

## Rainfall erosivity in Brazil: A review

Paulo Tarso Sanches Oliveira <sup>a,\*</sup>, Edson Wendland <sup>a</sup>, Mark A. Nearing <sup>b</sup>

<sup>a</sup> Department of Hydraulics and Sanitary Engineering, University of São Paulo, CxP. 359, São Carlos, SP, 13560-970, Brazil

<sup>b</sup> USDA-ARS, Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, AZ 85719, United States

### ARTICLE INFO

#### Article history:

Received 7 March 2012

Received in revised form 16 July 2012

Accepted 13 August 2012

#### Keywords:

Erosivity

Erosion

Water erosion

Annual precipitation

R factor

RUSLE

### ABSTRACT

In this paper, we review the erosivity studies conducted in Brazil to verify the quality and representativeness of the results generated and to provide a greater understanding of the rainfall erosivity (R factor) in Brazil. We searched the ISI Web of Science, Scopus, SciELO, and Google Scholar databases and in recent theses and dissertations to obtain the following information: latitude, longitude, city, states, length of record (years), altitude, precipitation, R factor, equations calculated and respective determination coefficient ( $R^2$ ). We found 35 studies in Brazil that used pluviographic rainfall data to calculate the rainfall erosivity. These studies were concentrated in the cities of the south and southeast regions (~60% of all the cities studied in Brazil) with a few studies in other regions, mainly in the north. The annual rainfall erosivity in Brazil ranged from 1672 to 22,452 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>. The lowest values were found in the northeast region, and the highest values were found in the north region. The rainfall erosivity tends to increase from east to west, particularly in the northern part of the country. In Brazil, there are 73 regression equations to calculate erosivity. These equations can be useful to map rainfall erosivity for the entire country. To this end, techniques already established in Brazil may be used for the interpolation of rainfall erosivity, such as geostatistics and artificial neural networks.

© 2012 Elsevier B.V. All rights reserved.

### Contents

1. Introduction . . . . .	139
2. Materials and methods . . . . .	140
3. Results and discussion . . . . .	140
3.1. Calculation of the erosivity index ( $EI_{30}$ ) in Brazil . . . . .	140
3.2. Mapping rainfall erosivity . . . . .	142
3.3. Spatial distribution of erosivity studies in Brazil . . . . .	143
4. Conclusions . . . . .	145
Acknowledgments . . . . .	145
References . . . . .	145

### 1. Introduction

Soil loss prediction is important to assess the risks of soil erosion and to determine appropriate soil use and management (Oliveira et al., 2011a). Several mathematical models (empirical, conceptual and physical-based processes) have been developed to estimate soil erosion on different spatial and temporal scales (Ferro, 2010; Moehansyah et al., 2004). The erosion models vary from complex procedures that require a series of input parameters, such as Water Erosion Prediction Project

(WEPP) (Nearing et al., 1989), Kinematic Runoff and Erosion (KINEROS) (Woolhiser et al., 1990) and European Soil Erosion Model (EUROSEM) (Morgan et al., 1998) to more simplified methods, such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) and Morgan-Morgan and Finney (MMF) (Morgan, 2001).

Models that require multiple input parameters may not be feasible for use in locations with no data or with difficult access, as in several regions of Brazil. Several authors consider the USLE to provide an excellent model for predicting soil loss because of its applicability (in terms of required input data) and the reliability of the obtained soil loss estimates (Ferro, 2010; Risse et al., 1993). The application of USLE on a river basin scale has been facilitated by the use of

\* Corresponding author. Tel.: +55 16 3373 8270; fax: +55 16 3373 9541.

E-mail addresses: paulot@sc.usp.br (P.T.S. Oliveira), ew@sc.usp.br (E. Wendland), mark.nearing@ars.usda.gov (M.A. Nearing).

Geographic Information Systems (GIS). This combination is considered a useful tool for soil and water conservation planning (Oliveira et al., 2011a).

The USLE is the most widely used erosion model in the world, and it provides useful information for the adequate planning of soil and water conservation. This model is characterized by establishing an estimate of the average annual soil loss caused by rill and interrill erosion (Kinnell, 2010; Oliveira et al., 2011a). The input data for the model are composed of natural factors (rainfall erosivity – R, erodibility – K, slope length – L, and slope – S) and anthropogenic factors (cover and management – C, and conservation practices – P). Among the factors that compose the USLE and RUSLE, the rainfall erosivity (R factor) is highly important because precipitation is the driving force of erosion and has a direct influence on aggregate breakdown and runoff. Erosivity is also an important parameter for soil erosion risk assessment under future land use and climate change (Meusburger et al., 2011; Nearing et al., 2005).

Several studies using natural and artificial rain have been conducted to understand the role of droplet size and the distribution of rainfall on the detachment of soil particles. However, the data are difficult to measure and are scarce, both spatially and temporally. Accordingly, studies related to rainfall, such as the maximum intensity over a period of time, the total energy of the rain or the rate of direct breakdown of the soil, have been conducted (Angulo-Martínez and Beguería, 2009). As an example of the erosivity index, we can cite the R factor of the USLE, which summarizes all the erosive events quantified by the  $EI_{30}$  index throughout the year (Wischmeier and Smith, 1978), the  $KE > 25$  index for southern Africa (Hudson, 1971), the Alm index for Nigeria (Lal, 1976), and the modified Fournier index for Morocco (Arnoldus, 1977).

The  $EI_{30}$  index has been the most widely used index (Hoyos et al., 2005) and provides a good correlation with soil loss in several studies in Brazil (Bertol et al., 2007, 2008; Lombardi Neto and Moldenhauer, 1992; Silva et al., 2009a). However, a series of more than 20 years of rain gauge is recommended to calculate this factor, but this length of time series is not found in many parts of the world (Capolongo et al., 2008; Hoyos et al., 2005; Lee and Heo, 2011). Simplified methods for predicting rainfall erosivity using readily available data have been presented and are used in many countries because the high-resolution rainfall data needed to directly compute the rainfall erosivity are not available for many locations; moreover, calculations of such data (when available) are intricate and time consuming (Lee and Heo, 2011). Models that relate the erosivity index with pluviometric data (e.g., monthly precipitation, annual total precipitation and modified Fournier index) were proposed to obtain the R factor. These daily pluviometric records are generally available for most locations with good spatial and temporal coverage, allowing the calculation of the erosivity index in regions that have no pluviographic rainfall data (Angulo-Martínez and Beguería, 2009; Renard and Freimund, 1994; Silva, 2004).

In Brazil, some regression equations are used widely to obtain the local values of erosivity from pluviometric data. However, the interpretation of the input data must be realistic and must match the local climate characteristics. In this paper, we review the erosivity studies conducted in Brazil to verify the quality and representativeness of the results generated and to provide a better understanding of the rainfall erosivity in Brazil. The R factor was used as the index to show the rainfall erosivity.

## 2. Materials and methods

Rainfall erosivity has been calculated for Brazilian regions using recording rain gauge data as the source of input. We review the ISI Web of Science, Scopus, SciELO, and Google Scholar databases and recent theses and dissertations that have not been published in journals. The following information was obtained from the published

works: latitude, longitude, city, states, length of record (years), altitude, precipitation, R factor, equations calculated and respective determination coefficient ( $R^2$ ).

We analyze the spatial distribution of the erosivity studies for the regions of Brazil to determine which areas have an abundance or lack of information. In addition, the erosivity information was compared with the calculated values of erosivity derived from regression equations.

## 3. Results and discussion

### 3.1. Calculation of the erosivity index ( $EI_{30}$ ) in Brazil

The erosivity index ( $EI_{30}$ ) is determined for isolated rainfalls and classified as either erosive or nonerosive. In Brazil, periods of rainfall are considered to be isolated and non-erosive when they are separated by periods of precipitation between 0 (no rain) and 1.0 mm for at least 6 h and are considered to be erosive when 6.0 mm of rain falls in 15 min or 10.0 mm of rain falls over a longer time period (Oliveira et al., 2011a; Wischmeier, 1959).

Erosive rain is analyzed by identifying the segments with the same inclination that represent periods of rain with the same intensity. For each segment with uniform rainfall, the unitary kinetic energy is determined by Eq. (1) (Wischmeier and Smith, 1978).

$$e = 0.119 + 0.0873 \log_{10} i \quad (1)$$

where  $e$  is the unitary kinetic energy ( $\text{MJ ha}^{-1} \text{mm}^{-1}$ ) and  $i$  represents the segments of rainfall intensity ( $\text{mm h}^{-1}$ ).

The rainfall kinetic energy can be directly calculated from drop size distribution and terminal velocity of the drops. This way, is important to study better these relationship at different regions (Cerdà, 1997). In Brazil, Wagner and Massambini (1988) developed the relationship between kinetic energy and rainfall intensity from 533 samples of the drop size distribution. The authors concluded that the equation generated (from observed data) to calculate kinetic energy don't have any significant difference of the equation from Wischmeier and Smith (1978). Thus, Eq. (1) still widely used in Brazil.

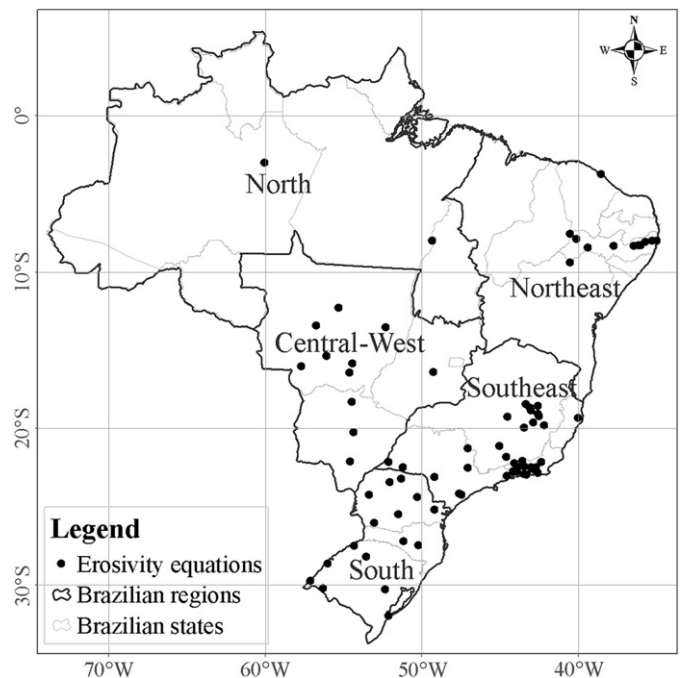


Fig. 1. Spatial distribution of studies on erosivity in Brazil.

**Table 1**  
Studies on erosivity in Brazil.

Latitude	Longitude	City	States	Years	Altitude	Precipitation	R factor	Equations	R <sup>2</sup>	Authors
3° 0' 0"S	60° 0' 0"W	Manaus	AM	–	–	2219	14,129	$E_{I30} = 42.77 + 3.76 (MFI)$	–	Oliveira and Medina, 1990
3° 44' 0"S	38° 33' 0"W	Fortaleza	CE	20	20	1677	6774	–	–	Dias and Silva, 2003
19° 35' 0"S	40° 0' 0"W	Aracruz	ES	7	40	1400	8536	$E_{I30} = 40.578 + 7.9075 (P)$	0.61	Martins et al., 2010
16° 41' 0"S	49° 23' 0"W	Goiânia	GO	5	750	1280	8353	$E_{I30} = 215.33 + 30.23 (MFI)$	0.77	Silva et al., 1997
21° 8' 24"S	45° 0' 0"W	Lavras	MG	15	919	1530	5403	–	–	Evangelista et al., 2006
19° 25' 0"S	44° 15' 0"W	Sete Lagoas	MG	3	732	1340	5835	$E_{I30} = 25.3 + 43.35 (MFI) - 0.232 (MFI)^2$	–	Marques et al., 1997
19° 04' 11"S	42° 32' 56"W	Açucena	MG	3	493	1481	18,646	$E_{I30} = 158.35 (MFI)^{0.85}$	0.88	Silva et al., 2010b
19° 38' 23"S	42° 51' 13"W	Antônio Dias	MG	3	420	1198	12,919	$E_{I30} = -119.27 + 7.84 (P)$	0.9	Silva et al., 2010b
19° 13' 20"S	42° 29' 41"W	Belo Oriente	MG	3	280	1223	8670	$E_{I30} = 215.4 (MFI)^{0.65}$	0.89	Silva et al., 2010b
19° 47' 55"S	42° 08' 51"W	Caratinga	MG	3	660	1037	10,115	$E_{I30} = 321.63 (MFI)^{0.48}$	0.86	Silva et al., 2010b
18° 33' 25"S	42° 32' 35"W	Peçanha	MG	3	890	1100	9013	$E_{I30} = -141.07 + 9.63 (P)$	0.9	Silva et al., 2010b
18° 40' 23"S	43° 04' 52"W	Sabinópolis	MG	3	760	1078	8670	$E_{I30} = 123.33 (MFI)^{0.74}$	0.95	Silva et al., 2010b
19° 57' 26"S	43° 24' 60"W	Santa Bárbara	MG	3	810	1272	9145	$E_{I30} = 170.59 (MFI)^{0.64}$	0.93	Silva et al., 2010b
18° 27' 19"S	43° 18' 16"W	Sto. Ant. Itambé	MG	3	720	1411	15,280	$E_{I30} = 179.33 (MFI)^{0.77}$	0.9	Silva et al., 2010b
18° 51' 87"S	42° 58' 29"W	Sto D. do Prata	MG	3	621	1102	13,145	$E_{I30} = 114.42 (MFI)^{0.81}$	0.86	Silva et al., 2010b
22° 6' 54"S	54° 33' 39"W	Dourados	MS	8	458	1378	9256	$E_{I30} = 73.464 + 56.562 (MFI)$ $E_{I30} = 80.305 (MFI)^{0.8966}$	0.80 0.88	Oliveira et al., 2011b
18° 18' 10"S	54° 26' 43"W	Coxim	MS	4	238	1371	10,439	$E_{I30} = 247.35 + 41.036 (MFI)$ $E_{I30} = 138.33 (MFI)^{0.7431}$	0.90 0.91	Oliveira et al., 2011b
20° 15' 57"S	54° 18' 54"W	Campo Grande	MS	3	592	1419	9872	$E_{I30} = 171.40 + 42.173 (MFI)$ $E_{I30} = 139.44 (MFI)^{0.6784}$	0.78 0.91	Oliveira et al., 2011b
15° 37' 18"S	56° 06' 30"W	Cuiabá	MT	18	151	1387	8810	$E_{I30} = 109.412 (MFI)^{0.744}$	0.91	Almeida et al., 2011a
16° 27' 0"S	54° 34' 12"W	Rondonópolis	MT	6	284	1274	6641	$E_{I30} = 133.2004291 (MFI)^{0.5372499}$	0.90	Almeida et al., 2011b
16° 03' 0"S	57° 40' 48"W	Caceres	MT	7	118	1191	5056	$E_{I30} = 172.6326451 (MFI)^{0.5245258}$	0.94	Almeida et al., 2011b
15° 39' 0"S	57° 29' 00"W	Caceres	MT	9	135	1369	8493	$E_{I30} = 56.115 (MFI)^{0.9504}$	0.87	Morais et al., 1991
16° 02' 0"S	57° 16' 00"W	Caceres	MT	7	155	1316	7830	$E_{I30} = 36.849 (MFI)^{1.0852}$	0.84	Morais et al., 1991
13° 33' 0"S	52° 15' 36"W	Canarana	MT	–	406	1796	12,516	$E_{I30} = 317.397829 (MFI)^{0.484654}$	0.86	Almeida et al., 2011c
12° 17' 24"S	55° 17' 24"W	Vera	MT	–	379	2259	15,965	$E_{I30} = 399.538719 (MFI)^{0.458718}$	0.84	Almeida et al., 2011c
15° 50' 24"S	54° 23' 24"W	Poxoréu	MT	–	370	1688	8652	$E_{I30} = 272.865645 (MFI)^{0.419164}$	0.66	Almeida et al., 2011c
13° 26' 24"S	56° 42' 36"W	São J. Rio Claro	MT	–	360	1881	7107	$E_{I30} = 147.262400 (MFI)^{0.533025}$	0.83	Almeida et al., 2011c
8° 13' 42"S	49° 21' 58"W	Conc. Araguaia	PA	8	203	1729	11,487	$E_{I30} = 321.5 + 36.2 (MFI)$	0.89	Oliveira, 1996
5° 24' 35"S	49° 06' 48"W	Marabá	PA	–	98	1969	13,915	–	–	Oliveira et al., 1992
1° 04' 48"S	46° 47' 21"W	Bragança	PA	–	21	2318	12,351	–	–	Oliveira et al., 1992
2° 15' 30"S	49° 31' 06"W	Cametá	PA	–	11	2255	14,756	–	–	Oliveira et al., 1989
3° 47' 04"S	49° 42' 18"W	Tucuruí	PA	–	203	2207	14,487	–	–	Oliveira et al., 1989
3° 01' 41"S	47° 21' 10"W	Paragominas	PA	–	140	1954	13,251	–	–	Oliveira et al., 1989
1° 26' 37"S	48° 28' 30"W	Belém	PA	–	15	3144	22,452	–	–	Oliveira et al., 1995
7° 58' 48"S	35° 8' 60"W	Olinda	PE	10	61	1852	6325	$E_{I30} = 57.25 + 30.8 (MFI)$ $E_{I30} = 69.24 (MFI)^{0.75}$	0.88 0.87	Cantalice et al., 2009
8° 24' 4"S	35° 25' 54"W	Catende	PE	5	160	699	3601	$E_{I30} = 57.32 (MFI)^{0.618}$	0.75	Cantalice et al., 2009
8° 0' 1"S	35° 10' 42"W	Gloria do Goitá	PE	10	153	956	3212	$E_{I30} = 97.79 + 15 (MFI)$ $E_{I30} = 50.75 (MFI)^{0.724}$	0.72 0.78	Cantalice et al., 2009
8° 17' 17"S	35° 58' 56"W	Caruaru	PE	9	540	501	1909	$E_{I30} = 61.81 (MFI)^{0.58}$	0.67	Cantalice et al., 2009
8° 11' 33"S	36° 4' 53"W	São Caetano	PE	11	650	500	1672	$E_{I30} = 61.81 (MFI)^{0.58}$	0.67	Cantalice et al., 2009
8° 20' 38"S	36° 25' 26"W	Belo Jardim	PE	7	610	628	2862	$E_{I30} = 61.81 (MFI)^{0.58}$	0.67	Cantalice et al., 2009
7° 34' 12"S	40° 30' 02"W	Araripina	PE	9	630	719	2860	$E_{I30} = 73.34 + 23.18 (MFI)$ $E_{I30} = 95.48 (MFI)^{0.56}$	0.94 0.82	Cantalice et al., 2009
8° 17' 1"S	39° 14' 7"W	Cabrobó	PE	9	336	446	2518	$E_{I30} = 73.34 + 23.18 (MFI)$ $E_{I30} = 95.48 (MFI)^{0.56}$	0.94 0.82	Cantalice et al., 2009
7° 52' 57"S	40° 04' 49"W	Ouricuri	PE	11	450	580	2538	$E_{I30} = 73.34 + 23.18 (MFI)$ $E_{I30} = 95.48 (MFI)^{0.56}$	0.94 0.82	Cantalice et al., 2009
9° 23' 33"S	40° 30' 16"W	Petrolina	PE	8	370	438	3480	$E_{I30} = 73.34 + 23.18 (MFI)$ $E_{I30} = 95.48 (MFI)^{0.56}$	0.94 0.82	Cantalice et al., 2009
8° 19' 16"S	37° 43' 26"W	Poço da Cruz	PE	8	470	498	3159	$E_{I30} = 73.34 + 23.18 (MFI)$ $E_{I30} = 95.48 (MFI)^{0.56}$	0.94 0.82	Cantalice et al., 2009
24° 15' 18"S	53° 20' 35"W	Oeste Paraná	PR	–	–	–	–	$E_{I30} = 182.86 + 56.21 (MFI)$	–	Rufino et al., 1993
26° 4' 21"S	53° 1' 31"W	Sudoeste Paraná	PR	–	–	–	–	$E_{I30} = 144.86 + 55.20 (MFI)$	–	Rufino et al., 1993
22° 28' 57"S	51° 11' 29"W	Norte Paraná	PR	–	–	–	–	$E_{I30} = 216.31 + 41.30 (MFI)$	–	Rufino et al., 1993
23° 13' 25"S	51° 16' 13"W	Noroeste Paraná	PR	–	–	–	–	$E_{I30} = 164.12 + 39.44 (MFI)$	–	Rufino et al., 1993
23° 26' 43"S	52° 1' 54"W	Centro Paraná	PR	–	–	–	–	$E_{I30} = 191.79 + 48.40 (MFI)$	–	Rufino et al., 1993
25° 30' 55"S	51° 27' 51"W	Centro S. Paraná	PR	–	–	–	–	$E_{I30} = 107.52 + 46.89 (MFI)$	–	Rufino et al., 1993
24° 24' 19"S	50° 15' 45"W	Centro L. Paraná	PR	–	–	–	–	$E_{I30} = 93.29 + 41.20 (MFI)$	–	Rufino et al., 1993
25° 13' 30"S	49° 8' 32"W	Leste Paraná	PR	–	–	–	–	$E_{I30} = 33.26 + 40.71 (MFI)$	–	Rufino et al., 1993
22° 10' 12"S	42° 19' 17"W	Nova Friburgo	RJ	5	857	1063	5431	$E_{I30} = -67.99 + 33.86 (MFI)$	0.85	Carvalho et al., 2005
22° 27' 30"S	43° 24' 39"W	Seropédica	RJ	7	33	1118	5472	$E_{I30} = 64.87 + 38.14 (MFI)$	0.82	Carvalho et al., 2005
22° 04' 04"S	43° 33' 30"W	Rio das Flores	RJ	5	400	1028	4118	$E_{I30} = 112.54 + 20.70 (MFI)$	0.82	Gonçalves et al., 2006
22° 13' 39"S	44° 03' 41"W	Valença	RJ	7	567	1550	6971	$E_{I30} = 194.08 + 27.74 (MFI)$	0.82	Gonçalves et al., 2006
23° 1' 48"S	44° 31' 12"W	Angra dos Reis	RJ	6	6	2034	10,140	$E_{I30} = 73.21 + 44.61 (MFI)$	0.84	Gonçalves et al., 2006
21° 50' 24"S	44° 34' 48"W	Carmo	RJ	15	146	1013	5653	$E_{I30} = 223.87 + 21.00 (MFI)$	0.72	Gonçalves et al., 2006
22° 28' 48"S	43° 50' 24"W	Barra do Pirai	RJ	14	371	1486	4985	$E_{I30} = 50.36 + 24.53 (MFI)$	0.96	Gonçalves et al., 2006
22° 41' 60"S	43° 52' 48"W	Pirai	RJ	15	462	1451	6696	$E_{I30} = 112.54 + 20.70 (MFI)$	0.82	Gonçalves et al., 2006
22° 45' 0"S	44° 7' 12"W	Rio Claro	RJ	15	479	1466	9031	$E_{I30} = 118.71 + 38.48 (MFI)$	0.98	Gonçalves et al., 2006
22° 42' 36"S	42° 42' 0"W	Rio Bonito	RJ	16	40	1387	5289	$E_{I30} = 38.48 + 35.13 (MFI)$	0.81	Gonçalves et al., 2006
22° 34' 48"S	42° 56' 24"W	Magé	RJ	19	10	1859	10,235	$E_{I30} = 64.59 + 47.68 (MFI)$	0.89	Gonçalves et al., 2006

(continued on next page)

Table 1 (continued)

Latitude	Longitude	City	States	Years	Altitude	Precipitation	R factor	Equations	R <sup>2</sup>	Authors
22° 28' 48"S	42° 39' 36"W	Conc. Macabu	RJ	15	40	1915	7961	El <sub>30</sub> = 39.86 + 37.90 (MFI)	0.91	Gonçalves et al., 2006
22° 28' 48"S	43° 0' 0"W	Magé	RJ	16	640	3006	15,806	El <sub>30</sub> = 146.28 + 46.37 (MFI)	0.70	Gonçalves et al., 2006
22° 51' 0"S	42° 32' 60"W	Saquarema	RJ	15	10	1252	5448	El <sub>30</sub> = - 13.36 + 50.02 (MFI)	0.65	Gonçalves et al., 2006
22° 55' 12"S	43° 25' 12"W	Rio de Janeiro	RJ	17	40	1280	4439	El <sub>30</sub> = 3.89 + 37.76 (MFI)	0.79	Gonçalves et al., 2006
22° 57' 36"S	43° 16' 48"W	Rio de Janeiro	RJ	16	460	2170	9331	El <sub>30</sub> = - 76.27 + 53.31 (MFI)	0.40	Gonçalves et al., 2006
22° 42' 38"S	43° 52' 41"W	Piraiá	RJ	18	462	-	6772	-	-	Machado et al., 2008
30° 23' 0"S	56° 26' 0"W	Quaraí	RS	38	100	1513	9292	El <sub>30</sub> = - 47.35 + 82.72 (MFI)	0.84	Bazzano et al., 2007
32° 01' 0"S	52° 09' 0"W	Rio Grande	RS	23	15	1162	5135	Non-significant correlation	-	Bazzano et al., 2010
28° 39' 0"S	56° 0' 0"W	São Borja	RS	48	99	1540	9751	El <sub>30</sub> = 99.646 + 63.874 (MFI)	0.77	Cassol et al., 2008
								El <sub>30</sub> = 55.564 (MFI) <sup>1.1054</sup>	0.84	
30° 32' 0"S	52° 31' 0"W	Enc. do Sul	RS	31	420	1279	5534	Non-significant correlation	-	Eltz et al., 2011
29° 45' 0"S	57° 05' 0"W	Uruguaiana	RS	29	74	1171	8875	El <sub>30</sub> = - 96735 + 81.967 (MFI)	0.94	Hickmann et al., 2008
28° 33' 0"S	53° 54' 0"W	Ijuí	RS	31	448	1667	8825	El <sub>30</sub> = 330.86 + 34.54 (MFI)	0.40	Cassol et al., 2007
								El <sub>30</sub> = 109.65 (MFI) <sup>0.76</sup>	0.53	
27° 51' 0"S	54° 29' 0"W	Santa Rosa	RS	29	273	1832	11,217	El <sub>30</sub> = 354.71 + 44.927 (MFI)	0.41	Mazurana et al., 2009
								El <sub>30</sub> = 118.52 (MFI) <sup>0.8034</sup>	0.50	
27° 24' 0"S	51° 12' 0"W	Campos Novos	SC	10	947	1754	6329	El <sub>30</sub> = 238.585 + 22.626 (MFI)	0.50	Bertol, 1994
								El <sub>30</sub> = 59.265 (MFI) <sup>1.087</sup>	0.86	
27° 49' 0"S	50° 20' 0"W	Lages	SC	10	953	1549	5790	-	-	Bertol et al., 2002
22° 37' 0"S	52° 10' 0"W	Teod. Sampaio	SP	19	255	1282	7172	El <sub>30</sub> = 106.8183 + 46.9562 (MFI)	0.93	Colodro et al., 2002
22° 31' 12"S	47° 2' 40"W	Campinas	SP	22	670	1280	6738	El <sub>30</sub> = 68.730 (MFI) <sup>0.841</sup>	0.98	Lombardi Neto and Moldenhauer, 1992
23° 13' 0"S	49° 14' 0"W	Piraju	SP	23	571	1482	7074	El <sub>30</sub> = 72.5488 (MFI) <sup>0.8488</sup>	0.93	Roque et al., 2001
24° 17' 0"S	47° 57' 0"W	Sete Barras	SP	9	30	1434	12,664	El <sub>30</sub> = 316.20 + 55.40 (MFI)	0.98	Silva et al., 2009b
24° 24' 0"S	47° 45' 0"W	Juquiã	SP	7	60	824	6145	El <sub>30</sub> = 207.21 + 40.65 (MFI)	0.90	Silva et al., 2009b
21° 16' 58"S	47° 0' 36"W	Mococa	SP	-	-	-	-	El <sub>30</sub> = 111.173 (MFI) <sup>0.691</sup>	0.98	Carvalho et al., 1991

Years = length of record, altitude (m), P = average annual precipitation (mm), R = R factor (MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>), and (-) not available.

States by region: north (Amazonas, AM and Pará, PA); northeast (Ceará, CE and Pernambuco, PE); central-west (Mato Grosso do Sul, MS; Mato Grosso, MT and Goiás, GO); southeast (Espírito Santo, ES; Minas Gerais, MG; Rio de Janeiro, RJ and São Paulo, SP) and south (Paraná, PR; Rio Grande do Sul, RS and Santa Catarina, SC).

The value obtained in Eq. (1) is multiplied by the amount of rain in the respective uniform segment to express the kinetic energy of the segment in MJ ha<sup>-1</sup>. The total kinetic energy of rain (Ect) is obtained by adding the kinetic energy of all the uniform segments of rain. The El<sub>30</sub> is defined as the product of the maximum rain intensity during a 30-minute period (I<sub>30</sub>) and the Ect.

$$El_{30} = Ect I_{30} \quad (2)$$

where El<sub>30</sub> is the rainfall erosivity index (MJ mm ha<sup>-1</sup> h<sup>-1</sup>), Ect is the total kinetic energy of the rain (MJ ha<sup>-1</sup>), and I<sub>30</sub> is the maximum rain intensity during a 30-minute period (mm h<sup>-1</sup>).

The RUSLE R factor is obtained from the average annual values of the El<sub>30</sub> erosion index:

$$R = \frac{1}{n} \sum_{j=1}^n \sum_{k=1}^{m_j} (El_{30})_k \quad (3)$$

where R is the average of the annual rainfall erosivity (MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>), n is the number of years of records, m<sub>j</sub> is the number of erosive events in a given year j, and El<sub>30</sub> is the rainfall erosivity index of a single event k.

After calculating the values of El<sub>30</sub>, a regression analysis is performed, usually using the Fournier index modified by Lombardi Neto (1977) or mean annual precipitation (P) (Eq. (4)) as independent variables. In Brazil, several researchers showed that the modified Fournier index (MFI) have achieved best results in the calculating of the R Factor (Carvalho et al., 2005; Cassol et al., 2008; Lombardi Neto and Moldenhauer, 1992; Oliveira et al., 2011b). These resulting regression equations generally are used to calculate the erosivity from pluviometric data in regions that have no pluviographic rainfall data.

$$MFI = p_i^2 P^{-1} \quad (4)$$

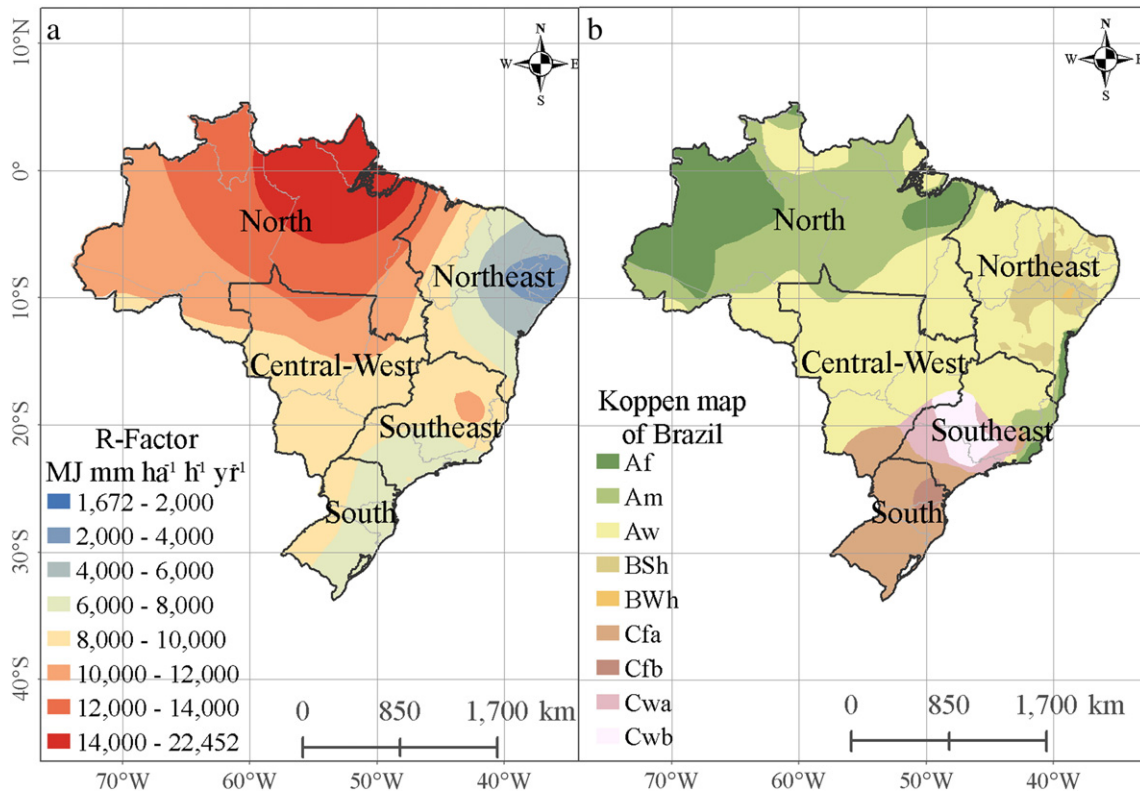
where MFI is the modified Fournier index, p is the mean monthly precipitation at month i (mm), and P is the mean annual precipitation (mm).

### 3.2. Mapping rainfall erosivity

The erosivity map can be obtained by interpolation methods using sampled values to estimate the erosivity values in places where no rainfall data are available (Montebeller et al., 2007). Until the late 1980s, interpolation techniques such as inverse distance, Thiessen polygons, or isohyetal method were the most popular techniques for the interpolation of rainfall data (Goovaerts, 1999). Silva (2004) used point erosivity values (calculated from regression equations) and the inverse distance method to obtain an erosivity map of Brazil. This study provided a good overall understanding of the occurrence of larger and smaller values of erosivity throughout the country.

Since the 1990s, a geostatistical interpolation method based on the regionalized variables theory has been widely used (Goovaerts, 1999) because it allows estimation at nonsampled points without bias and with minimum variance (Montebeller et al., 2007). Several studies were performed using the Kriging interpolation method to obtain erosivity maps. We can cite the works of Shamshad et al. (2008) in Peninsular Malaysia, Angulo-Martínez et al. (2009) in northeastern Spain, Zhang et al. (2010) in northeastern China, Meusburger et al. (2011) in Switzerland, and Bonilla and Vidal (2011) in central Chile. In Brazil, erosivity maps were created by Vieira and Lombardi Neto (1995) in São Paulo State, Mello et al. (2007) in Minas Gerais State, Montebeller et al. (2007) in Rio de Janeiro State, and Oliveira et al. (2011b) in Mato Grosso do Sul State.

In addition to the use of the geostatistical method for erosivity mapping, the application of machine learning techniques (ML) also is successfully used as a tool to obtain values of erosivity in places where no rainfall data are available. One of the main techniques of ML is Artificial Neural Networks (ANN), which have been used satisfactorily for this purpose (Licznar, 2005). In Brazil, ANN was used to



**Fig. 2.** a. R factor map of Brazil (an approximation). b. Koppen climate classification of Brazil. Where Af, equatorial, fully humid; Am, equatorial, monsoonal; Aw, equatorial, winter dry; BSh, hot arid steppe; BWh, hot arid desert; Cfa, humid, warm temperate, hot summer; Cfb, humid, warm temperate, warm summer; Cwa, winter dry, warm temperate, hot summer; Cwb, winter dry, warm temperate, warm summer.

estimate the rainfall erosivity in the States of São Paulo (Moreira et al., 2006), Minas Gerais (Moreira et al., 2008), and Mato Grosso do Sul (Alves Sobrinho et al., 2011), and Silva et al. (2010a) worked in the Vale do Ribeira, in southern São Paulo State. Like the rainfall erosivity mapping by geostatistical techniques, studies using ANN are concentrated in the southeastern region of Brazil. Thus, we find it necessary to perform further studies in other regions of Brazil because this kind of regional approach helps in effective land-use planning.

3.3. Spatial distribution of erosivity studies in Brazil

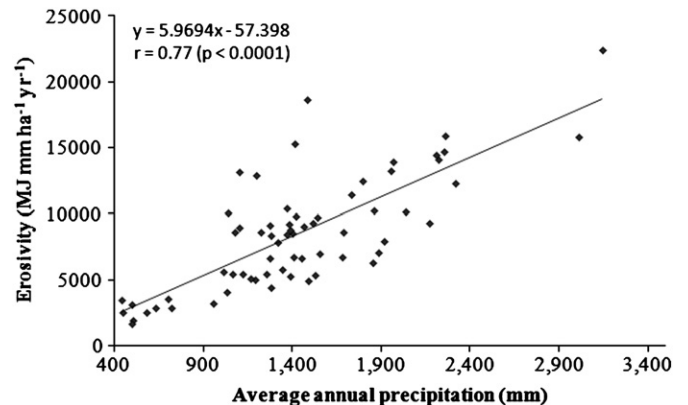
We found 35 studies that used pluviographic rainfall data to calculate the rainfall erosivity. These studies focused on 80 cities in 14 of

the 26 Brazilian states, i.e. with no studies on erosivity in the other half of the states. Most studies concentrated on the cities of the south and southeast regions (~60% of all the cities studied in Brazil), with only a few studies in other regions, mainly in the north and central-west (Fig. 1 and Table 1). This concentration occurs because the south and southeast regions are the most economically prosperous and have a higher population density.

The rainfall erosivity values observed in Brazil ranges from 1672 to 22,452 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>. The average erosivity (±sd) observed is 8403 ± 4090 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>. Lower values are found in the northeastern region, in the state of Pernambuco (PE), and the highest values are found in the north region (States of Para – PA and Amazonas – AM) and southeast region (States of Minas Gerais – MG, Rio de Janeiro – RJ, and Sao Paulo – SP) (Table 1 and Fig. 2a). Fig. 2a was derived using the data presented in Table 1 and kriging interpolation method. However, this map is

**Table 2**  
Range of rainfall erosivity values for several locations of the world.

Locate	Erosivity (MJ mm ha <sup>-1</sup> h <sup>-1</sup> yr <sup>-1</sup> )	Source
<i>Tropical sites</i>		
Honduras	2980–7297	Mikhailova et al. (1997)
Peninsular Malaysia	9000–14,000	Shamshad et al. (2008)
Colombian Andes	10,409–15,975	Hoyos et al. (2005)
El Salvador Republic	7196–17,856	Silva et al. (2011)
Southeastern Nigeria	12,814–18,611	Obi and Salako (1995)
Brazil	1672–22,452	Present paper
Australia's tropics	1080–33,500	Yu (1998)
<i>Temperate sites</i>		
Slovenia	1318–2995	Mikos et al. (2006)
Mediterranean region	100–3203	Diodato and Bellocchi (2010)
Northeastern Spain	40–4500	Angulo-Martínez et al. (2009)
Switzerland	124–5611	Meusburger et al. (2011)
Korea	2109–6876	Lee and Heo (2011)
Central Chile	50–7400	Bonilla and Vidal (2011)
United States	85–11,900	Renard and Freimund (1994)



**Fig. 3.** Correlation between annual erosivity and annual precipitation.

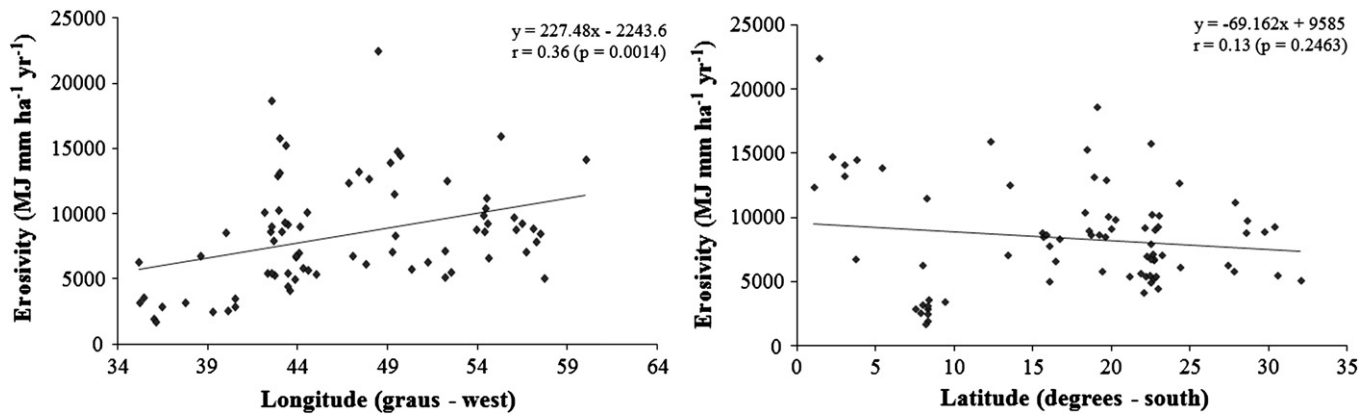


Fig. 4. Correlation of the longitude and latitude with the annual erosivity.

illustrative only because it is based on a sparse data set. To obtain a more accurate erosivity map, we recommend applying the equations presented in Table 1 in pluviometric data of other Brazilian places and after with several data points elaborating the map.

The influence of the climate in the annual rainfall erosivity can be observed in Fig. 2. The lower values are found in the northeast, in regions with climates hot arid steppe (BSh), and hot arid desert (BWh). In these regions, the average annual precipitation is below 800 mm. We found the highest annual erosivity values, such as those in the cities of Belem, PA and Tucuruí, PA, with erosivity values of the 22,452 and 14,756 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>, respectively. This region has an equatorial, humid (Af) and equatorial monsoonal (Am) climates, with average annual precipitation of the 2300 mm and high intensity rainfall, thus resulting in high erosivity values.

The range of rainfall erosivity values of Brazil is similar to the range observed in other tropical regions, and they are higher than the observed in temperate climate regions (Table 2). These higher erosivity values observed in the tropics are caused by the high amount of precipitation, intensity and kinetic energy of rain. The main rainfall generating mechanism in most tropical regions is convection. As a result, the tropics receive more rain at higher intensities than the temperate regions, dominated by midlatitude cyclones (Hoyos et al., 2005).

The correlation between annual precipitation and erosivity ( $r=0.77$ ) was significant at the 0.05 level (Fig. 3). However, the pattern of rainfall erosivity in Brazil cannot be explained only by annual precipitation. Several researchers found that high values of annual precipitation does not necessarily produce higher values of erosivity (Bazzano et al., 2010; Mello et al., 2007; Oliveira et al., 2011b; Silva et al., 2010b). In Brazil, the greatest erosivity values are caused by intense rainfall occurring in certain times of the year.

We found that there was a significant correlation between longitude ( $r=0.36$ ) and annual erosivity at the 0.05 level (Fig. 4). Despite of the low value of the correlation coefficient, it is possible to verify the erosivity increase from east to west. It occurs mainly due to the low erosivity in the northeastern region and high in northwest

Table 3  
Classifications for the interpretation of the annual erosivity index of Brazil.

Erosivity <sup>a</sup> (MJ mm ha <sup>-1</sup> h <sup>-1</sup> )	Erosivity class	Observed data (%)
$R \leq 2452$	Low erosivity	2.6
$2452 < R \leq 4905$	Medium erosivity	13.2
$4905 < R \leq 7357$	Medium-strong erosivity	31.6
$7357 < R \leq 9810$	Strong erosivity	23.7
$R > 9810$	Very strong erosivity	28.9

<sup>a</sup> Source: Carvalho (2008), modified to S.I. metric units according to Foster et al. (1981).

region. We did not find significant correlation between latitude ( $r=0.13$ ) and annual erosivity at the 0.05 level.

According to classifications for the interpretation of the annual erosivity index of Brazil, we found that the erosivity rainfall values exceed 7357 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup> (strong erosivity) in 52.6% of the data (Table 3). From this results we found that in Brazil there are several areas of water erosion risk, mainly southeastern and central-west regions. In these regions the rapid expansion of sugar cane cultivation for production sugar and biofuel is occurring (Loarie et al., 2011). Thus, the knowledge of these areas with higher erosivity rainfall values is essential to assess the soil erosion risk and to support to soil and water conservation planning (Oliveira et al., 2011a).

In Brazil, 73 equations correlate the rainfall erosivity index ( $EI_{30}$ ) with the mean annual precipitation (P) or the modified Fournier index (MFI) (Table 1 and Fig. 1). The equations presented in Table 1 can be used in areas that have no pluviographic rainfall data but that have similar climatic conditions. However, the equations cannot be extrapolated to a generalized form without underestimating or overestimating the erosivity values. Studies must be conducted on the local climate to determine which equation is best suited to the desired region.

Silva (2004) proposed the division of Brazil into eight homogeneous regions according to rainfall. A single equation was designated for each region to allow the rainfall erosivity for each month to be estimated from the rainfall coefficient. In this proposal, the same equation was applied to several states. We compare the R factor values presented in Table 1 with the results calculated by Silva (2004). We conclude that despite providing a significant contribution

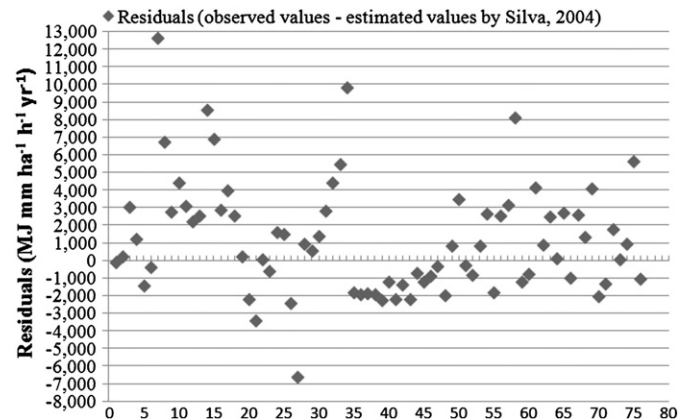


Fig. 5. Residual values of erosivity (observed values – estimated values by Silva, 2004).

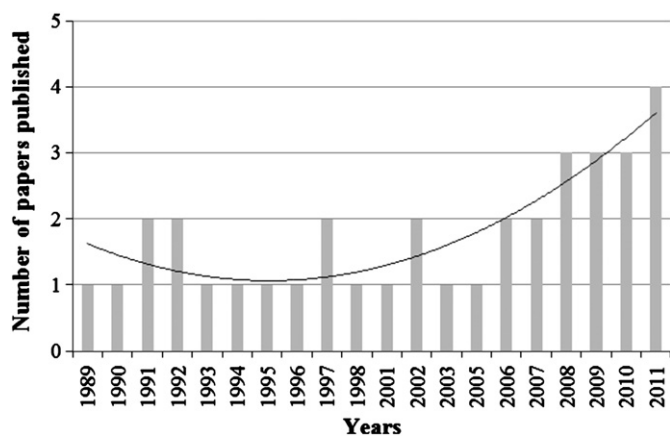


Fig. 6. Number of papers published per year.

to the understanding of rainfall erosivity in Brazil, the generalization of these equations produces many errors (Fig. 5). Therefore, the choice of equation to be used in different locations should be performed with caution and should be based on local climate studies.

Before Silva (2004), there were few studies on rainfall erosivity and few equations adjusted for the regions of Brazil. Since 2005, the number of publications on rainfall erosivity has increased significantly (Fig. 6). From the information presented in this present paper, new studies can be developed to map rainfall erosivity for the entire country. The equations that we found (Table 1) can be used with pluviometric data available for all Brazil by Agência Nacional de Águas (ANA) on website (<http://hidroweb.ana.gov.br/>). Furthermore, we recommend the inclusion of the rainfall return periods and the climate change in future studies.

In addition, the computational advances and the consolidation of the use of methodologies such as artificial neural networks and geostatistics techniques to obtain the rainfall erosivity can help to develop a more precise study for Brazil. These studies are fundamental for achieving effective environmental planning and may assist in analyzing vulnerability, risk forecasting and allocating financial resources for farmers in risk areas (Oliveira et al., 2011a; Rodrigues et al., 2011).

We found that 85% of the analyzed studies were developed using a historical series of less than 20 years, so only 15% of these studies used the minimum series required for RUSLE calculation (Renard et al., 1997) (Fig. 7).

In Brazil, in general, hydrological and meteorological information is scarce or difficult to access (Montebeller et al., 2007; Oliveira et al., 2011b). This is a constant problem in the development of research models in this country. We recommend maintaining the existing

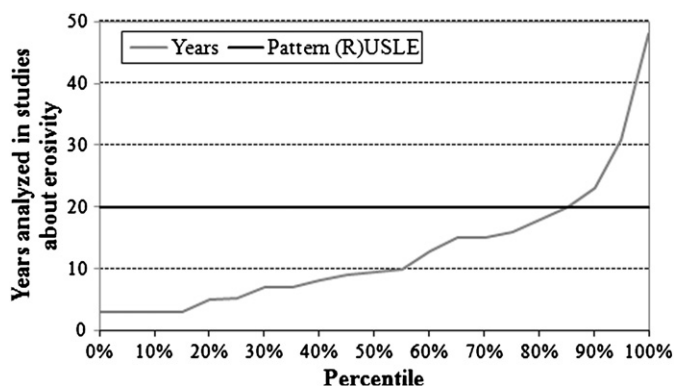


Fig. 7. Years of data analyzed in studies on erosivity.

stations and establishing new stations because this is the only way to obtain more realistic results. In addition, the development of new regional and global models and new scientific discoveries are needed to obtain basic data for the calibration and validation of the results.

#### 4. Conclusions

The annual rainfall erosivity in Brazil, based on our review, ranges from 1672 to 22,452 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup>. The lowest values are found in the northeastern region, and the highest values are found in the north region and the southeastern region. The rainfall erosivity tends to increase from east to west, particularly in the northern part of the country.

We conclude that there are few studies on erosivity in Brazil and that these studies are concentrated in the south and southeast regions. In addition, the number of years of data used in most of those studies was less than the recommended standard for the application of RUSLE (20 years of data).

The regression equations of rainfall erosivity cannot be extrapolated to a generalized form without underestimating or overestimating the erosivity values. Studies must be conducted on the local climate to determine which equation is best suited to the desired region.

In Brazil, there are 73 regression equations to calculate erosivity. These equations can be useful to map rainfall erosivity for the entire country. To this end, techniques already established in Brazil may be used for the interpolation of rainfall erosivity, such as geostatistics and artificial neural networks.

#### Acknowledgments

The authors thank the Fundação de Amparo à Pesquisa do Estado de São Paulo – FAPESP (Processes 2010/18788-5 and 2011/14273-3) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico – CNPq (Process 470846/2011-9) whose financial support made the development of the present study feasible.

#### References

- Almeida, C.O.S., Amorin, R.S.S., Couto, E.G., Eltz, F.L.F., Borges, L.E.C., 2011a. Erosive potential of rainfall in Cuiabá, MT: distribution and correlation with rainfall. *Revista Brasileira de Engenharia Agrícola e Ambiental* 15, 178–184. <http://dx.doi.org/10.1590/S1415-43662011000200011>.
- Almeida, C.O.S., Amorin, R.S.S., Eltz, F.L.F., Couto, E.G., Pelissari, A.L., 2011b. Correlação do índice de erosividade (EI 30) com o coeficiente de chuvas em Cáceres (MT) e Rondonópolis (MT). *Proc. XXXIII Congresso Brasileiro de Ciência do Solo, Uberlândia*, pp. 1–4.
- Almeida, C.O.S., Amorin, R.S.S., Eltz, F.L.F., Couto, E.G., Jordani, S.A., 2011c. Erosividade em quatro municípios do estado de Mato Grosso e suas correlações com dados pluviométricos. *Proc. XXXIII Congresso Brasileiro de Ciência do Solo, Uberlândia*, pp. 1–4.
- Alves Sobrinho, T., Pertussatti, C.A., Rebutti, L.C.S., Oliveira, P.T.S., 2011. Estimation of local rainfall erosivity using artificial neural network. *Ambiente & Água* 6, 246–254. <http://dx.doi.org/10.4136/ambi-agua.197>.
- Angulo-Martínez, M., Beguería, S., 2009. Estimating rainfall erosivity from daily precipitation records: a comparison among methods using data from the Ebro Basin (NE Spain). *Journal of Hydrology* 379, 111–121. <http://dx.doi.org/10.1016/j.jhydrol.2009.09.051>.
- Angulo-Martínez, M., López-Vicente, M., Vicente-Serrano, S.M., Beguería, S., 2009. Mapping rainfall erosivity at a regional scale: a comparison of interpolation methods in the Ebro Basin (NE Spain). *Hydrology and Earth System Sciences* 13, 1907–1920.
- Arnoldus, H.M.J., 1977. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. *FAO Soils Bulletin* 34, 39–51.
- Bazzano, M.G.P., Eltz, F.L.F., Cassol, E.A., 2007. Erosivity, rainfall coefficient and patterns and return period in Quaraí, RS, Brazil. *Revista Brasileira de Ciência do Solo* 31, 1205–1217.
- Bazzano, M.G.P., Eltz, F.L.F., Cassol, E.A., 2010. Erosivity and hydrological characteristics of rainfalls in Rio Grande (RS, Brazil). *Revista Brasileira de Ciência do Solo* 34, 235–244.
- Bertol, I., 1994. Evaluation for rain erosivity for Campos Novos (SC) during the 1981–1990 period. *Pesquisa Agropecuária Brasileira* 29, 1453–1458.
- Bertol, I., Schick, J., Batistela, O., Leite, D., Visentin, D., Cogo, N.P., 2002. Rain erosivity and its distribution between 1989 and 1998 in the district of Lages, state of Santa Catarina, Brazil. *Revista Brasileira de Ciência do Solo* 26, 455–464.
- Bertol, I., Leite, D., Engel, F.L., Cogo, N.P., González, A.P., 2007. Erodibility of a typical hapludox evaluated under field conditions. *Revista Brasileira de Ciência do Solo* 31, 541–549. <http://dx.doi.org/10.1590/S0100-06832007000300014>.

- Bertol, I., Zoldan Junior, W.A., Fabian, E.L., Zavaschi, E., Pegoraro, R., Gonzáles, A.P., 2008. Effect of chiseling and rainfall erosivity on some characteristics of water erosion in a nitosol under distinct management systems. *Revista Brasileira de Ciência do Solo* 32, 747–757. <http://dx.doi.org/10.1590/S0100-06832008000200027>.
- Bonilla, C.A., Vidal, K.L., 2011. Rainfall erosivity in Central Chile. *Journal of Hydrology* 410, 126–133. <http://dx.doi.org/10.1016/j.jhydrol.2011.09.022>.
- Cantaleira, J.R., Bezerra, S.A., Figueira, S.B., Inácio, E.S., Silva, M.D., 2009. Isoerodents of Pernambuco state – Brazil: 1 St.Approximation. *Caatinga* 22, 75–80.
- Capolongo, D., Diadato, N., Mannaerts, C.M., Piccarreta, M., Strobl, R.O., 2008. Analyzing temporal changes in climate erosivity using a simplified rainfall erosivity model in Basilicata (southern Italy). *Journal of Hydrology* 356, 119–130.
- Carvalho, N.O., 2008. *Hidrossedimentologia Prática*, 2ª ed. Interciência, Rio de Janeiro, Brazil. 599 pp.
- Carvalho, M.P.E., Lombardi, Neto F., Vasques, Filho J., Catâneo, A., 1991. Correlação entre o índice de erosividade E130 médio mensal e o coeficiente de chuva do município de Mococa, SP. Científica – Revista de Agronomia 19, 1–7.
- Carvalho, D.F., Montebeller, C.A., Franco, E.M., Valcarcel, R., Bertol, I., 2005. Rainfall patterns and erosion indices at Seropedica and Nova Friburgo, Rio de Janeiro – Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental* 9, 7–14. <http://dx.doi.org/10.1590/S1415-43662005000100001>.
- Cassol, E.A., Martins, D., Eltz, F.L.F., Lima, V.S., Bueno, A.C., 2007. Erosivity and hydrological patterns of Ijuí (RS, Brazil) rainfalls in the period of 1963 to 1993. *Revista Brasileira de Agrometeorologia* 15, 220–231.
- Cassol, E.A., Eltz, F.L.F., Martin, D., Lemos, A.M., Lima, V.S., Bueno, A.C., 2008. Erosivity, hydrological patterns, return period and probability of occurrence of rainfalls at São Borja, RS, Brazil. *Revista Brasileira de Ciência do Solo* 32, 1239–1251. <http://dx.doi.org/10.1590/S0100-06832008000300031>.
- Cerdà, A., 1997. Rainfall drop size distribution in Western Mediterranean Basin, València, Spain. *Catena* 31, 23–38. [http://dx.doi.org/10.1016/S0341-8162\(97\)00019-2](http://dx.doi.org/10.1016/S0341-8162(97)00019-2).
- Colodro, G., Carvalho, M.P., Roque, C.G., Prado, R.M., 2002. Rainfall erosivity: its distribution and relationship with the non-recording rain gauge precipitation at Teodoro Sampaio, São Paulo, Brazil. *Revista Brasileira de Ciência do Solo* 26, 809–818.
- Dias, A.S., Silva, J.R.C., 2003. Rainfall erosivity in Fortaleza, Ceará State, Brazil: I – distribution, probability of occurrence and return period – 1st approximation. *Revista Brasileira de Ciência do Solo* 27, 335–345. <http://dx.doi.org/10.1590/S0100-06832003000200013>.
- Diadato, N., Bellocchi, G., 2010. MedREM, a rainfall erosivity model for the Mediterranean region. *Journal of Hydrology* 387, 119–127. <http://dx.doi.org/10.1016/j.jhydrol.2010.04.003>.
- Eltz, F.L.F., Cassol, E.A., Pasolini, P.B., 2011. Erosivity potential and characteristics of rainfalls at Encruzilhada do Sul, RS. *Revista Brasileira de Engenharia Agrícola e Ambiental* 15, 331–337. <http://dx.doi.org/10.1590/S1415-43662011000400001>.
- Evangelista, A.W.P., Carvalho, L.G., Dantas, A.A.A., Bernardino, D.T., 2006. Rainfall erosive potential in Lavras, Minas Gerais state, Brazil: distribution, occurrence probability and return period. *Irriga* 11, 1–11.
- Ferro, V., 2010. Deducing the USLE mathematical structure by dimensional analysis and self-similarity theory. *Biosystems Engineering* 106, 216–220. <http://dx.doi.org/10.1016/j.biosystemseng.2010.03.006>.
- Foster, G.R., McCool, D.K., Renard, K.G., Moldenhauer, W.C., 1981. Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation* 36, 355–359.
- Gonçalves, F.A., Silva, D.D., Pruski, F.F., Carvalho, D.F., Cruz, E.S., 2006. Indices and spatialization of rainfall erosivity in Rio de Janeiro State, Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental* 10, 269–276. <http://dx.doi.org/10.1590/S1415-43662006000200003>.
- Goovaerts, P., 1999. Using elevation to aid the geostatistical mapping of rainfall erosivity. *Catena* 34, 227–242. [http://dx.doi.org/10.1016/S0341-8162\(98\)00116-7](http://dx.doi.org/10.1016/S0341-8162(98)00116-7).
- Hickmann, C., Eltz, F.L.F., Cassol, E.A., Cogo, C.M., 2008. Rainfall erosivity in Uruguaiana, Rio Grande do Sul, Brazil from 1963 to 1991 determined by the E130 index. *Revista Brasileira de Ciência do Solo* 32, 825–831. <http://dx.doi.org/10.1590/S0100-06832008000200035>.
- Hoyos, N., Waylen, P.R., Jaramillo, A., 2005. Seasonal and spatial patterns of erosivity in a tropical watershed of the Colombian Andes. *Journal of Hydrology* 314, 177–191. <http://dx.doi.org/10.1016/j.jhydrol.2005.03.014>.
- Hudson, N., 1971. *Soil Conservation*. Cornell University Press, Ithaca.
- Kinnell, P.A., 2010. Event soil loss, runoff and the Universal Soil Loss Equation family of models: a review. *Journal of Hydrology* 385, 384–397. <http://dx.doi.org/10.1016/j.jhydrol.2010.01.024>.
- Lal, R., 1976. Soil erosion on alfisols in Western Nigeria III—Effects of rainfall characteristics. *Geoderma* 16, 389–401. [http://dx.doi.org/10.1016/0016-7061\(76\)90003-3](http://dx.doi.org/10.1016/0016-7061(76)90003-3).
- Lee, J.H., Heo, J.H., 2011. Evaluation of estimation methods for rainfall erosivity based on annual precipitation in Korea. *Journal of Hydrology* 409, 30–48. <http://dx.doi.org/10.1016/j.jhydrol.2011.07.031>.
- Licznar, P., 2005. Artificial neural networks use for rainfall-runoff erosivity factor estimation. *Electronic Journal of Polish Agricultural Universities* 8, 4.
- Loarie, S.R., Lobell, D.B., Asner, G.P., Mu, Q., Field, C.B., 2011. Direct impacts on local climate of sugar-cane expansion in Brazil. *Nature Climate Change* 1, 105–109. <http://dx.doi.org/10.1038/NCLIMATE1067>.
- Lombardi Neto, F., 1977. Rainfall erosivity – its distribution and relationship with soil loss at Campinas, Brazil. West Lafayette: Purdue Univ., 53p. M.Sc. Thesis.
- Lombardi Neto, F., Moldenhauer, W.C., 1992. Rainfall erosivity – its distribution and relationship with soil loss at Campinas, state of São Paulo, Brazil. *Bragantia* 51, 189–196. <http://dx.doi.org/10.1590/S0006-87051992000200008>.
- Machado, R.L., Carvalho, D.F., Costa, J.R., Oliveira Neto, D.H., Pinto, M.F., 2008. Analysis of rainfall erosivity associated to pluvial precipitation patterns in the Ribeirão das Lajes region, Rio de Janeiro state, Brazil. *Revista Brasileira de Ciência do Solo* 32, 2113–2123. <http://dx.doi.org/10.1590/S0100-06832008000500031>.
- Marques, J.J.G.S.M., Alvarenga, R.C., Curi, N., Santana, D.P., Silva, M.L.N., 1997. Rainfall erosivity indices, soil losses and erodibility factor for two soils from the cerrado region – first approximation. *Revista Brasileira de Ciência do Solo* 21, 427–434.
- Martins, S.G., Avanzi, J.C., Silva, M.L.N., Curi, N., Norton, L.D., Fonseca, S., 2010. Rainfall erosivity and rainfall return period in the experimental watershed of Aracruz, in the coastal plain of Espírito Santo, Brazil. *Revista Brasileira de Ciência do Solo* 34, 999–1004. <http://dx.doi.org/10.1590/S0100-06832010000300042>.
- Mazurana, J., Cassol, E.A., Santos, L.C., Eltz, F.L.F., Bueno, A.C., 2009. Erosivity, hydrological patterns and return period of erosive rainfalls at Santa Rosa, RS – Brazil. *Revista Brasileira de Engenharia Agrícola e Ambiental* 13, 975–983. <http://dx.doi.org/10.1590/S1415-43662009000700016>.
- Mello, C.R., Sá, M.A.C., Curi, N., Mello, J.M., Viola, M.R., Silva, A.M., 2007. Monthly and annual rainfall erosivity for Minas Gerais State. *Pesquisa Agropecuária Brasileira* 42, 537–545. <http://dx.doi.org/10.1590/S0100-204X2007000400011>.
- Meusburger, K., Steel, A., Panagos, P., Montanarella, L., Alewell, C., 2011. Spatial and temporal variability of rainfall erosivity factor for Switzerland. *Hydrology and Earth System Sciences Discussions* 8, 8291–8314. <http://dx.doi.org/10.5194/hessd-8-8291-2011>.
- Mikhailova, E.A., Bryant, R.B., Shwager, S.J., Smith, S.D., 1997. Predicting rainfall erosivity in Honduras. *Soil Science Society of America Journal* 61, 273–279.
- Mikos, M., Jost, D., Petrovsek, G., 2006. Rainfall and runoff erosivity in the alpine climate of north Slovenia: a comparison of different estimation methods. *Hydrological Sciences Journal* 51, 115–126. <http://dx.doi.org/10.1623/hysj.51.1.115>.
- Moehansyah, H., Maheshwari, B.L., Armstrong, J., 2004. Field evaluation of selected soil erosion models for catchment management in Indonesia. *Biosystems Engineering* 88, 491–506. <http://dx.doi.org/10.1016/j.biosystemseng.2004.04.013>.
- Montebeller, C.A., Ceddia, M.B., Carvalho, D.F., Vieira, S.R., Franco, E.M., 2007. Spatial variability of the rainfall erosive potential in the State of Rio de Janeiro, Brazil. *Engenharia Agrícola* 27, 426–435. <http://dx.doi.org/10.1590/S0100-69162007000300010>.
- Morais, L.F.B., Silva, V., Naschenveng, C., Hardoin, P.C., Almeida, J.E.L., Weber, O.L.S., Boel, E., Durigon, V., 1991. Índice E130 e sua relação com o coeficiente de chuva do sudoeste do Mato Grosso. *Revista Brasileira de Ciência do Solo* 15, 339–344.
- Moreira, M.C., Cecílio, R.A., Pinto, F.A.C., Pruski, F.F., 2006. Estimates of rainfall erosivity in São Paulo state by an artificial neural network. *Revista Brasileira de Ciência do Solo* 30, 1069–1076. <http://dx.doi.org/10.1590/S0100-06832006000600016>.
- Moreira, M.C., Pruski, F.F., Oliveira, T.E.C., Pinto, F.A.C., Silva, D.D., 2008. NetErosividade MG: rainfall erosivity for Minas Gerais state, Brazil. *Revista Brasileira de Ciência do Solo* 32, 1349–1353. <http://dx.doi.org/10.1590/S0100-06832008000300041>.
- Morgan, R.P.C., 2001. A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model. *Catena* 44, 305–322. [http://dx.doi.org/10.1016/S0341-8162\(00\)00171-5](http://dx.doi.org/10.1016/S0341-8162(00)00171-5).
- Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., Styczen, M.E., 1998. The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms* 23, 527–544. [http://dx.doi.org/10.1002/\(SICI\)1096-9837\(199806\)23:6<527::AID-ESP868>3.0.CO;2-5](http://dx.doi.org/10.1002/(SICI)1096-9837(199806)23:6<527::AID-ESP868>3.0.CO;2-5).
- Nearing, M.A., Foster, G.R., Lane, L.J., Finkner, S.C., 1989. A process based soil erosion model for USDA Water Erosion Prediction Project technology. *Transactions of ASAE* 32, 1587–1593.
- Nearing, M.A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Le Bissonnais, Y., Nichols, M.H., Nunes, J.P., Renschler, C.S., Souchère, V., van Oost, K., 2005. Modeling response of soil erosion and runoff to changes in precipitation and cover. *Catena* 61, 131–154. <http://dx.doi.org/10.1016/j.catena.2005.03.007>.
- Obi, M.E., Salako, F.K., 1995. Rainfall parameters influencing erosivity in southeastern Nigeria. *Catena* 24, 275–287. [http://dx.doi.org/10.1016/0341-8162\(95\)00024-5](http://dx.doi.org/10.1016/0341-8162(95)00024-5).
- Oliveira Jr., R.C., 1996. Índice de Erosividade das Chuvas na Região de Conceição do Araguaia, Pará. EMBRAPA-CPATU, Belém. 20 pp.
- Oliveira Jr., R.C., Medina, B.F., 1990. A erosividade das chuvas em Manaus (AM). *Revista Brasileira de Ciência do Solo* 14, 235–239.
- Oliveira Jr., R.C., Lopes, O.M.N., Melo, A.S., 1989. A erosividade das chuvas em Cametá, Tucuruí e Paragominas, no Estado do Pará. *Boletim da FCAP, Belém* 18, 2–26.
- Oliveira Jr., R.C., Rodrigues, T.E., Melo, A.S., 1992. A erosividade das chuvas nos municípios de Bragança e Marabá no Estado do Pará. *Boletim do Museu Paraense Emílio Goeldi Série Ciências da Terra, Belém* 4, 45–57.
- Oliveira Jr., R.C., Chaves, R.S., Melo, A.S., 1995. A erosividade das chuvas em Belém. *Boletim da FCAP, Belém* 22, 35–52.
- Oliveira, P.T.S., Alves, Sobrinho T., Rodrigues, D.B.B., Panachuki, E., 2011a. Erosion risk mapping applied to environmental zoning. *Water Resources Management* 25, 1021–1036. <http://dx.doi.org/10.1007/s11269-010-9739-0>.
- Oliveira, P.T.S., Rodrigues, D.B.B., Alves, Sobrinho T., Carvalho, D.F., Panachuki, E., 2011b. Spatial variability of the rainfall erosive potential in the State of Mato Grosso do Sul, Brazil. *Engenharia Agrícola* 32, 69–79. <http://dx.doi.org/10.1590/S0100-69162012000100008>.
- Renard, K.G., Freimund, J.R., 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. *Journal of Hydrology* 157, 287–306. [http://dx.doi.org/10.1016/0022-1694\(94\)90110-4](http://dx.doi.org/10.1016/0022-1694(94)90110-4).
- Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C., 1997. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE)*. Agriculture Handbook, 703. USDA, Washington.
- Risse, L.M., Nearing, M.A., Nicks, A.D., Laflen, J.M., 1993. Error Assessment in the Universal Soil Loss Equation. *Soil Science Society of America Journal* 57, 825–833.
- Rodrigues, D.B.B., Alves, Sobrinho T., Oliveira, P.T.S., Panachuki, E., 2011. New approach to the Brazilian model of environmental services. *Revista Brasileira de Ciência do Solo* 35, 1037–1045. <http://dx.doi.org/10.1590/S0100-06832011000300037>.
- Roque, C.G., Carvalho, M.P., Prado, R.M., 2001. Rainfall erosivity factor at Piraju (SP), Brazil: distribution, probability of occurrence, return period and correlation with rainfall coefficient. *Revista Brasileira de Ciência do Solo* 25, 147–156.



- Rufino, R.L., Biscaia, R.C.M., Merten, G.H., 1993. Determinação do potencial erosivo da chuva do estado do Paraná através da pluviometria: terceira aproximação. *Revista Brasileira de Ciência do Solo* 17, 439–444.
- Shamshad, A., Azhari, M.N., Isa, M.H., Wan Hussin, W.M.A., Parida, B.P., 2008. Development of an appropriate procedure for estimation of RUSLE EI30 index and preparation of erosivity maps for Pulau Penang in Peninsular Malaysia. *Catena* 72, 423–432. <http://dx.doi.org/10.1016/j.catena.2007.08.002>.
- Silva, A.M., 2004. Rainfall erosivity map for Brazil. *Catena* 57, 251–259. <http://dx.doi.org/10.1016/j.catena.2003.11.006>.
- Silva, M.L.N., Freitas, P.L., Blancaneaux, P., Curi, N., 1997. Rainfall erosivity indices in the Goiânia region, Goiás state, Brazil. *Pesquisa Agropecuária Brasileira* 32, 977–985.
- Silva, R.B., Iori, P., Silva, F.A.M., 2009a. Proposition and compare of equations to estimate the rainfall erosivity in two cities of São Paulo state. *Irriga* 14, 533–547.
- Silva, A.M., Silva, M.L.N., Curi, N., Avanzi, J.C., Ferreira, M.M., 2009b. Rainfall erosivity and erodibility of Cambisol (Inceptisol) and Latosol (Oxisol) in the region of Lavras, Southern Minas Gerais state, Brazil. *Revista Brasileira de Ciência do Solo* 33, 1811–1820. <http://dx.doi.org/10.1590/S0100-06832009000600028>.
- Silva, M.A., Silva, M.L.N., Curi, N., Santos, G.R., Marques, J.J.G.S.M., Menezes, M.D., Leite, F.P., 2010a. Evaluation and spatialization of rainfall erosivity in the Rio Doce Valley, central-eastern region of Minas Gerais, Brazil. *Revista Brasileira de Ciência do Solo* 34, 1029–1039. <http://dx.doi.org/10.1590/S0100-06832010000400003>.
- Silva, R.B., Iori, P., Armesto, C., Bendini, H.N., 2010b. Assessing rainfall erosivity with artificial neural networks for the Ribeira Valley, Brazil. *International Journal of Agronomy*. <http://dx.doi.org/10.1155/2010/365249> 7 pp.
- Silva, A.M., Wiecheteck, M., Zuercher, B.W., 2011. Spatial assessment of indices for characterizing the erosive force of rainfall in El Salvador Republic. *Environmental Engineering Science* 28, 309–316. <http://dx.doi.org/10.1089/ees.2010.0296>.
- Vieira, S.R., Lombardi Neto, F., 1995. Spatial variability of rainfall erosivity for the State of São Paulo, Brazil. *Bragantia* 54, 405–412. <http://dx.doi.org/10.1590/S0006-87051995000200018>.
- Wagner, C.S., Massambini, O., 1988. Análise da relação intensidade de chuva: energia de Wischmeier & Smith e sua aplicabilidade à região de São Paulo. *Revista Brasileira de Ciência do Solo* 12, 197–203.
- Wischmeier, W.H., 1959. A rainfall erosion index for a universal soil-loss equation. *Soil Science Society of America Journal* 23, 246–249.
- Wischmeier, W.H., Smith, D.D., 1978. Predicting Rainfall Erosion Losses. A guide to conservation planning. : Agriculture Handbook, 537. USDA, Washington. 58 pp.
- Woolhiser, D.A., Smith, R.E., Goodrich, D.C., 1990. KINEROS: A Kinematic Runoff and Erosion Model: Documentation and User Manual, ARS-77. U.S. Department of Agriculture, Agricultural Research Service. 130 pp.
- Yu, B., 1998. Rainfall erosivity and its estimation for Australia's tropics. *Australian Journal of Soil Research* 36, 143–165.
- Zhang, Y.G., Nearing, M.A., Zhang, X.C., Xie, Y., Wei, H., 2010. Projected rainfall erosivity changes under climate change from multimodel and multiscenario projections in Northeast China. *Journal of Hydrology* 384, 97–106. <http://dx.doi.org/10.1016/j.jhydrol.2010.01.013>.