The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2042-5945.htm

Spatial–temporal dynamics of rainfall erosivity in the state of Espírito Santo (Brazil) from remote sensing data

Luana Lavagnoli Moreira
Institute of Hydraulic Research, Federal University of Rio Grande do Sul, Porto Alegre, Brazil
Rafael Rezende Novais
Celulose Nipo Brasileira, Ipatinga, Brazil
Dimaghi Schwamback
Department of Hydraulics and Sanitation, University of São Paulo, São Paulo, Brazil, and
Salomão Martins de Carvalho Júnior
Federal Institute of Education Science and Technology of Espírito Santo, Vitoria, Brazil

Received 13 August 2019
Revised 30 March 2020
Accepted 8 April 2020

Abstract

Purpose – The most common methodology to estimate erosivity is using rainfall data obtained from rain monitoring stations. However, the quality of this estimation may be compromised due to low density, operational problems and maintenance cost of rainfall monitoring stations, common problem encountered in developing countries such as Brazil. The objective of this study was to evaluate the applicability of pluviometric data obtained by TRMM satellite images for the spatiotemporal characterization of erosivity in the state of Espírito Santo (Brazil).

Design/methodology/approach – For this, rainfall data and annual and monthly erosivities of 71 rainfall stations were statistically compared with those from TRMM images.

Findings – For this, rainfall data and annual and monthly erosivities of 71 rainfall stations were statistically compared with those from TRMM images. The estimate proved that TRMM is efficient since the NSE values were higher than 0.70 and the coefficient of determination was higher than 0.77 for monthly and annual erosivities, but in most months and yearly, erosivity was overestimated.

Practical implications – The use of satellite images to estimate rainfall allowed the spatial representation over time (months) of the oscillating degree of erosivity in the state of Espírito Santo (Brazil). The spatialization may provide an identification of areas and periods in which are essential for the implementation of land use management in order to minimize environmental problems related to soil loss.

Originality/value – The technique applied may be an alternative to overcome common problems on rainfall monitoring station, such as low density, low data reliability, high manutention and maintenance cost and operational problems.

Keywords TRMM satellite, Erosion, Precipitation, Geoprocessing techniques

Paper type Technical paper

1. Introduction

In recent decades, the intensification of soil erosion has become a global concern due to the growing population. A bigger population will need more food, grains, energy and space to live, so there will be required more intense agriculture techniques and natural vegetation removal to open new areas (Park *et al.*, 2011; Singh and Panda, 2017). However, a natural process may limit all of this development: water erosion. Even though it is a natural process, water erosion is being potentialized due to anthropic changes in soil cover, which causes soil degradation through the removal of nutrients, organic matter and their detachment particles (Montanarella *et al.*, 2016).

World Journal of Science, Technology and Sustainable Development
Vol. 17 No. 3, 2020
pp. 297-309

2042-5945
DOI 10.1108/WJSTSD-08-2019-0059

Despite the series of uncertainties and discrepant variations involving estimates of soil loss by water erosion on a global scale, FAO and ITPS (2015) indicate values of the order of 20–30 Gt of soil loss due to hydrological processes. This loss not only poses threats to environmental resources and food production but also entails economic losses. In Brazil, several studies have tried to estimate the costs associated with soil degradation, among them, Bertol *et al.* (2007) reached values of 14.83–24.94 dollars per hectare per year in the South region, while Sarcinelli *et al.* (2009) point out a value varying from 28.32 to 72.65 dollars per hectare per year in the Southeast region.

For the state of Espírito Santo, located in the Brazilian Southeast coastal portion, the State Agribusiness Development Center – CEDAGRO (2012) indicates that almost 9% of the state lands have some level of degradation, where organic matter and nutrients were partially removed. In terms of agricultural area, this represents 17% of the total area available to food production, indicating a worrying situation, especially in a state at which agriculture represents the main economic activity (IJSN, 2017).

Considering this, it is evident the urgent importance of identification of areas with high potential susceptibility of soil loss in order to provide information for an effective and adequate land use planning and to ensure the development of soil conservation strategies (Singh and Panda, 2017). Additionally, the development of regional erosivity maps is crucial in the estimation of soil loss due to water erosion as well as the possibility of understanding its spatial variability (Beguería *et al.*, 2018). In recent years, efforts have been made by several international (Liu *et al.*, 2018; Risal *et al.*, 2018; Shin *et al.*, 2019) and Brazilian (Mello *et al.*, 2012, 2013; Oliveira *et al.*, 2013; Back *et al.*, 2018; de Oliveira *et al.*, 2018) authors to spatialize the rainfall erosivity factor at different scales.

Although the importance addressing erosivity, for an adequate estimation it is required a long rainfall record date of at least 20 years, which is an obstacle in developing countries such as Brazil (Sanchez-Moreno *et al.*, 2014) due to a limited number of pluviometric monitoring stations and their high operation and maintenance cost.

In order to overcome the cited limitation earlier, it raises the use of satellite images as a tool for the provision of spatially distributed rainfall estimation applicable to large areas (Teng *et al.*, 2017). Among the database, the Tropical Rainfall Measuring Mission (TRMM) has been widely used in several climatic and hydrological studies (Yang *et al.*, 2017; Li *et al.*, 2018; Fang *et al.*, 2019), such as the special case of input data in erosivity estimation processes (Vrieling *et al.*, 2010; Vrieling *et al.*, 2014; Teng *et al.*, 2017).

From a positive point of view, the TRMM satellite covers a wide range in the globe, bus its data accuracy depends on the algorithm used to convert the radiance emitted by the clouds and raindrops into precipitation, as well as the quality of the data measured *in situ* that are used in the calibration process (Sanchez-Moreno *et al.*, 2014).

Therefore, even though the TRMM satellite data may represent a powerful tool to overcome the existing limited rainfall data, it is important to address the possible differences between rainfall values estimated by remote sensing and those measured at monitoring stations and how it may affect the erosivity factor estimation.

The positive validation (small margin of error compared with the *in situ* data) of the data produced using the TRMM satellite will allow its use in the monitoring of rainfall and the calculation of erosivity, while the opposite will result in the identification of error sources and consequent positive validation. The determination of erosivity for a given area is an important step in the use of physical and empirical models in the mapping and estimation of soil loss in a watershed that aims its planning and sustainable management of soil and water. Once the areas with the greatest susceptibility to erosion have been identified, the implementation of remediation and control techniques occurs with greater efficiency, in addition to pulping public resources due to their better implementation and management.

Considering this, the present paper proposes: (1) comparing annual and monthly rainfall and erosivity obtained through historical series (1998–2017) of rainfall monitoring stations and TRMM satellite images; (2) analyzing statistically the use of TRMM data in the estimation of erosivity; and (3) evaluating the spatial and temporal characterization of rainfall erosivity obtained by remote sensing techniques.

2. Materials and methods

The study is applied to the state of Espírito Santo, located in the coastal Southeast portion of Brazil, covering an area of 46.095 km^2 and altitudes varying from sea level to 2.890 m. According to Köppen–Geiger classification, the state has a tropical climate, which is composed of four subclassifications: Coast (Am and Af), Northwest (Aw), Mountainous (Cfa, Cfb, Cwa, Cwb and Cwc) and South coast (Aw), as presented in Figure 1(a).

Monthly rainfall data series (1998–2017) were obtained by the estimation from TRMM satellite with a spatial resolution of 0.25° × 0.25° (approximately 27 × 27 km). These images were inserted in a geographic information system (GIS) and the monthly and annual rainfall averages were obtained through the Cell Statistics tool available in ArcGIS software version 10.3.

The erosivity values obtained through the precipitation data estimated by the TRMM satellite were evaluated by comparing with the erosivity from rainfall monitoring stations. In order to estimate the erosivity from rainfall data, information from all the rainfall monitoring stations inside the Espírito Santo state, provided by the National Water Agency (ANA) through the Hidroweb website (2018), was collected. Of the total of 359 stations with data available, only 71 (19.8%) were used in this study Figure 1(b), since the rest did not present information about the temporal period analyzed (1998–2017). Afterward, monthly and annual precipitated totals were obtained from each station using the software Hidro version 1.2. Subsequently, the preprocessing of the precipitation data was performed, which consisted of filling the gaps by applying the Regional Weighting Method (Bertoni and Tucci, 2015).

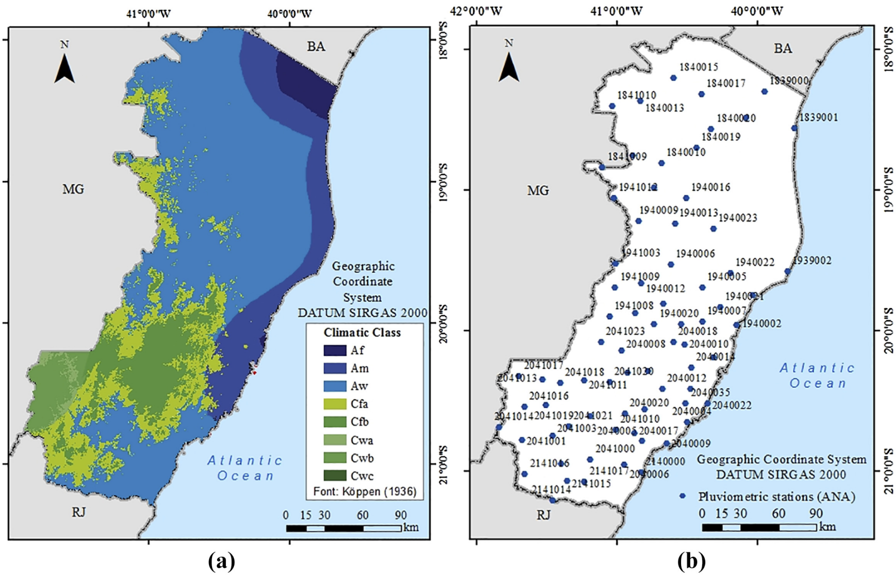

Figure 1.
Kôppen climatic classification in Espírito Santo state (a); rainfall monitoring stations available (b)

Erosivity could be defined as a function of kinetic energy and maximum rainfall intensity in 30 min (Wischmeier, 1959). Thus, the estimation of rainfall erosivity was conducted by applying the Modified Fournier Index (MFI) as proposed by Renard *et al.* (1996) Eqs. (1) and (2), which had its coefficients adjusted according to specific local particularities of areas close to the study area. Thus, the annual erosivity was obtained for each rain event Eq. (3).

$$\mathrm{MFI} = \frac{P_i^2}{P_a} \tag{1}$$

$$\mathrm{El}_{30} = a.\mathrm{MFI}^b ou\ a + b\mathrm{MFI}\ ou\ a + bP \tag{2}$$

$$R = \frac{1}{N}\sum_{j=1}^{N} \mathrm{El}_{30} \tag{3}$$

Where MFI = Modified Fournier Index; P = monthly average rainfall of the month i (mm); Pa = annual average rainfall (mm); El30 = monthly average erosivity (MJ.mm.ha^{-1}.h^{-1}.month^{-1}); a e b = adjustment coefficients; R = annual average erosivity (MJ.mm.ha^{-1}.h^{-1}.year^{-1}); N = number of years of the historical data.

Four regression equations were selected for the estimation of rainfall erosivity, applying the same procedure of Oliveira *et al.* (2013), which did a review of the erosivity equations available in scientific databases in Brazil and applied to estimate the erosivity of the entire country. Among the equations collected, only one is located in the state of Espírito Santo. The other equations were obtained for areas close to the state and that have similar climatic conditions, since this condition is fundamental for the use of this type of equation. Table 1 summarizes the source for each of the equations used. The climatic association was based on the Köppen–Geiger classification, as described previously and presented in Figure 1(a).

From the raster file containing monthly precipitation data for the TRMM satellite, monthly and annual erosivities of each region were estimated from the Raster Calculator tool, executed through ArcGIS 10.3 software. In this way, monthly and annual precipitation and erosivity maps were generated. Finally, the erosivity values were interpreted according to Santos' classification (Table 2).

On the other hand, the rainfall monitoring stations were inserted in a GIS according to its geographical coordinates. Thus, monthly and annual erosivities were estimated according to the location of the station on each of the four influence areas (Figure 2).

In order to validate the estimated erosivity values through rainfall data obtained from the TRMM satellite images, these were compared to the erosivity values calculated from rainfall monitoring stations using the following statistical functions: Nash–Sutcliffe coefficient (NSE); BIAS parameter; coefficient of determination (R^2).

Table 1.
Equations used for the determination of erosivity

Region	Equation	Source	Study area development
Coastal	$\mathrm{EI}_{30} = -40,578 + 7,9075\,(P)$	Martins *et al.* (2010)	Aracruz (ES)
Northwest	$\mathrm{EI}_{30} = 215,4\,(\mathrm{MFI})^{0.65}$	Da Silva *et al.* (2010)	Belo Oriente (MG)
Mountainous	$\mathrm{EI}_{30} = -67,99 + 33,86\,(\mathrm{MFI})$	De Carvalho *et al.* (2005)	Nova Friburgo (RJ)
South coastal	$\mathrm{EI}_{30} = 39,86 + 37,90\,(\mathrm{MFI})$	Gonçalves *et al.* (2006)	Conceição de Macabu (RJ)

Note(s): *UTM SIRGAS 2000 Zone 24S

3. Results and discussion

By comparing precipitation data obtained by satellite and rainfall monitoring stations, the monthly relative differences are preferably in the range of −20% (satellite overestimated the rainfall by 20%) and 10% (satellite estimation underestimated the rainfall estimate by 10%). These values obtained are similar to those from Lelis *et al.* (2018), in which they found relative differences comprised in the interval of −20 to 20% in rainfall data obtained by TRMM and by a rainfall monitoring station in the Eastern region of the state of São Paulo (Brazil). This was also observed by Collischonn (2006), with a range of −15 to 15% in the São Francisco river basin (Brazil). On the other hand, we obtained that annual erosivity had a better result, with a greater part of the relative difference values in the range of −11 to 3% between the results obtained by satellite and pluviometric stations. In Figure 3 is given a boxplot presenting the annual erosivity estimated from rainfall monitoring station and TRMM images data, where it is possible to compare those data according to mean, maximum,

Classification	Erosivity Monthly (MJ.mm.ha^{-1}.h^{-1}.month^{-1})	Yearly (MJ.mm.ha^{-1}.h^{-1}.year^{-1})
Very low	<250	<2,500
Low	250–500	2,500–5,000
Moderate	500–700	5,000–7,000
High	700–1,000	7,000–10,000
Very high	>1,000	>10,000

Table 2. Interpretation key to levels of erosivity according to monthly and yearly classes (Santos, 2008)

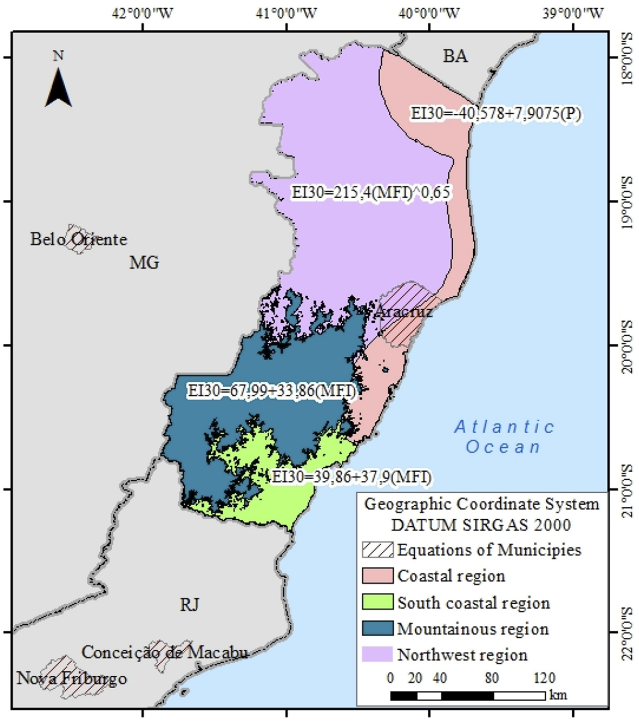

Figure 2. Spatial distribution of the erosivity equation in the state of Espírito Santo

minimum and median data. Additionally, Figure 4 presents the same information but on a monthly time lapse.

From Figure 5, we have a suitable correlation between the annual erosivity values from satellite and rainfall monitoring station data since we obtained an 86.8% of linear adjustment.

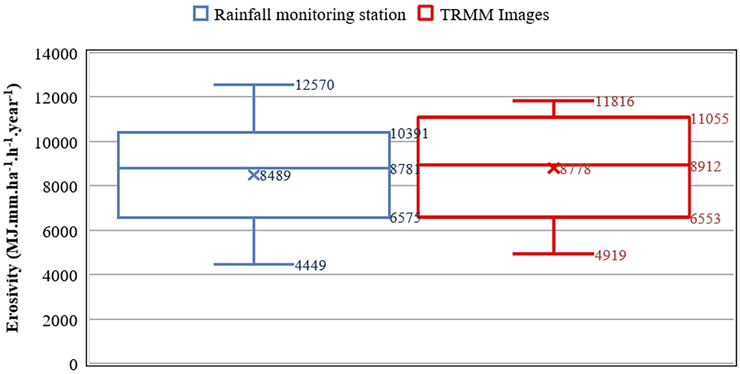

Figure 3.
Annual erosivity estimated from rainfall monitoring station and TRMM images data

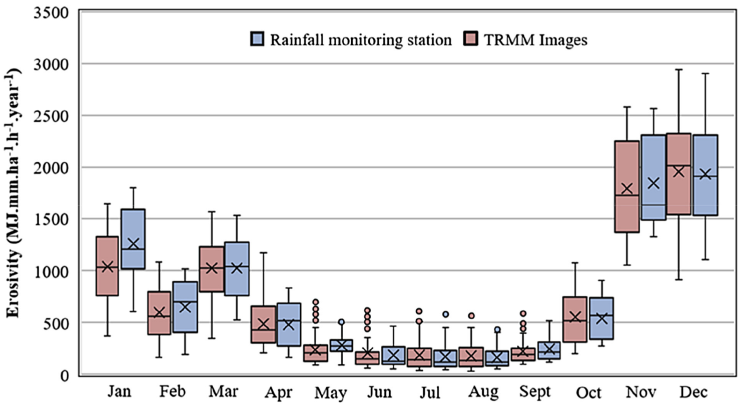

Figure 4.
Monthly erosivity estimated from rainfall monitoring station and TRMM images data

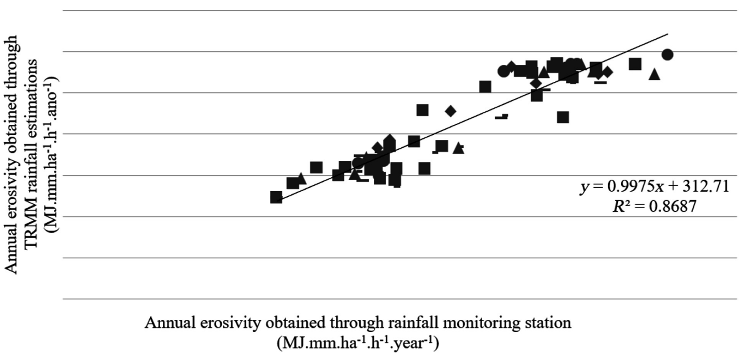

Figure 5.
Comparison between annual erosivity obtained from TRMM satellite images and rainfall monitoring stations

Table 3. Monthly statistical coefficients between erosivity from satellite and monitoring station

Month	NSE	Statistical function BIAS	R^2
January	0.28	1.21	0.87
February	0.82	1.08	0.93
March	0.67	1.00	0.85
April	0.66	0.99	0.83
May	0.51	1.16	0.77
June	0.76	0.89	0.91
July	0.81	0.91	0.91
August	0.75	0.91	0.89
September	0.73	1.11	0.90
October	0.85	0.98	0.93
November	0.79	1.03	0.89
December	0.64	0.99	0.81
Annual	0.83	1.03	0.93

From the statistical metrics presented in Table 3, it can be seen that the erosivity estimation from rainfall station and TRMM satellite image was efficient about the NSE values for most months, with values greater than 0.70, with emphasis on the annual erosivity (0.83). However, we did not have a satisfactory correlation for January (NSE = 0.28).

Regarding the BIAS parameter, the satellite erosivity was underestimated in April, June, July, August, October and December, while on the rest of the months, data were overestimated. It is important to note, however, that the values of the BIAS parameter were usually close to the optimal (equal to 1), suggesting a good appropriation of the estimation. The BIAS values ranged from 0.89 to 1.21, similar to those found in the Soares *et al.* (2016) studies in the state of Paraíba and Oliveira *et al.* (2014) in the Brazilian Cerrado region, where both applied TRMM images.

The coefficient of determination varied between 0.77 and 0.93 indicating that the monthly erosivity estimation from the satellite was consistent. Even though July had the worst correlation (0.77), the months of February, June, July and October had a great correlation in a way the annual correlation is considered very high according to Hinkle *et al.* (2003). In the other months, the correlation is considered high.

Since this estimation was considered statistically adequate, the use of rainfall data obtained from the TRMM satellite image to estimate erosivity in the state of Espírito Santo has proved to be effective. Thus, frequent problems of rainfall monitoring station data needed for erosivity estimation, such as spatial–temporal variability of rainfall, low density and operational problems (Soares *et al.*, 2016), can be overcome by using the remote sensing database available to the whole world. Once we spatialize the erosivity, it is a possible indication of areas where conservation practices on soil and land cover are necessary to avoid soil loss due to water erosion. Furthermore, governments with limited financial resources may apply their investments in areas that are under greater environmental fragility.

Figure 6 shows the spatial distributions of annual erosivity and precipitation in the state of Espírito Santo from TRMM satellite image data between 1998 and 2017. Additionally, Figure 5 shows the same information while considering a monthly time lapse.

As observed in Figure 6, high precipitation (greater than 1,400 mm) was recorded in the southwest portion of the state, where the mountain region of Caparaó is located. The high incidence of rainfalls is mainly due to the rugged topographic area with altitudes higher than 2000 m, which promote the orographic precipitation phenomena. Through Figure 7, it is possible to notice that in this same region the maximum monthly precipitations of the state (>250 mm) occur in January, November and December, which comprise the rainy season. The

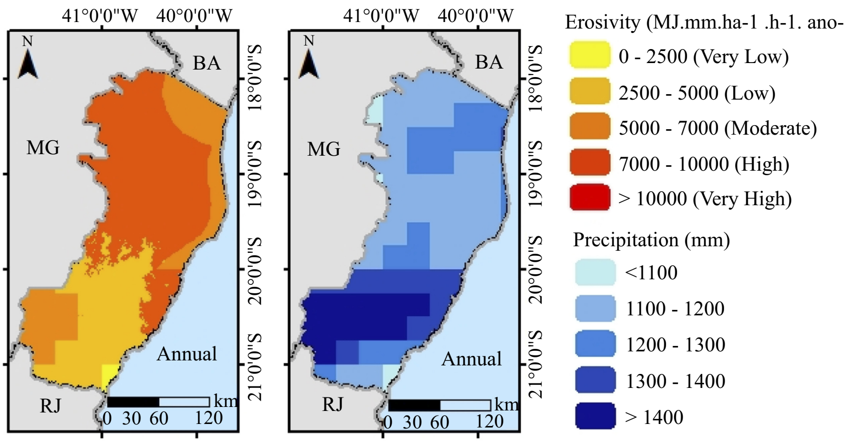

Figure 6.
Spatial distribution of annual erosivity and precipitation in the state of Espírito Santo

minimum monthly precipitation (<50 mm) occurs on dry months (May, June, July and August) in the state central region, where there is a lower interference of the sea humidity. The monthly precipitations obtained corroborate the climatic classification of Koppen for this region that is characterized by dry winter and rainy summer.

The lowest annual and monthly rainfall measurements were recorded in the northern region of the state. In this region, annual mean precipitation values were less than 1,200 mm, and monthly averages were less than 100 mm in most of the months, except March, November and December.

In terms of annual erosivity, the state Northwestern region has the highest values, ranging from 5,000 to 7,000 MJ.ha^{-1}.mm.h^{-1}.ano^{-1}, classified as a region with high erosive potential by applying the key interpretation of Santos (2008). Similar results were obtained by Mello *et al.* (2012), which mapped erosivity in the state of Espírito Santo through rain gauge data. The most intense erosivity potential (high and very high potential) occurs in the rainy season months (January, February, March, November and December) where there are intense rainstorms. These intense events are characterized by convective rainfall, typical of tropical regions, which present high intensity and short duration. Heavy rains during the summer and spring in the Southeast region of Brazil are also related to the activity of the South Atlantic Convergence Zone (SACZ). SACZ is a large and prolonged convergence zone of moisture fluxes extended from the Amazon region to the Brazilian Southeast region resulted from the interaction of the circulation of several meteorological systems: cold fronts on the Southeast coast, Upper Tropospheric Cyclonic Vortices in the Northeast and the Bolivian anticyclonic circulation (Cavalcanti, 2012).

As a result of intense and recurrent action of the SACZ, in November and December, the erosive potential is classified as very high (>1,000 MJ.ha^{-1}.mm.h^{-1}.m^{-1}). In January, February and March are areas of very high erosive potential, mainly in the northwest and coastal regions, explained by the high concentration of sea humidity and high temperatures in this period, causing the formation of convective rainfall.

In the Caparaó region (Southwestern state portion), the annual and monthly erosivities were lower than those from the northwest region, although annual and monthly precipitation totals were higher. Annual erosivity was classified as moderate. According to Mello *et al.* (2012), this fact may be related to more distributed rainfall over the year. On dry months, the altitude promotes orographic precipitation and on rainy months, the milder temperatures decrease the saturation pressure of water vapor and thus reduce intense convective events.

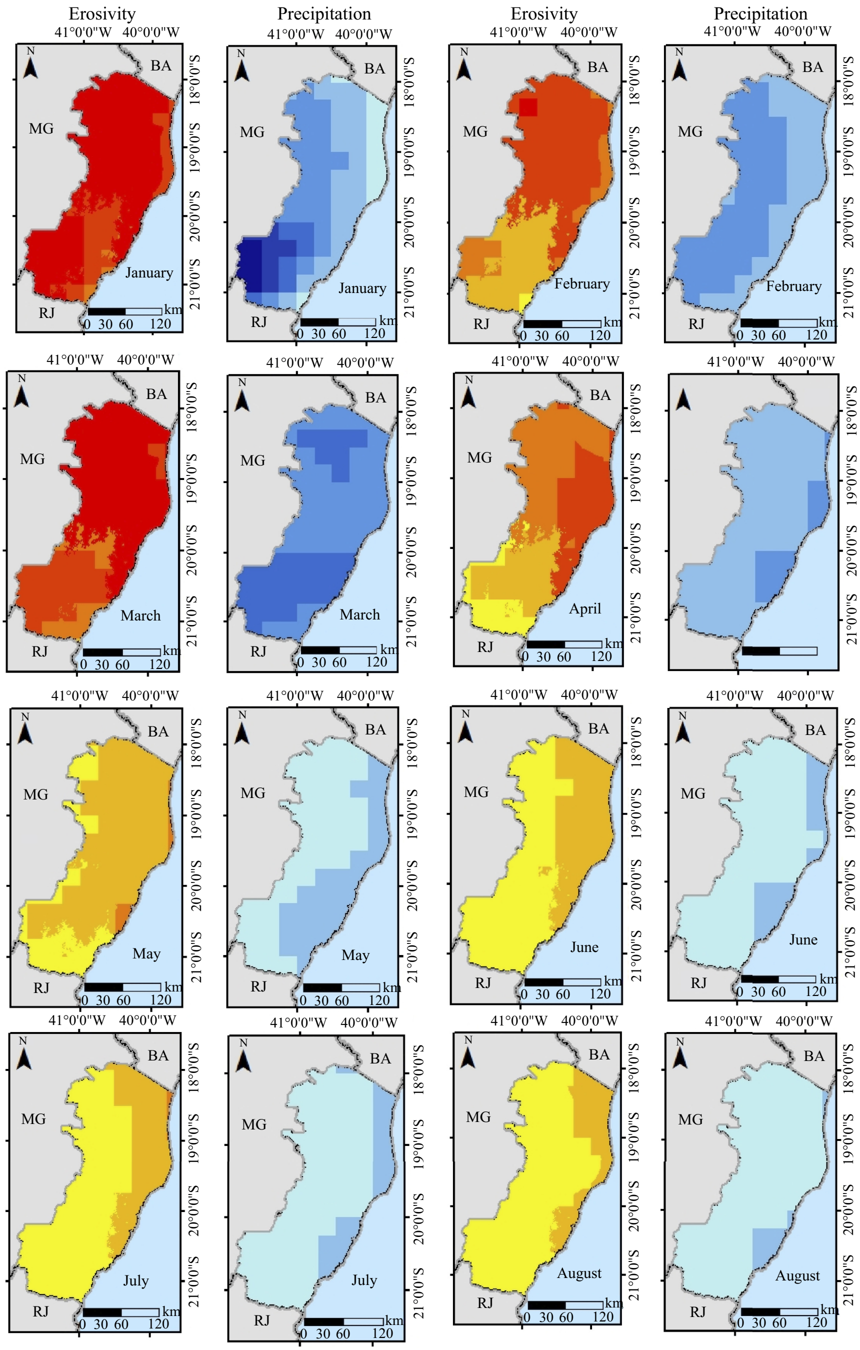

Figure 7.
Spatial distribution of monthly erosivity and precipitation in the state of Espírito Santo

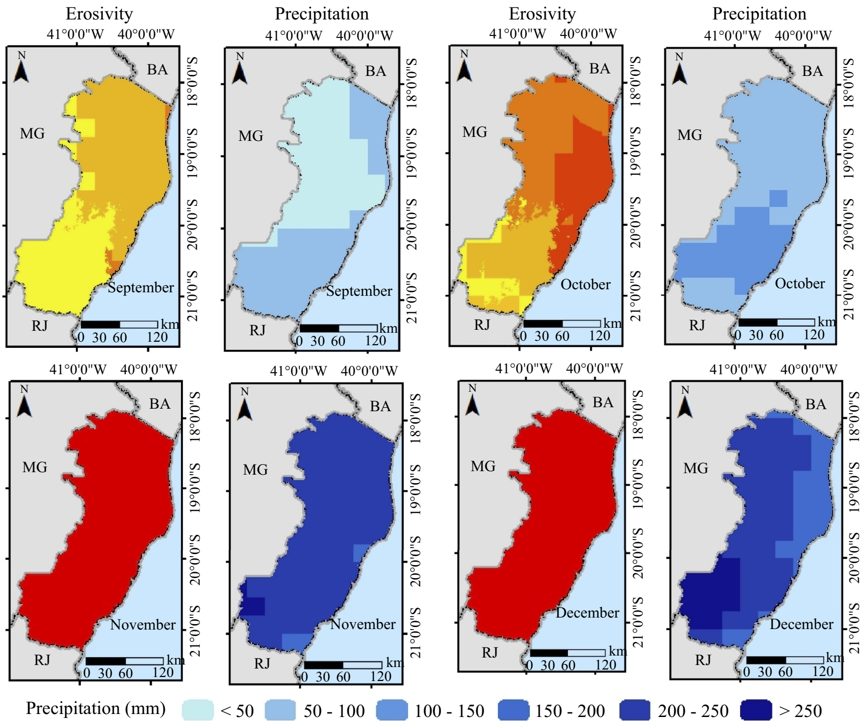

Figure 7.

Following the lowest annual rainfall estimation, the southern coastal region also has the lowest erosivity, classified as low erosive potential. A similar result was found in the southern coastal region, ranging from 4.142 to 5.432 MJ.ha^{-1}.mm.h^{-1}.ano^{-1}, also categorized as low erosivity.

The spatial and temporal variation of rainfall erosivity is crucial for numerous applications and investigations, such as erosion, landslide risk, agricultural management and soil conservation practices (Meusburger *et al.*, 2012), erosion being the most common. The annual erosivity spatialization helps in the identification of areas with higher erosion susceptibility that require immediate soil conservation practices to control erosion. Additionally, the monthly rainfall discrimination allows fulfilling of existing gaps in the rainfall monitoring and identification of the period where rainfall and erosion are more likely to occur.

4. Conclusion

The estimation of monthly and annual erosivities for the state of Espírito Santo using rainfall data obtained from the TRMM satellite was statistically adequate while compared to the one from rain gauge stations. Thus, the technique applied may be an alternative to overcome common problems in rainfall monitoring stations, such as low density, low data reliability, high manutention and maintenance cost and operational problems.

Finally, the use of satellite images to estimate rainfall allowed the spatial representation over time (months) of the oscillating degree of erosivity in the state of Espírito Santo (Brazil). The spatialization may provide an identification of areas and periods in which essential for the implementation of land use management in order to minimize environmental problems related to soil loss.

References

Back, Á.J., Alberton, J.V. and Poleto, C. (2018), "Erosivity index and characteristics of erosive rainfall from the far western region of Santa Catarina, Brazil", *Journal of Environmental Engineering*, Vol. 144 No. 7, p. 04018049, doi: 10.1061/(asce)ee.1943-7870.0001388.

Beguería, S., Serrano-Notivoli, R. and Tomas-Burguera, M. (2018), "Computation of rainfall erosivity from daily precipitation amounts", *The Science of the Total Environment*, Elsevier B.V., Vol. 637-638, pp. 359-373, doi: 10.1016/j.scitotenv.2018.04.400.

Bertol, I., Cogo, N.P., Schick, J.J., Gudagnin, J.C. and Amaral, A.J. (2007), "Aspectos financeiros relacionados às perdas de nutrientes por erosão hídrica em diferentes sistemas de manejo do solo", *Revista Brasileira de Ciência do Solo*, Vol. 31 No. 1, pp. 133-142.

Bertoni, J.C. and Tucci, C.E.M. (2015), "Precipitação", *Hidrologia: Ciência e aplicação*, 4th ed., ABRH, Porto Alegre, pp. 177-241.

Cavalcanti, I.F.A. (2012), "Large scale and synoptic features associated with extreme precipitation over South America: a review and case studies for the first decade of the 21st century", *Atmospheric Research*, Elsevier B.V., Vol. 118, pp. 27-40, doi: 10.1016/j.atmosres.2012.06.012.

CEDAGRO (2012), "Levantamento de áreas agrícolas degradadas no estado do Espírito Santo", Vitória, available at: http://www.cedagro.org.br/artigos/20121101104240_areas_Degradadas_Documento_Completo.pdf.

Collischonn, B. (2006), *Uso de precipitação estimada pelo satélite TRMM em modelo hidrológico distribuído*, Master thesis, University of Rio Grande do Sul, Porto Alegre.

Da Silva, M.A., Silva, M.L.N., Curi, N., Dos Santos, G.R., Marques, J.J.G.S.M., Menezes, M.D. and Leite, F.P. (2010), "Avaliação e espacialização da erosividade da chuva no Vale do Rio Doce, Região Centro-Leste do estado de Minas Geraus", *Revista Brasileira de Ciencia do Solo*, Vol. 34, pp. 1029-1039.

De Carvalho, D.F., Montebeller, C.A., Franco, E.M., Valcarcel, R. and Bertol, I. (2005), "Padrões de precipitação e índices de erosividade para as chuvas de Seropédica e Nova Friburgo, RJ", *Revista Brasileira de Engenharia Agrícola e Ambiental*, Vol. 9 No. 1, pp. 7-14. available at: http://www.scielo.br/pdf/rbeaa/v9n1/v9n1a02.pdf%5Cnhttp://www.scielo.br/scielo.php?script=sci_arttext&pid=S1415-43662005000100002&lng=en&nrm=iso.

de Oliveira, J.P.B., Cacíleo, R.A., Pruski, F.F., Zanetti, S.S. and Moreira, M.C. (2018), "Assessing the use of rainfall synthetic series to estimate rainfall erosivity in Brazil", *Catena*, Elsevier, Vol. 171, pp. 327-336, doi: 10.1016/j.catena.2018.07.031.

Fang, J., Yang, W., Luan, Y., Du, J., Lin, A. and Zhao, L. (2019), "Evaluation of the TRMM 3B42 and GPM IMERG products for extreme precipitation analysis over China", *Atmospheric Research*, Elsevier, Vol. 223, pp. 24-38, doi: 10.1016/j.atmosres.2019.03.001.

FAO and ITPS (2015), *Status of the World's Soil Resources (SWSR) - Main Report*, Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils Rome.

Gonçalves, F.A., Silva, D.D., Pruski, F.F., Carvalho, D. and Cruz, E. (2006), "Índices e espacialização da erosividade das chuvas para o Estado do Rio de Janeiro", *Revista Brasileira de Engenharia Agricola e Ambiental*, Vol. 10 No. 2, pp. 269-276.

Hinkle, D.E., Wiersma, W. and Jurs, S.G. (2003), *Applied Statistics for the Behavioral Sciences*, Houghton Mifflin, Boston, MA.

IJSN (2017), "Gross domestic product (GDP) of municipalities - 2017", available at: http://www.ijsn.es.gov.br/assuntos/pib-municipal (accessed 30 June 2018).

Lelis, L.C.S., Bosquilia, R.W.D. and Duarte, S.N. (2018), "Assessment of precipitation data generated by GPM and TRMM satellites", *Revista Brasileira de Meteorologia*, Vol. 33 No. 1, pp. 153-163, doi: 10.1590/0102-7786331004.

Li, D., Christakos, G., Ding, X. and Wu, J. (2018), "Adequacy of TRMM satellite rainfall data in driving the SWAT modeling of Tiaoxi catchment (Taihu lake basin, China)", *Journal of Hydrology*, Elsevier B.V., Vol. 556, pp. 1139-1152, doi: 10.1016/j.jhydrol.2017.01.006.

Liu, D., Li, Y., Shen, X., Xie, Y. and Zhang, Y. (2018), "Flood risk perception of rural households in western mountainous regions of Henan Province, China", *International Journal of Disaster Risk Reduction*, Elsevier, Vol. 27 No. 2001, pp. 155-160, doi: 10.1016/j.ijdrr.2017.09.051.

Martins, S.G., Avanzi, J.C., Silva, M.K.N., Curi, N., Norton, L.D. and Fonseca, S. (2010), "Rainfall erosivity and rainfall return period in the experimental watershed of Aracruz, in the coastal plain of Espirito Santo, Brazil", *Revista Brasileira de Ciencia do Solo*, Vol. 34, pp. 999-1004, doi: 10.1590/S0100-06832010000300042.

Mello, C.R.D., Viola, M.R., Curi, N. and Silva, A.M. (2012), "Distribuição espacial da precipitação e erosividade mensal e anual da chuva no Estado do Espírito Santo", *Revista Brasileira de Ciencia do Solo*, Vol. 36, pp. 1878-1891, doi: 10.1590/S0100-204X2007000400012.

Mello, C.R., Viola, M.R., Beskow, S. and Norton, L.D. (2013), "Multivariate models for annual rainfall erosivity in Brazil", *Geoderma*, Elsevier B.V., Vol. 202-203, pp. 88-102, doi: 10.1016/j.geoderma.2013.03.009.

Meusburger, K., Steel, A., Panagos, P., Montanarella, L. and Alewell, C. (2012), "Spatial and temporal variability of rainfall erosivity factor for Switzerland", *Hydrology and Earth System Sciences*, Vol. 16, pp. 167-177, doi: 10.5194/hess-16-167-2012.

Montanarella, L., Montanarella, L., Pennock, D.J., McKenzie, N., Badraoui, M., Chude, V., Baptista, I., Mamo, T., Yemefack, M., Singh Aulakh, M., Yagi, K., Young Hong, S., Vijarnsorn, P., Zhang, G.-L., Arrouays, D., Black, H., Krasilnikov, P., Sobocká, J., Alegre, J., Henriquez, C.R., de Lourdes Mendonça-Santos, M., Taboada, M., Espinosa-Victoria, D., AlShankiti, A., AlaviPanah, S.K., Elsheikh, E.A.E.M., Hempel, J., Camps Arbestain, M., Nachtergaele, F. and Vargas, R. (2016), "'World's soils are under threat", *Soil*, Vol. 2 No. 1, pp. 79-82, doi: 10.5194/soil-2-79-2016.

Oliveira, P.T.S., Wendland, E. and Nearing, M.A. (2013), "Rainfall erosivity in Brazil: a review", *Catena*, Elsevier B.V., Vol. 100, pp. 139-147, doi: 10.1016/j.catena.2012.08.006.

Oliveira, P.T.S., Nearing, M., Moran, M.S., Goodrich, D.C., Wendland, E. and Gupta, H. (2014), "Trends in water balance components across the Brazilian Cerrado", *Water Resources Research*, Vol. 50, pp. 7100-7114, doi: 10.1002/2013WR015202.

Park, S., Oh, C., Jeon, S., Jung, H. and Choi, C. (2011), "Soil erosion risk in Korean watersheds, assessed using the revised universal soil loss equation", *Journal of Hydrology*, Vol. 399 Nos 3-4, pp. 263-273, doi: 10.1016/j.jhydrol.2011.01.004.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. (1996), *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (Rusle)*.

Risal, A., Lim, K.J., Yang, J.E., Noh, H., Pathak, R. and Kim, J. (2018), "Development of web-based WERM-S module for estimating spatially distributed rainfall erosivity index (EI30) using RADAR rainfall data", *Catena*, Elsevier, Vol. 161, pp. 37-49, doi: 10.1016/j.catena.2017.10.015.

Sanchez-Moreno, J.F., Mannaerts, C.M. and Jetten, V. (2014), "Applicability of satellite rainfall estimates for erosion studies in small offshore areas: a case study in Cape Verde Islands", *Catena*, Elsevier B.V., Vol. 121, pp. 365-374, doi: 10.1016/j.catena.2014.05.029.

Santos, C.N. (2008), *El Niño, La Niña e a erosividade das chuvas no Estado do Rio Grande do Sul*, Federal University of Pelotas, Pelotas.

Sarcinelli, O., Marques, J.F. and Romeiro, A.R. (2009), "Custos e benefícios da adoção de práticas e medidas para conservação do solo agrícola: um estudo de caso na microbacia hidrográfica do córrego Oriçanguinha", *Informações Economicas*, Vol. 39 No. 4, pp. 1-12.

Shin, J.Y., Kim, T., Heo, J.H. and Lee, J.H. (2019), "Spatial and temporal variations in rainfall erosivity and erosivity density in South Korea", *Catena*, Elsevier, Vol. 176, pp. 125-144, doi: 10.1016/j.catena.2019.01.005.

Singh, G. and Panda, R.K. (2017), "Grid-cell based assessment of soil erosion potential for identification of critical erosion prone areas using USLE, GIS and remote sensing: a case study in the Kapgari watershed, India", *International Soil and Water Conservation Research*, Elsevier B.V., Vol. 5 No. 3, pp. 202-211, doi: 10.1016/j.iswcr.2017.05.006.

Soares, A., Paz, A. and Piccilli, D. (2016), "Avaliação das estimativas de chuva do satélite TRMM no Estado da Paraíba", *Revista Brasileira de Recursos Hídricos*, Vol. 21 No. 2, pp. 288-299, doi: 10.21168/rbrh.v21n2.p288-299.

Teng, H., *et al.* (2017), "Improving rainfall erosivity estimates using merged TRMM and gauge data", *Remote Sensing*, Vol. 9 No. 11, doi: 10.3390/rs9111134.

Vrieling, A., Sterk, G. and de Jong, S.M. (2010), "Satellite-based estimation of rainfall erosivity for Africa", *Journal of Hydrology*, Elsevier B.V., Vol. 395 Nos 3-4, pp. 235-241, doi: 10.1016/j.jhydrol.2010.10.035.

Vrieling, A., Hoedjes, J.C.B. and van der Velde, M. (2014), "Towards large-scale monitoring of soil erosion in Africa: accounting for the dynamics of rainfall erosivity", *Global and Planetary Change*, Elsevier B.V., Vol. 115, pp. 33-43, doi: 10.1016/j.gloplacha.2014.01.009.

Wischmeier, W.H. (1959), "A rainfall erosion index for a universal soil-loss equation", *Soil Science Society of America Journal*, Vol. 23, pp. 246-249, doi: 10.2136/sssaj1959.03615995002300030027x.

Yang, N., Zhang, K., Hong, Y., Zhao, Q., Huang, Q., Xu, Q., Xue, X. and Chen, S. (2017), "Evaluation of the TRMM multisatellite precipitation analysis and its applicability in supporting reservoir operation and water resources management in Hanjiang basin, China", *Journal of Hydrology*, Elsevier B.V., Vol. 549, pp. 313-325, doi: 10.1016/j.jhydrol.2017.04.006.

Corresponding author
Luana Lavagnoli Moreira can be contacted at: lavagnoliluana@gmail.com