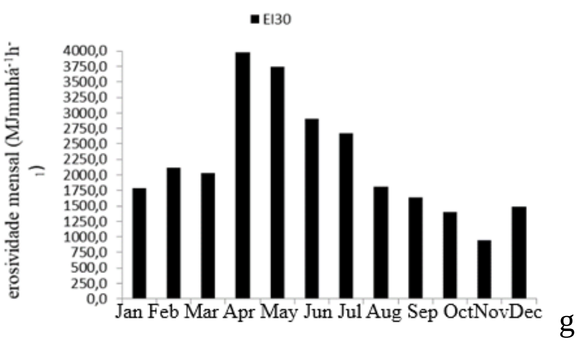


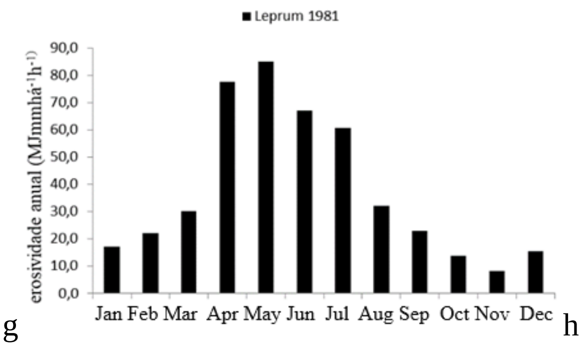
Figures 2e and 2f - Monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019, according to the model of (e) Val et al. (1986) and (f) Rufino et al. (1993).

Source: França (2021).

In the mathematical model proposed by Wischmeier *et al.*(1978) called EI_{30} (Figure 2g) results erosive oscillations between1000 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$ and 4000 $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$from November to April. From August to November, there is a simultaneous decay of the erosive indexes caused by the absence of rain in the study area. With the approach of rains or even isolated and occasional rain, it is observed that the erosive values increase between December and March.

In Figure 2h, the monthly values of rainfall erosivity, obtained by the mathematical model proposed by Leprun (1981), are provided. The values displayed by this model describe behavior similar to the previous models, where the period with the greatest potential in the studied area are the months of April to September, which concentrates 65% of the erosive potential. In this period is required the adoption of soil and water management and conservation practices, in arable and non-arable areas, to avoid environmental damage due to soil degradation processes by water erosion.

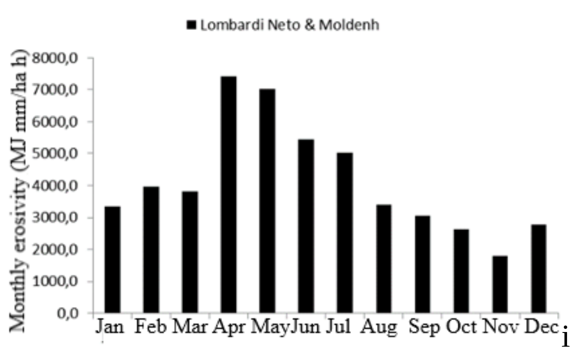


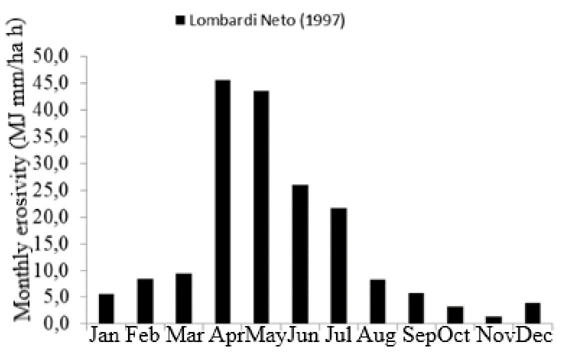


Figures 2g and 2h - Monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019, according to the model of (g) EI30 and annual and historical averages of the aforementioned mathematical models (h) Leprun (1981).

Source: França (2021).

Figures 2i and 2j show the monthly erosivity indices for the municipality of Amparo de São Francisco, from 1963 to 2019 based on models by (i) Lombardi et al.(1980) and (j) Lombardi Neto (1997). The models have very different erosive values. The months with the highest erosive indexes have their similarities and register in April to August. From September to March, the lowest erosive indexes are observed. For the studied area, it is not possible to define which model has the greatest significance for erosive indices.





Figures 2i and 2j - Monthly erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019, according to the model of (i) Lombardi et al. (1980) and (j) Lombardi Neto (1997).

Source: França (2021).

Figure 2k shows the annual variability of the erosivity index for Amparo de São Francisco, Sergipe, from 1963 to 2019 and the historical averages of the mentioned mathematical models studied. The models by Morais et al.(1991), Silva (2001), and the model by Lombardi Neto et al.(1980) are those with the greatest erosive powers. The other models worked to have their erosive power below the historical average. This variability of models is defined by several authors, aiming to provide adequate information to users and government agencies, so that they can carry out planning, aiming at better land use.

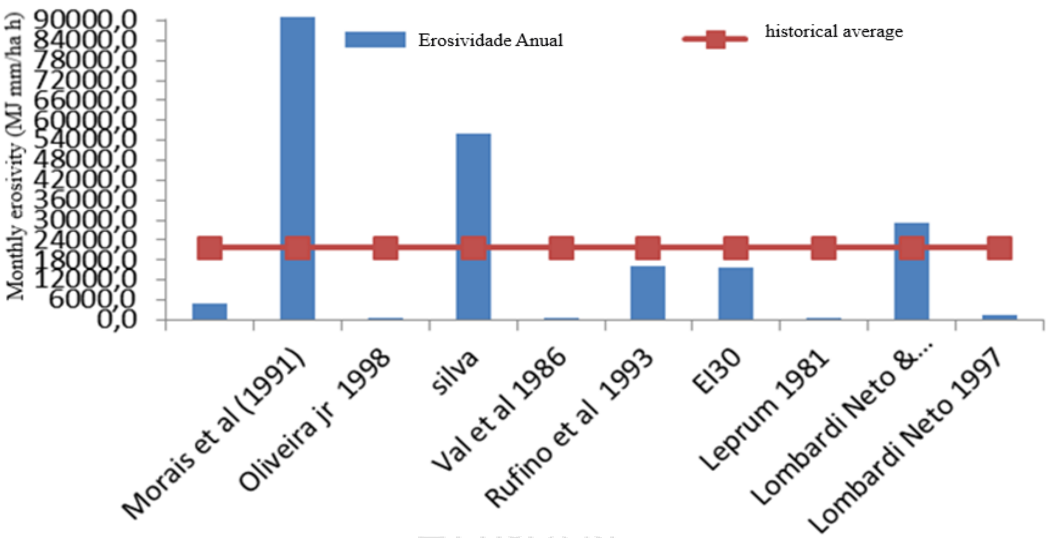


Figure 2k - Annual erosivity index for the municipality of Amparo de São Francisco, Sergipe State, Brazil, from 1963 to 2019 and historical averages of the aforementioned mathematical models.

Source: França (2021).

The estimated and differentiated values of erosivity for various locations in the Northeast Region (NEB) have been studied by several authors. Silva et al.(2003) studying the erosive potential of rainfall in Fortaleza, in the state of Ceará, found rainfall with high erosive potential. Amaralet al. (2014) in their studies for the state of Paraíba, found results that are similar in the category of erosivity classes in the study area in this work. The results of the studies by the authors (LEPRUN 1981; SILVA 2004; SANTOS et al. 2009; CANTALICE et al. 2009; SILVA et al. 2012), showed that for the state of Pernambuco, erosive values are similar to the data discussed here in this work. Due to the scarcity of rainfall information in some locations or regions, the estimation of the erosivity index has been carried out with models that use rainfall data (SILVa et al., 2009).

Figure 3a shows the relationship between the rainfall erosivity (Rc in $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$) and the rainfall coefficient (mm) for Amparo de São Francisco, formulated by the mathematical model of Lombardi et al.(1980) and for Figure 3b Lombardi Neto (1997). Using the linear models adjustable to the data, the coefficient of determination of R^2 of 0.93 and R^2 of 0.89 was obtained for the respective models. The results showed that the regression curves can be applied to the studied area. Morais et al. (1991) used the model proposed by Lombardi Neto (1977) for rainfall data from southwestern Mato Grosso do Sul, state of Brazil, and obtained a coefficient of determination of 0.92.

Amaral et al.(2014) applied the model indicated by Lombardi Neto et a*l*.(1992) to the rainfall data of the state of Paraíba and managed to determine a correlation coefficient between erosivity and a 0.94 rainfall coefficient for the state.

Figure 3c shows the correlation between the erosivity index and the rainfall coefficient obtained by the mathematical model proposed by Oliveira Júnior et a*l*.(1988), with adjustment for a linear model, with $R^2 = 0.77$. Amaral et al.(2014) working with rainfall data from the state of Paraíba, obtained a strong coefficient of determination index. Silva (2004) studying the applicability of several mathematical models for estimating rainfall erosivity in Brazil, recommended that the model proposed by Silva (2004) can be used in the Brazilian Semiarid Region.

Figure 3d shows the relationship between rainfall erosivity (Rc in $MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$) and the rainfall coefficient proposed by the mathematical model of Morais et al. (1991) obtaining an $R^2 = 0.68$, demonstrating a strong correlation between the studied parameters. Santos & Montenegro (2012), studying the erosivity of the Agreste Central Region of Pernambuco state, Brazil, obtained a coefficient of determination of 0.71, with an adjusted trend line of the power type.

In Figure 3e, there is a representation of the regression line with a positive coefficient of determination $R^2 = 0.98$, estimated by the mathematical model proposed by (Val et al., 1986; Chaves et al., 1997) used the model by Val et al.(1986) for rainfall erosivity data for the municipality of Patos, Paraíba state, Brazil, located in Alto Sertão region, and determined similar significance levels to those found in this study.

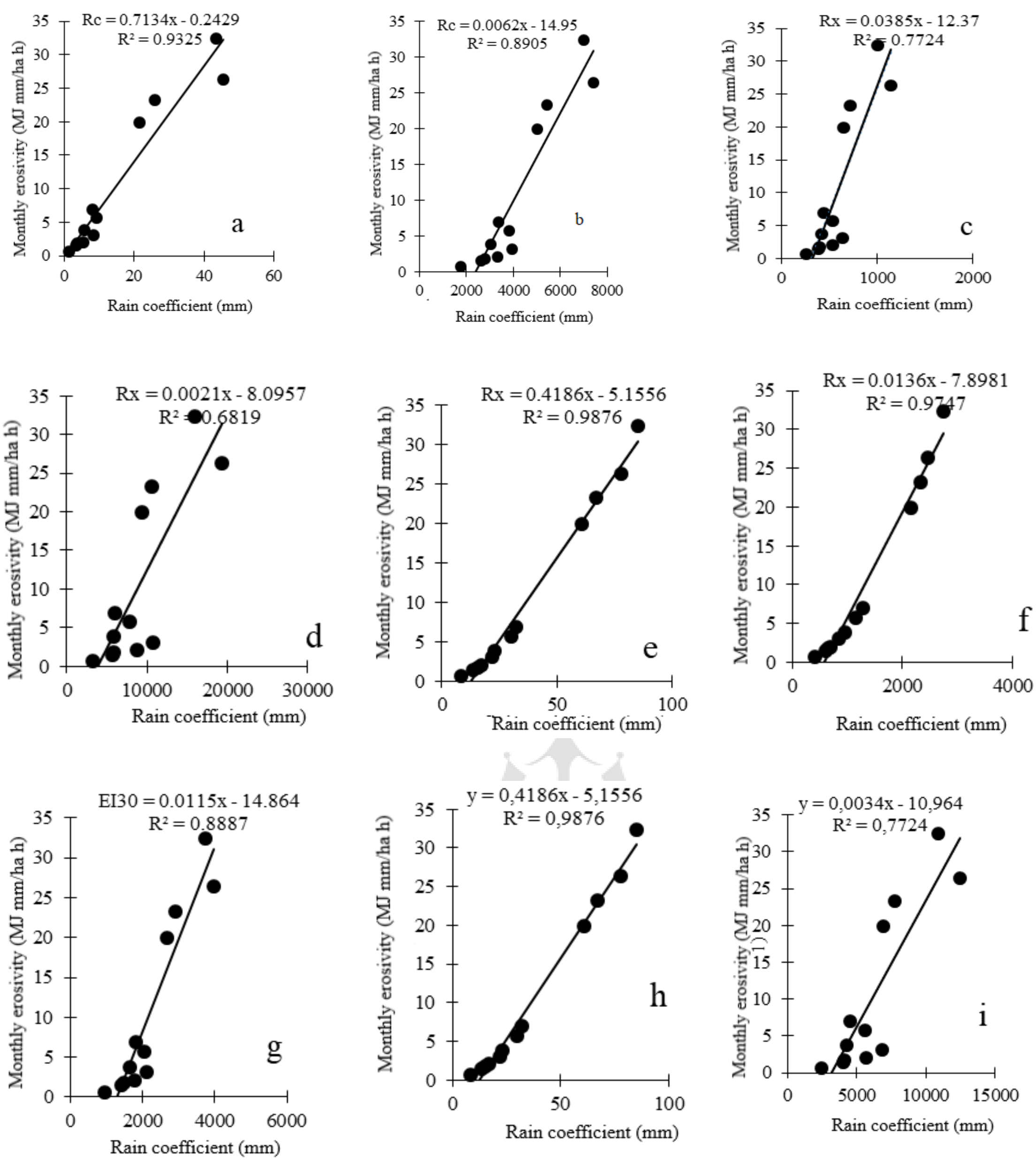


Figure 3 -Relationship between rainfall erosivity (Rc in MJ.mm.ha^{-1}.h^{-1}.yr^{-1}) and the rainfall coefficient for the municipality of Amparo de São Francisco, Sergipe state, Brazil, from 1963 to 2019, obtained by mathematical models for the authors: (a) Lombardi et al. (1980); (b) Lombardi Neto (1997); (c) Oliveira Jr.; Medina (1988); (d) Morais et al. (1991); (e) Val et al. (1986); (f) Rufino et al. (1993); (g) Wischmeier et al. (1978); (h) Leprun (1981); (i) Silva (2001).

Source: França (2021).

Figure 3f shows the model developed by Rufino et al.(1993) exposing a positive regression line with a high degree of reliability in the application of its model for the municipality of Amparo de São Francisco.

Figure 3g shows the mathematical model defined by Wischmeier & Smith (1978) as soil loss (EI_{30}). This model presents a positive regression line and R^2 of very good significance and that can be used in the erosive computation of Amparo de São Francisco.

The correlation between the monthly erosivity index estimated by the model proposed by Leprun (1981) and the rainfall coefficient can be seen in figure 3h. The correlation was fitted to a linear trend line, with a coefficient of determination of 0.98 with strong significance. In Figure 3i can be seen the mathematical model developed by Silva (2001) with a positive straight line and very good R^2.

CONCLUSIONS

The mathematical models of Morais et al.(1991) and Silva (2001), adjustable to linear models, obtained coefficients of determinations R^2 of 0.68 and 0.77, respectively, being therefore considered as non-applicable models for the area of study. The other models studied can be used because the R^2 obtained can be considered good for the study region.

The high erosive values for the ten models studied show that between April and July there are high erosive indices and the lowest erosive power is centered on November for all models.

It is suggested to adopt a program with reforestation practices using native plants and grasses that aim to minimize the effect of the erosive process. Planting techniques in contour lines must also be adopted, aiming to reduce the water velocity during the rainy season, especially in the case of extreme isolated rain events.

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Image *Author -1*	***Author Name – Corresponding Author*** ***Manoel Vieira de frança*** Universidade Federal Rural de Pernambuco, Brasil
Image *Author -2*	*Raimundo Mainar de Medeiros* Universidade Federal Rural de Pernambuco, Brasil
Image *Author -3*	**Romildo Morant de Holanda** Universidade Federal Rural de Pernambuco, Brasil
Image *Author -4*	**Luciano Marcelo Fallé Saboya** Universidade Federal de Campina Grande, Brasil
Image *Author -5*	**Francisco de Assis Salviano de Souza** Universidade Federal de Campina Grande, Brasil
Image *Author -6*	**Fernando Cartaxo Rolim Neto** Universidade Federal Rural de Pernambuco, Brasil