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Papers

Spatial distribution of rainfall erosivity in the manuel alves da natividade river basin, state of tocantins, Brazil

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Hydrology.
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Abstract
The objective of this work is to calculate the values of erosivity and map the monthly and annual rainfall erosivity in the Manuel Alves da Natividade river basin in the southeastern region of the state of Tocantins, Brazil, based on ordinary kriging (KO) interpolator and the performance evaluation of the spherical, exponential and Gaussian models using rainfall data for the period 1983-2013. Geostatistics was applied to map erosivity on both monthly and annual scales. The annual erosivity showed values between 8,332 and 9,253 MJ mm ha^{-1} h^{-1} $year^{-1}$, with a peak in December, when it reached values of up to 2,170 MJ mm ha^{-1} h^{-1} $year^{-1}$ per month. From May to September, erosivity presented values lower than critical, considered as 500 MJ mm ha^{-1} h^{-1} $year^{-1}$ per month. Three critical regions were identified for planning actions aiming soil and water conservation: the northwest, the north and the central area of the Manuel Alves da Natividade river basin.

INTRODUCTION

The erosivity index (EI) expresses the erosive potential of rainfalls (WISCHMEIER, 1958). According to Hickmann et al. (2008), the potential capacity of rainfalls to cause erosion can be defined as erosivity expressed through this index. Also according to these authors, irreversible damage to the soil and reduction in crop yields occur because of erosion, which is

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why water erosion control programs are necessary for a stable agricultural practice.

According to Viola et al. (2014), the knowledge of erosivity in space and time is fundamental for the planning of soil and water management and conservation practices that aim to minimize the adverse effects of water erosion. In this sense, the determination of the values of erosivity throughout the year allows identifying the months on which the risks of soil loss are the highest, which is why it plays an important role in planning conservation practices based on soil maximum cover in critical seasons of greater erosive capacity of rainfalls (WISCHMEIER; SMITH, 1978; BERTONI; LOMBARDI NETO, 1993).

The expansion of the agricultural frontier in the state of Tocantins, Brazil, reflects the growing demand for agricultural commodities. With the continuous development of production techniques, the state has been increasing its agricultural area. Thus, concerning soil management and conservation, the type of crop must be considered, but it is also of great importance to understand the soil structure aiming productive efficiency, which involves the interpretation of data related to the intensity and the frequency of rainfalls (SILVA NETO et al., 2015).

Silva (2004) stated that erosion maps can be useful for environmentalists and agronomists to obtain knowledge about the erosivity potential of rainfalls in certain locations to implement the necessary precautions to minimize soil erosion in these areas.

Studies on rain erosivity were developed by Viola et al. (2014) for the state of Tocantins and by Silva Neto (2015) for the city of Taguatinga, in the southeastern region of the state. Considering the national scope, Oliveira et al. (2015) carried out studies with the objective of spatializing the erosivity of rainfalls in Brazil using synthetic rainfall series. That work was carried out for the national territory using data from 142 pluviographic stations. For several regions of Brazil, the erosive potential of rainfalls has been extensively studied: Morais et al. (1991) for the southwest of Mato Grosso, Lombardi Neto and Moldenhauer (1992) for the city of Campinas (state of São Paulo), Silva et al. (1997) for the Goiânia region, Mello et al. (2007) and Silva et al. (2010) for the state of Minas Gerais, and Cassol et al. (2008) for São Borja in Rio Grande do Sul state.

At the international level, rainfall erosivity is an important object of study. Haas et al. (2018), in studies carried out to model climatic conditions and erosivity rates in the northern Black Forest, Germany, stated that stable forest ecosystems are not prone to soil loss. In addition, rainfall erosivity is low and practices that promote erosion, such as cuts, are rare. However, from a climate change perspective, the authors claimed that an increase in extreme weather phenomena is expected. For example, in the southwest of Germany, the occurrence of strong storms during the winter is expected.

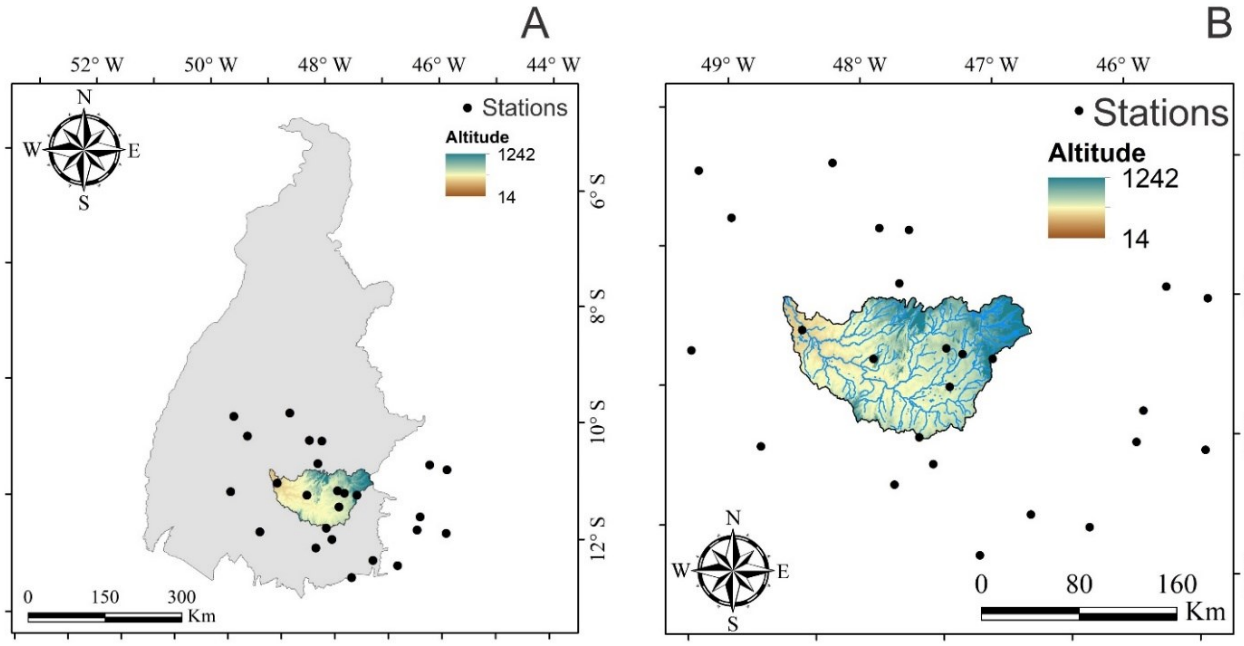
Vrieling et al. (2010) claimed that, in Africa, human-induced soil erosion results from an increasing pressure on natural resources, leading to more intensive land use (for example, through land use changes), a reality that is similar as to what occurred in the Brazilian Cerrado after the expansion of the agricultural frontier.

Considering the importance of rainfall erosivity regarding soil loss, especially in very degraded areas with a high concentration of rainfalls, the objective of this work is to calculate the values of erosivity and map the monthly and annual rainfall erosivity in the Manuel Alves da Natividade river basin in the southeastern region of the state of Tocantins, Brazil, based on ordinary kriging (KO) interpolator and the performance evaluation of the spherical, exponential and Gaussian models using rainfall data for the period 1983-2013.

The Manuel Alves da Natividade river basin belongs to the Tocantins River hydrographic system (right bank), with a drainage area of 14,934.93 km² covering eleven municipalities and an area of approximately 22,576 km² (Figure 1). It is of great importance for the state of Tocantins, as it is located within the Manuel Alves Project, in the southeast region, one of the major irrigation projects in the country because of the size of its water reservoir and the extension of the irrigable area by micro-sprinkling, conventional dripping and sprinkling. Pineapple, banana, coconut, papaya, passion fruit and watermelon are cultivated there, in addition to cassava, corn, tomatoes, cabutiá pumpkin, sugar cane, guava, and peach palm (SEPLAN, 2012).

MATERIAL AND METHODS

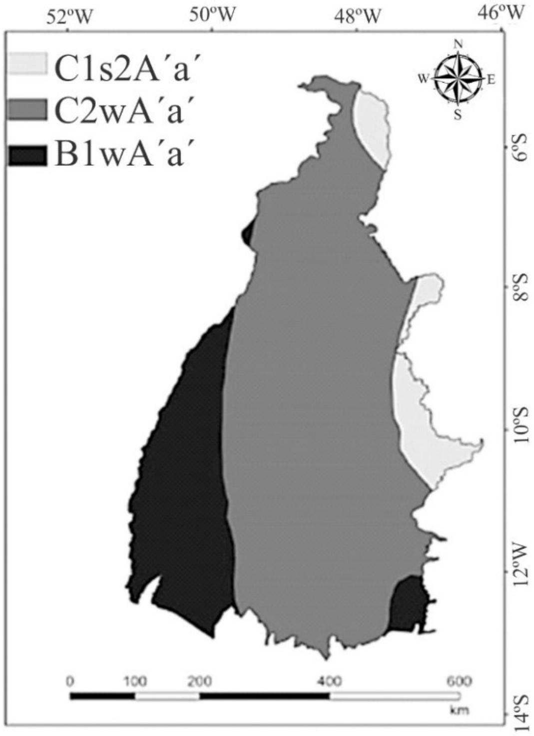
Figure 1. Location of the Manuel Alves da Natividade river basin (A) and distribution of the stations used to map rainfall erosivity in ASTER digital elevation model (B).



Source: Adapted from INPE, 2016. Org.: Author, 2018.

According to Souza (2019), there are three homogeneous climatic regions in the state of Tocantins (Figure 2), namely a) the climatic region C1s2A'a': dry sub-humid climate, with a high concentration of rainfalls in the summer, megathermic; b) climate region C2wA'a': sub-humid climate, with a moderate water deficiency in the winter, megathermic; and c) climate region B1wA'a': humid climate, with a moderate water deficiency in the winter, megathermic. The Manuel Alves river basin area comprises the C2wA'a' climate region.

Figure 2. Climatic classification of Thornthwaite and Matter for the state of Tocantins



Source: Souza et al. (2019). Org.: Author, 2018.

In this study, data obtained from the Hydrological Information System (HidroWEB) of the National Water Agency (ANA), a federal agency responsible for implementing water resource management in Brazil, were used. Twenty-five pluviometric stations were selected in the area of the basin and its surroundings, thus obtaining historical series with monitoring in an average period of thirty years (between 1983 and 2013).

To calculate the erosivity of rainfalls in a location, it is recommended that the average value of the erosion index be estimated for a period of at least twenty years (HICKMANN et al., 2008). The Wischmeier and Smith (1958) equation, which is considered a reference for these studies, tends to underestimate the erosivity of rainfalls in tropical regions.

The rainfall erosivity, called Factor "R" or EI30 erosivity index, numerically represents the erosive force in MJ mm ha^{-1} h^{-1} $year^{-1}$ as a unit of measurement; it is obtained by the multiplying kinetic energy (KE), expressing the rainfall hitting the ground, by the maximum intensity verified in 30 minutes, according to Equation 1.

$$Ei_{30} = Ec.I_{30min} \quad (1)$$

The explanatory variable for calculating the index EI_{30} was the Fournier index (Rc). In determining rainfall erosivity, Equation 2 was used as determined by Silva et al. (1997) defined by:

$$Ei_{30} = 216.15 + 30.762 \times Rc \quad (2)$$

Where (EI30) is the erosivity of rainfalls for each month (MJ mm ha^{-1} h^{-1} $year^{-1}$) and Rc is the Fournier Index, determined by Equation 3:

$$Rc = \left(\frac{M_X^2}{P}\right) \quad (3)$$

Where M_x is the average of the total monthly rainfall in mm, and P is the average of the total annual rainfall in mm, thus determining the Fournier index. This equation was used due to the predominant rainfall pattern in the region of the Manuel Alves da Natividade river basin, validated by studies by Viola et al. (2014), using the rainfall concentration index (RCI), similar as the regime of rainfalls in the area under study.

The annual rainfall erosivity index (R) is the sum of the monthly values of this index, according to Equation 4:

$$R = \sum_{1}^{12} Ei_{30} \quad (4)$$

For the mapping of erosivity, ordinary kriging (KO) interpolators were tested, inverse distance weighting (IDW), considering powers from 2 to 5, using the interpolator with the best performance.

For the geostatistical analysis, an essential step consists in adjusting the theoretical semivariogram model, obtaining values for the parameters that structure these models (nugget effect, contribution and scope). In this study, spherical, exponential and Gaussian semivariogram models were evaluated, and the weighted least squares (WLS) adjustment method was applied. Equations 5, 6 and 7 represent the spherical, exponential and Gaussian semivariogram models, respectively.

$$\gamma(h) = C_0 + C_1 . \left[\frac{3}{2} . \left(\frac{h}{a}\right) - \frac{1}{2} . \left(\frac{h}{a}\right)^3\right], \text{ if } 0 < h < a; \ \gamma(h) = C0 + C1; \ h \geq a \quad (5)$$

$$\gamma(h) = C_0 + C_1 . \left[1 - \exp\left(\frac{-3 . h}{a}\right)\right], \text{ if } 0 < h < a; \ \gamma(h) = C0 + C1; \ h > a \quad (6)$$

$$\gamma(h) = C_0 + C_1 . \left\{1 - \exp\left[-3. \left(\frac{h}{a}\right)^2\right]\right\}, \text{ if } 0 < h < a; \ \gamma(h) = C0 + C1; \ h > a \quad (7)$$

Where γ *(h)* is the semivariation, C_1 is the contribution of the semivariogram (difference between the threshold and the nugget effect), a is the reach, C_0 is the nugget effect, and h is the distance between the pairs of points.

In order to analyze the spatial dependence structure of the adjusted semivariogram models, the degree of spatial dependence (SD) was calculated, obtained according to Cambardella et al. (1994) by:

$$SD = \left(\frac{C_1}{C_0 + C_1}\right) . 100 \quad (8)$$

Considering the SD, the following classification can be adopted: SD < 25% (low), between 25 and 75% (moderate) and > 75% (high) (CAMBARDELLA et al., 1994).

To verify the quality of erosivity spatialization, the cross-validation technique was applied. This technique consists of estimating the values of the variable under study for the exact location of the sampled points, allowing quantifying the mean absolute percentage error (MAPE) in %, according to Equation 9 (LEWIS, 1997):

$$MAPE = \frac{1}{n} . \sum_{i=1}^{n} \left|\frac{Obs_i - Est_i}{Obs_i}\right| . 100 \quad (9)$$

Where n is the number of pluviometric stations whose data were used to determine the Factor (R), Obs_i is the erosivity observed for the station i, and Est_i is the estimated erosivity for the position of the station i.

In the present work, the classification proposed by Lewis (1997) was adopted, which presents the following ranges of values: MAPE <10%: "very good," 10% ≤ MAPE <20%: "good," 20% ≤ MAPE <30%: "reasonable," and MAPE ≥ 30%: "imprecise."

The BIAS was calculated according to Liew et al. (2007) using Equation 10. The BIAS value corresponds to the percentage of bias of the estimated variables in relation to the observed variables.

$$BIAS = \frac{\sum_{i=1}^{n}(Obs_i - Est_i)}{\sum_{i=1}^{n}(Obs_i)} . 100 \quad (10)$$

The maps are in Conic Projection of Albers, Datum SIRGAS 2000. The rainfall erosivity (EI30), in MJ mm ha^{-1} h^{-1} $year^{-1}$, was mapped using an orange scale: the lowest value classes are shown by a light coloring, followed by a gradual darker coloring as it increases.

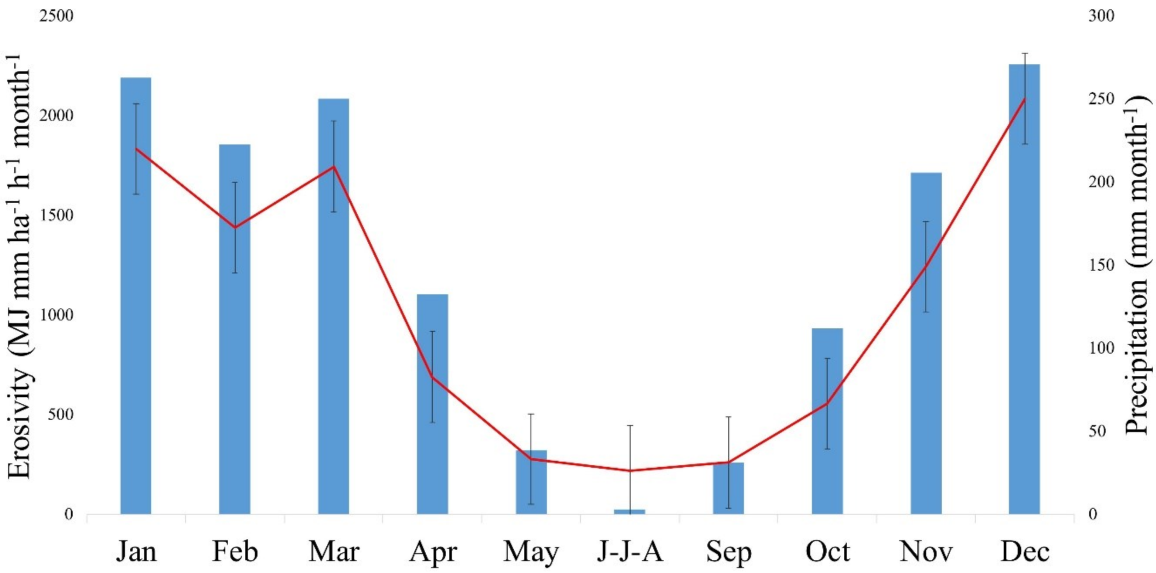
RESULTS AND DISCUSSION

It is possible to identify two distinct periods in the distribution of rainfalls over the Manuel Alves da Natividade river basin. The rainy period is concentrated from October to April, while the dry period is concentrated from May to September, when the average monthly rainfall did not exceed 50 mm. Analyzing the rainfall regime in Tocantins as a whole, Viola et al. (2014) also identified these two periods: in the first period, the rains are better distributed throughout the year over an extensive range from the north of Bananal Island (southwest of the state) to the south of the Bico do Papagaio region; in the second period, the rains are more concentrated, covering the entire south and the extreme north of the state.

Reboita et al. (2010) and Viola et al. (2014) stated that such difference in the seasonality of rainfalls is a marked characteristic of the central region of Brazil, where, during the drought period, there is an intensification of the anticyclone phenomenon in the South Atlantic Ocean, with reduction of the presence of water vapor in the atmosphere, which prevents the formation of rain clouds and the displacement of frontal systems.

The months with the highest rainfall rates for the basin are the same for the state as a whole (December-March), whose accumulated depth reached more than 1,005 mm (Figure 3). In this period, the erosive potential of rainfalls reached 68.4% of the total annual value, indicating that the critical period of erosive impact of rainfalls is concentrated in these four months (VIOLA et al., 2014).

Figure 3. Monthly averages of rainfalls and erosivity between 1983 and 2013 for the 25 stations used in the modeling process of the Manuel Alves da Natividade river basin. The line with dotted intervals represents the range of variation in erosivity.



Source: Prepared by the author, 2018.

It is important to highlight that throughout the rainy season, erosivity was above 500 MJ mm ha^{-1} h^{-1} month^{-1} and the average erosivity for the rainy period (October to March) was 1,481 MJ mm ha^{-1} h^{-1} month^{-1}, considered high values that indicate soil loss above the tolerated level, attributing to this period a criticality with respect to erosion and demanding the maintenance of the soil with vegetal cover to reduce the erosive actions of rainfalls and, consequently, the high losses of soil (SILVA et al., 1997; VIOLA et al. 2014).

Considering only the four rainiest months in the region of the Manuel Alves da Natividade river basin, the recorded erosivity corresponds to about 7,095.07 MJ mm ha^{-1} h^{-1} year^{-1}. The accumulated total for the rest of the year corresponds to 3,238.53 MJ mm ha^{-1} h^{-1} year^{-1}, i.e., 46.2% of the annual erosivity.

The annual erosivity determined in the basin varied between 8,332 and 14,403 MJ mm ha^{-1} h^{-1} year^{-1}. The values vary slightly with those found by Viola et al. (2014), considering erosivity for the entire state of Tocantins, i.e., between 6.599 and 14,000 MJ mm ha^{-1} h^{-1} year^{-1}. Within the Brazilian territory, Oliveira et al. (2015) found annual rainfall erosivity values ranging from 2,000 to 20,000 MJ mm ha^{-1} h^{-1} year^{-1}.

Table 1 shows that 96% of the data observed in the 25 stations classify the annual erosivity as "very high," and classify the remaining 4% as "high," revealing the need to use appropriate soil management and conservation techniques to avoid soil loss due to rainfall erosivity.

Table 1. Interpretation classes of annual erosivity Factor (R)

Rainfall Erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$)	Level of Erosivity	Observed data (%)
$R \leq 2,452$	Low Erosivity	**0**
$2,452 < R \leq 4,905$	Medium Erosivity	**0**
$4,905 < R \leq 7,357$	Medium-High Erosivity	**0**
$7,357 < R \leq 9,810$	High Erosivity	**44**
$R > 9,810$	Very High Erosivity	**56**

Source: Carvalho (2008), modified to the international metric of units according to Foster et al. (1981). Org.: Adapted by the author, 2018.

For the spatialization of rainfall erosivity data (Factor R), the spherical model performed better (20%) in ten analyses, the exponential model performed better in 40%, the same percentage as the Gaussian model, which also performed better (40%) among the situations analyzed (Table 2). It is noteworthy that for June, July and August, an average rainfall was obtained considering the scarcity of rainfalls in this period, an average used for geostatistical analysis and for the spatialization of rainfall erosivity.

Table 2. Nugget effect (C0), reach (A), contribution (C1), mean absolute percentage error (MAPE) and degree of spatial dependence (SD) for the exponential and spherical semivariogram models.

Parameter	1	2	3	4	5	6	7	8	9	10
					Spherical Model					
C0	44,964.14	21,931.74	0.00	0.00	0.00	0.00	2.84	1,004.53	3,181.65	216.24
A (Km)	242.19	221.23	261.79	128.80	124.72	106.96	99.79	210.19	186.07	98.89
C1	86,248.08	106,163.94	436,273.30	39,184.98	886.92	11.35	157.48	6,272.18	1,851.61	4,922.34
MAPE (%)	15.23	17.42	24.03	21.07	5.83	0.71	3.65	7.91	5.09	2.90
SD (%)	65.73	82.88	100.00	100.00	100.00	100,00	98.23	86.20	36.79	95.79
					Exponential Model					
C0	28,529.14	7,927.03	0.00	0.00	0.00	0.00	0.00	575.33	1,002.45	0.00
A (Km)	292.53	268.39	444.84	39.18	247.14	169.25	137.04	349.92	95.15	130.56
C1	109,408.5 9	127,410.38	505,792.85	40,329.76	1,054. 57	12.72	172.47	7,900.72	3,866.29	5,480.33
MAPE (%)	15.04	16.97	23.11	22.98	5.77	0.75	3.63	7.99	4.70	2.90
SD (%)	79.32	94.14	100.00	100.00	100.00	100.00	100.00	93.21	79.41	100.00
					Gaussian Model					
C0	46,239.63	35,385.42	21,974.91	765.98	117.38	0.19	41.38	1,968.11	3,621.79	1,524.07
A (Km)	158.34	189.54	214.59	110.52	113.23	95.15	99.79	192.44	186.07	95.15
C1	79,775.42	94,344.12	430,076.98	41,138.63	791.88	11.82	123.85	5,490.89	1,521.55	3,676.33
MAPE (%)	14.63	17.64	25.45	21.95	5.69	0.72	3.68	7.41	2.95	2.95
SD (%)	63.31	72.72	95.14	98.17	87.09	98.43	74.96	73.61	29.58	70.69

(1) January, (2) February, (3) March, (4) April, (5) May, (6) June/July/August, (7) September, (8) October, (9) November, and (10) December. Source: Prepared by the author, 2018.

Table 2 shows the performance and the parameters of the spherical, exponential and Gaussian semivariogram models obtained through ordinary kriging. The MAPE was lower than 20% for all months except for March and April, when it presented maximum values. For the period of June, July and August, considering the average for the period, the low MAPE values are justified by the adjustment parameters of the equation, which produced results with low variability for the period.

Considering the annual erosivity, the exponential model performed better than the spherical and the Gaussian models based on MAPE; in addition, a 100% of spatial dependence stands out in the exponential model. In both tested models of semivariograms, according to Cambardella et al. (1994), there is a "high" spatial dependence (above 75%) (Table 3).

Table 3. Parameters of the exponential, spherical and Gaussian semivariogram models (nugget effect - C0, contribution - C1, reach - A), degree of spatial dependence (SD), bias and mean absolute percentage error (MAPE) obtained by cross-validation for annual rainfall erosivity in the Manuel Alves da Natividade River Basin.

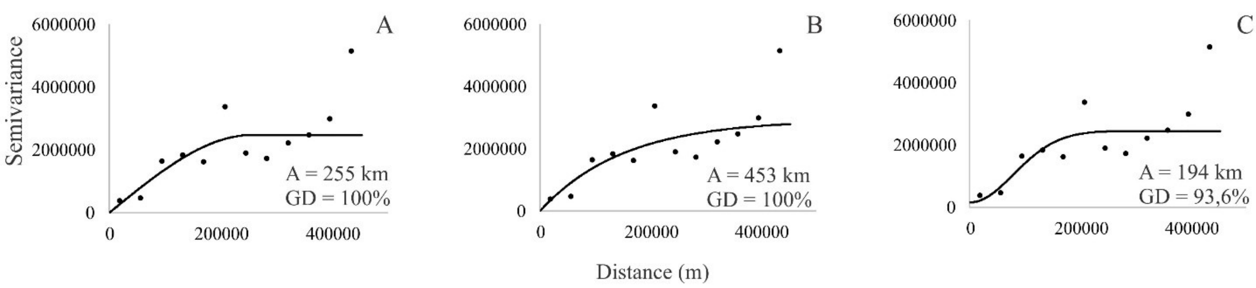
	Nugget E. - C0	Reach (Km)	Contribution - C1	BIAS (%)	MAPE (%)	SD (%)
Spherical	0,00	255.54	2,471,316.02	0.89	8.42	100.00
Exponential	0,00	453.34	2,937,989.24	0.96	8.26	100.00
Gaussian	155,023.93	194.21	2,294,880.31	0.96	8.64	93.67

Source: Prepared by the author, 2018.

Figures 4 and 5 show the semivariogram models with the lowest MAPE for monthly and annual analyses, respectively. There is a moderate adherence between experimental semivariogram models, with a high spatial dependence for most analyses, excluding January, October and November, with SDs equivalent to 63%, 73.3% and 29.6%, respectively, which present a moderate spatial dependence (CAMBARDELLA et al., 1994).

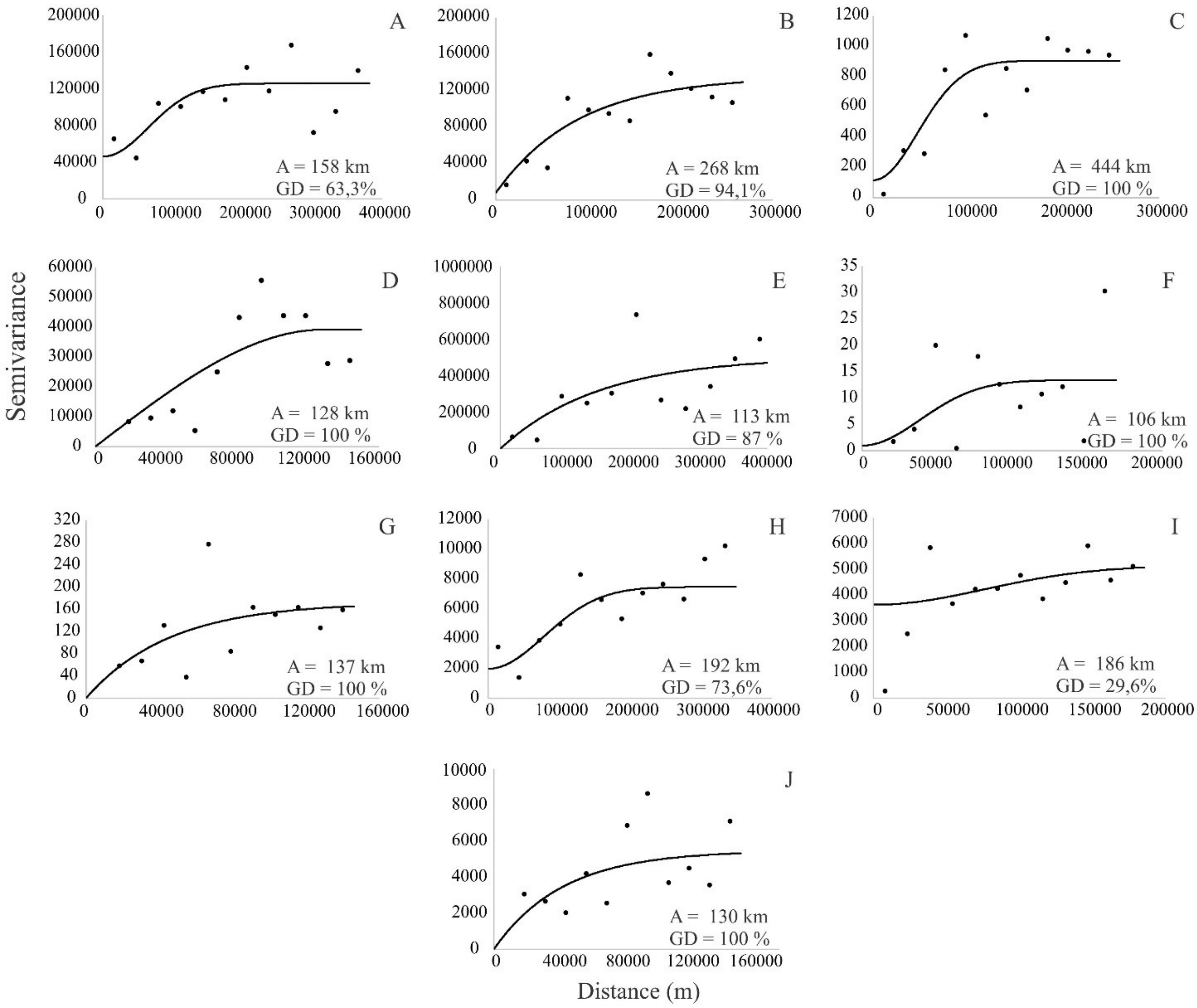
The reach of the spatial dependence structure varied between 106 (June, July and August) and 440 km (March), which indicates that geostatistical techniques can produce good results in mapping erosivity in the Manuel Alves da Natividade river basin.

Figure 4. Semivariograms adjusted for the erosive potential of rainfalls in the Manuel Alves da Natividade river basin: spherical (A), exponential (B) and Gaussian (C) models.



Source: Prepared by the author, 2018.

Figure 5. Adjusted semivariograms for the erosive potential of rainfalls in the Manuel Alves da Natividade river basin for January (A), February (B), March (C), April (D), May (E), June-July- August (F), September (G), October (H), November (I), and December (J), with emphasis on reach (A) and degree of spatial dependence (SD).



Source: Prepared by the author, 2018.

Regarding the spatialization of rainfall erosivity in the Manuel Alves da Natividade river basin, the highest values found for the first three months of the year are concentrated in the west, northeast and northwest regions of the basin, respectively. In January, values varied between 1,283 and 2,384 MJ mm ha^{-1} h^{-1} $month^{-1}$. In February, the variation was between 1,184 and 2,373 MJ mm ha^{-1} h^{-1} $month^{-1}$; in March, the values varied between 973 and 3,936 MJ mm ha^{-1} h^{-1} $month^{-1}$.

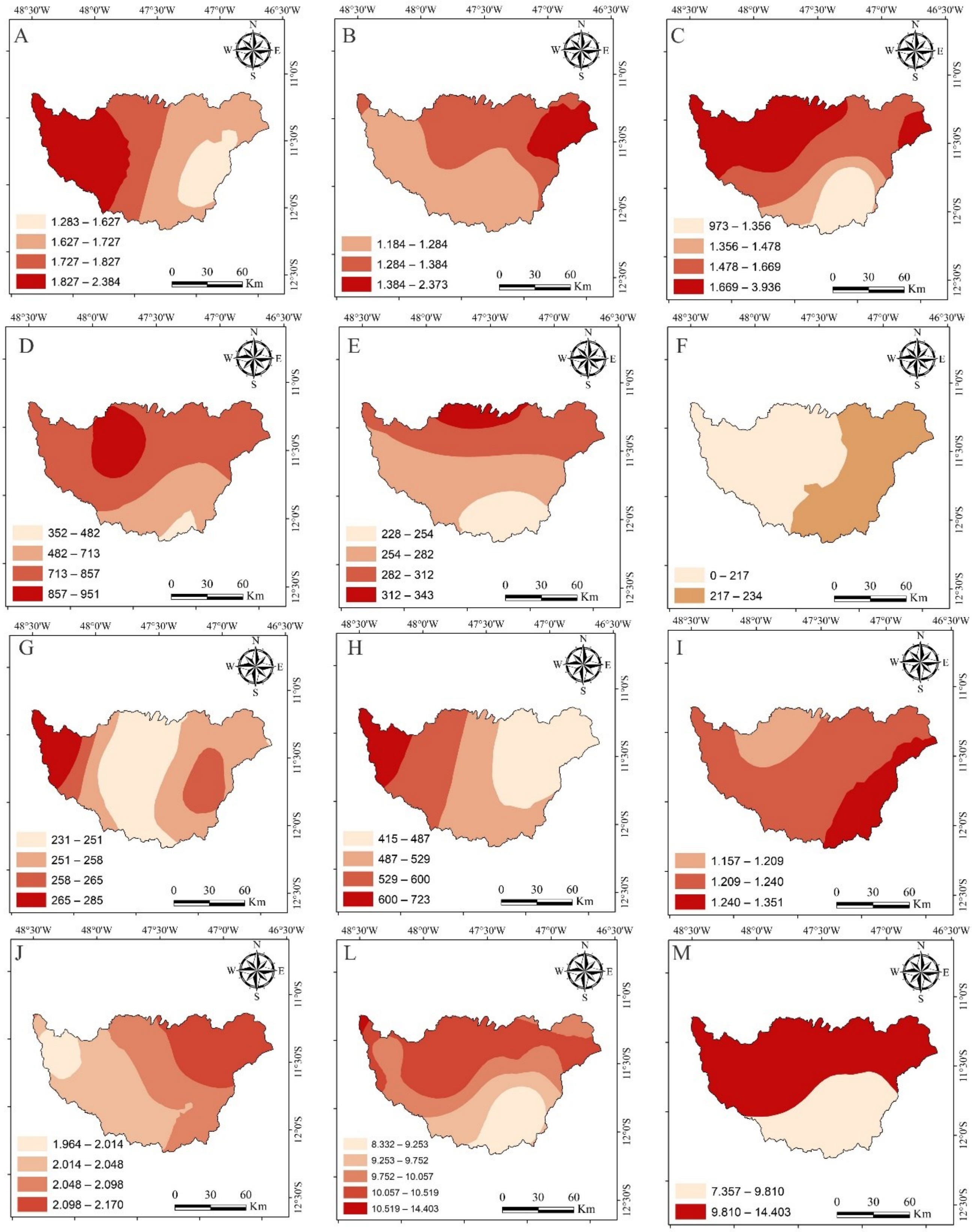
For April and May, the areas of critical occurrence of erosivity were concentrated in the central-north portion of the basin, varying between 352 and 951 MJ mm ha^{-1} h^{-1} $month^{-1}$ in April and between 228 and 343 MJ mm ha^{-1} h^{-1} $month^{-1}$ in May. The average values corresponding to the period of June, July and August did not exceed 234 MJ mm ha^{-1} h^{-1} $month^{-1}$, with the highest values in the eastern portion of the basin. For the months of September and October, the eastern portion of the basin, where the values were the highest, the variation in erosivity was between 231 and 285 MJ mm ha^{-1} h^{-1} $month^{-1}$ in September and between 415 and 723 MJ mm ha^{-1} h^{-1} $month^{-1}$ in October. In November, the southeastern portion of the basin showed the highest erosivity values, which varied between 1,157 and 1351 MJ mm ha^{-1} h^{-1} $month^{-1}$. In December, the values varied between 1,964 and 2,170 MJ mm ha^{-1} h^{-1} $month^{-1}$, and the northeast of the basin presented the most critical values.

Considering the spatialization of annual erosivity, the southeast region of the basin presented the lowest values of erosivity, varying between 8,332 and 9,253 MJ mm ha^{-1} h^{-1} $year^{-1}$. The highest values of erosivity occurred in a small portion of the north and northwest region, with a variation between 10,519 and 14,403 MJ mm ha^{-1} h^{-1} $year^{-1}$; the large north portion of the Manuel Alves of Natividade river basin presented values between 10,057 and 10,519 (Figure 6).

It is important to highlight that erosivity is intrinsically related to the intensity of rainfalls; therefore, as the intensity-duration-frequency ratio of rainfall increases, the greater the erosive potential of rainfalls (Factor R). Amanambu et al. (2019), in studies on spatial variability of rainfall erosivity in the Niger river basin, West Africa, found annual erosivity values between 715 and 17,824 MJ mm ha^{-1} h^{-1} $year^{-1}$. Although it is not a general rule for all cases, the authors claimed that the increase in the annual amount of rainfalls has led to an increase in erosivity and vice-versa. Silva Neto (2016), in studies on the intense rainfalls in the state of Tocantins, determined the intensity of a 30-minute rain for a return time of ten years between 101 and 108 mm h^{-1} for the southeastern region of the state of Tocantins, where the hydrographic basin under study is located, which justifies the high levels of erosive rainfalls in the Manuel Alves da Natividade river basin.

Concrete measures are necessary to mitigate erosive processes resulting from rainfalls, such as the fencing of critical areas to prevent the flow of animals, conservation of native vegetation, reforestation of areas with a greater declivity, and the introduction of level curves in order to reduce runoff. Pio de Santana et al. (2007) stated that the adoption of a management system considering the limitations of the terrain, even in highly erosive areas, may minimize the erosivity of rainfalls and that the interactive responses between climate, vegetation, land and forms of soil use and occupation need to be adequately quantified and monitored.

Figure 6. Spatial distribution of rainfall erosivity in the Manuel Alves da Natividade river basin (MJ mm ha^{-1} h^{-1} year^{-1}) for January (A), February (B), March (C), April (D), May (E), June-July-August (F), September (G), October (H), November (I), and December (J), annual erosivity (L) and classification of erosivity according to Foster et al. (1981) (M).



Source: Prepared by the author, 2018.

It should be noted that the erosivity values were determined using a pre-adjusted equation based on the geographic distribution of annual rainfalls for homogeneous regions of the Brazilian territory, in which the equation proposed by Silva et al. (1997) was applied as validated by Viola et al. (2014). It is of fundamental importance to conduct further studies aiming to determine the erosivity of rainfalls in the Manuel Alves da Natividade river basin using adjustments of erosivity equations for rainfalls in the area of the basin in order to investigate the possibility of overestimation and underestimation of the values found.

Another important aspect refers to the geostatistical techniques that, according to Mello et al. (2007), are being widely applied, showing a better efficiency than others. This is mainly due to the control of a portion of the random error produced by the mutual spatial influence between samples, known as spatial dependence, which classical statistics do not consider.

FINAL CONSIDERATIONS

The Manuel Alves da Natividade river basin presents a severe natural risk to water erosion mainly in the northwest, north and central regions.

The rainfall erosivity in the state of Tocantins, regarding both the monthly and annual time scales, presents a spatial continuity structure between moderate and high, with a reach between 106 and 453 km.

The spatialization of erosivity in the basin on a monthly and annual scale presented critical areas and periods related to the erosive potential of rainfalls. This is information for planning the use and sustainable management of the soil and for the implementation of actions for the conservation of the soil and the water of the Manuel Alves da Natividade river basin; such measures could be area fencing, native forest conservation, reforestation, contour cultivation, terracing, water catchment, and stabilization structures.

Geostatistical techniques perform better than classical statistics due to the control of part of the random error produced by the mutual spatial influence between the samples, known as spatial dependence. However, the use of a reduced number of stations in the basin area and its surroundings can be a limitation to these techniques as it makes it difficult to analyze spatial dependence.

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