



Estimating potential soil sheet Erosion in a Brazilian semiarid county using USLE, GIS, and remote sensing data

Cassiano José Lages Marinho Falcão  ·
Simone Mirtes de Araújo Duarte · Aline da
Silva Veloso

Received: 21 March 2019 / Accepted: 7 November 2019 / Published online: 16 December 2019
© Springer Nature Switzerland AG 2019

Abstract The present study aimed to estimate soil erosion in Machados County, Brazil. Rainfall erosivity was calculated using monthly and annual precipitation averages over a 30-year interval, soil erodibility was obtained with a granularity-based equation, and topography and land cover were obtained from DEM data and Sentinel – 2B imagery, respectively. A GIS interface was used to spatialize parameter results and for topography and land cover analysis. The achieved results allowed surmising that the soil loss for the study region risk is low, but significant, with a mean value of 8.11 t/ha year. About a quarter of the total area presented high soil loss, above 20 t/ha year. The biggest influential factors were soil erodibility, with a mean value of 0.028, and land cover, averaging 0.1409. The topographic factor averaged 3.414 and rain erosivity, found to be 2747.22 mm/year, is considered low for the region. Given a lack of conservative practices observed during field work, the soil stewardship *P* factor was considered 1 for the assessment. The use of orbital images to obtain *C* factor and the expression applied to calculate soil erodibility provided adequate results. In addition, there is a need for research to monitor and quantify erosion processes in Brazilian semiarid, as well as their erosion tolerance.

Keywords Soil erosion · USLE · GIS · DEM · Orbital image data

Introduction

Soil erosion is the detachment and carriage of its superficial layers by wind, rainfall, or waterways. Frequently worsened by anthropic actions on soil surface that make it more vulnerable to natural weathering agents, erosion is a land degrading process that results from agriculture and livestock industry since their conceptions. Rainfall erosion is among the main causes for land degradation in Brazil and other developing countries (Grepperud 1945, Vieira et al. 2015), averaging 30–40 t/ha year (Barrow 1991). Removing the first and most fertile soil layer, water erosion promotes massive economical loss due to fertilizers costs and degradation of arable lands results in even bigger environmental and monetary losses (Bertoni and Lombardi Neto 2012).

Caused by water runoff, sheet erosion is characterized by a uniform and diffuse water layer on the soil surface that causes a progressive and homogenous degradation. Hard to identify and quantify, as it evenly affects a large area, it is also the most hazardous among water erosion types. Sheet erosion rate is influenced by weathering agents, land topography, vegetation cover, and the soil itself (Blanco and Lal 2010).

Aiming for sustainable land use and exploration, several models based on land use, geomorphology, vegetation, and climate data were developed aiming to

C. J. Falcão (✉)
Forest Sciences Department, Universidade Federal Rural de
Pernambuco, Paulista, Pernambuco, Brazil
e-mail: cassianolages@gmail.com

S. M. Duarte · A. da Silva Veloso
Forest Sciences Department, Universidade Federal Rural de
Pernambuco, Recife, Pernambuco, Brazil

predict and quantify soil loss and sedimentation through sheet erosion, allowing better land management. One such model is the Universal Soil Loss Equation (USLE), an empirical model built by Wischmeier and Smith (1978) from experimental data. The USLE is a widely used equation prioritizing watershed management but also applied to larger areas (Griffin et al. 1988; Jain and Kothyari 2000 and Dickinson and Collins 1998).

Remote sensing data and GIS software may be used to greatly enhance erosion assessment, providing specialized results and greater ease for topographic analysis (Durigon et al. 2014). These tools have been combined with increasing occurrence (Peng et al. 2011; Durigon et al. 2014; Moore and Wilson 1992 and Zhang et al. 2009) and most models for topographic parameters or sheet erosion estimation already apply GIS tools and utilities.

As land management in Brazil is still largely based on administrative divisions, a county-based approach was considered adequate to encourage local efforts. Machados County is localized in a semiarid region of Pernambuco state, Brazil, and its main income sources are banana and sugarcane crops, followed by livestock industry. With a wavy to mountainous relief and irregular rainfall patterns, employing soil preservation practices, which were not observed in field evaluations, is recommended at least. As soil erosion becomes an increasingly severe problem, it becomes necessary to assess and locate high-risk areas and erosion modelling shows itself as a way of achieving this. Given the unavailability of detailed data for several regions already presenting soil degradation, the use of remote sensing data was deemed necessary. Given the presented context, and considering the increasing occurrences of soil erosion in northeastern Brazil, the present study aimed to estimate soil erosion in Machados County, Brazil.

Methodology

Description of study area

Machados is a county located in the semiarid region from Pernambuco state, in Brazil. Part of the Goiana River basin, it is within the coordinates $7^{\circ} 45' 00.05''/7^{\circ} 39' 29.26''$ south and $35^{\circ} 32' 52.02''/35^{\circ} 27' 08.74''$ west (Fig. 1). The city has a total area of 54.738 km^2 and is 77 km afar from the state capital, Recife. Its economy

revolves mostly around agriculture and cattle farming, often present on highly steep terrains with little to no sustainable practices.

The county's terrain is mostly composed of hills and valleys with more than half its area above 20% declivity and heights ranging from 152 to 462 m, and its predominant soils are lixisols. Lixisols and other soils with medium or fine texture tend to have poor infiltration rates, increasing water runoff and superficial erosion (Pimentel et al. 1995; Guerra et al. 2014). Gleysols, characteristic from water-saturated areas, are also present around a major drainage course and represent 5.92% of the studied area. The soils were classified in accordance with the WRB system (IUSS Working Group WRB 2015). Soil class distribution can be observed in Fig. 2.

Situated 72.5 km from the coast, the county is within the transition from the Atlantic rainforest to Brazilian semiarid and the local vegetation presents characteristics from both biomes, although the territory is predominantly used for agriculture and pasture. Precipitations average on an annual value of 3044 mm per year and are concentrated between April and August. Despite being on the transition to a semiarid region, the county does not suffer from long droughts.

USLE analysis

The potential sheet erosion (P) was determined with the USLE method, as shown in Eq. 1. To that end, the factors K , LS , CP , and R were determined as described below, converted to raster format and then used to estimate the potential erosion. All geoprocessing analysis was done through using QGIS software.

$$P = R \cdot K \cdot LS \cdot CP \quad (1)$$

where: E is the laminar soil erosion, in Kg/ha/year , K is the soil erodibility factor, R is the precipitation erosivity factor, LS is the declivity and slope length factor, and CP is the land cover and preservation practices factor.

Rain erosivity (R)

Rain erosivity was calculated through Eq. 2 (Bertoni and Lombardi Neto 2012), using monthly and yearly mean rainfall values as variables. Given the studied area size, only one meteorological station was needed for the data used. The monthly precipitation data was by the

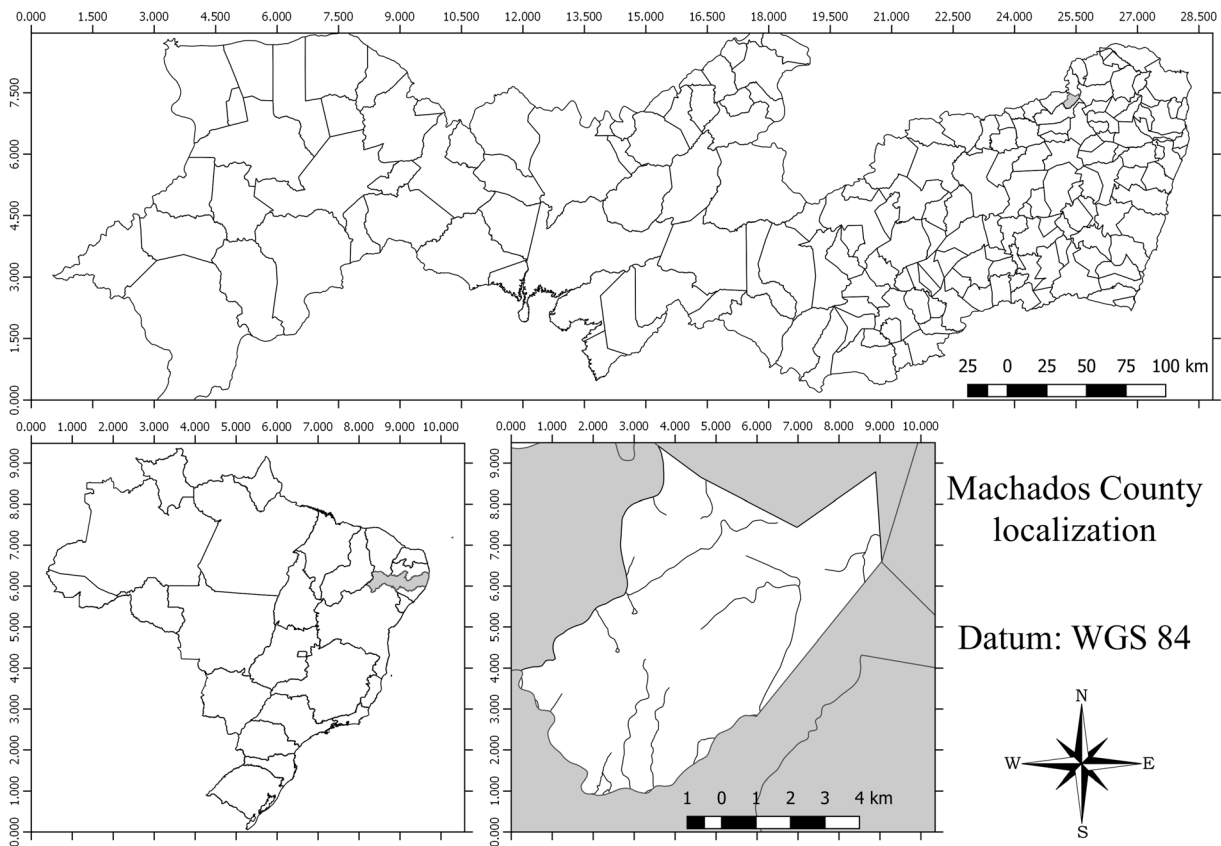


Fig. 1 Study area localization

APAC 2018, on a 30-year span. The data for the years 2006–2013 was not found; thus, rainfall statistic used ranges from 1982 to 2006 and from 2013 to 2018.

$$EI = 67.355 \left(\frac{R^2}{P} \right)^{12} \times 0.85 \tag{2}$$

where EI is the monthly average rainfall erosivity, *R* is the monthly average precipitation in millimeter, and *P* is the annual average precipitation in millimeter.

Soil erodibility (K)

The erodibility factor was estimated using Eq. 3, by Bouyoucos (1935), which calculates the factor from soil granulometry. Soil profiles were obtained from EMBRAPA (Accessed in october 2017). The five identified profiles were collected, and 3 composite samples extracted from each. Only the superficial layer was analyzed, since it is the most affected by sheet erosion.

$$K = ((a + b)/c)/100 \tag{3}$$

where *K* is the erodibility factor; *a* is the sand content, in %; *b* is the silt content, in %; and *c* is the clay content, in %.

Grain size analysis was done on the Soil Physics laboratory from Universidade Federal Rural de Pernambuco, following the method proposed by De Almeida (2008). Sand fraction was determined through sifting with 53-µm sieves, after the seized fractions were dried on a kiln and weighted. The dry sand mass was then compared with the sample mass. To determine clay content, the samples were mixed on a solution with 25 mL of CaCO₃ and water totaling 250 mL. The solutions were centrifuged for 16 h at 180 rpm and then decanted for 24 h, then transferred to a beaker, which was filled with water up to 940 mL. The clay content was finally measured with a densimeter. Silt content was obtained by subtracting the previous values, allowing calculation of the soil erodibility factor.

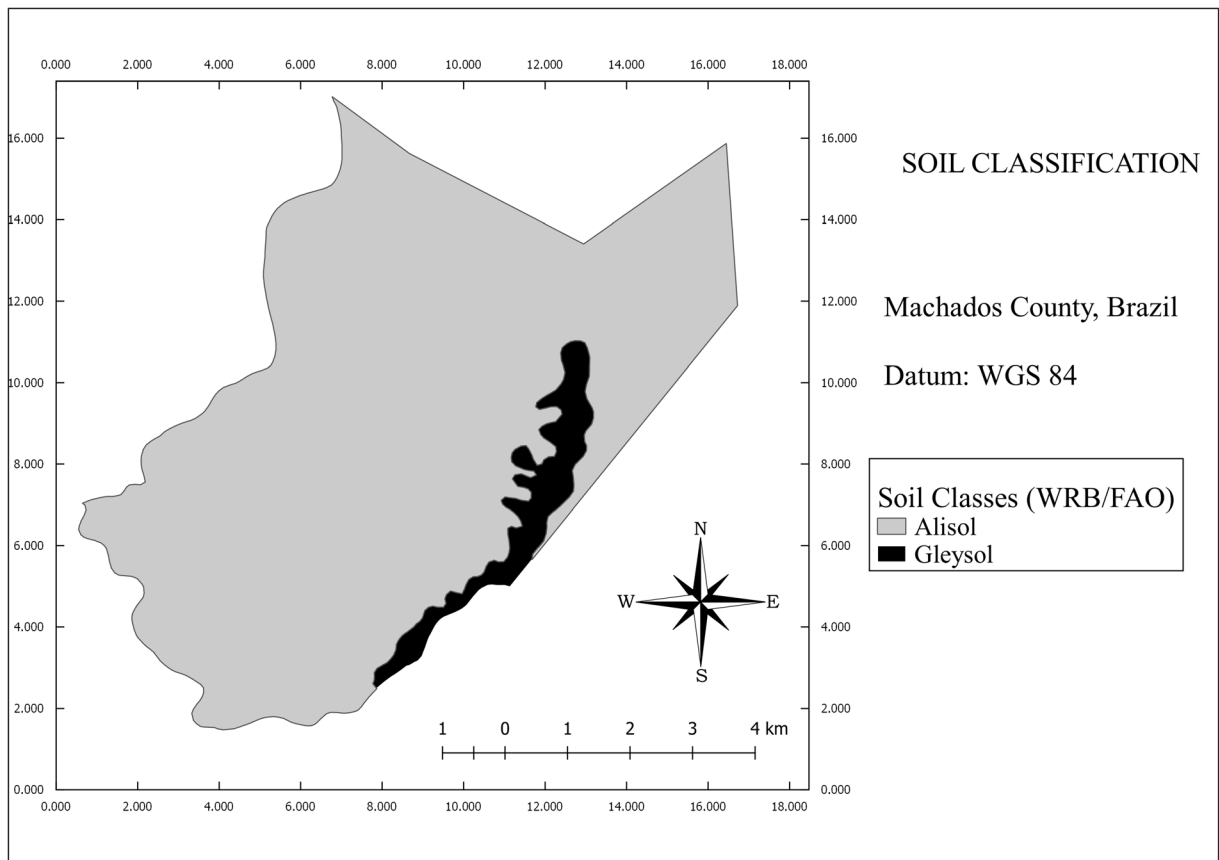


Fig. 2 Soil classes

Topographic factor (LS)

The declivity and slope length factors present on the original USLE are often combined on a single topographic factor. In the present study, DEM data was used to calculate both parameters and integrate them on a single topographic variable, using the expression designed by Mitasova and Mitas (1999), as follows:

$$LS = \left(FA \times \frac{CS}{22.13} \right)^{0.6} \times \left(\frac{\sin SL \times 0.01745}{0.0896} \right)^{1.3} \times 1.4 \tag{4}$$

where LS is the topographic factor, FA is the flow accumulation, and SL is the slope of DEM.

The Digital Elevation Model of the area was provided by Banco de Dados Geomorfométricos do Brasil (2018), with a resolution of 30 m. For the declivity maps the classification suggested by EMBRAPA

(1979) was used. The flow accumulation was calculated using the Multiple Flow Direction approach from Freeman (1991).

Land cover and conservative practices factor (CP)

During field study on the local, a severe and possibly absolute lack of soil conservation practices was perceived; thus, the soil preservation factor (*P*) was considered one during this estimation, and incorporated in the *C* factor. Durigon et al. (2014) employed a number of TM Landsat 5 images to obtain an association between Normalized Difference Vegetation Index (NDVI) and *C* factor for Atlantic Rainforest regions, resulting in Eq. 5 here used to calculate the land cover factor, as follows:

$$C = \frac{1-NDVI}{2} \tag{5}$$

Sentinel 2B data was used to obtain the Normalized Difference index, after atmospheric correction using the

6S (Second Simulation of the Satellite GISnal in the Solar Spectrum) model (Vermote et al. 1997).

Results and discussion

Rainfall erosivity (*R*)

Annual precipitations ranged between 20.5 and 1533.2 mm per year, reached respectively in 2006 and 2000, with a mean value of 1046.97 mm/year. Monthly precipitations varied from 17.45 mm in November to 175.95 mm in June. The mean value for the period was 87.21 mm. The rainfall erosivity value for the study totaled 2747.22 MJ mm/ha h year. Considered on the expected range for the Brazilian semiarid, the *R* factor is low according to the classification from Oliveira et al. (2012). Cantalice et al. (2009), after finding *R* values

from 1500 and 3500 MJ mm/ha h year on a characterization in the whole state, classified the erosivity here determined as average. da Silva (2004) on an assessment of erosivity in Brazilian territory found values ranging from 200 to 400 MJ mm/ha year in Brazil Northeastern region.

Availability of rainfall data was considered one of the main difficulties in the assessment of local erosivity. Since individual precipitation records were not available, the relationship between monthly rainfall data and erosivity described on Eq. 2 was used. As the county only has a single meteorological station on its proximity, the erosivity factor was considered a constant in the USLE. Given the reduced size of the assessed region, precipitation occurrences may be considered mostly uniform.

It is worth mentioning that the erosivity is only a mean value on a given period and, as any other climatic

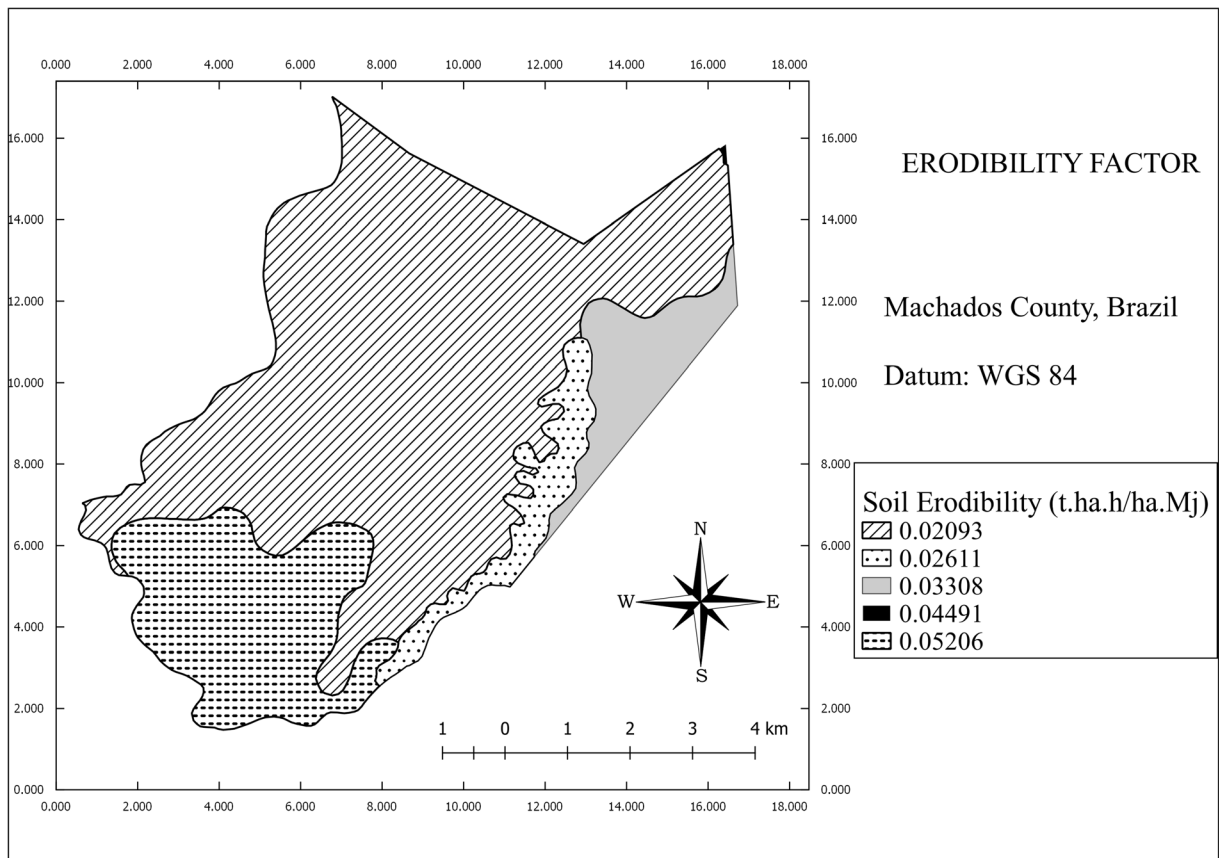


Fig. 3 Soil erodibility

Table 1 Declivity classes

Declivity (%)	Declivity class	Area (km ²)	Area (%)
0–3	Plane	0.7688	1.404
3–8	Slightly wavy	4.6288	8.456
8–20	Wavy	19.4337	35.502
20–45	Strongly wavy	28.879	52.757
45–75	Mountainous	1.026	1.874
> 75	Strongly mountainous	0.0029	0.005

agent, rainfall intensity, and its impact on soil erosion variates along time. In Machados County, the annual *R* values range from 7.92 to 4670.17 MJ mm/ha h year and, given the nature of the USLE, estimated erosion changes accordingly. It becomes necessary on any area risking soil degradation due to rain erosion to adequate preservation practices to varying precipitation intensities, rather than an average number.

Soil erodibility (*K*)

Sand, clay, and silt contents obtained from grain size analysis on the sampled soils are described in Table 2. The values found are within the expected for the superficial layer of lixisols and gleysols. The *K* factors met range between 0.0209375 and 0.0520625. The average erodibility for the study area is 0.028. The erosivity map is shown In Fig. 3.

A limitation of the applied methodology for erodibility assessment is that only the superficial layer is evaluated. Some soil types, such as lixisols, have higher clay concentrations on their subsuperficial layers increasing their water runoff and, consequently, erosion susceptibility. Soil erodibility was one of the main responsible for the spatial variation in the estimated laminar erosion, mainly due to the evaluated rate for the southwestern region almost doubles the average erodibility.

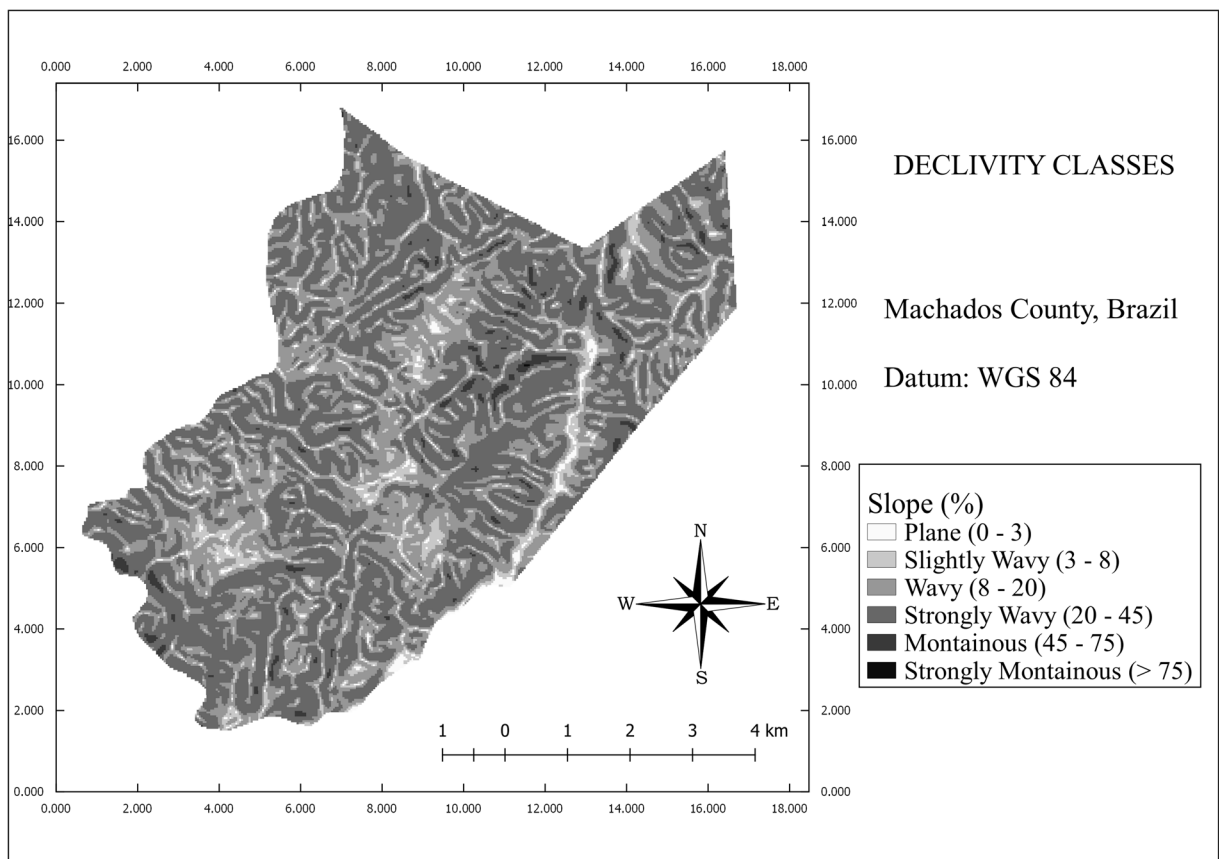


Fig. 4 Declivity classes

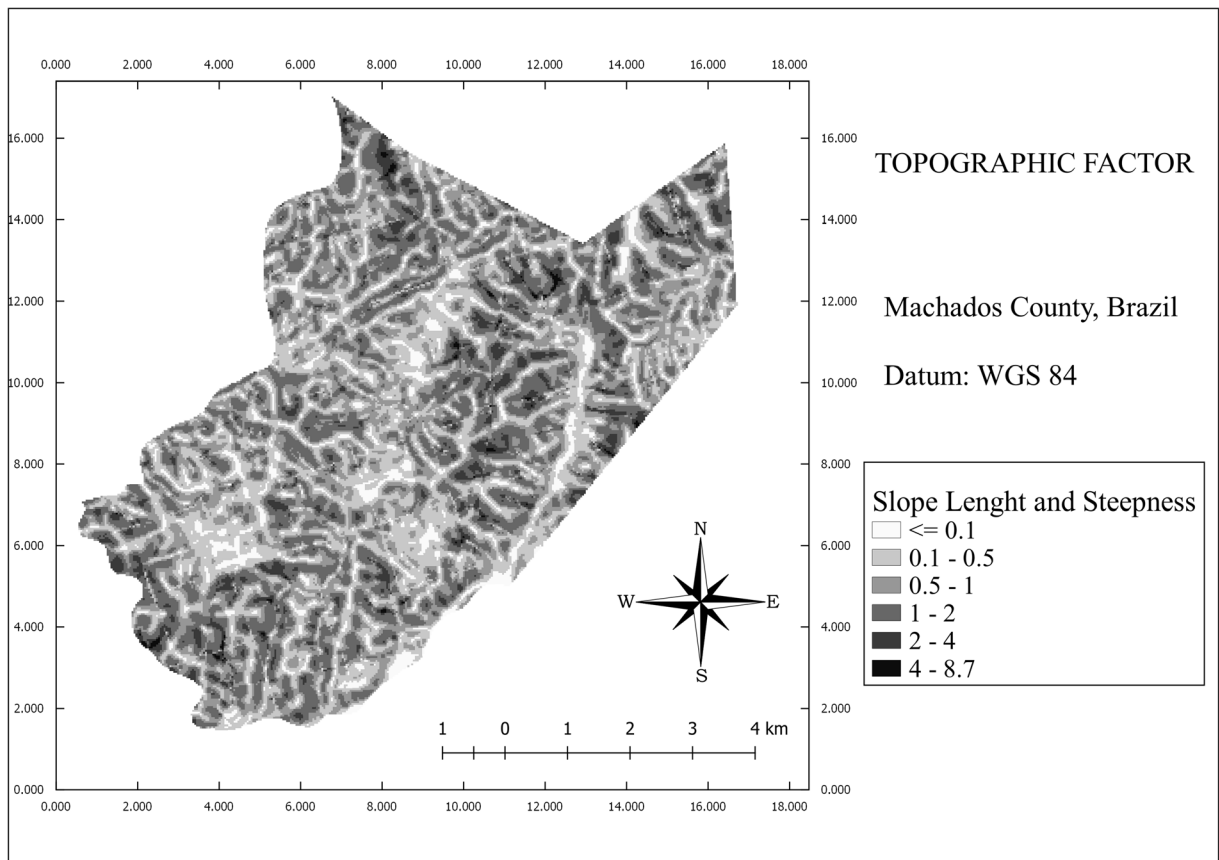


Fig. 5 Topographic factor

Topographic factor (LS)

The DEM data analysis on the study area indicates a strongly wavy relief, with declivities reaching 82.5%. Still, Table 1 allows noticing that the most relevant declivity classes, wavy and strongly wavy, make up for more than 85% of the total area.

Examining the table, one can conclude the class strongly mountainous is almost inexpressive within the county and, for practical purposes, one can consider

Table 2 Topographic factor

T factor	Area (km)	Area (%)
0–0.1	0.443112	0.810
0.1–0.5	5.556405	10.151
0.5–1	7.123782	13.014
1–2	8.655451	15.813
2–4	12.66054	23.129
4–8.7	20.29871	37.083

75% as the highest declivity in the region. The slope map can be observed in Fig. 4.

The topographic factor, obtained through Eq. 4, presented minimum and maximum values of 0 and 8.668, respectively. The average value found was 3.414. Given the higher exponent the expression used gives to slope steepness, it can be theorized that declivity had the strongest influence on the topographic factor spatial variation, reinforced by the correlation between LS and slope maps. The topographic factor map is shown in Fig. 5.

Among the limitations of employing DEM data on slope length and steepness evaluation is the resolution of the elevation data, 30 m on the present paper. Despite the accentuated declivity of the area, the topographic factors found were rather low, probably caused by lower flow accumulation values for the region, given its proximity to the Goiana River Basin limits.

Observing Table 2 allows noticing the LS factor tends to higher values, with more than 60% of the

total area belonging to the two highest classes, relatively matching with the declivity classification, where more than half the county has strongly wavy or mountainous slopes.

Land cover and conservation practices factor (CP)

The land cover factor, representative of the effects of vegetation cover on erosion, is visible in Fig. 6. The lowest results come from hill tops and other highly steep reliefs still covered by native vegetation, as well as water-saturated areas with occurrence of gleysols. Higher soil use factors appear in pasture grasslands and main drainage canals. Banana farms, also widely present in the county, showed average *C* values in comparison. The maximum and minimum results found were 0.4114 and 0.000478, respectively; the mean land cover parameter for the area equaled 0.1409.

Laminar erosion (*E*)

Once obtained all variables, those were integrated using Eq. 1. The map resuming the estimated results is in Fig. 7. With an average value of 8.81 t ha/year, Machado's County can be considered an area with average risk of soil degradation due to laminar erosion. Both land use and the topographic factor had the highest influences on the spatial variation of the results, as one can conclude from observing Fig. 7. The erosion concentrates itself on the south part of the area, where a combination of highly erodible soil, steep relief, and perennial agriculture pushed the soil loss to 40 t ha/year and above. The other two "spots" that concentrate erosion are also on areas of heavy soil exploration and undulating landscape. On the other end of the spectrum, the less erodible regions are also within preserved native vegetation, which subsides the effects of wavy terrain.

As it may be seen in Table 3, more than half of the assessed territory has below moderated annual erosion,

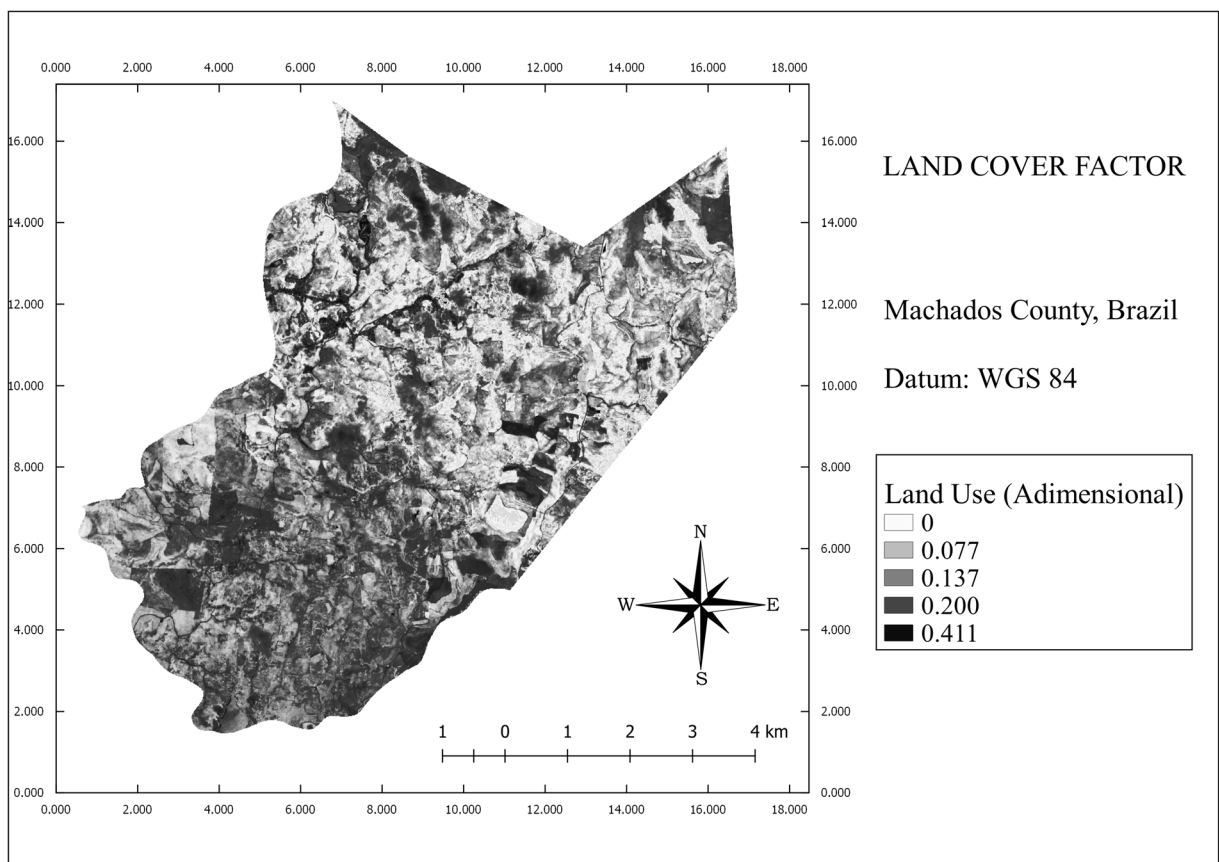


Fig. 6 Land cover factor

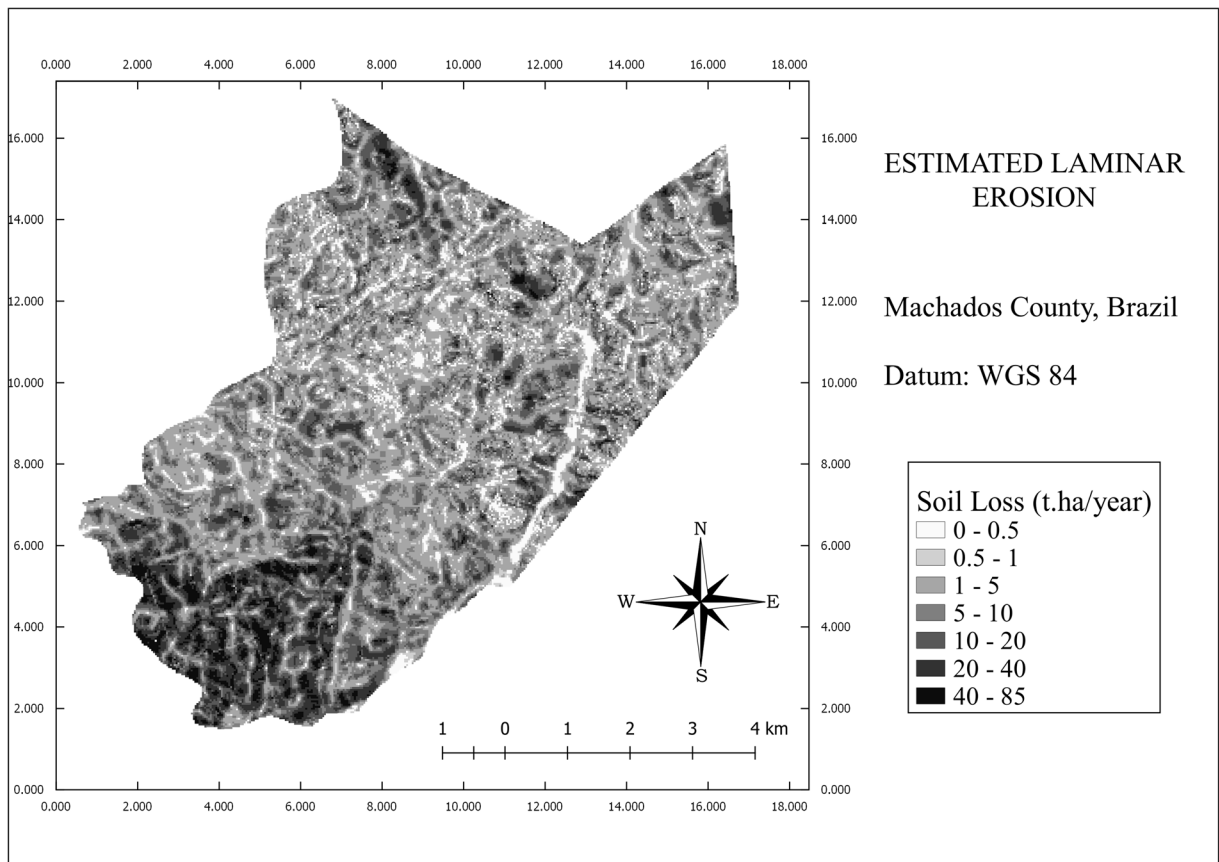


Fig. 7 Sheet erosion

and only 21.55% are considered moderated. The rainfall erosivity factor, of 2747.22 MJ mm/ha h year, is the main reason for the small soil losses, compensating for the elevated topographic and land use indexes. Although the mean results indicate low soil degradation risks, the areas with higher than average estimated sheet erosion, surpassing 20% of the total, must be still taken into consideration, and demand further examinations and the application of conservationist practices.

Table 3 Sheet erosion classes

Erosion class	Erosion (t/ha year)	Area (%)	Area (km)
Extremely low	0–0.5	7.616	4.169
Very low	0.5–1	7.971	4.363
Low	1–5	40.420	22.125
Moderated	5–10	22.441	12.284
High	10–20	14.265	7.808
Very high	20–40	6.043	3.308
Extremely high	>40	1.243	0.681

This study faced several limitations, such as the lack of specified land use and soil erodibility data, the low resolution of DEM data, and the landscape of the analyzed area, which hampered fieldwork. Laboratorial resources also limited the chosen methodology to soil erodibility determination. No less important are the limitations of the USLE model itself, using a mean precipitation erosivity index for example. Even with its limitations, USLE, GIS, and remote Sensing are valuable tools on research and management of land use and its environmental hazards, with growing use on several countries, both on small and large scales.

Conclusions

The present paper solidifies the use of GIS on erosion processes modelling, which allows the application of diverse methodologies on both small and large areas producing georeferenced and easily comparable results.

The orbital images and methodology used to estimate land cover factor proved themselves satisfactory and can be considered an alternative for regions with insufficiently accurate or actualized data.

The obtained erosion, averaging 8.81 t/ha year, areas covered by extremely low, very low, low, moderate, high, very high, and extremely high erosion potential zones are 7.616%, 7.971%, 40.420%, 22.441%, 14.265%, 6.043%, and 1.243%, respectively. Machados County may be considered as averagely susceptible to sheet erosion, despite its highly wavy relief. Temporal variations are not considered by the applied expression, however, and additional conservative measures are needed on periods of higher precipitation and on high-risk classes.

Soil erosion is a rarely considered factor in territorial management in Brazil. Soil preservation is essential to any sustainable development goals, and sheet erosion is one of its biggest threats, making important stimulus and subsidy for their quantification on both small and large scales. Posterior evaluations are still needed for erosion tolerance to obtain a complete portrait of hydric erosion processes within the region, as well as surveys of conservationist practices to adequate cattle farming and agriculture to Machados environmental needs. The results here obtained show that soil degradation is a real risk in northeastern Brazil, corroborating the multiple erosion cases spread throughout the region and raising an alert for the urgency of sheet erosion in Brazilian semiarid.

References

- Banco de Dados Geomorfométricos do Brasil. (2018). *INPE – INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS*. <http://www.dsr.inpe.br/topodata/dados.php>.
- Barrow, C. J. (1991). *Land degradation*. Cambridge: Cambridge University Press.
- Bertoni, J., & Lombardi Neto, F. (2012). *Conservação do Solo* (8th ed.). São Paulo: Ícone Editora.
- Blanco, H., & Lal, R. (2010). *Principles of soil conservation and management* (pp. 15–33). Heidelberg: Columbus, Springer Science Business Media B.V.
- Bouyoucos, G. J. (1935). The clay ratio as a criterion of the susceptibility of soils to erosion. *American Society of Agronomy Journal*, 27, 738–741.
- Cantalice, J. R. B., Bezerra, S. A., Figueira, S. B., Inácio, E., Dos, S. B., Silva, M. D. R., & De, O. (2009). Linhas isoerosivas do estado de Pernambuco - 1ª aproximação. *Revista Caatinga*, 22, 75–80.
- Silva da, A. M. (2004). Rainfall erosivity map for Brazil. *Catena*, 57(3), 251–259.
- Almeida, B. G. De. (2008). *Métodos alternativos de determinação de parâmetros físicos do solo e uso de condicionadores químicos no estudo da qualidade do solo*. Piracicaba, Escola Superior de Agricultura Luiz de Queiroz, Universidade de São Paulo Tese de Doutorado em Solos e Nutrição de Plantas. Accessed 19 Dec 2018.
- Dickinson, A., & Collins, R. (1998). *Predicting erosion and sediment yield at the catchment scale, soil erosion at multiple scales* (pp. 317–342). Wallingford: CAB International.
- Durigon, V. L., Carvalho, D. F., Antunes, M. A. H., Oliveira, P. T. S., & Fernandes, M. M. (2014). NDVI time series for monitoring RUSLE cover management factor in a tropical watershed. *International Journal of Remote Sensing*, 35, 441–453. <https://doi.org/10.1080/01431161.2013.871081>.
- Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA. *Serviço Nacional de Levantamento e Conservação de Solos (Rio de Janeiro, RJ)*. In: Reunião Técnica de Levantamento de Solos, 10., 1979, Rio de Janeiro. Símula... Rio de Janeiro, 1979. 83 p. (EMBRAPA-SNLCS. Miscelânea, 1).
- Freeman, G. T. (1991). Calculating catchment area with divergent flow based on a regular grid. *Computers and Geosciences*, 17, 413–422.
- Grepperud, S. (1945). Soil conservation and government policies in tropical area: does aid worsen the incentives for arresting erosion. *Agricultural Economy*, 12, 120–140.
- Griffin, M. L., Beasley, D. B., Fletcher, J. J., & Foster, G. R. (1988). Estimating soil loss on topographically non-uniform field and farm units. *Journal of Soil and Water Conservation*, 43(4), 326–331.
- Guerra, A. J. T., Fullen, M. A., Jorge, M., & Do, C. O. (2014). Alexandre, S.T. Soil erosion and conservation in Brazil. *Anuário do Instituto de Geociências*, 37, 81–91.
- Iuss Working Group Wrb. (2015). World reference base for soil resources. In *World Soil Resources Reports No 106*. Rome: FAO.
- Jain, M. K. & Kothyari U. C. (2000). Estimation of soil erosion and sediment yield using GIS, *Hydrological Sciences Journal*, 45(5), 771–786
- Mitasova, H., Mitas Z. (1999). *Modeling soil detachment with RUSLE 3D using GIS*. University of Illinois at Urbana – Champaign, IL, USA
- Moore, I. D., & Wilson, J. P. (1992). Length-slope factors for the revised universal soil loss equation: simplified method or estimation. *Journal of Soil and Water Conservation*, 45, 423–428.
- Oliveira, P. T. S., Wendland, E., & Nearing, M. A. (2012). Rainfall erosivity in Brazil: a review. *Catena*, 100, 139–147. Available in: <http://heros.sites.ufms.br/files/2015/08/Rainfall-erosivity-in-Brazil.pdf>. Accessed 24 Nov 2018.
- Peng, W., Zhou, J., He, Z., & Yang, C.-J. (2011). Integrated use of remote sensing and GIS for predicting soil erosion process. *XXI ISPRS Congress*, Beijing, 17, 4, 1647–1651.
- APAC - Agência Pernambucana de Águas e Clima. (2018). *Monitoramento pluviométrico*. <http://www.apac.pe.gov.br/meteorologia/monitoramento-pluvio.php>. Accessed 12 Oct 2018.
- Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., Mcnair, M., Crist, S., Sphritz, L., Fitton, L., Saffouri, R., & And Blair, R. (1995). Environmental and economic costs of

- soil erosion and conservation benefits. *Science*, 276(531S), 1117–1123.
- Prado, R. B., Fidalgo, E. C. C., Monteiro, J. M. G., Schuler, A. E., Vezzani, F. M., Garcia, J. R., de Oliveira, A. P., Viana, J. H. M., Pedreira, B. d. C. C. G., Mendes, I. d. C., Reatto, A., Parron, L. M., Clemente, E. d. P., Donagemma, G. K., Turetta, A. P. D., & Simões, M. (2016). Current overview and potential applications of the soil ecosystem services approach in Brazil. *Pesquisa Agropecuária Brasileira*, 51(9), 1021–1038.
- SISolos. SISTEMA de informação de solos brasileiros: consulta pública. <https://www.sisolos.cnptia.embrapa.br/>. Accessed 13 Jan 2015.
- SiSolos - Sistema de Informação de Solos Brasileiros. EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária, <https://www.sisolos.cnptia.embrapa.br/> (2018).
- Vermote, E. F., Tanré, D., Deuze, J. L., Herman, M., Morcette, J. J. (1997). Second simulation of the satellite signal in the solar spectrum, 6S: an overview. *IEEE Transactions on Geoscience and Remote Sensing*, 35(3), 675–686
- Vieira, R. D. S. P., Tomasella, J., Alvalá, R. C. S., Sestini, M. F., Affonso, A. G., Rodriguez, D. A., De Oliveira, S. B. P., De Souza, M. S. B., Calil, P. M., De Carvalho, M. A., Valeriano, D. M., Campello, F. C. B., & Santana, M. O. (2015). Identifying areas susceptible to desertification in the Brazilian northeast. *Solid Earth*, 6(1), 347–360.
- Wischmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses: a guide to conservation planning*. Washington, D.C: Department of Agriculture (Agriculture handbook, 537). 58p.
- Zhang, Y., Degroote, J., Wolter, C., & Sugumaran, R. (2009). Integration of Modified Universal soil Loss Equation (MUSLE) into a GIS framework to assess soil erosion risk. *Land Degradation and Development*, 20, 84–91.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.