Erosividade da chuva

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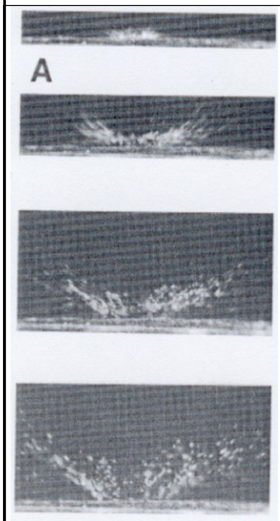

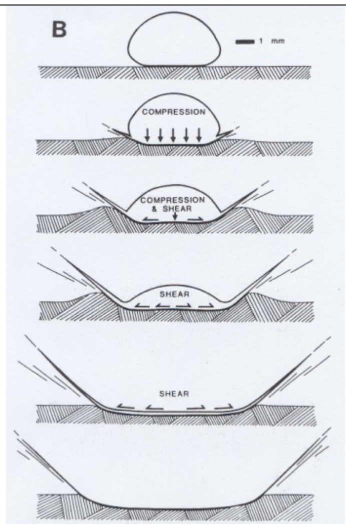

low shear strength $\tau = 2.6$ kPa

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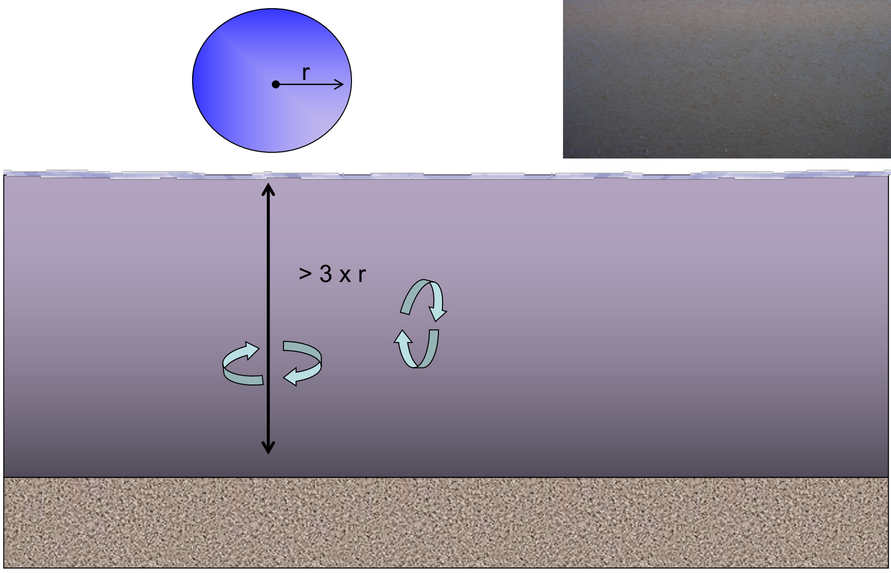
Capacidade de transporte



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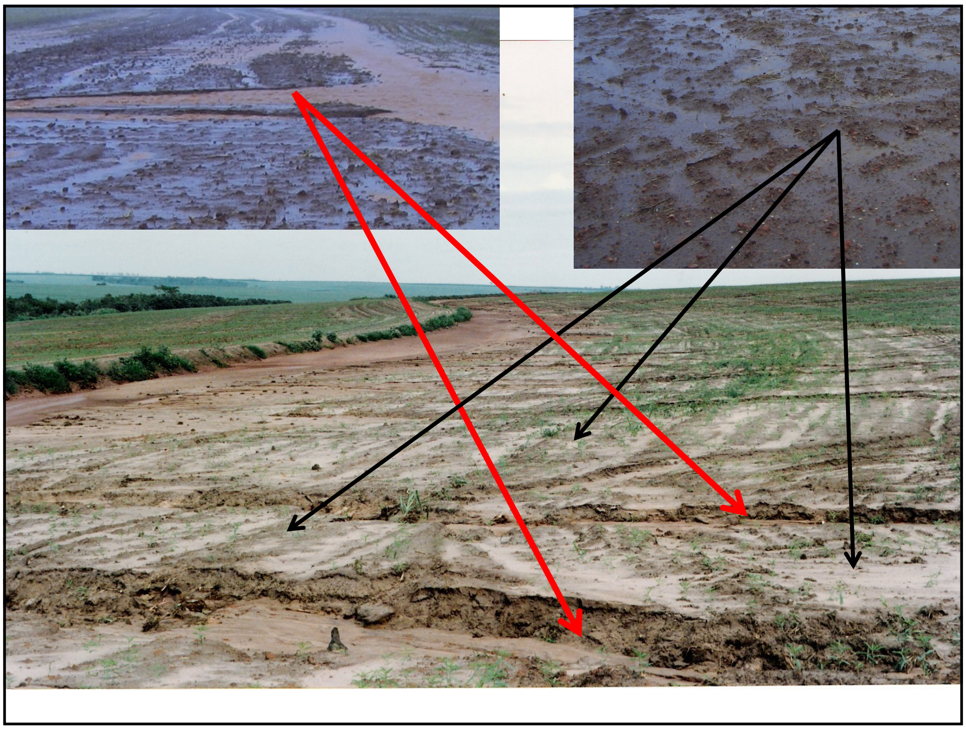

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Erosividade da Chuva

Quantidade de Chuva

-Dados de chuva em totais ou médias mensais ou anuais pouco significam em relação à erosão.

- Dados de chuva totais diários, limitados a observações a cada 24hs, pouco significado em relação à erosão.

Distribuição da chuva

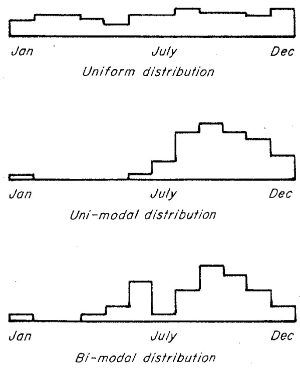

FIGURE 3.1 *Patterns of distribution of annual rainfall*

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Intensidade da Chuva:

- fator mais importante

- quanto maior a intensidade da chuva maior a perda por erosão

  exemplo: para uma chuva total de 21mm, uma intensidade de 7,9mm/h produziu uma perda de terra 100 vezes maior que uma de 1mm/h

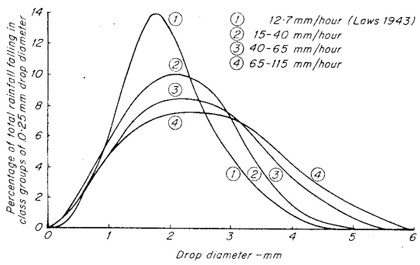

FIGURE 3.4 *Drop size distribution at low and medium intensities*

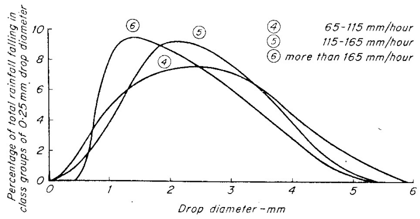

FIGURE 3.5 *Drop size distribution at high intensities*

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Table 1

Reported relationships between time-specific kinetic energy (KE_{time}) and intensities (I) of rains. The expression of KE_{mm} not reported in this table can easily be obtained by the relation (see Eq. (3)) KE_{mm} ($J\ m^{-2}\ mm^{-1}$) = KE_{time} ($J\ m^{-2}\ h^{-1}$)/I (DSD, drop-size distribution; n.a., not available)

Reference	KE_{time} ($J\ m^{-2}\ h^{-1}$)–I ($mm\ h^{-1}$) relation	Location	Range of I ($mm\ h^{-1}$)
Bollinne et al., 1984	$12.32I + 0.56I^2$	Belgium	0.27–38.6
Brandt, 1990	$I\,(8.95 + 8.44 \log_{10} I)$	USA, DSD from Marshall and Palmer (1948)	n.a.
Brown and Foster, 1987	$29I\,(1 - 0.72e^{-0.05I})$	USA	0–250
Carter et al., 1974	$11.32I + 0.5546I^2 - 0.5009 \times 10^{-2}I^3 + 0.126 \times 10^{-4}I^4$	South Central USA	1–250
Cerro et al., 1998	$38.4I\,(1 - 0.538e^{-0.029I})$	Barcelona, Spain	n.a.
Coutinho and Tomás, 1995	$35.9I\,(1 - 0.559e^{-0.034I})$	Portugal	0–120
Hudson, 1965	$29.86(I - 4.29)$	Zimbabwe	n.a.
Jayawardena and Rezaur, 2000b	$36.8I\,(1 - 0.691e^{-0.038I})$	Honk Kong	0–150
Kinnell, 1981	$I(17.124 + 5.229 \log_{10} I)$	Miami, Florida	1.89–309
	$30.132(I - 5.484)$		
	$29.31I\,(1 - 0.281e^{-0.018I})$		
Kinnell, 1981	$I\,(9.705 + 9.258 \log_{10} I)$	Rhodesia (from Hudson (1961))	18.5–228.6
	$29.863(I - 4.287)$		
	$29.22I\,(1 - 0.894\ e^{-0.0477I})$		
McGregor and Mutchler, 1976	$I\,(27.3 + 21.68e^{-0.048I} - 41.26e^{-0.072\ I})$	Mississipi, USA	n.a.
Onaga et al., 1988	$I\,(9.81 + 10.6 \log_{10} I)$	Okinawa, Japan	n.a.
Park et al., 1980	$21.1069I^{1.156}$	USA	n.a.
Renard et al., 1992	$29I\,(1 - 0.72e^{-0.05I})$	USA	n.a.
Rosewell, 1986	$29I\,(1 - 0.596e^{-0.0404I})$	Gunnedah, Australia	1–145.9
Rosewell, 1986	$26.35I\,(1 - 0.669e^{-0.0349I})$	Brisbane, Australia	1–161.2
Rosewell, 1986	$24.48\,(I - 1.253)$	Melbourne, Australia	n.a.
Rosewell, 1986	$24.80\,(I - 1.292)$	Cowra, Australia	n.a.
Sempere-Torres et al., 1992	$34I - 190$	Cévennes, France	20–100
Smith and De Veaux, 1992	$13I^{1.21}$	Oregon, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.23}$	Alaska, USA	n.a.
Smith and De Veaux, 1992	$18I^{1.24}$	Arizona, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.17}$	New Jersey, USA	n.a.
Smith and De Veaux, 1992	$10I^{1.18}$	North Carolina, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.14}$	Florida, USA	n.a.
Steiner and Smith, 2000	$11I^{1.25}$	Northern Mississippi, USA	n.a.
Tracy et al., 1984	$210Ie^{-0.0766I^{0.175}} - 211.8$ if $I < 76\ mm\ h^{-1}$	Arizona	n.a.
Uijlenhoet and Stricker, 1999a	$7.20I^{1.32}$	Based on Marshall and Palmer parameterisation	n.a.
	$8.53I^{1.29}$		
	$8.46I^{1.17}$		
	$8.89I^{1.28}$		
	$10.8I^{1.06}$		
	$7.74I^{1.35}$		
Usòn and Ramos, 2001	$23.4I - 18$	NE Spain	< 20
Wischmeier and Smith, 1958	$I\,(11.87 + 8.73 \log_{10} I)$	Washington, USA; DSD from Laws and Parsons (1943)	n.a.
Zanchi and Torri, 1980	$I\,(9.81 + 11.25 \log_{10} I)$	Italy	n.a.

258 C. Salles et al. / Journal of Hydrology 257 (2002) 256–270

Salles et al., 2002

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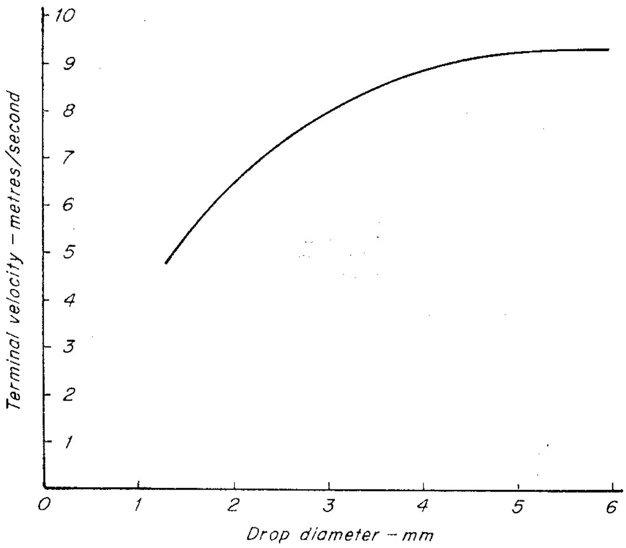

FIGURE 3.8 *The terminal velocity of raindrops* (data from LAWS 1941)

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Energia Cinética da Gota de Chuva

É muito importante conhecer a força com que a chuva impacta contra o solo.
A energia cinética é uma função da massa e da velocidade:

$$Ec = \frac{1}{2}mv^2$$

Energia cinética da chuva e da enxurrada:

	Chuva	Enxurrada
Massa	Suponha uma massa de queda da chuva = R	Suponha 25% de enxurrada, e a massa da enxurrada = R/4
Velocidade	Suponha uma velocidade de 8m/s	Suponha a velocidade de escorrimento na superfície de 1m/s
Energia Cinética	$1/2 \times R \times (8)^2 = 32R$	$1/2 \times R/4 \times (1)^2 = R/8$

Desta forma a chuva tem 256 vezes mais energia cinética que a enxurrada

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Duração da chuva:

- complemento da intensidade

- a combinação dos dois determina a chuva total

- importante para determinar o limite no qual o solo para de infiltrar a água e começa a enxurrada.

Frequência de chuva:

-fator importante que influi nas perdas de terra por erosão.

Se intervalos são curtos ⇒ o teor de umidade do solo é alta ⇒ enxurradas mais volumosas (inclusive com chuvas de menor intensidade)

Se intervalos maiores ⇒ o solo esta seco ⇒boa infiltração inicial ⇒ pouca enxurrada com chuvas de baixa intensidade.

Períodos de estiagem ⇒ diminuição da proteção vegetal por falta de umidade ⇒ maiores riscos de erosão nas primeiras chuvas

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Modelos estatísticos:

Zingg, 1940	$A = C' \; L^{0.6} \; S^{1.4}$
Smith, 1941	$A = C'' \; L^{0.6} \; S^{1.4} \; P$
Browning, 1947	$A = C''' \; L^{0.6} \; S^{1.4} \; P$
Musgrave, 1947	$A' = (P_{30}/1.25)^{1.75} \; K' \; (L/72)^{0.35} \; (S/10)^{1.35} \; C^{*}$
USLE, 1965	$A = EI_{30} \; K \; (L/72.6)^{0.5} \; (0.065 + .045\,S + .0065\,S^{2}) \; C \; P$
USLE, 1978	$A = EI_{30} \; K \; (L/72.6)^{0.5} \; (65.4 \sin^{2}\Theta + 4.56 \sin\Theta + 0.065) \; C \; P$
RUSLE, 1997	$A = EI_{30} \; K \; (L/72.6)^{m} \; (a \sin\Theta + b) \; C \; P$

A – Soil loss in tons/acre
A′ – Soil loss in inches/year
C′, C″, C‴ – Coefficients
C* – vegetal cover factor
P_{30} – Maximum Precipitation amount (inches) falling in 30 minutes in a storm
K′, K – Soil erodibility factors
L – Slope length in feet
S – Slope in percent
Θ – Slope angle in degrees
C – Cropping management factor
E – Storm rainfall energy in hundreds of foot-tons per acre
I_{30} – Maximum rainfall intensity in a 30 minute period within a storm in inches per hour
P – Conservation practice factor
M – Exponent on length term-values depend on slope or slope and rill/interrill ratio
a, b – coefficients in function making up slope term – values depend on slope

Energia cinética
Intensidade máxima

↓

Conversão estatística utilizando funções do volume e da intensidade de precipitação

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USLE

A = RKLSCP

A = Long term average annual soil loss
R = Rainfall erosivity
K = Soil erodibility
L and S = Slope factors
C = Crop factor
P = Management factor

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Rainfall Erosivity (R)

Wischmeier and Smith, 1978

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

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

$$EI_{30} = Ect \ I_{30} \qquad (2)$$

where EI_{30} is the rainfall erosivity index (MJ mm ha^{-1} h^{-1}), Ect is the total kinetic energy of the rain (MJ ha^{-1}), and I_{30} is the maximum rain intensity during a 30-minute period (mm h^{-1}).

RUSLE

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

where R is the average of the annual rainfall erosivity (MJ mm ha^{-1} h^{-1} yr^{-1}), n is the number of years of records, m_j is the number of erosive events in a given year j, and EI_{30} is the rainfall erosivity index of a single event k.

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Rainfall erosivity map for Brazil

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x = índice mensal
M = Precipitação média mensal
P = Precipitação média anual

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).

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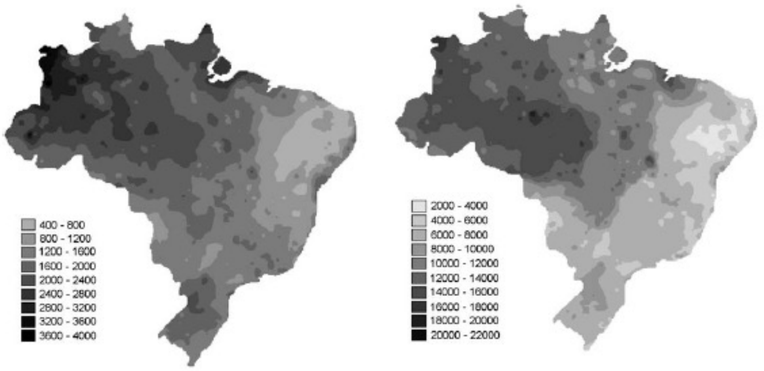

Fig. 2. Comparison of the annual pluviometric (left, in mm year^{-1}) and the annual erosivity maps (in MJ mm ha^{-1} h^{-1} year^{-1}).

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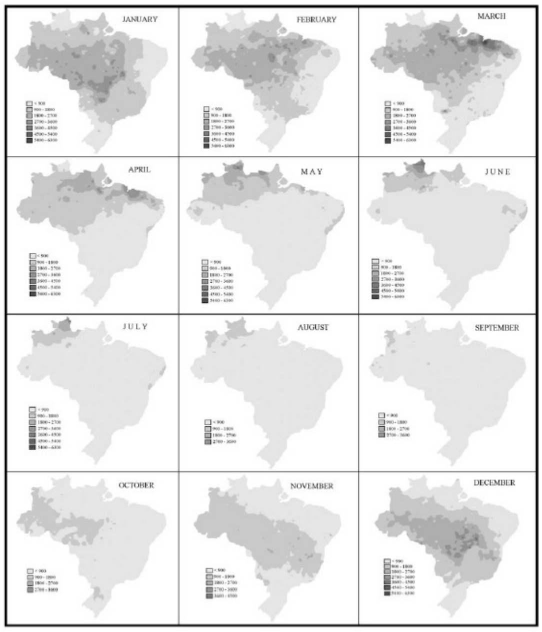

Fig. 5. Geography of the erosivity along the Brazilian territory (monthly average).

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Rainfall erosivity in Brazil: A review

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

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Equações da Erosividade no Brasil

Table 1
Studies on erosivity in Brazil.

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

(continued on next page)

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Equações da
Erosividade no Brasil

Table 1 (*continued*)

Latitude	Longitude	City	States	Years	Altitude	Precipitation	R factor	Equations	R^2	Authors
22° 28′ 48″S	42° 39′ 36″W	Conc. Macabu	RJ	15	40	1915	7961	$EI_{30} = 39.86 + 37.90$ (MFI)	0.91	Gonçalves et al., 2006
22° 28′ 48″S	43° 0′ 0″W	Magé	RJ	16	640	3006	15,806	$EI_{30} = 146.28 + 46.37$ (MFI)	0.70	Gonçalves et al., 2006
22° 51′ 0″S	42° 32′ 60″W	Saquarema	RJ	15	10	1252	5448	$EI_{30} = -13.36 + 50.02$ (MFI)	0.65	Gonçalves et al., 2006
22° 55′ 12″S	43° 25′ 12″W	Rio de Janeiro	RJ	17	40	1280	4439	$EI_{30} = 3.89 + 37.76$ (MFI)	0.79	Gonçalves et al., 2006
22° 57′ 36″S	43° 16′ 48″W	Rio de Janeiro	RJ	16	460	2170	9331	$EI_{30} = -76.27 + 53.31$ (MFI)	0.40	Gonçalves et al., 2006
22° 42′ 38″S	43° 52′ 41″W	Piraí	RJ	18	462	–	6772	–	–	Machado et al., 2008
30° 23′ 0″S	56° 26′ 0″W	Quaraí	RS	38	100	1513	9292	$EI_{30} = -47.35 + 82.72$ (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	$EI_{30} = 99.646 + 63.874$ (MFI) $EI_{30} = 55.564\ (MFI)^{1.1054}$	0.77 0.84	Cassol et al., 2008
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	$EI_{30} = -96735 + 81.967$ (MFI)	0.94	Hickmann et al., 2008
28° 33′ 0″S	53° 54′ 0″W	Ijuí	RS	31	448	1667	8825	$EI_{30} = 330.86 + 34.54$ (MFI) $EI_{30} = 109.65\ (MFI)^{0.76}$	0.40 0.53	Cassol et al., 2007
27° 51′ 0″S	54° 29′ 0″W	Santa Rosa	RS	29	273	1832	11,217	$EI_{30} = 354.71 + 44.927$ (MFI) $EI_{30} = 118.52\ (MFI)^{0.8034}$	0.41 0.50	Mazurana et al., 2009
27° 24′ 0″S	51° 12′ 0″W	Campos Novos	SC	10	947	1754	6329	$EI_{30} = 238.585 + 22.626$ (MFI) $EI_{30} = 59.265\ (MFI)^{1.087}$	0.50 0.86	Bertol, 1994
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	$EI_{30} = 106.8183 + 46.9562$ (MFI)	0.93	Colodro et al., 2002
22° 31′ 12″S	47° 2′ 40″W	Campinas	SP	22	670	1280	6738	$EI_{30} = 68.730\ (MFI)^{0.841}$	0.98	Lombardi Neto and Moldenhauer, 1992
23° 13′ 0″S	49° 14′ 0″W	Piraju	SP	23	571	1482	7074	$EI_{30} = 72.5488\ (MFI)^{0.8488}$	0.93	Roque et al., 2001
24° 17′ 0″S	47° 57′ 0″W	Sete Barras	SP	9	30	1434	12,664	$EI_{30} = 316.20 + 55.40$ (MFI)	0.98	Silva et al., 2009b
24° 24′ 0″S	47° 45′ 0″W	Juquiá	SP	7	60	824	6145	$EI_{30} = 207.21 + 40.65$ (MFI)	0.90	Silva et al., 2009b
21° 16′ 58″S	47° 0′ 36″W	Mococa	SP	–	–	–	–	$EI_{30} = 111.173\ (MFI)^{0.691}$	0.98	Carvalho et al., 1991

Years = length of record, altitude (m), P = average annual precipitation (mm), R = R factor (MJ mm ha^{-1} h^{-1} yr^{-1}), 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).

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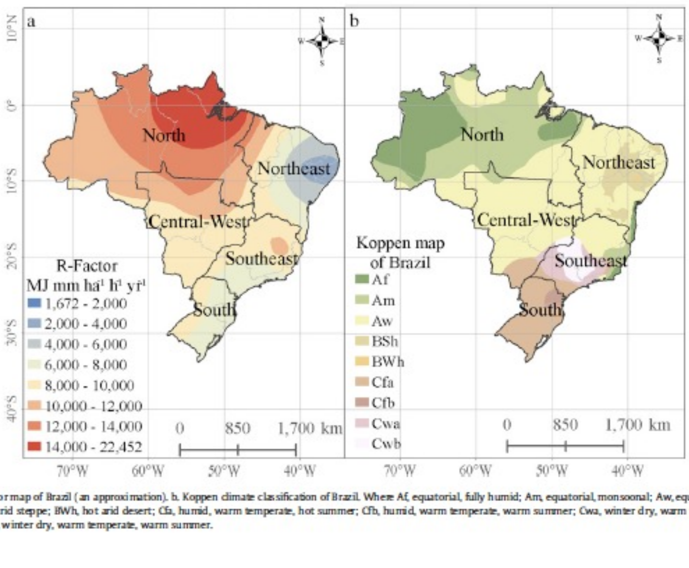

Fig. 2. a. R factor map of Brazil (an approximation). b. Koppen climate classification of Brazil. Where Af, equatorial, fully humid; Am, equatorial, monsoonal; Aw, equatorial, winter dry; BSh, hot arid steppe; BWh, hot arid desert; Cfa, humid, warm temperate, hot summer; Cfb, humid, warm temperate, warm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

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

Locate	Erosivity ($MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$)	Source
Tropical sites		
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)
Temperate sites		
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)

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

Erosivity[a] ($MJ\ mm\ ha^{-1}\ h^{-1}$)	Erosivity class	Observed data (%)
$R \le 2452$	Low erosivity	2.6
$2452 < R \le 4905$	Medium erosivity	13.2
$4905 < R \le 7357$	Medium-strong erosivity	31.6
$7357 < R \le 9810$	Strong erosivity	23.7
$R > 9810$	Very strong erosivity	28.9

[a] Source: Carvalho (2008), modified to S.I. metric units according to Foster et al. (1981).

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Process Based Models: Mass balance differential equation

$$\delta(cq)/\delta x + \delta(ch)/\delta t + S = 0$$

c = Sediment concentration (kg/m^3)
q = Runoff discharge (m^2/s)
x = Distance in the direction of flow (m)
h = Depth of flow (m)
t = Time (s)
S = Source/sink term ($kg/(m^2 s)$)

WEPP

$$dG/dx = Dr + Di$$

G = Sediment load per unit width in the flow (kg/(m s)) = cq
Dr = net rill erosion rate per unit area of rill bottom ($kg/(m^2\ s)$) (+ or -)
Di = Interrill sediment delivery to rill ($kg/(m^2\ s)$)

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Gerador de Clima: Cligen (WEPP e RUSLE)

CLIGEN uses a separate copy of its random number generator for each of 9 parameters:

- Maximum Temperature
- Minimum Temperature
- Dewpoint Temperature
- Radiation
- Probability of Precipitation
- Amount of Precipitation
- Time to Peak Intensity
- Wind Velocity
- Wind Direction

Table 1
Precipitation-related parameters for CLIGEN

Required parameters	Variable name	Number of values
Average precipitation on wet days for each month	meanP	12[a]
Standard deviation of daily precipitation for each month	sdP	12[a]
Coefficient of skewness of daily precipitation for each month	skP	12[a]
The probability of a wet day following a wet day for each month	Pr(*W*|*W*)	12[a]
The probability of a wet day following a dry day for each month	Pr(*W*|*D*)	12[a]
Average maximum 30-min peak intensity	MX.5P	12[a]
Cumulative distribution of the time to peak as a fraction of the storm duration[b]	timePk	12[b]

[a] One value for each month.
[b] The distribution is represented by 12 discrete values.

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Arquivo de parâmetros do Cligen

PIRACICA SP 129271 0
LATT= -22.71 LONG= -47.64 YEARS= 80. TYPE= 3
ELEVATION = 1791. TP5 = 1.74 TP6= 2.75

MEANP	0.65	0.57	0.45	0.26	0.27	0.18	0.15	0.18	0.31	0.41	0.46	0.58
SDEVP	0.49	0.52	0.45	0.32	0.30	0.24	0.24	0.17	0.25	0.37	0.42	0.47
SQEWP	2.75	3.62	3.18	4.63	5.25	5.21	5.21	6.15	3.69	3.39	3.24	2.96
P(W/W)	0.36	0.32	0.22	0.10	0.10	0.08	0.06	0.07	0.13	0.17	0.22	0.33
P(W/D)	0.13	0.17	0.15	0.12	0.12	0.08	0.07	0.08	0.12	0.16	0.16	0.16
TMAXAV	86.76	87.58	86.74	83.01	78.76	76.98	77.94	81.05	82.09	84.69	85.71	85.68
TMINAV	66.24	66.29	64.40	59.86	54.10	50.41	49.57	52.29	56.43	60.55	63.01	65.21
SDTMAX	2.18	2.65	1.84	2.59	3.33	2.43	2.41	2.52	3.62	2.63	2.86	2.11
SDTMIN	1.78	1.82	1.69	3.15	3.56	2.84	2.81	2.30	1.91	1.91	2.23	1.80
SOLRAD	494.	487.	443.	404.	323.	305.	330.	380.	407.	477.	498.	482.
SDSOL	131.0	117.0	115.0	107.0	90.0	70.0	64.0	66.0	103.0	123.0	137.0	124.0
MX5P	1.42	1.89	1.67	1.85	1.17	1.17	0.55	0.75	0.90	1.20	1.39	1.31
DEWPT	68.67	69.17	67.87	63.27	59.05	56.30	54.39	55.72	58.57	63.01	65.14	67.78
TimePk	0.290	0.426	0.536	0.621	0.701	0.761	0.813	0.863	0.910	0.942	0.974	1.000
MEAN	5.53	5.17	5.01	5.01	4.59	4.84	5.45	5.68	6.36	6.75	6.75	5.99
STDDEV	1.74	1.80	1.52	1.52	1.48	1.43	1.66	1.85	1.81	2.09	2.45	2.34
SKEW	0.80	1.21	1.30	1.30	1.87	0.95	0.52	1.19	1.81	1.75	1.87	0.93

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Entrada de dados pelo WEPP

da	mo	year	prcp	dur	tp	ip	tmax	tmin	rad	w-vl	w-dir	tdew
			(mm)	(h)			(C)	(C)	(l/d)	(m/s)(Deg)	(C)	
1	1	1	22.6	2.42	0.04	5.81	30.0	18.9	214.	5.5	234.	22.3
2	1	1	13.3	1.64	0.26	6.93	29.0	18.2	374.	5.9	188.	20.7
3	1	1	41.9	1.57	0.77	7.01	29.4	18.3	578.	5.0	86.	18.0
4	1	1	0.0	0.00	0.00	0.00	32.1	18.1	464.	5.9	264.	18.1
5	1	1	87.5	4.97	0.28	9.70	30.3	20.0	353.	5.4	179.	21.2
6	1	1	11.8	1.91	0.05	6.32	31.7	21.3	327.	6.1	183.	21.4
7	1	1	0.0	0.00	0.00	0.00	29.5	20.4	410.	4.8	45.	20.0
8	1	1	0.0	0.00	0.00	0.00	31.5	19.8	591.	3.8	97.	20.2
9	1	1	8.3	3.99	0.61	8.28	30.4	20.0	563.	6.4	357.	20.8
10	1	1	10.2	3.68	0.23	7.55	30.9	18.6	526.	4.2	305.	21.2
11	1	1	0.0	0.00	0.00	0.00	30.9	18.3	631.	0.0	0.	17.0
12	1	1	0.0	0.00	0.00	0.00	29.8	18.5	725.	4.0	324.	21.2
13	1	1	0.0	0.00	0.00	0.00	29.3	19.8	474.	7.1	273.	22.4

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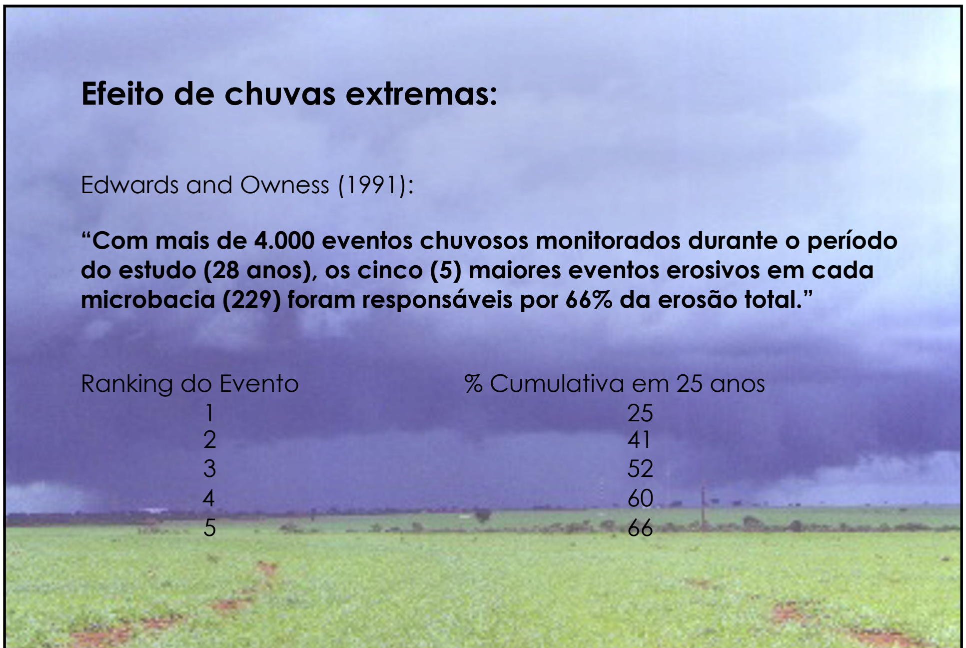

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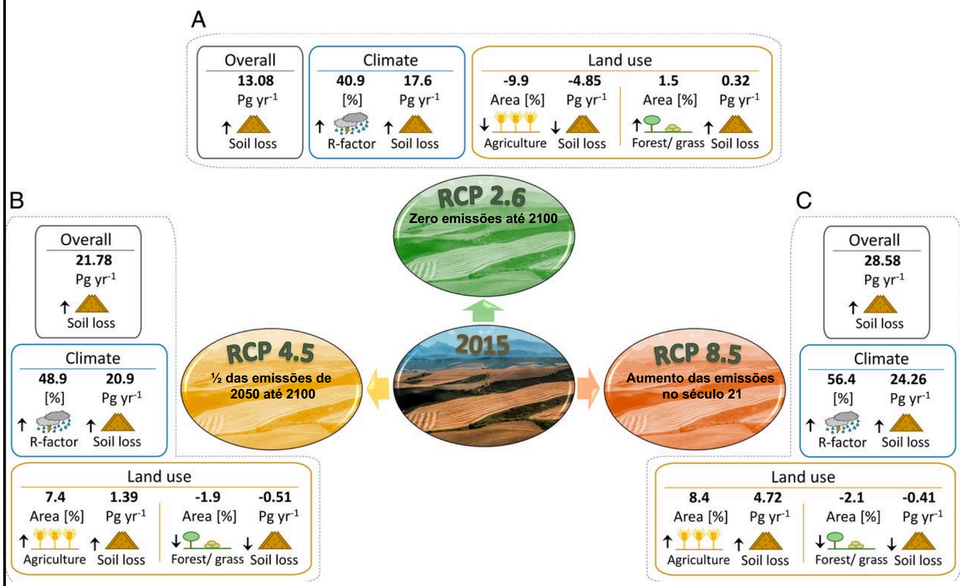

Pasquale Borrelli et al. PNAS 2020;117:36:21994-22001

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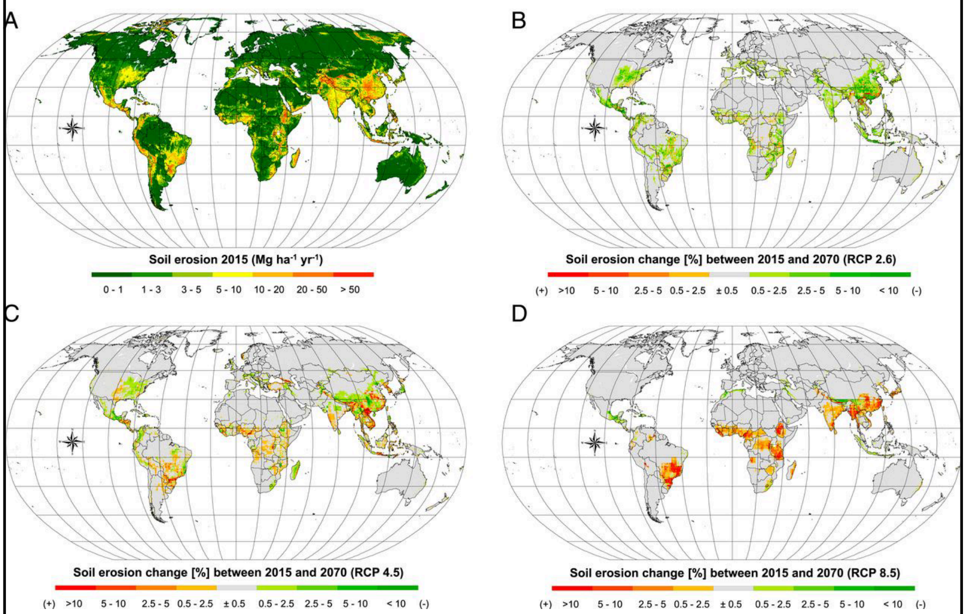

Pasquale Borrelli et al. PNAS 2020;117:36:21994-22001

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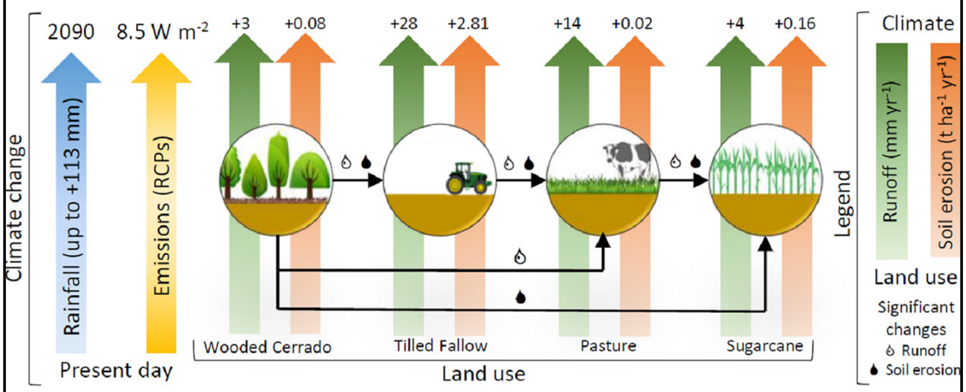

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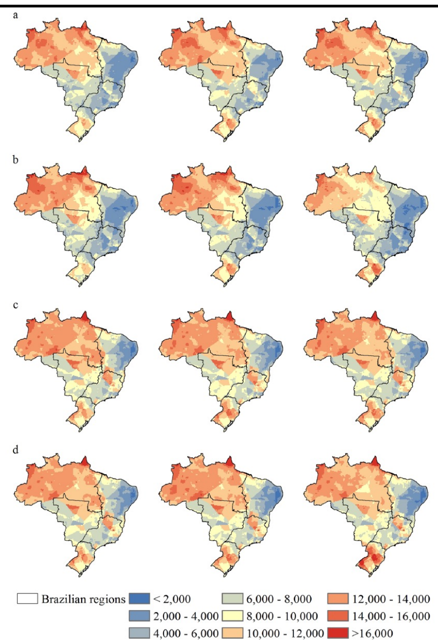

Figure 2. Estimated rainfall erosivity for Brazilian regions through 21st century. (**a**) RCP4.5 scenario of HadGEM2-ES model for three periods (2007–2040, 2041–2070 and 2071–2099). (**b**) RCP8.5 scenario of HadGEM2-ES model for three periods (2007–2040, 2041–2070 and 2071–2099). (**c**) RCP4.5 scenario of MIROC5 model for three periods (2007–2040, 2041–2070 and 2071–2099). (**d**) RCP8.5 scenario of MIROC5 model for three periods (2007–2040, 2041–2070 and 2071–2099). Values in MJ mm $ha^{-1} h^{-1} year^{-1}$. Maps created with ESRI ArcGIS 10.1 (www.esri.com).

Erosividade da Chuva

Os cenários modelados mostraram as seguintes tendências:

⇩ Regiões N, NE, CE e SE

⇧ Região S

Almagro et al DOI: 10.1038/s41598-017-08298-y

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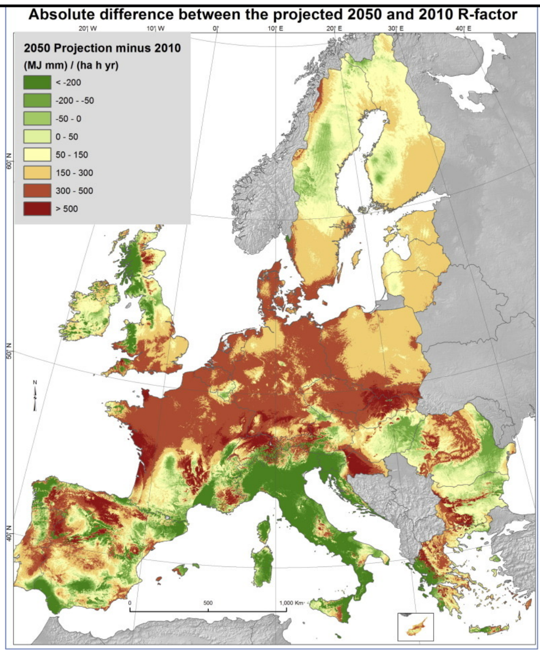

Erosividade da Chuva

- O aumento geral da erosividade da chuva na Europa em 18% até 2050

⇧ Norte-Centro da Europa, Canal da Mancha, Holanda e Norte da França.

⇩ partes da bacia do Mediterrâneo

Panagos et al. 2017 DOI: 10.1016/j.jhydrol.2017.03.006

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