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Rainfall erosivity map for Brazil

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Abstract

Rainfall erosivity is the potential ability for rainfall to cause soil loss. Erosivity can be quantified by means of the *R* factor calculation of the universal soil loss equation (USLE). The purpose of this study was to investigate the spatial distribution of annual rainfall erosivity in Brazil. For each of eight Brazilian regions covering the whole of the territory of Brazil, one adapted equation was applied using pluviometric records obtained from 1600 weather stations. A geographic information system (GIS) was used to interpolate the values and to generate a map showing spatial variations of erosivity. The annual values of erosivity ranged from 3116 to 20,035 MJ mm ha^{-1} h^{-1} $year^{-1}$. The region with highest annual values was the extreme northwestern, while the northeastern region showed the lowest annual values of erosivity. For the most part of the Brazilian territory, December and January revealed the highest erosivity values, while the lowest values were observed from June to September.

Keywords: Rainfall erosivity; Brazil; GIS; USLE; *R* factor; Soil conservation

1. Introduction

The universal soil loss equation (USLE) is a mathematical model to predict soil loss (Wischmeier and Smith, 1978). It has widely been used to estimate the soil loss and/or to estimate the numerical values of the different components of the erosive process. The USLE is:

$$A = RKLSCP \tag{1}$$

where A is the rate of soil loss (t ha^{-1} $year^{-1}$), R is a factor for annual rainfall erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$), K is a factor for soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}), L is a factor for slope length, S is a factor for slope steepness, C is a factor for cover

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management, and P is a factor for supporting practices. The last four factors are dimensionless (Wischmeier and Smith, 1978; Renard and Freimund, 1994).

The concept of rainfall erosivity presented by Hudson (1971) and Wischmeier and Smith (1978) describes the erosivity as an interaction between kinetic energy of raindrops and the soil surface. This can result in a greater or lower degree of detachment and down-slope transport of soil particles according to the amount of energy and intensity of rain by considering the same soil type, the same topographic conditions, soil cover, and management.

The original method to calculate the erosivity values (R factor) for a storm event requires pluviographical records (Wischmeier and Smith, 1978). This kind of information is difficult to obtain in many parts of the world, and its processing is time-consuming and hardworking (Bertoni and Lombardi Neto, 1990).

In addition, other equations can also estimate, with good accuracy, monthly and/or annual values of rainfall erosivity by using pluviometric records, such as annual and monthly rainfall averages (Bertoni and Lombardi Neto, 1990; Renard and Freimund, 1994). For instance, the Fournier index presented in Eq. (2) represents an equation widely used for this purpose.

$$\mathrm{Cc} = \frac{M_x^2}{P} \tag{2}$$

where Cc is the Fournier index, M is monthly value of precipitation (mm) for month x, and P is the annual value of precipitation (mm).

On the one hand, various authors have found good relationships between the Fournier index and annual values of rainfall erosivity (Bertoni and Lombardi Neto, 1990; Lombardi Neto and Moldenhauer, 1992; De Oliveira and Medina, 1990; Morais et al., 1991; Val et al., 1986; Oduro-Afriyie, 1996). According to Bertoni and Lombardi Neto (1990), the ideal condition is to compute a data set of at least 20-year rainfall, but it is possible to determine the erosivity using 10-year rainfall records (Lombardi Neto, 2000). Mannaerts and Gabriels (2000) studied rainfall erosivity for Cape Verde Islands by means of 7-year rainfall pluviometric records.

On the other hand, for some regions of the Brazilian territory, some authors have found good relationships with linear or exponential equations (respectively: $y = ax + b$ or $y = ax^b$, where x is the storm amount, y is the R factor of the USLE, and a and b are constant) by using also pluviometric data (De Oliveira, 1988; Leprun, 1981; Rufino et al., 1993). For Cape Verde Islands, Mannaerts and Gabriels (2000) calculated significant relations with exponential equation by considering storms greater than 9 mm (erosive storms).

After calculation of erosivity values for a region, erosivity maps, named Isoerodent maps, can be established by interpolating the data and application of GIS technology. For instance, Wischmeier and Smith (1978) published the Isoerodent map for the USA, Leprun (1981) developed the Isoerodent map for the Brazilian northeastern region, Bertoni and Lombardi Neto (1990) for Sao Paulo state (Brazil), and Qi et al. (2000) for the Republic of Korea.

The Isoerodent map represents an important source of information about the potential of erosion for a region. According to Pereira et al. (1994), some guidelines have been established for Brazil to generate standardized information about erosion, more specifically, about soil erodibility, rainfall erosivity, and other factors linked to erosion. Regarding rainfall erosivity, Pereira et al. (1994) also stated that it is important "to study and evaluate the patterns of distribution of the rainfall erosivity and the possible effects about its variability and competence to cause soil erosion."

Erosivity maps can be useful for soil conservationists and agronomists to get knowledge about rainfall erosivity potential for certain locations in order to implement the necessary

Number	Equation	Author(s)
1	$R_X = 3.76 * \left(\frac{M_X^2}{P}\right) + 42.77$	Oliveira Jr. and Medina (1990)
2	$R_X = 36.849 * \left(\frac{M_X^2}{P}\right)^{1.0852}$	Morais et al. (1991)
3	$R_X = (0.66 * M_X) + 8.88$	Oliveira Jr. (1988)
4	$R_X = 42.307 * \left(\frac{M_X^2}{P}\right) + 69.763$	Silva (2001)
5	$R_X = 0.13 * (M_X^{1.24})$	Leprun (1981)
6	$R_X = 12.592 * \left(\frac{M_X^2}{P}\right)^{0.6030}$	Val et al. (1986)
7	$R_X = 68.73 * \left(\frac{M_X^2}{P}\right)^{0.841}$	Lombardi Neto and Moldenhauer (1992)
8	$R_X = 19.55 + (4.20 * M_X)$	Rufino et al. (1993)

Fig. 1. Equations used to determine the monthly/annual values of the erosivity according to the area of the territory and their respective authors. Eqs. number (1), (2), (4), (6), and (7) were based from the Fournier's model. Eqs. (3) and (8) are linear models and Eq. (5) is an exponential model. R_x is R factor (MJ mm ha^{-1} h^{-1} year^{-1}) for month x, M_x is average monthly precipitation depth (mm), and P is average annual precipitation (mm) (Silva, 2001).

precautions to minimize soil erosion in those areas. Civil and construction engineers may also utilize the map for the design and construction of buildings, roads, dams, and pipelines (Oduro-Afriyie, 1996).

Based on these considerations, the goal of this paper was to create a rainfall erosivity map for Brazil and to study some spatial and temporal characteristics of rainfall erosivity within the study area.

2. Materials and methods

Pluviometric records were obtained from 1600 weather stations in Brazil. The record lengths were at least 10 years, but most of the stations had a continuous recording more than 20 years.

The equations used to determine the monthly/annual erosivity values were obtained by literature (Fig. 1). Some relationships use the Fournier index, while others use linear or exponential equations. The regions whereupon the equation was applied were chosen according to geographic distribution of the annual rainfall depth in Brazil.

After application of these specific equations on the data sets according to the geographic locations of the gauging stations, data were interpolated to generate the first version of the Brazilian erosivity map. In order to remove any spatially random noise, a 7 × 7 mean filter command of the IDRISI software version 32.2 was applied (Eastman, 2001). The new map generated was "smoother" than the first version. This procedure was carried out for all maps presented in Chapter 3.

In order to make an easier visual distinction between the classes in the maps, the range of the values was divided into seven classes using the command "Reclass" of the IDRISI software (Eastman, 2001).

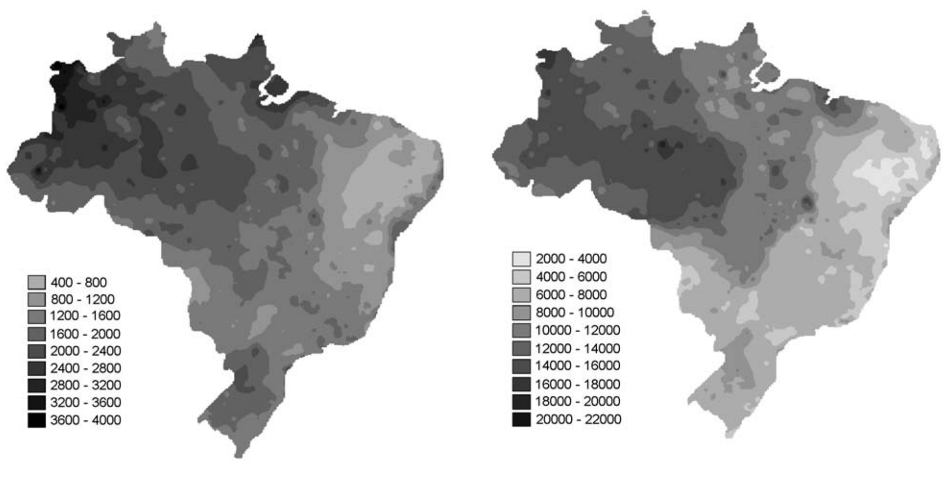

Fig. 2. Comparison of the annual pluviometric (left, in mm $year^{-1}$) and the annual erosivity maps (in MJ mm ha^{-1} h^{-1} $year^{-1}$).

3. Results and discussion

Fig. 2 shows both annual pluviometric and the annual erosivity maps. The pluviometric map corresponds to the map created at the Brazilian Institute for Meteorology (2003) and was used to allow the comparison between spatial distribution of the annual rainfall depth and the geographic distribution of annual rainfall erosivity.

The annual rainfall erosivity map shows a range of 3116 to 20,035 MJ mm ha^{-1} h^{-1} $year^{-1}$. The region with the lowest values is represented by the northeastern region, while the highest values are found in the northern region (the Amazon region) (Fig. 2).

According to Table 1, 4.7% of the total area was classified by medium annual erosivity values, 26.3% was classified as medium-strong, 10.6% showed strong values, and 58.4% was classified as very strong. No region was classified by low erosivity values. This clearly demonstrates the importance of rainfall within the erosion processes in Brazil because rainfall erosivity accounts for about 80% of the variation of soil loss (Wischmeier and Smith, 1978).

The annual pluviometric values ranged from 404 to 3860 mm $year^{-1}$. Regression analyses between the pluviometric and the annual erosivity maps, using the IDRISI software, showed a high correlation coefficient of $r^2 = 0.975$ ($\alpha = 1\%$) and suggest that for Brazil, the geographic distribution of the annual erosivity is closely related to annual pluviometric values (annual precipitation depth).

The correlation found between longitude and annual erosivity was $r^2 = 0.484$ (significant $\alpha = 1\%$) and the correlation between latitude and annual erosivity was $r^2 = 0.229$ (significant $\alpha = 1\%$) (Figs. 3 and 4). However, despite of significant correlations in both cases, the main axis of spatial variation of the annual erosivity values is longitudinal.

The Brazilian annual rainfall erosivity map presented in this study confirms the results obtained by Leprun (1981) for the Brazilian northeastern region as well as the data presented by Silva (1999) for Tocantins state. In both maps, the trend of increasing annual erosivity values from east to west—as found in the present study—was also found.

The monthly erosivity maps are shown in Fig. 5. From January to March, there is a shift of the highest value classes (dark patches in the maps) from the central area (border region between Mato Grosso and Goiás states) to the area near the Marajó island in the mouth of the Amazon river (for a complete visualization of the geopolitic division of the Brazilian territory, see the web site of the Brazilian Institute for Geography and Statistic, 2003). From April to September, these classes change from Marajó island to the extreme north–northwestern region (Roraima state).

Table 1
Class for interpretation of annual erosivity index (R)

Erosivity (MJ mm $year^{-1}$ ha^{-1} h^{-1})	Erosivity class
$R \leq 2452$	low erosivity
$2452 < R \leq 4905$	medium erosivity
$4905 < R \leq 7357$	medium-strong erosivity
$7357 < R \leq 9810$	strong erosivity
$R > 9810$	very strong erosivity

Source: Carvalho (1994), modified to S.I. metric units according to Foster et al. (1981).

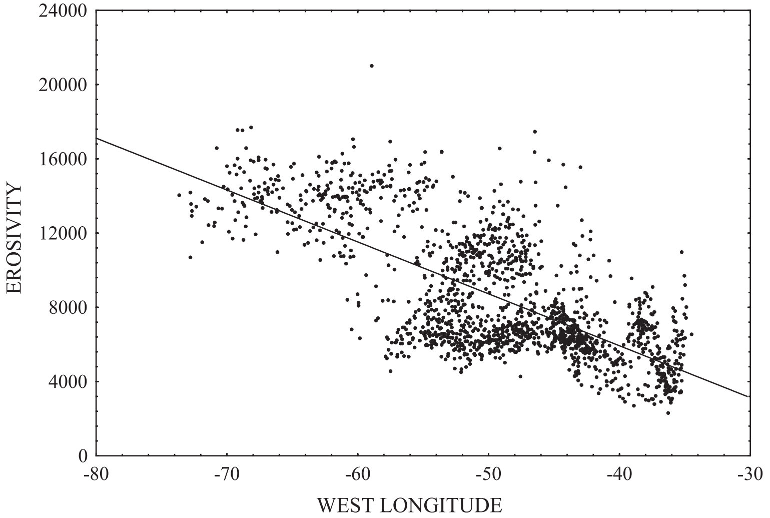

Fig. 3. Relationship between longitude (degrees) and annual erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$).

For the southern region, no clear changes of temporal erosivity over the year were observed. An exception represents the western region of Paraná state, where erosivity seems to have some importance in October, the beginning of the rainy season.

Due to high variation of vegetation and soils in Brazil, a high variability of responses to erosive processes and sediment yields can be implied (Bertoni and Lombardi Neto, 1990;

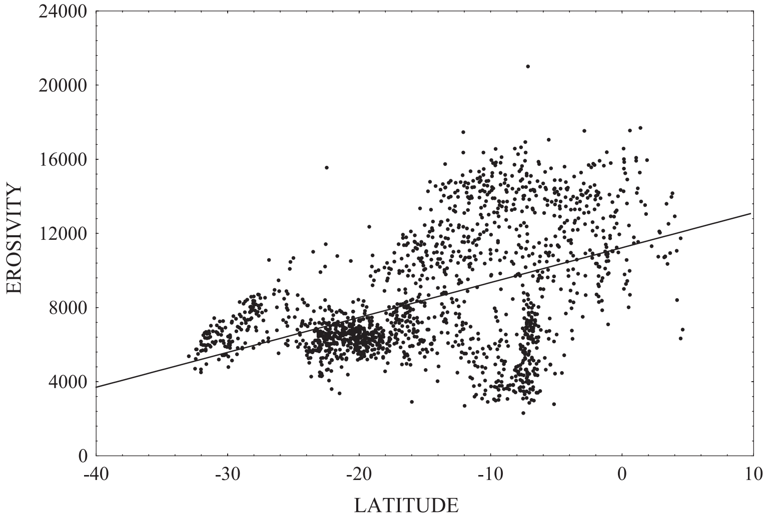

Fig. 4. Relationship between latitude (degrees) and annual erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$). The negative values of latitude correspond to southern latitudes and the positive to northern latitudes.

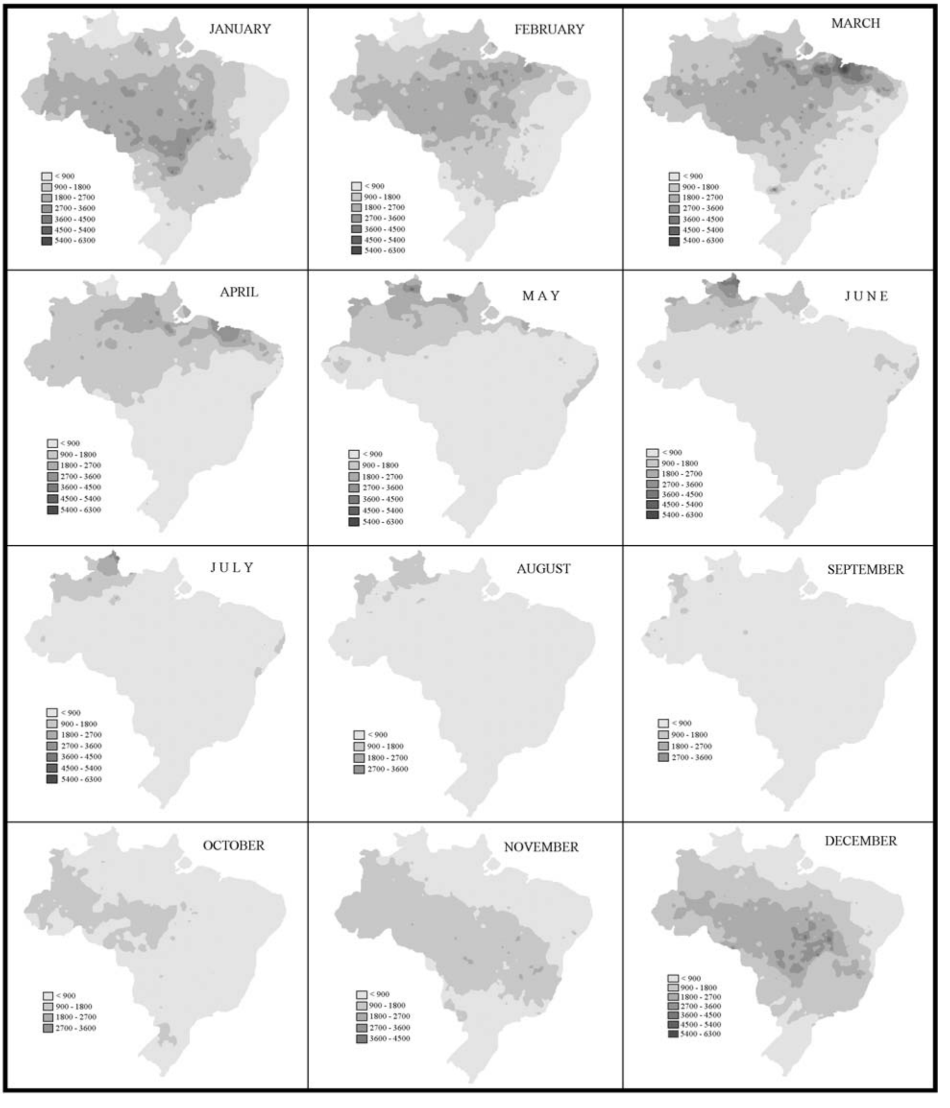

Fig. 5. Geography of the erosivity along the Brazilian territory (monthly average).

Carvalho, 1994). However, in the regions where the dry season is more pronounced (like in the northeastern region), a major part of the soils are bare during this period. At the beginning of the wet season, torrential rains may occur with high erosive effects.

Moreover, there is a high diversification of land use throughout the Brazilian territory. According to the Brazilian Institute for Geography and Statistic (2003), a high population density and a high diversity of land use is located in the southeastern and southern regions of Brazil. More than half of the Brazilian population lives in the coastal regions, and the urbanization rate in many cities is increasing. These anthropogenic factors can also enlarge potential erosion because the land cover becomes more vulnerable for rainfall erosive processes.

Also, burning represents a practice that encourages erosion (Primavesi, 1987) and constitutes a critical environmental problem in almost all of Brazil, especially in the states of the center-western, northeastern, and northern regions (Brazilian Institute for Spatial Research, 2003). In southeastern Brazil, burning is still used for sugar cane production, despite current alternative technologies. Conservation practices have been adopted in some agricultural regions of Brazil; however, their applications are normally associated with the degree of technological development of the region, which is highly heterogeneous throughout the country.

It is important to note that wind has a low potentiality to cause erosion in Brazil (Bertoni and Lombardi Neto, 1990). Only parts of Rio Grande do Sul state (southern region) have presented the occurrence of soil loss by wind erosion. The other parts of the territory are primarily affected by pluvial-caused erosion.

Agriculture and livestock activities represent about 18.7% and 8.4%, respectively, of Brazilian gross domestic product (Center for Advanced Studies in Applied Economy, 2003). These activities are important for Brazil's economy and require soil as the main natural resource for their development. Not protecting the soil against the erosion may reduce soil productivity more than 60% in a few years (Bertoni and Lombardi Neto, 1990).

4. Conclusion

The annual rainfall erosivity in Brazil ranged from 3116 to 20,035 MJ mm ha^{-1} h^{-1} $year^{-1}$, whereupon the northwestern region presented the highest values of annual erosivity, while the northeastern region showed the lowest annual values. The major part of the study area (68.8%) revealed annual erosivity values classified as strong or very strong. The maps presented are useful to illustrate how rainfall erosivity influences soil erosion and to deliver an important source of information for predicting erosion in Brazil.

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